THE GEOLOGY OF EASTERN LURRISK,

CO. MAYO, EIRE.

by

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Frontispiece. Croaghrimcara and Glennagashleeny
"What in mee is dark
Illumin, what is low raise and support;
That to the highth of this great argument
I may assert Eternal Providence,
And justifie the wayes of God to men"

Paradise Lost.
J. Milton (1608-1674)
# LIST OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter I</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Review of previous work</td>
<td>4</td>
</tr>
<tr>
<td>Names used</td>
<td>20</td>
</tr>
<tr>
<td>Ages of rocks</td>
<td>20</td>
</tr>
<tr>
<td>The Pleistocene glaciation</td>
<td>23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter II</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordovician stratigraphy</td>
<td>37</td>
</tr>
<tr>
<td>Deposits of Areing age</td>
<td>37</td>
</tr>
<tr>
<td>Introduction</td>
<td>37</td>
</tr>
<tr>
<td>The Letterbrock Conglomerate Group</td>
<td>41</td>
</tr>
<tr>
<td>Conglomerate</td>
<td>42</td>
</tr>
<tr>
<td>Massive Grits</td>
<td>45</td>
</tr>
<tr>
<td>Interbedded grits and slates</td>
<td>55</td>
</tr>
<tr>
<td>The Owenmore Group</td>
<td>62</td>
</tr>
<tr>
<td>Palaeogeography of Owenmore Times</td>
<td>66</td>
</tr>
<tr>
<td>The Sheeffry Series</td>
<td>71</td>
</tr>
<tr>
<td>1. The Drummin Group</td>
<td>71</td>
</tr>
<tr>
<td>2. The Lugaloughan Volcanic Group</td>
<td>75</td>
</tr>
<tr>
<td>3. The Lugacolliewee Group</td>
<td>77</td>
</tr>
<tr>
<td>4. The Spink Group</td>
<td>79</td>
</tr>
<tr>
<td>5. The Cuilmore Volcanic Formation</td>
<td>85</td>
</tr>
<tr>
<td>6. The Creggan-a-tiadwar Group</td>
<td>85</td>
</tr>
<tr>
<td>7. The Banded Group</td>
<td>89</td>
</tr>
<tr>
<td>8. The Derrylea Group</td>
<td>89</td>
</tr>
<tr>
<td>Petrographical correlation</td>
<td>99</td>
</tr>
<tr>
<td>Classification of sandstones</td>
<td>107</td>
</tr>
<tr>
<td>Spilite</td>
<td>114</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter III</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Glenummera Series</td>
<td>121</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter IV</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Partry Series</td>
<td>136</td>
</tr>
<tr>
<td>Current bedding</td>
<td>140</td>
</tr>
<tr>
<td>Channels ..................................................</td>
<td>142</td>
</tr>
<tr>
<td>Conglomerate &amp; sand lenses .......................</td>
<td>146</td>
</tr>
<tr>
<td>Ripples ..................................................</td>
<td>148</td>
</tr>
<tr>
<td>Other bedding structures ..........................</td>
<td>149</td>
</tr>
<tr>
<td>Orientation of organic remains ..................</td>
<td>150</td>
</tr>
<tr>
<td>The Pebbles of the Partry Series ................</td>
<td>151</td>
</tr>
<tr>
<td>a) Introduction ........................................</td>
<td>151</td>
</tr>
<tr>
<td>b) Previous accounts of the conglomerates ....</td>
<td>151</td>
</tr>
<tr>
<td>c) Composition of the pebbles ...................</td>
<td>152</td>
</tr>
<tr>
<td>d) Size of the pebbles .............................</td>
<td>156</td>
</tr>
<tr>
<td>e) Imbrication .........................................</td>
<td>160</td>
</tr>
<tr>
<td>f) Orientation of the long-axis of the pebbles</td>
<td>163</td>
</tr>
<tr>
<td>g) Creintation of the median axis ..............</td>
<td>168</td>
</tr>
<tr>
<td>h) Roundness ...........................................</td>
<td>169</td>
</tr>
<tr>
<td>i) Sphericity ..........................................</td>
<td>172</td>
</tr>
<tr>
<td>The Petrology of the Sandstones of the Partry Series</td>
<td>174</td>
</tr>
<tr>
<td>Size analysis ..........................................</td>
<td>174</td>
</tr>
<tr>
<td>Presentation of results ............................</td>
<td>176</td>
</tr>
<tr>
<td>Sedimentary petrography ............................</td>
<td>184</td>
</tr>
<tr>
<td>Quartz ..................................................</td>
<td>184</td>
</tr>
<tr>
<td>Feldspars ...............................................</td>
<td>185</td>
</tr>
<tr>
<td>Lithic Components ....................................</td>
<td>186</td>
</tr>
<tr>
<td>Micas ....................................................</td>
<td>187</td>
</tr>
<tr>
<td>Heavy detrital minerals ............................</td>
<td>189</td>
</tr>
<tr>
<td>Iron minerals ..........................................</td>
<td>196</td>
</tr>
<tr>
<td>Depositional environment of the Partry Series</td>
<td>198</td>
</tr>
<tr>
<td>The Age of the Partry Series ....................</td>
<td>202</td>
</tr>
<tr>
<td>The Mweelrea Volcanics ............................</td>
<td>204</td>
</tr>
<tr>
<td>MT 1 ....................................................</td>
<td>204</td>
</tr>
<tr>
<td>MT 3 &amp; 4 ................................................</td>
<td>206</td>
</tr>
<tr>
<td>MT 5 .....................................................</td>
<td>207</td>
</tr>
<tr>
<td>MT 6 &amp; 7 ................................................</td>
<td>208</td>
</tr>
<tr>
<td>Petrography ............................................</td>
<td>211</td>
</tr>
<tr>
<td>Chapter V</td>
<td>Intrusions into the Partry Series</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td></td>
<td>Silurian stratigraphy</td>
</tr>
<tr>
<td>Upper Owenduff Group</td>
<td>233</td>
</tr>
<tr>
<td>1. Cregganbaun Conglomerate Group</td>
<td>234</td>
</tr>
<tr>
<td>2. Cregganbaun Quartzite Group</td>
<td>235</td>
</tr>
<tr>
<td>3. Green slate Group</td>
<td>236</td>
</tr>
<tr>
<td>4. Interbedded pelitic &amp; psammitic Group</td>
<td>238</td>
</tr>
<tr>
<td>5. Mixed Group</td>
<td>238</td>
</tr>
<tr>
<td>6. Lough Nacóra Group</td>
<td>239</td>
</tr>
<tr>
<td>Sedimentary Structures</td>
<td>240</td>
</tr>
<tr>
<td>7. Massive current-bedded Group</td>
<td>243</td>
</tr>
<tr>
<td>Falaeogeography of the Upper Owenduff Group</td>
<td>244</td>
</tr>
</tbody>
</table>

| Chapter VI | Structure | 251 |
|           | Introduction | 251 |
|           | First phase of folding | 251 |
|           | Axes of minor folds | 253 |
|           | Axial plane cleavages | 253 |
|           | Second phase of folding | 255 |
|           | The f2 folding in the Partry Series | 263 |
|           | Strain-slip cleavages | 265 |
|           | Cleavages S2a and S2b | 265 |
|           | Cleavages S4a and S4b | 266 |
|           | The folds in the Glenummera Series | 267 |
|           | Quartz veins | 268 |
|           | Faults and joints | 269 |
|           | Metamorphism | 275 |

| Chapter VII | The serpentine intrusion | 276 |
|            | Petrography | 278 |

| Chapter VIII | The Dalradian Rocks | 283 |
List of Text-figures.

Fig. 1. Structural setting of the area.
Fig. 2. Stratigraphical succession.
Fig. 3. Principal localities referred to in the text.
Fig. 4. Simplified geological maps of Murrisk.
Fig. 5. Past and present workers in Murrisk and N. Connemara.
Fig. 6. Glacial features of Eastern Murrisk.
Fig. 7. Direction of ice flow in part of western Connacht.
Fig. 8. Map of the Letterbrock area.
Figs. 9, 10, 11 Sedimentary structures in the Letterbrock Conglomerate Group.
Fig. 12. Sedimentary features of the Owenmore Series.
Fig. 15. Complex internal structure of a slumped bed.
Fig. 16. Thicknesses of graded beds in a sequence from the Lugacolliwee Group.
Fig. 17. Interpretation of the bifurcation of the acid tuff beds of the Spink Group.
Fig. 18. Orientation of sedimentary lineations in the Derrylea Group.
Fig. 19. Variations in the heavy mineral content of thin sections from the Derrylea Group.
Fig. 20. QFL diagram for the Sheeffry Series.
Fig. 21. MLQ diagram for the Sheeffry Series.
Fig. 22. Grain size analyses from the Arenig grits.
Fig. 23. Graphical representation of Inman parameters of L. Arenig sediments.
Figs. 24, 26, 28. Orientation of the depositional slope of the sediments of the Glenummera Series.
Fig. 25. Isopachytes for sediment between tuff beds and the Mweelrea-Glenummera boundary.
Fig. 27. Inclination of the tuff beds relative to the facies change boundary.
Fig. 29. Map of the known outcrop of the Partry Series of Mayo and N. Galway.
Figs. 30, 31. Orientation of intersections of bedding planes and false-bedding in the Partry Series.
Fig. 32. Asymmetrical channel from Derryveeny.

Figs. 33, 34. Sedimentary features from the Partry Series.

Figs. 35, 36. The structure of some conglomerates of the Partry Series.

Fig. 37. Sequence low in the course of Bruffaunnagreeve.

Fig. 38. Cross-sectional area of the ends of pebbles from Glennagashleeny.

Fig. 39. Imbrication of pebbles in the Eastern facies of the Partry Series.

Fig. 40. Rose diagrams to show the orientation of the long axes of pebbles in the bedding planes of the Partry Series conglomerates.

Fig. 41. The influence of two interacting currents.

Fig. 42. Roundness of pebbles in the Partry Series conglomerates.

Fig. 43. Plots to show variations in the distribution of more than 100 grains.

Fig. 44. Grain size frequency distribution histograms.

Figs. 45, 46. Cumulative frequency distribution curves.

Fig. 47. Grain size frequency in the Partry Series.

Fig. 48. Graphical representation of the Inman parameters of the sediments of the Partry Series.

Fig. 49. Comparison of analyses with those of Davies (1962).

Fig. 50. Analyses plotted against three perpendicular axes.

Fig. 51. Skewness-sorting relationships of river and beach sands (after Friedman).

Fig. 52. Ratios of metamorphic and non-metamorphic quartz.

Fig. 53. Secondary micas in a hollow in a quartz grain.

Fig. 54. NLQ analyses of the Owenmore, Sheeffry, Glenummera and Partry Series.

Fig. 55. Facies changes in the Partry Series.

Fig. 56. Nodular structures in welded tuff at top of the Glen Mask waterfall.

Fig. 57. Interpretation of facies changes in the Lower Owenduff Group (after Dewey).
Table of equivalents used by Dewey & Anderson.

Sedimentary structures in the Upper Owen-duff Group.

Palaeogeography of the Wenlock of the northern part of Ireland.

Stereographic plot of F₁ structures.

Minor folds associated with F₁ and F₂.

Different styles of folding in adjacent beds of pelite and psammite on Boheh Hill.

Orientation of 'eyed' folds from the Tawny-nameeltoge area.

Ellipsoids of deformed clacareous segregations.

Intersection of 1₁ lineation and S₂ axial plane cleavage to show the location of 1₂a.

Structural map of the Owenwee-Letterbrock area.

Detail of structural mapping on Boheh Hill.

Unfolding of current-bedding oversteepened along S₂ cleavage.

Untilting sedimentary lineations from the Partry Series.

Late stage fracturing of two series of quartz veins.

Map of the Lettereeneen fault zone in Glen Mask.

Swing of beds and joints at Téevinish.

Conjugate folds in the Dalradian rocks of Carrownalurgan.

Intersection of Dewey's 1960 contours of the sub-Carboniferous surface with the present topography.

Revised location of the contours of the sub-Carboniferous surface in Eastern Murrisk.

Table of events in Murrisk.
List of Plates

Plate 1. Sands and gravels of the glacial outwash plain, Creggandarragh.
Plate 2. Channel in outwash sands and gravels, Creggandarragh.
Plate 3. Ice-polished surface showing slump structure, in the Drummin Group, Rooghaun.
Plate 4. Cutting out of beds by erosion in the Drummin Group, Rooghaun.
Plate 5. Virtually undeformed conglomerate of the Derrylea Group, Croaghrimcarra.
Plate 6. Sheared pebbles eroded to leave hollows in the conglomerate of the Derrylea Group, Croaghrimcarra.
Plate 7. The pillow lavas of Bohaun.
Plate 8. Bedded tuffs which lie above the lavas at Bohaun.
Plate 9. The basal bed of the Partry Series resting unconformably on the top of the Glenummera Series, Glennagashleeny.
Plate 10. Pebbles within the highly cleaved slates of the Glenummera Series, Lough Shee.
Plate 12. Diffuse conglomerate of the eastern facies of the Partry Series, Bohaun Hill.
Plate 13. Reversely graded, concentrated conglomerate, Glennagashleeny.
Plate 15. Coarse concentrated conglomerate of eastern facies, beside Sruffaunnagreave.
Plate 17. Nodular weathering in welded tuffs at the top of the Glen Mask waterfall.
Plate 18. Pebble-filled channel cut into inverted welded tuffs at Glen Mask waterfall.
Plate 19. Chilled top of sill at contact with Partry Series sediments, Tonnasaile.
Plate 20. Regular banding shown by nodules of natro-lite near the top of the sill on Tonnasaile.


Plate 22. Oversteepened current bedding in the Lough Nacorra Group, eastern Owenwee.

Plate 23. Difference of style of folding in slate and siltstone, Bohagh Hill.

Plate 24. Complex surface patterns due to folding of slates, Aghamore Hill.


Plate 26. Intense quartz veining in the Cregganbaun Quartzite at Black Mountain.

Plate 27. Jointing in the sandstones of the Oughty Group, Aghamore.

Plate 28. Detail of jointing and quartz veining in the Oughty Group.

Plate 29. The valley along the Highland Boundary Fault, looking east, with Black Mountain on the right.
Abstract

The stratigraphy of the Ordovician and Silurian rocks of Eastern Murrisk, Co. Mayo, Eire, is described and the facies changes in relation to the rocks of neighbouring areas interpreted.

During Ordovician times the South Mayo trough, initially deep, became steadily infilled with sediments, principally derived from the rising Connemara Cordillera to the south-east. These sediments are described, and variation in the principal constituents analysed.

The Silurian rocks of shelf facies occurring in the Croagh Patrick Syncline are described, and the effect of two phases of post-Wenlockian deformation and the resultant structures discussed.

Two phases of injection have been recognised in the serpentine intrusion along the Highland Boundary Fault, the latter being post-Wenlockian.

Pre-Carboniferous peneplanation was followed by submergence and deposition of shallow water sediments during the Lower Carboniferous. Tertiary faulting led to a renewal of movement along older faults, and produced fault blocks which control the present day topography. The whole area was subsequently modified during the Pleistocene glaciation.
CHAPTER I.

INTRODUCTION.

The undulating plains of Central Ireland impinge upon the foothills of the Connemara Mountains in the Barony of Murrisk. The easternmost extension of these mountains is the long low ridge of the Partry Mountains, which lie to the north-west of Lough Mask, and reaches beyond the eastern extremity of Murrisk into the Barony of Carra.

During the summers of 1960 and 1961, and the spring of 1962, a detailed geological survey was carried out in about 75 square miles of country, stretching from the southern slopes of the Partry Mountains northwards as far as the shores of Clew Bay near Westport (Fig. 1). The mapping was carried out on a scale of six inches to the mile, on the Irish Ordnance Survey sheets 88, 97, 98, 99, 108, 109, and 116a of County Mayo.

Lower Palaeozoic rocks underlie most of the rather subdued terrain of this part of Murrisk: at the base of the exposed succession is the Owenmore Series, of conglomerates and greywackes; followed by the Sheeffry Series, of greywackes, and slates with some ashes; the Glenummera Series, principally of slates; the Partry Series, a red sandstone and conglomerate bearing division in which occur welded tuffs. The Silurian sediments are chiefly sandstones, which rest unconformably on the Ordovician rocks.

Particular attention was given to those rocks which occur below the unconformity at the base of the Upper Carboniferous Series.
Fig. 1. Structural setting of the area.

- Post-Silurian
- Lower Palaeozoic
- Metamorphic rocks
- Granite

- Malin Head
- Donegal Bay
- Galway Bay
- Highland Boundary Fault
Topographically the eastern part of Murrisk may be divided into seven sectors from south to north:

1) The Partry Mountains, which form the highest ground in the area, reach 1,768 ft. (535 m) to the west of Lough Glenawough. The north-facing slope is a relatively steep escarpment, which is broken at Glennagashleeny, where direct access by road from northwest to south-east across the range is possible. The top of the range is relatively flat, and represents the level of the Carboniferous peneplain, which decreases in height from south-west to north-east, and is covered in most places by a blanket of peat, through which occasional exposures protrude. The southern slopes are cut by open valleys at Derryveeny and Gortbunnacullin, and are largely used for open grazing. The intense settlement of the villages along the western shore of Lough Mask reaches up to approximately the line of the unconformity at the base of the Partry Series.

2) The Derrinkee Bog, which stretches from north of Lough Glenawough eastwards beyond the mountain road and continues into the valley of the Aille River. In its upper parts the bog lies on the surface of a series of more than a dozen terraces, but in its lowest part it approaches the present streams where much of the peat has been removed either by natural or human agency. Along this valley, which is partly controlled by the Erriff tear fault, rocks of Carboniferous age encroach westwards to beyond Derrinkee.
3) The Slieve Mahanagh - Corveagh Hill ridge lies to the north of the wide Aille-Derrycraff River valley, and reaches a maximum height of 785 ft. (250m). The gently sloping southern side is covered by peat and poorly exposed; the northern side is steeply inclined.

4) The narrow north-east and south-west valley of Rooghaun-Cordarragh marks another incursion of Carboniferous sediments, and separates Slieve Mahanagh from the Liscarney, Carrowrevagh, Letterbrock and Boheh group of hills. Each of these areas of high ground has been stripped of its peat cover, and is relatively symmetrical in profile, with the exception of Boheh Hill, the northern limit of which is marked by abrupt cliffs along the line of the Knappaghmanagh fault.

5) The Knappagh-Knappaghbeg vale is a relatively intensely cultivated, low-lying tract of land, occupied by glacial outwash deposits. Drumlins, moraines, and scattered erratics increase northward until a wide moraine belt is reached immediately south of the 'Black Mountain' ridge.

6) The 'Black Mountain' Ridge represents a huge roche moutonné, formed by northward moving ice. In retreat this ice deposited the moraine belt, but, when fully extended, may have crossed this important line of low hills which builds up further to the west into the Croagh Patrick massif. The ridge is formed principally of quartzite, and is mostly uncultivated.

7) North of the 'Black Mountain' lie serpentines and rocks
of Dalradian age in poorly exposed country which has a thick cover of drift. The long axes of the drumlins here indicate an east to west movement of ice. This belt of country continues as far as the faults by the railway line immediately south of Westport, beyond which the fine grazing lands of the Carboniferous Limestone country replace the poorer pastures further south.

**Review of Previous Work.**

The publication of the first geological map of Ireland, by Sir Richard Griffith (1838) drew attention to the existence of Lower Palaeozoic rocks in Mayo and Galway. The northern (Silurian) district he referred to as of 'Primary mica-schist', and he considered that the succession became younger to the south in the 'Lower Silurian Clay Slate'.

Murchison, in 'Siluria' (1859), believed the oldest sediments to be the Llandoveryian rocks to the south of Killary harbour, and that the sediments became younger northwards. All rocks older than Llandovery were believed to have been metamorphosed to form the Connemara Schists. Kelly (1860), however, believed these metamorphic rocks were of pre-Ordovician age. He also recorded the presence of 'intrusive porphyries' in the Mweelrea Group of the Partry Series.

Kinahan (1874) published a preliminary account of the findings of the Geological Survey of Ireland, whose officers had spent part of the early 1870's mapping in the area. A clear picture of the succession was given for the first time, although some
of the correlations were highly speculative. Kinahan considered the Connemara Schists as Cambro-Silurian in age, and believed them to be older than the rocks of the Sheeffry Mountains. The shallow water origin of the Mweelrea (Partry Series) sediments was stressed, and their lateral change to a deeper water facies suggested.

Hull (1874) considered the Mweelrea welded tuffs to have originated as lava flows.

Kinahan, Symes, Nolan, and Leonard (1876), in the Memoir of the Irish Geological Survey which accompanied sheets 73, 74, 83, and 84, followed the lines indicated by Kinahan (1874). The presence of red conglomerates and sandstones below the lowest Mweelrea Tuff horizon in the area between Lough Glenawough and Loughanshee was believed to indicate an unconformity below the 'Upper Silurian'. Both to the west and the south-east there is a 'felsite' (now regarded as a welded tuff) at the base of the series, resting on the older, 'metamorphic rocks'. Kinahan further gave dip readings to show an angular break below the Tuff band. On the map (Sheet 84), however, the rocks below the Tuff are indicated as being of 'Upper Silurian' type.

The older rocks, below the base of the 'Upper Silurian', were grouped together as the 'Doolough' Series, and considered to be equivalent to the Lower Connemara Schists. Those of the Mweelrea (=Partry) Series were equated with the Upper Connemara Schists.

Kinahan produced many papers in the years 1878-1889, but
these consisted principally of restatements of beliefs already formed. In the most important of these papers (1882), a north-south section through South Mayo and Galway was given. The 'Doolough' Series was indicated as the lateral equivalent of the Upper Connemara Schists. Older Rocks, not exposed in Murrisk, were thought to be the equivalents of the Lower Schists. In 1879 Kinahan referred the 'Doolough' Series to an Arenig age, and considered any passage beds to the Cambrian as unexposed. The term 'Great Micalite Series' was applied to the 'Doolough' Series.

Sheet No. 26 of geological sections published on a scale of six inches to a mile by the Geological Survey of Ireland on behalf of Symes and McHenry (1879) clearly indicates that these authors considered an unconformity to exist at the base of the Mweelrea Group.

Kelly (1860) and Callaway (1887) both believed that the Connemara Schists were of Pro-Cambrian age, unconformably overlain by Lower Palaeozoic rocks of low metamorphic grade. Cal-laway pointed to the presence of boulders in the conglomerates of the Mweelrea Group very similar to the rocks of the metamorphic zone of Connemara.

Geikie (1889) also expressed disbelief concerning the age of the Connemara Schists, which he considered to be of incorrect composition for rocks which had been derived from the Ordovician and Silurian sediments. Geikie, the successor
to Hull as Director of the Irish Geological Survey, also disagreed with Kinahan over the presence of an unconformity at the base of the Mweelrea sediments.

During 1893-95 Kilroe visited the area for the Geological Survey. Geikie (1897) stated that Kilroe recognised the volcanics of the Tourmakeady district as being interbedded with rocks which he showed to be of Lower Silurian age (i.e. Ordovician). On the eastern side of the Partry Mountains pillow structures are seen, and Geikie makes the first record of similar pillow lavas on the north of the mountains, at Bohaun, where shearing has badly distorted their shapes.

Kilroe (1907) published his own account of the revision of the official Survey interpretation of the area. The Lee-nane and Rosroe grits he believed to be older than the Doolough Series, and younger than a series of pillow lavas, cherts, and black slates (Bencraff beds), which contained Arenig fossils. From his map it is clear that Kilroe considered the Doolough Series to commence at the northern boundary of the Derrylea Group of the Sheffry Series. The rocks to the north he classified as Llandoverian in age. The Doolough Series of Bala age, was thought to occupy the entire eastern end of the Partry Mountains, and the true Mweelrea sediments (in its restricted sense here it is approximately equivalent to the Maumtrasna Group of the Partry Series) were of Llandoverian age.
Concerning the sequence, Kilroe stated that "a conformable passage is traceable from the Lower Silurian (Ordovician) grits and slates to the Upper Silurian (Silurian) rocks at Cregganbaun". He further stated that the Mweelrea sediments were conformable upon the Doolough Series. In the sense which he uses the term, the Mweelrea sediments are indeed conformable upon the underlying rocks. On the eastern side of the Partry Mountains, however, Kilroe stated (p. 131) that "felsites may perhaps lie unconformably on black slate." The 'felsites referred to here are clearly those in a position at the base of the Partry Series, some way below the Mweelrea as used in the restricted sense. They lie in marked angular discordance upon the older beds of the Tourmakeady district.

Later (p. 150) he considered the Tourmakeady Beds to be equivalent in age to the Cregganbaun Group of further north. He thought the Mweelrea sediments were of Llandoveryian age.

Kilroe mistakenly refers to the pillow lavas of Bohaun as being near "Glenawough Lough", a misinterpretation from the map, for the lavas are four miles from this lake, and are situated near Croaghcorom Lough.

The most important contribution of Kilroe to the knowledge of the geology of Murrisk was the first detailed account of the structure of the Silurian rocks of the Croagh Patrick Syncline. The synclinal nature was recognised, the stratigraphy established, and the complexity of minor folds and
overthrusting acknowledged. The sericitic highly cleaved schists and "silky phyllites" were described in detail for the first time. Kilroe further recognised that the metamorphic rocks of the Silurian syncline were different in age and type from the Dalradian Westport Grits and Black Slates.

In 1905 the Geological Survey of Ireland was transferred to the Department of Agriculture and Technical Instruction for Ireland, and official publications decreased in numbers. In the 1907 report of the Director, Grenville Cole makes mention of the then unpublished revision of maps of central Mayo. The Report of the Director in 1908 detailed further investigations in the area, which were aimed at establishing the succession of the older rocks. The Report concluded that "a considerable amount of work needs to be done in Mayo and Galway before the Survey Maps of these areas can adequately represent the succession of the Palaeozoic strata."

Carruthers and Muff (1907) demonstrated the existence of graptolite faunas in the Arenig rocks of the Sheeffry Mountains. They addressed the British Association in Dublin in 1908 on the geology of the Leenane district, but published a fuller account the following year (1909). As a result of their palaeontological examination they established a sequence in which the Bencraft beds were of Lower Arenig age, and the "Doolough Series" of Upper Arenig age, in each case using evidence of graptolite assemblages. The presence of Ogygia in calcareous nodules in
the lowest slates of the Mweelrea Group indicated a Llandeilian age. Since this occurrence is low in the Mweelrea succession (here the term is in its original, wider sense and includes both Mweelrea and Maumtrasna Groups of Dewey), they pointed out that the upper part of the sequence may be of Bala age. They made the interesting deduction from the evidence of fresh feldspars, occurrence of lenticular beds of pebbles, and frequency of false-bedded sandstones, that the Mweelrea sediments might have been deposited under arid continental conditions.

In view of the evident confusion as to which sediments comprised the Mweelrea Group, it is not surprising that a controversy arose concerning the possible existence of an unconformity at the base of these sediments. Geikie (1889) and Kilroe (1907) referred to the upper part of the Partry Series, termed the Maumtrasna Group in this thesis. Kinahan (1874-91) referred to the lower part of the Partry Series, termed the Mweelrea Group by Dewey (1960). In effect, Kinahan believed in the presence of an unconformity at the base of the Partry Series, and Geikie considered him wrong because in his view there was no unconformity in the middle of the Partry Series. A consideration of the base of what is at present referred to as the Partry Series reveals that to the west of the Lettereen fault there is perfect conformity with gradual change, from slates, through sandstone layers to grits and conglomerates.
To the east of the fault the grits and conglomerates rest on slates in the Glennagashleeny-Glen Mask district, on pillow lavas and agglomerates, probably of Arenig age, at Bohaun, and on 'felsites' in stream H of Gardiner and Reynolds (1909) at Derassa. This suggests an unconformable relationship. In the fault zone of the Lettereeneen fault some conglomerates, in which slates act as matrix, have been seen. These may indicate some form of syn-depositional movement along the fault, the western side being down-thrown relative to the east. Clearly the controversy could have been partially resolved had Kinahan and Geikie visited the field together. In this respect Kinahan (1891) may have been partly justified in his allegation that Geikie had not seen sufficient of the rocks in Murrisk to judge competently. Each could however, have formed his early opinion of the relationships from different positions on the outcrop of the Series. If Geikie examined only the area to the west in the Lseinane district, he would only have seen a conformable junction at the base. Similarly, if Kinahan mapped to the east of the Lettereeneen fault first, then he would have seen a marked unconformity at the base of the Series, and this may have coloured his future attitude to the junction.

Gardiner and Reynolds (1909) described the rocks of the Tourmakeady district, which lies outside the area under discussion in this thesis. They referred to the coarse grits and conglomerates of Balsall age, which lie to the west of and above
the Arenig and 'Llandéilo' beds, as being "in direct relation to the green felsite." Since this felsite is later (p. 129) stated to be intrusive in nature, there is an implied unconformity, although at no point is an unconformity stated to exist. They point to the belief of Kilroe (1907), reiterated by Carruthers and Muff (1909), that the grits and conglomerates were partly of Llandeilian and partly Bala age. In 1910, in a report on the geology of the Glensaul district, Gardiner and Reynolds show the Bala(?) beds to occur above a stratigraphical break, below which beds of clearly Arenig age were identified. Those beds previously (1909) considered as of Llandeilian age, and lying below the upper conglomerates, were now considered to be Arenig.

The presence of pillow lavas below the conglomerates was recorded east of the Partry Mountains. A similar situation may obtain on the west of the mountains, at Bohaun, where beds of grits and conglomerates of probable Arenig age are faulted against pillow lavas. The two groups of spilitic lavas may be equivalent.

Wager and Andrew (1930) demonstrated that the schists of Connemara are of garnet and sillimanite grade of metamorphism while the Ordovician and Silurian rocks of Murrisk are uniformly of chlorite grade. Since this break of metamorphic grade is abrupt the metamorphism of the schists could not have occurred during the Ordovician – Silurian period.
Bailey and Holtedahl (1938) considered that the rocks of Murrisk occupy a position analogous to that of the Midland Valley of Scotland. "The Highland Border Belt", they stated, "is represented by serpentine, traceable for 13 Kms along the strike." This serpentine runs in an east-west direction across the northern part of Murrisk. South of the serpentine belt they identified two tight synclines in the Silurian rocks which, they noted, are unconformable on the Ordovician. They followed Wager and Andrew (1930) in believing the Connemara Schists to be of Pre-Cambrian age, but pointed out that "the unconformity at the base of the Silurian speaks of strong intra- or post-Ordovician movement." The Mweelrea beds were noted for their great thickness and increasing arkosic character in the higher horizons.

Harper (1948), in a description of the Rossroe Grits, south of Killary Harbour, concluded that a shoreline was relatively near and to the south during the Upper Arenig, from evidence of coarse sediments of southerly origin.

Theokritoff (1951), after brief reconnaissance, suggested a division of the Ordovician rocks of the Doolough Series near Leenane into four parts: The Shanecroan Slates, Sheeffry Grit, Glenummera Slates, and the Mweelrea Grit, in ascending order of age. Stanton, (1953) discredited the Shanecroan Slates, and showed them to be a sheared form of Sheeffry Grits. Theokritoff also recognised the existence of a second Silurian syncline,
to the south of Killary Harbour.

Stanton (1953; and 1959) provided a modern interpretation of the Ordovician and Silurian rocks of the area. He established three principal stratigraphical terms:

3. Mweelrea Grit (Caradoc and/or Llandeilo)
2. Glenumma G Slate(? Llanvirn)
1. Sheeffry Grit (Arenig)

The Sheeffry Grit is a series consisting principally of greywackes and slates, in which the slate proportion increases northward. This observation apparently supports the suggestion that a shoreline lies to the south of Killary Harbour (McLaren and Miller 1948).

The Glenumma Slates are a group of locally fossiliferous slates which grade upwards, through an intermediate zone of flagstones into the Mweelrea Grits. Tuffaceous horizons are also present in this series.

Stanton (1959) considered that the Mweelrea Grits are truly conformable upon the Glenumma Slates in S.W. Murrisk. As indicated above such a relationship is seen in the western part of Eastern Murrisk. (The discontinuity is only seen in the area north, east and south-east of Glen Mask).

Fossiliferous horizons occur within the Grits, and are clearly of marine origin. The Grits were considered to have been deposited under water. Stanton suggested that the Connemara Schists may have been the source, since much of the
detritus is similar in composition to those rocks. Within the Mweelrea Group he recognised five layers of welded tuffs, which form good marker horizons.

Stanton considered the Cregganbaun Series (Silurian) to be Llandoveryan rather than Wenlockian, but without additional evidence. He provided the first detailed stratigraphical description of the south-western part of the Croagh Patrick syncline.

The structure of the western part of Murrisk is shown to be complex in the Sheeffry Grits, but with the exception of the Mweelrea syncline none of the folds have been traced eastwards into central Murrisk by Dewey (1960).

McKie and Burke (1955) postulated that the greywackes and pillow lavas of the S. Connemara Series were equivalent in age to the Arenig rocks of Murrisk. They also believed the Galway granite to be of Taconic age.

McKerrow and Campbell (1960) continued the mapping of the Lower Palaeozoic inlier, using the divisions established by Stanton (1953). They noted that the rocks of the Tourmakeady district and the Sheeffry Grits were of similar age. They showed a similar sequence to that of the Tourmakeady district to the south of Lough Nafooey, with cherts, spilitic lava, limestone, and basic tuffs. The conglomerates of the Mount Partry Beds are coarse, and contain boulders attributed to a source in the Connemara Schists.
Fragments of green slates in the base of the Mweelrea sediments were taken to suggest pre-Mweelrea erosion, and McKerrow and Campbell clearly believed in the existence of a basal Mweelrea unconformity in this area. They state that above I. B. (≡ M. T. 1.) conglomerates dominate the sequence. Thinning of the series and increased coarseness were believed to indicate proximity to a southern margin to the basin of deposition. The absence of 'sillar bases in the 'ignimbrite' beds was taken to indicate terrestrial deposition, and a possible vent for their extrusion was postulated to exist at Curraghcreagh.

Their principal contribution lies in the description of the Silurian rocks of the southern syncline, where they located an unconformity within the Owenduff Group. The Lower Owenduff Group is composed of sandstones, some of which are fossiliferous but the Upper Owenduff Group is said to consist of greywackes which pass upwards into current-beded sandstones (of non-turbidite origin), and slates. The Salrock Group consists entirely of slates.

McKerrow and Campbell (1960) disagree with Bailey and Holtedahl (1938), who considered the Salrock fault as the continuation of the Southern Uplands Fault. They state that there is no close parallel between the two faults, and that since the Salrock fault dies out eastwards, and has a different direction of throw, they cannot be equivalent. It is
interesting to note that if there is some form of scissors movement along the fault, then at some point the throw will virtually disappear and direction will become reversed. No additional evidence on this problem is given in this thesis.

Anderson (1960) divided the sediments of the Croagh Patrick Syncline into three groups: the Knockfadda Psammite, the Cregganbaun Pelitic and Calcareous Group; and the Croagh Patrick Quartzitic Group, which is basal to the Series. He made no attempt to correlate these subdivisions with those of McKerrow and Campbell (1960) from further south. At the base in most of the area is a conglomerate with deformed pebbles. This conglomerate Anderson believed to continue eastwards to Moher Lough, but no exposures exist along the outcrop of this conglomerate for the two miles which lie in the Eastern Murrisk area. The easternmost conglomerates of this Group observed on the southern limb during the present work were in the Oughtty area.

Anderson gave a simplified account of the structural history, in which two phases of folding were recognised. He stated that the truly synclinal nature is demonstrable from the relationship of bedding to cleavage. In many cases in the southern limb bedding is overturned and the relationship which is seen is misleading if interpreted on this basis. There are ample sedimentary structures which provide irrefutable indication of the nature of the structure. Anderson recognised
a structural culmination to the north of Bouris, from which the minor folds of the first phase of folding plunge in each direction. The second phase of folding produced northwestward plunging minor folds.

A late Palaeozoic regional metamorphism during which the rocks reached a high chlorite-muscovite grade was considered by Anderson to be responsible for the present metamorphic state of the rocks. During the second phase of folding new chlorite flakes developed parallel to the axial planes of the minor folds.

Dewey (1960), in a study of Central Murrisk, examined the facies of the rocks with particular emphasis on the Sheeffry Grits. Subdivision of the Sheeffry Grits was undertaken and greywackes of the turbidite facies were shown to have been deposited in a trough which extended in an east-west direction. A changing environment indicated the growing influence of a source to the south and turbidites, both axial and lateral to the main trough, were recognised.

With the dominance of the southerly source deposition of the Mweelrea Series took place. This was believed to be of deltaic origin, subject to periodic flooding, to account for the slate horizons. The welded tuffs of the Mweelrea Group were given some attention, and a source in the Tourmakeady - Lough Nafooey area postulated.

Division of the lower part of the Silurian succession
in the Croagh Patrick Syncline, using the equivalents of divisions of McKerrow and Campbell (1960) was suggested, and study of some of the sedimentary structures attempted. Dewey again recognised an unconformity in the Llandoverian rocks of the Owenduff Group, and demonstrated a source to the east.

A detailed study of structures in the Silurian rocks of the Croagh Patrick Syncline was given, and seven phases of movement demonstrated, two of which produced fold features. Dewey disagreed with Anderson concerning the orientation of the minor folds of the second phase of folding. Anderson stated that these plunge steeply to the northwest; Dewey observed them plunging gently to the east. The present work indicates that these two sets of folds are of the same generation, and that their difference of orientation is dependent almost entirely upon the orientation of the bedding planes prior to the second phase of deformation. Where bedding is steep, or southward dipping as in the Oughty-Letterbrock area, the minor folds plunge northwestwards. Only a complete examination of the two areas is able to resolve this difference.

Dewey considered that the Galway granites were intruded during the Arenig and relates them to acid tuffs within the Sheeffry Series. He suggested that the granites were first unroofed during deposition of the Glenummera Series and eroded with the over-lying Connemara Schists, the meta-
<table>
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<tr>
<th>Layer</th>
<th>Thickness</th>
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<tr>
<td>Carboniferous</td>
<td>Limestone</td>
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<td>Sandstone</td>
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<td>Conglomerate</td>
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<td>Silurian</td>
<td>Upper Owenduff Group</td>
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<td></td>
<td>Massive sandstones 2800'</td>
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<td></td>
<td>Siltstones 1000'</td>
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<td>Green slates 1100'</td>
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<td></td>
<td>Quartzite 600'</td>
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<td>L. Owenduff Gp.</td>
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<td>Black slates 25'</td>
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<td>Ordovician</td>
<td>Maumtrasna Group 9500'</td>
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<td>Derrylea Group 4200'</td>
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<td>Banded Group 0-300'</td>
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<td>Creggan-a-tiadwar Group 1000'</td>
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<td>Lugacolliewe Group 2800'</td>
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<td>Lugaloughan Volcanics 0-3'</td>
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<td>Drummin Group 1000-2400'</td>
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<td>Sheeffry Series</td>
<td>Owenmore Group 2800'</td>
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<td></td>
<td>Letterbrock Conglomerate Group 1350'</td>
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morphism of which he believed to be of Upper Cambrian age.

Dewey (1962) detailed the sedimentary features of the Derrylea Group of the Sheeffry Series. He considered that the Highland Boundary Fault formed an arcuate scarp defining the northern boundary of the depositional trough during the Upper Arenig. To the south the Connemara Cordillera acted as the source for lateral turbidites and an extension of these mountains to the north-east provided material which formed an unstable deltaic accumulation from which flowed turbidites along the axis of the trough. He pointed out that the grey-wackes of McKie and Burke postulated a somewhat similar origin.

A table of the formation names to be used in this thesis is given in Fig. 2. Of these, two differ from previous usage. The Glenummera Slate Series of Dewey (1960) is referred to as the 'Glenummera Series', since it is not entirely of slates, but contains important horizons of sandstones and conglomerates. The term 'Partry Series' is used for the sediments which rest on the Glenummera Series but are believed to be older than the Silurian. Within the Partry Series are the Mweelrea Group, and the Mamtrasna Group, the former being the synonym of the 'Mweelrea Grit Series' of Dewey (1960) and the 'Mweelrea Grit' of Stanton (1953 and 1959).

The Ages of the Rocks.

Carruthers and Muff (1907) discovered a graptolite fauna
with Didymograptus hirundo in the upper part of the Sheeffry Series near Doolough. Stanton (1953) found further graptolites including Didymograptus extensus some 4,000 ft. lower in the succession in S.W. Murrisk. Thus most of the rocks of the Sheeffry Series are of Middle or Upper Arenig age. The Owenmore Series is probably of Lower or Lower Middle Arenig age.

The succeeding Glenummera Series, which lies beneath the Partry Series, contains a fauna, found by Stanton (1953), and believed by Dewey (1960) to be of possible Llanvirn age. The Tourmakeady Beds are overlain unconformably by the Partry Series, and themselves contain a brachiopod-trilobite fauna of Llanvirn age (Gardiner and Reynolds, 1909, and Williams - in Dewey, 1960 -)

Stanton (1953) examined a trilobite-brachiopod fauna discovered by Carruthers and Muff (1907) in the slate bands of the central part of the Mweelrea Group in S. W. Murrisk. This fauna, in the lower part of the Partry Series, was thought to be of Llandeilian - Caradocian age. No fossils have been found in the Maumtrasna Group.

The Geological Survey of Ireland (1876) recorded fossils from the Cregganbaun area and assigned them to a "probable Wenlockian" age. Stanton (1953) believed the rocks to be Llandoveryian. McKerrow (in Anderson, 1960) also considered fossils from this area to be of Llandoveryian age. Williams
Fig. 3. Principal localities referred to in the text.

Clew Bay
Belclare
Carrowmalurgan
Owenwee R.
Knappagh
Lough
Aghagower
Knappagh L.
Letterbrook
Moher Lough
Liscarney
Derrycraft
Carrowreagh
Roighaun
Carrownalurgan
Creggan Lough
Cordarragh
Derrinkee
Lough
Claddy
Sliave Mahanagh
Sraheen
Derrinkee
Lough
Carrowreagh
Cordarragh
Sraheen
Gortbunnacullin
Croaghrimbeg
Croaghcrom
Tonlegee
Sraheena Lough
Croaghcrom L
Sraheen
Garrangerra
Glennagashleeny
Lough
Glen Mask
Loughanshee
Glen Mask
Croaghrimbeg
Lough Gtewaugh
Lough
Glenmask
Erriff
9° 30'W
53° 40'N
Erri
Glen
Tourmakeady
Shangort
Derreenascooba
Derrendaffderg
Kiltavallia
Tawynasagy
Killassaghna
Bahaun
Gartbunnacullin
Carr owkennedy
Slive
Mahanagh
Claddy
Derrinkee
Lough
Carrowreagh
Cordarragh
Sraheen
Derrycraft
Carrowreagh
Roighaun
Carrownalurgan
Creggan Lough
Cordarragh

Scale of one inch to the mile.
(in Anderson 1960) considered them to be Upper Llandovery or Wenlock and Anderson (1960) considered them to be of Wenlock age. Dewey (1960) again on unpublished evidence of McKerrow assigned them to the Upper Llandovery. In the present work both these ages will be accepted for the rocks.

No additional palaeontological evidence indicating the ages of the rocks has been found during the present work, and the three age relationships remain:

The Sheeffry Series, of Middle and Upper Arenig age;

The Glenummemera Series of Llanvirn age; and

The Mweelrea Group of Llandeilian – Caradocian age.

Beds of tuff occur throughout the sequence, and enable correlation of the enclosing facies to be made. The welded tuffs of the Mweelrea Group are particularly good examples of this, for they provide excellent marker horizons in an otherwise complex sedimentary sequence. One such bed shows that the base of the Mweelrea Group is a diachronous feature, for the same tuff may be traced from within the Mweelrea Group to over 1000 ft. down the succession in the Glenummemera Series.

Faulting.

Several phases of faulting have affected the rocks in the area. The dominant break is the Erriff fault (Dewey 1960), which runs north-east – south-west across the area.
to this is the Carrowkennedy hinge fault, about 4 miles to the north. Associated with the principal foldings which have affected the Silurian rocks are at least two slides (Bailey 1910 p. 593), more east north-east to west south-west in direction. Approximately parallel to these runs the Highland Boundary fault (Bailey and Holtedahl, 1938), which crosses the north of the area.

The Lettereeneen fault zone is bounded by a pair of major north-north-west to south-south-east trending fractures between which the faults appear to have juxtaposed the Mweelrea Group and the Maumtrasna Group, since there is an abrupt change of facies across the break. They are pre-Carboniferous in age, for the sub-Carboniferous surface cuts across the up-turned rocks in the faulted block. Later, north and south post-Carboniferous faults have cut this surface in the Glennagashleeny area. Another post-Carboniferous fault brings the Dalradian and Carboniferous Series into contact south of Westport. Many of the earlier faults were re-activated during this period of faulting.

**The Pleistocene Glaciation.**

Evidence of two glacial environments is seen in Eastern Murrisk. In the south, a highland glaciation is indicated by the great corrie now occupied by Lough Glenawough, and the steep sided valleys of Glen Mask and Glensaul. To the north of the
Partry Mountains the open, low-lying ground is characterised by the presence of ice-polished pavements, subdued roches moutonnées, and a thick cover of outwash sands and gravels, typical of lowland glaciation. North of the Black Mountain ridge there is a thick cover of drift in the form of drumlins, again suggesting a lowland environment of deposition.

Highland Glaciation.

The corrie of Lough Glenawough is a huge amphitheatre, rather more than half a mile wide; and bounded on three sides by steep cliffs of sandstones and conglomerates of the Mweelrea Group. This hollow was the centre of formation of the ice. A combination of frost cracking and plucking removed much of the debris from the walls of the corrie. This debris was used by the ice to carve a hollow in the floor of the corrie, from whence the ice rose over the lip, to flow away northwards.

The corrie lake is not deep, and its floor is littered with angular blocks of sandstones which have fallen from the walls. The nearly circular shape of the lake is characteristic of those found in such a location, and it shows an apparent false outlet on the northwestern side, while the stream drains from the north eastern side. The plan of many glacial lakes in North Wales, e.g. Llyn y Gader, Glaslyn, and Marchlyn Mawr, shows a distinctive rectangular protrusion from the regular circular or arcuate outline of the lake. From this strange protrusion may flow the present drainage, but in many cases this appears to be
an old outlet channel, perhaps formed when the present outlet was blocked by ice or even moraine. Solid rock is exposed around the north-western side of the lake and it is only the north-eastern part where morainic deposits are present.

The three courses of the headwaters of the Aille River flow into a hollow, which appears to have been the site of the head of the Glen Mask glacier. The main valley of Glen Mask is steep-sided, and above the drift, which now occupies much of the floor, the sides rise steeply for 300-400 ft. (100-130 m). The valley is relatively narrow, perfectly straight, and has several large roches moutonnées on each side. The tributary stream on the southern wall clearly flows in from a hanging valley, and indeed, the three streams of the headwaters also fall steeply into the principal valley. The spectacular waterfall, where the stream drops 180 ft. (60m), marks the point where the terrace deposits of drift have been cut away and the solid rock is exposed in the stream for the first time. The break of slope probably also represents the lip of the corrie, for above the falls the valley opens out again into a wide hollow.

Other centres from which ice flowed include the small hollow of Loughanshee on the northern side of the Partry Mts., and Glennagashleeny. The hollow now occupied by Loughanshee is very steep-sided, and cuts no more than 600 ft. (180m) into the face of the mountain. Like the corrie of Lough Glenawough, it owes its location partly to the presence of faulting and intense
Fig. 4. Simplified geological maps of Murrisk.

a) The geology as known before the present work

b) After the present revision.
jointing in the rocks. The lake has been dammed behind two moraines deposited during the final stages of melting.

The possible existence of a small glacier in Glennagashleeny is deduced from the presence of striations on the south-eastern flank of Croaghrimcara Hill, and from the presence of deep drift which covers much of the open valley. During the period of melting, it is clear that the ice split, some remaining and flowing southwards off Croaghrimcara Hill, which is partly surrounded by a low morainic arc. Part of this terminal moraine blocked the drainage and led to the presence of a lake, the now dry bed of which is evident south east of the hill.

The Glennagashleeny glacier may not have been of major importance on its own, for ice may have flowed northwards from the eastern side of the Partry Mountains across the wide col at this point. Ice originating in the eastern part of the Connemara mountains further south flowed northwards along an arcuate path clearly indicated by the drumlins which form islands in Lough Mask. (Fig. 6). At the height of the glaciation this ice flowed across the north-eastern end of the Partry Mountains, where the range is at its lowest. This is evidenced by occasional striations on the eastward facing slope, and, more forcibly, by the presence of extensive deeply scored, ice-polished surfaces on the northern side of the crest of the ridge, near the summit of Bohaun. This is a direct contradiction of conclusions reached by Dewey (1960), who believed the watershed of the
Fig. 5. Past and present workers in Murrisk and North Connemara.
Partry Mountains to have been an important divide during glaciation.

North of Derrindaffderg, where the rocks are well exposed the striations of the ice from the Central Plains are ubiquitous. From the shapes of the roches moutonnées and the directions of the striations it is clear that the ice moved in a dominantly northward or north-westward direction. Striations due to continued movement along this direction are seen in Teevinish, where striae due to both Partry Mountain ice and Central Plains ice occur on different surfaces.

During retreat of the ice, detached remnants remained as small valley glaciers and névées in the open hollows on the south-eastern slopes of the Partry Mountains. These small glaciers rarely produced moraines, and the large Derryveeny valley is filled with boulder clays carried by ice from the South West. Unable to pass over the ridge during retreat, the ice melted in the valley, depositing the boulder clays.

Ice, originating in corries on the northern side of the Partry Mountains, and some which entered the area from the Erriff valley to the west, flowed generally northwards or north-north-eastwards. The ice accentuated the hollows in the Slieve Mahanagh ridge, at Cordarragh and Corveagh. The hollows are largely controlled by faulting, which is prevalent in these two areas. At the eastern end of the ridge, the ice
Fig. 6. Glacial features of Eastern Murrisk.

- Outwash Plain
- Terraces
- Drumlin
- Moraine
- Striation
- 1, 2, 3 Corries

Miles
from the Central Plains flowed in a north-westerly direction, and was clearly swinging round towards Clew Bay. This acted in such a way as to confine the Partry Mountain ice and ensure its constant northward movement.

It is important at this stage to consider the regional setting during the height of the glaciation. From Fig. 7 it will be seen that Clew Bay formed the principal route by which ice flowed into the Atlantic from this part of Ireland. While the Central Plains were covered by the ice sheet during the height of the glaciation, some of the ice from the Connemara Mountains flowed northwards towards the Clew Bay outfall. The ice was countered by a major flow towards the south-west down the valley of the Newport river. The two masses of ice met in the Westport area and together flowed westwards into Clew Bay. The features of the individual flows are clear on the surface, with drumlins aligned in the flow direction in each case. In the area immediately east of Westport, however, the chaotic topography may result from the confluence of the two streams.

The existence of the powerful westerly moving ice stream north of the Croagh Patrick - Black Mountain ridge, may have enabled this subdued line of hills to contain much of the Partry Mountain ice to the south of its eastern end during the later stages of glaciation. During the height of glacial activity it is possible that some ice crossed the ridge, which resembles a huge roche moutonnée. During the phase of northward flow
Fig. 7. Direction of ice flow in part of western Connacht.
Boheh Hill acted as a 'crag' behind which was deposited a 'tail' of boulder clay, which stretches into the townlands of Knappaghmanagh. However, during the retreat of the ice sheets the Partry Mountain ice reached as far as this line for a long period. This static phase during retreat of the ice is indicated by the wide belt of moraines, found to the south of the ridge in the Farnaght - Knappagh - Derrygarve area. These moraines, often over 50 ft. (18m) in height, have rounded outlines, and in many cases consist almost entirely of angular blocks of greywackes from the Derrylea Group. Some show small jasper pebbles, indicating an origin in the Croaghrimcara area. The morainic belt decreases in width westwards, but is everywhere followed, to the south, by an extensive cover of glacial outwash sands and gravels.

There are many small exposures in these out-wash deposits, but by the road Creggandarragh is a large disused sand pit in which are seen most of the features recorded at other localities on the outwash plain. This now disused quarry was actively worked until the late 1920's for the very clean quartz rich sands which were used for building. The sands were worked to a level 35 ft. (11m) below the level of the road, and so a total thickness of 50 ft. (18m) of sands and gravels are known at this locality.

The sands are clearly water-deposited and show distinct false-bedding indicating south-easterly derivation. The partly-
Plate 1. Sands and gravels of the glacial outwash plain, Creggandarragh.

Plate 2. Channel in outwash sands and gravels, Creggandarragh.
rounded pebbles in the finer layers of gravel show no preferred orientation of their axes although most are parallel to the bedding. The coarser gravels often show a crude form of reversed grading with larger boulders in the top layers, and smaller ones lower down. The sands are often banked up on to any boulders which project upwards into the succeeding beds. Some of the very large blocks appear to have been dropped into position, for they break through and buckle earlier deposits. Such a method of introduction suggests that the blocks may have been transported in the final stages by floating ice on the surface of a lake. This is not inconsistent with the clear evidence for deposition under water seen in the sands and fine gravels. Channels up to 2 ft. (60cms) deep, and infilled with coarse boulders cut into previous deposits and may themselves be cut across at the top of late bedding planes. Pebbles of slate in the sands and gravels are often split as though by frost shattering, the many fragments being embedded in the sands in very close proximity to each other.

The pebbles of the gravels are varied in composition, being mainly of pink arkose, like the sandstones of the Mweelrea Group, but also including grey and green sandstones, green slate, pink welded tuff and granite.

The existence of a lake during early stages of regression of the ice sheets, bounded to the north-east by the Central Plains ice, to the south by the ice from the Partry Mountains and the Sheeffry Hills, and on the north by the Black Mountain - Croagh Patrick
ridge may be responsible for some of the anomalies in the present drainage of the area. The first outlet of the lake appears to have been by way of the narrow wind gap to the north-west of Knappagh. This may have acted as the principal outlet for only a short period, before the main flow cut the present course of the Owenwee River, which is deeply entrenched where it cuts through the ridge.

During further retreat of the ice a series of small moraines were deposited on the western flank of Boheh Hill. These stretched onto the low ground near the Boheh Loughs, and it is probable that at this stage any drainage which existed in the valley of the Owenwee River was diverted northward, and through the gap at Knappagh. The moraines to the north of the Letterbrock Ridge consist principally of greywackes of the Sheeffry Series, with some Silurian Quartzites, and occasional boulders of sandstone from the Mweelrea Group.

Later stages of retreat are marked by moraines, which lie in arcs to the north and south of Carrowrevagh Hill, and broken lines of moraines in the Carrowkennedy area. Some small temporary moraine-dammed lakes formed in the Carrowkennedy area, for three sections of varved clays have been seen. (In none of these have more that 25 alternations of coarse and fine grained sediment been seen.) At Carrowkennedy the southwestern end of the Slieve Mahanagh ridge is bordered by trains of erratics. In the Claddy-Derryilra area the moraines are composed principally of boulder clay which supports arable farming, and each moraine is outlined by the walls of isolated fields. Many of the features in the area of the Carrowkennedy -
Owenmore bog are due to retreat of ice centred on the Sheeffry Hills.

The drift immediately west of Knappaghbeg Lough is composed mainly of alternations of sands and clays. The repetition resembles a very coarse varved succession, with the beds dipping at 10° northwards. The gravel debris is mainly of southerly origin, and imbrication is seen in some of the pebbles. The uppermost bed in this section is 3 ft. (1m) in thickness, and contrasts sharply with the lower members. The debris contained in it is coarser and more closely packed, and consists almost exclusively of fragments of purple Silurian slates. Slump structures indicate that the bed moved from the west, sometimes cutting into the underlying drift. This uppermost layer is the result of late glacial solifluction, which caused the unstable cover on the hills to the west to move downhill towards the east.

On the eastern side of the Boheh and Liscarney mass, another series of moraines is present, but in this case most of the glacial erratics originated in the Corveagh-Teevinish area. Still further east, south of the Aghagower area the cover of sandy drift forms high rounded ridges parallel to the front of the Slieve Mahanagh ridge and resting on the Carboniferous sediments. In the Mace district the drift is thin, and composed principally of Carboniferous debris. The drift increases in importance southwards and around Sraheena Lough deep stream sections reveal boulder clays of over 50 ft (18m) in thickness.
In the south-western area the phenomena due to retreat of the ice are dominated by the wide terraces above Derrinkee. These terraces were probably formed by ponding of waters due to the presence of a glacier in the Erriff valley. From Slieve Mahanagh it is possible to recognise twenty-two levels, some of which continue to the east of the road at Derrycraff. Dewey (1960) has stated that the prominent terraces of Derrinkee may be traced to Glenane, where they have fallen in height by about 270ft. (90m). Since Dewey has observed the drop in four levels, it is probable that the other eighteen less prominent terraces will show a similar drop.

In the Derrinkee area the terraces, which are mostly covered by bog, have been cut into by the Derrycraff River, and stand as sets of paired terraces on each side. The rise to each step is usually about 15ft. (5m), although some rise 20ft (6.5m) and others only 10ft (3m): the terrace levels may be wide, reaching a quarter of a mile in width in the most prominent terrace.

The regular nature of these terraces suggests that they are linked with a large former lake. Each of the levels may represent the floor level related to a particular outlet of the stream draining the lake. With successive drops of base level the level of the lake floor decreased and stepping resulted. Dewey (1960) has suggested that the 'principal' levels may be linked with breaches in the moraines which blocked the valleys, preventing westward flow of the water.
It is probable that the many peat-covered levels seen on the slopes of Slieve Mahanagh are of similar age and origin to those of the Derrinkee bog. The existence of a large lake towards the end of the Pleistocene glaciation draws attention to sands and clays which rest upon the moraines, and indeed form the sediments of the terraces in many cases. Above Erriff the deposits consist of sands and red clays, a study of which reveals that the retreat of the Erriff valley glacier did not take place in one simple phase of melting. The fluvio-glacial sands on the lower terraces of the Erriff valley are overlain by boulder clays, which probably mark a temporary readvance of the ice. At higher levels, however, the sands are overlain by thin deposits of red clays, the colouration of which is due to oxidation of iron, transported in solution, from the sediments of the Partry Series.

The sands are water deposited, and show false-bedding in many places. Horizontally bedded sands and gravels are seen in many exposures, the long axes of the pebbles being usually sub-parallel to the bedding. In the disused quarry at Bohaun there is a marked imbrication which suggests movement of the debris from the south-west towards the north-east. The sands are light coloured and consist principally of debris from the Mweelrea and Derrylea Groups, and the Glenummera Series. Individual grains are white, pink or pale green, while pebbles are usually of sandstone, with some welded tuffs, jaspers, and granites.

Nolan (1875) observed the wide terraces in the area and
believed that they extended high up the slopes above Glen-
nagashleeny. The terraces to which he referred are clearly related
to the small stream near the col and are in no way connected with
the Derrinkee terraces.
CHAPTER II

ORMVICIAN STRATIGRAPHY.

Deposits of Arenig Age.

Introduction

In Eastern Murrisk an area stretching from Liscarney and Letterbrock in the north as far as Erriff village in the south-west, and Croaghrimcara and Bohaun in the south-east, is occupied by a series of darkly coloured rocks largely of the greywacke suite, which are thought to be of Arenig age.

No fossils have been found during the present investigation, but Stanton (1953) discovered graptolites of the Didymograptus extensus zone in the Sheeffry Series of S.W. Murrisk, which are equivalent to the central part of the Arenig succession of East Murrisk. The succeeding Glenumbera Series contains a further fauna, believed by Dewey (1960) to be of Llanvirn age.

Since no unconformities occur within this part of the stratigraphical column in E. Murrisk, it is assumed that the rocks below the Sheeffry Series are older than Middle Arenig in age, and those above it, younger. It is possible that sedimentation was continued from Cambrian times into the U. Arenig here, but in the absence of evidence to indicate Cambrian age, all rocks from the Letterbrock Group upwards are assumed to be of Ordovician age.

In the north, where the oldest rocks are exposed, the sediments are inter-bedded greywackes and conglomerates, followed by a series
of greywackes (mostly of easterly derivation) intercalated with which are many beds of tuff. Higher still are greywackes in which both axial and lateral turbidites have been recognised, the lateral turbidites becoming conglomeratic in the extreme south, where some pillow lavas are associated.

Dewey (1960) recognised ten stratigraphical divisions in the Arenig rocks. These he divided into two Series, an upper, Sheeffry Series, and a lower, Owenmore Series. The problems of correlation of the sub-division from Central Murrisk to Eastern Murrisk are considerable, but the equivalents of his divisions have been recognised in E. Murrisk. Only in the extreme north and south are exposures continuous between the two areas, and the area between the Owenmore River and Derrakillew, through which pass eight of the intergroup boundaries, is occupied by bog in which exposures are non-existent.

The base of the Derrylea Group is easily identified in the village of Claddy, and has been traced eastwards along subdued whaleback exposures into Corveagh Hill. Below this are a few exposures of closely interbedded grits and slates, evidently partly of turbidite facies and with some autochthonous slates. No volcanics have been recognised in this group, which is no more than 300 ft. (92m) in thickness, and is apparently the equivalent of the Banded Group of Dewey (1960).

The next 1000ft. (310m) of the succession below the Banded Group is one of greywackes with few apparent bottom structures.
Load casting is common and grading, emphasized by swinging cleavages, is seen in some beds indicating younging towards the south. Reversed grading is not uncommon. Two cream-coloured acid tuff horizons occur within this Group - the Creggan-a-tiadwar Group, the base of which is not well defined here.

No horizon corresponding to the Cuilmore Volcanics has been recognised in Eastern Murrisk, perhaps due to lack of exposures compared with the excellent cliff sections along the Sheeffry Mountain roadsides, but it is possible that it may have thinned out eastwards.

Two very clear acid tuff horizons occur in the next group lower in the succession - the Spink Group. In this the grits and slates are very varied, and in deference to Dewey's identification, the most prominent of the tuffs has been taken to represent the base of the Group, which is, therefore, approximately 1250ft. (383m) thick at Carrowkennedy.

North of the tuffs, which bifurcate to the east, lie: a varied group of greywackes, slates and shales, bearing bottom structures indicating an easterly derivation. This is the Lugacolliwee Group, and is 2,800ft. (860m) thick.

The boundary between the Lugacolliwee Group and the Drummin Group may be approximately at the location of the tuff bed at Sruhaunderrakillew, which, although only 3ft.6in, (1m) in thickness, is believed to be the equivalent of the Lugaloughan Volcanics. This boundary may recur along the Rlhaun road where
associated pyrite is common.

The Drummin Group, according to Dewey (1960), consists of greywackes and silts with few volcanics and is largely of southerly provenance. This definition does not aid distinction of the Group elsewhere, but it is clear that these rocks - massive greywacke grits with graded silts and autochthonous black slates - must outcrop in the Carrowmore bog area. This group, which in Central Murrisk is recorded as being 2520ft. (775m) thick, is nowhere more than 2,400 ft. thick in Eastern Murrisk, and thins rapidly eastwards. Some of the 'thinning' may be due to the presence of the Carrowkennedy hinge fault (Dewey 1960) which runs south-westwards from Corveagh, where it bounds the southern margin of the Carboniferous embayment. The fault appears to run along the outcrop of the Drummin Group in the east and this may account for the decrease in thickness of the Group to 1,000 ft (310m) near Cordarragh.

In the north the Letterbrock Conglomerates are continuously exposed along the Letterbrock ridge and correlation between individual boulder beds is possible. The junction of the Letterbrock Conglomerate Group and the overlying Owenmore Group which was not defined by Dewey (1960) has here been taken to lie at 20ft. (6m) above the southernmost conglomerate of the Letterbrock ridge, at the top of the massive grit which overlies it. The isolate hill of Carrowrevagh is composed of massive greywackes and slates, with a few highly contorted grit horizons, and one distinct conglomerate bed. These rocks are assigned to the Owenmore Group from their position relative
Fig. 8. Map of the Letterbrock area

Upper Owenduff Group
Lower Owenduff Group
Interbedded grits and slates
Massive grits
Conglomerate
to the Letterbrock Conglomerates. However, only one basic tuff bed has been seen here, whereas Dewey (1960) has identified two such beds in the Owenmore Group. Two acid tuff beds occur on Liscarney Hill, and towards Lanmore, where the slates appear identical to those of the Owenmore Group. The proximity of the grits and slates of Liscarney Hill to the basal Silurian unconformity suggests that the sediments are probably lateral equivalents of the Letterbrock Conglomerate Group, and are composed of axial turbidites and autochthonous slates of this age. The location of the Letterbrock - Owenmore Group boundary east of Carrowrevagh is not known accurately because the greywacke suite of the Owenmore Group is clearly identical to the thin greywackes inter-bedded with Letterbrock Conglomerates and the massive grits associated with them. It has been provisionally placed to the north of the Lanmore Slate Quarry.

The Letterbrock Conglomerate Group.

A group of conglomerates interbedded with greywackes and slates is exposed along the southern flank of the Letterbrock ridge. In the western part of the ridge Dewey (1960) recognised this Group as being a distinct unit of the Owenmore Series, and he observed five composite beds of conglomerate which vary up to 50 ft (16m) in thickness. He called these the Letterbrock Conglomerates. Dewey described the composition of the boulders in the conglomerate, and concluded that some penecontemporaneous erosion had occurred, for fragments of greywackes and mud pellets are not uncommon.
Sedimentary structures in the Letterbrock Conglomerate Group.

Fig. 9. Broken grains of feldspar seen in thin section from near the Letterbrock slide at Lankill.

Fig. 10 (a) Slate balled up round slipped block of grit.

Fig. 10 (b) Slipped sandstone

Fig. 11 Conglomerate and surrounding grits. Northern side of Carrowrevagh Hill.
The Group is composed of beds of conglomerates, clean, light coloured, massive grits, and interbedded brown grits, and blue-green slates. In the eastern part of the ridge the beds of conglomerate are seen to thin out.

Dewey (1960) recognised a two-fold division of the Group: conglomerates, and greywackes. In the present work three sub-divisions have been recognised, conglomerate, massive grit, and interbedded slates, and as a result a fuller understanding of the mode of emplacement of the sediments has been obtained. The type locality for all three divisions is the large field north-west of B.M.415.8, by the bend in the road at Letterbrock.

**Conglomerate**

The conglomerates are usually composite, formed from several thin beds, and giving a maximum observed thickness of 50ft. (16m) in eastern Letterbrock. The individual beds, which reach up to an observed maximum thickness of 20ft. (6m), show a rudimentary form of grading. The pebbles and boulders in the lower parts are commonly 24-30 cms. and decrease in size upwards, the conglomerates often grading to micro-conglomerate and coarse grained sandstone.

The constituent pebbles are varied in type: pink and white metamorphic quartzite, white vein quartz, biotite-gneiss, white granite, chert, grey grits, shales and occasional small fragments of jasper and dolerite. The pebbles usually lie with both their long and intermediate axes sub-parallel to the bedding
Fig. 12. Sedimentary features of the Owenmore Series.

a) Sheared flame structure. Plan view. 500 yds S.W. of Lanmore Quarry, 120 yds east of the minor road.

b) Grading and load casts
Plan view. 600 yds S.W. of Lanmore Quarry, 70 from road

c) Detail of pebble distribution in Letterbrock Conglomerate.

d) Relationship of pebbles to underlying beds. 100 yds S.W. of spot height 420 beside the road at Letterbrock
(Fig 12c). Many long axes are slightly oblique to this direction, being along the tectonic stretching direction observed in the metamorphosed Silurian rocks to the north and at an angle of 200° to the bedding (Fig. 11). Despite this it is often possible, especially in the more southerly beds, to distinguish the order of emplacement of the pebbles, and so determine the direction of younging of the rocks. This direction has also been observed at the base of the conglomeratic beds, where large boulders often cause depressions in the under-lying bedding planes (Fig. 12d). This 'denting' of the bedding planes suggests that some of the earlier boulders at least were dropped into the sediments. No grooving has been observed in the base of the conglomerate horizons, nor have the conglomerates been recognised to cut into the beds below them. Nowhere has the bedding surface which directly under-lies the conglomerates been exposed for examination, with the result that no detail is known from observation concerning the movement of the boulders along the sea floor.

Few of the boulders and pebbles are angular, and almost all are well-rounded, indicating some pre-depositional period of rounding during transport. The presence of fragments of grey grits and darkly coloured slate within the conglomerates indicates that some penecontemporaneous erosion occurred at a position inter-mEDIATE between the source and the site of deposition of the conglomerate. The grit and slate pebbles are usually angular, and contrast markedly with the rounded debris of metamorphic origin.
Much of the angularity is original and suggests that the sediments had not become consolidated before erosion occurred. The angularity suggests that erosion may have been violent.

The matrix of the conglomerates is essentially a lithic feldspathic sandstone, and as such closely resembles the massive grits which overlie the conglomerates.

To the east of the northward directed road at Letterbrock, two conglomerate beds have been seen; to the west of the road three are present. On the southern side of each bed of conglomerates there is a layer of coarse grained, grey, massive grit, while on the north are alternations of thin beds of grit and slate. Within 400 yds. westwards from the road the southernmost two conglomerate horizons may be traced until they link to form a complex composed of at least five individual conglomeratic units. The change of facies in the intervening beds produces a feather-edge effect on the map (Fig 8). The alternating beds in the east are replaced by massive light grey grits, and these in turn pass laterally into true conglomerates with boulders up to 2 ft. (60 cm) in diameter.

To the north of this complex two additional thin beds of conglomerate appear and increase to 6 ft. in thickness in 100 ft. along the strike. In each case the massive grits lie to the south, interbedded thin grits and slates occurring to the north of the northernmost bed. Still further north, at the base of the main hill slope, the coarse grey grits which succeed the
inter-bedded assemblage, give way to a thick series of conglomeratic beds.

The facies changes illustrated in Fig. 8 give clear indications of a genetic association between the conglomerates and the massive grey grits.

**Massive Grits.**

When conglomerates are present the massive grits occur to the south of each bed. When conglomerates are absent, the massive grits are isolated between groups of finely interbedded grits and slates. The grits appear to be ill-sorted, frequently non-graded, but still relatively well-washed sandstones in which there is little material of clay grade. Where grading has been observed it always has the opposite sense to that in the inter-bedded grits and slates immediately adjacent to the bed.

In thin section the grits are identified as lithic feldspathic sandstones, in which the principal constituent is feldspar, usually plagioclase, and slightly less frequently potassuim feldspars. Extinction angles of up to 25° have been recorded in the plagioclase feldspars, which therefore range up to andesine, but mostly extinction is at a small angle and the feldspars are albite-oligoclase. The feldspars are often altered, and secondary sericite is particularly well developed in the K-feldspars. Many of the feldspar grains are well rounded.

Quartz is less abundant than feldspar, and is of two principal types (strained, and relatively unstrained) of metamorphic and
non-metamorphic origin respectively. The two types are approximately equally represented, and both form angular grains.

Lithic fragments comprise some 12 - 15% of the bulk rock total, and are varied in kind. Many are similar to the pebbles of the conglomerates, and such material as metamorphic quartzite, vein quartz, and gneiss have been recognised. Other material included a few grains with granophyric texture, some slate and siltstone, and one fragment of chert.

The cementation of this rock is achieved mainly by secondary growth of silica, probably from clay matrix material. Many intergranular spaces are filled with small amorphous crystals of silica. Sericite, which is particularly abundant in many of the greywacke sandstones of the rest of the Sheeffry Series, is relatively unimportant. There are some growths of sericite from clay matrix material.

Mica is also present in the form of biotite, many brown pleochroic flakes of which lie along the apparent cleavages which cross thin sections and are clear in hand specimens. The biotite is associated with some sericite, but no true white muscovite flakes have been seen in these rocks. The biotite is believed to be of secondary origin, for it shows no sedimentary compaction features. It corresponds in age to the first phase of folding in the Silurian rocks to the north. (q.v.)

Another secondary mineral is calcite, which forms up to 3%
of the rock. Euhedral crystals have not been seen in these but amorphous masses of the carbonate often follow zones which may be parallel to the bedding.

Grains of epidote are common in the grits and comprise 2-3% of the rock. They are not unquestionably of detrital origin, for many of the rocks of the Cregganbaun Series to the north may contain epidote due to metamorphism. However, since they are usually fragmental, it is thought that the epidotes in the massive grits are detrital.

Occasionally the lithic fragments are centres for the development of magnetite crystals. Such lithic material may have been of volcanic origin. Another iron mineral present is pyrite, which has been observed in the field, but not in thin section.

Sorting in the sandstones is poor, although the very fine-grained material has largely been removed. Material of over 0.05 mm. in diameter is abundant and haphazardly arranged. The rounding of the grains is dependent upon their composition; feldspar is better rounded than quartz, and lithic fragments vary in roundness according to their composition.

East of the Letterbrock area, between Liscarney and Lankill, a few beds of massive grit have been recognised. Thin sections of these reveal a similar composition to those of Letterbrock, but much breaking of the grains has occurred in this area. Large feldspar grains have been shattered into many small pieces (see
Fig 9) indicating large movements near here subsequent to deposition. Such movements are not thought to be linked with the formation of chlorite, which becomes more common in an easterly direction. The movement will later be shown to be connected with the slide of the first phase of folding - the Letterbrock - Liscarney slide (q.v.).

The massive grits show few sedimentary structures. Grading is rare and has been recorded in normal and reversed directions relative to that in the adjacent inter-bedded grits. The coarse grained part of each bed is thick, while the clay portion is very thin, comprising about 2% of the total thickness, and is never more than 15 cm. in thickness. Individual beds of the grit reach up to 25 ft. (8m) in thickness, but several beds often follow in succession, and a composite thickness of approximately 100 ft. (30m) is known.

At the base of the massive grits are structures which Dewey (1960) has described as "flow structures overturned from the north-north-east". Although he did not recognise the sub-division of massive grits and inter-bedded grits and slates, the structures illustrated in his fig. 15a have been identified at the base of the massive grits. Since Dewey states that the structures are overturned from the north-north-east, it is evident that he refers to the anti-dune and not the flame structures, which in fact point towards the east. It must be stressed at this juncture that sedimentary bottom structures are uncommon in the Letterbrock conglomerate Group as a whole. Less than a dozen examples have been
The Terms 'load cast', 'flow cast', and 'flame structure' must be used with considerable caution if implications concerning the direction of movements of the depositing currents are to be made.

The structures consist in many cases of drawn out, ripple-like structures of clay, overlain by sand. They were recognised by Sorby (1908), and many authors have since considered their mode of formation. Only the more recent work will, be considered in a brief review.

Prentice (1956) used the term 'flow cast structures', which he believed, were oriented perpendicular to the prevailing current. He considered that there may have been some post-depositional flow movement of the sediments down the geoslope. Kuenen & Prentice (1957) believed that the 'flow casts' which appear to be analogous to the synclines between the 'flame structures' of Walton (1956) are dominantly controlled by post-depositional movement. They further demonstrated that vertical movement on a 'flute cast' can lead to development of 'load casts', if it is caused to sink into the underlying surface. Deformation of the underlying structures should be seen where loading is the dominant formation factor. A third suggested mode of formation was drag during deposition from a turbidity current, which would tend to pull forward the clay projections.

Kelling & Walton (1957, p. 484) showed that for longitudinal
sections of successive flute casts, in which synformational erosion can be demonstrated, the direction of flow of the current is in the direction to which the 'flame structures' point. For a case of load casting in which no pre-depositional erosion occurred, the authors point out that unequal loading could produce asymmetrical load casts, which would have no directional significance. The inclination of the 'flame' may be due to compaction, thus producing an asymmetrical effect.

Birkenmayer (1958) pointed out that where 'flame structures' and 'load casts' are associated, asymmetry, if present, is in the same direction in each.

Nederlof (1959) concluded that asymmetrical structures may be due to either flowing or load casting.

Sanders (1960) considered all convolutions to be syn-depositional. The 'anticlines' or 'flame structures' he believed to be formed by deformation due to frictional drag caused by the current during deposition of the overlying sandstone. He noted the presence of false-bedded laminae beneath the 'flame structures', and in the sand above the basal lutite. He believed that the structures were formed due to cohesive sediment which produced bottom roughness in reaction to strong shearing movement of the current above it. The non-cohesive material infills the 'synclines'. 'Flame structures' are common features in turbidites and require changes of velocity to produce the convolutions, but any changes of velocity of the current would produce changes in the load carried by the current.
In cases in which syn-depositional origin of the structures may be proved, the 'syncline' (Sanders 1960) is referred to as the 'antidune' (Gilbert 1914), and is believed to migrate upstream, in contrast to the 'dune' phase, which moves downstream.

In some of the above cases, consideration of the structures has been purely in two dimensions. It is clear that Prentice (1956) recognised the importance of the three-dimensional effect, although he considered the load casts to be rather similar to tectonic folds in which the hinge was regular in orientation and perpendicular to the cross-section in which it is seen. Kelling & Walton (1957) gave an illustration to show sections through small flute-cast structures, in the formation of which they believed loading played an integral part. From their figure it is evident that the section illustrated as being approximately parallel to the current could equally have been produced along any plane within an arc of 45° centred on this orientation.

In some places where load cast structures have been seen in truly three dimensions, for example, further west in the Sheeffry Mountains, the features are not entirely linear, and occasionally approximate to circular in plan. A section through any one of these load casts would be similar to that shown on face 'a' of Kelling & Walton's (1957) text-figure. Any conclusion which considered that the presence of two 'flame structures' pointing in opposite directions signified approximate perpendicularity of the cross-section to the direction of flow of the current could be a serious misinterpretation. Not all load casts are of extreme shape and many
are intermediate between the markedly linear and circular types.

The dominant theme of the papers reviewed above is that where 'flow structures' are asymmetrical, the 'flame structure' points down the ancient geoslope. Where the structures are known in three dimensions the accurate location of this slope is possible. Whether the geoslope corresponds to the direction of flow of palaeocurrents must be deduced from other factors. Any two dimensional observations of pointing directions of 'flame structures' must be treated with caution but they may indicate the quadrant from which movement occurred.

In the Letterbrock area the 'flame structures' of the massive grits point towards the east, and the 'antidunes' are asymmetrical towards the west. No isolate flames have been observed to be asymmetrical in the opposite direction. No three-dimensional examples of either of these structures have been seen, but it is occasionally possible to measure the plunge of the axis of the 'flame structure'. Dewey records a plunge of 60° towards the west for one of these. Others measured during the present investigations vary considerably, from 30° towards 180° (indication of closure of the structure - and distinct non-linearity), to 75° towards 245° along the bedding.

On evidence of 'flame structures' alone, therefore, it is clear that the current may have flowed from the north-west during formation of the massive grits.
Clay pellet conglomerates are relatively common in the massive grits of the eastern part of the Letterbrock ridge. They result from the erosion and breaking up of the uppermost clay layer of the rock directly below - usually a well graded alternation of grits and slates. The nearly perfect rounding of some of the pellets is indicative of two important things: firstly the cohesive nature of the slate when it was deposited; and secondly the relative immunity of the pellets within a coarse grained sandstone to later tectonic deformation. The pellet conglomerates are thin, rarely more than one pellet thick, and are evidence of erosion at the base of the advancing turbid flow. They are not thought to represent the tongues of the flame casts from which the axial portion had been broken by the advancing turbidity flow, otherwise traces of the well developed and streaked out flame structures would still be preserved in the base of the succeeding grit horizon.

In one locality high on the hill, and south of the northernmost conglomerate, a mud pellet conglomerate reaches 8cms in thickness, and the fragments are markedly elongate parallel to the bedding, the ends of the fragments being angular.

The addition of fragments of a poorly consolidated mudstone to water results in an apparent increase in the volume of the sediment due to migration of water into the pore spaces. There is an accompanying increase in plasticity. Dilution of fragments of muddy sediments swept from the bottom during passage of a current could lead to a distinct rounding of the grains during movement.
Rolling of the debris may also achieve some rounding, but dilution is believed to be the principal mechanism involved in the rounding in this case. The angular fragments are believed to have undergone some degree of solidification or compaction before erosion occurred. Accordingly the mud broke into angular splinters which were transported without being diluted.

There is therefore evidence of the lapse of different lengths of time between deposition of the interbedded grit and slate sequence and the incoming of the massive grits. The degree of consolidation is proportional to the length of time between deposition and erosion. It therefore appears that the massive grits are of different origin from the interbedded grits and slates. If the sedimentary processes had been continuous, then in the pellet conglomerates the mud fragments would all have been rounded, or all angular, for the massive grits would always have been deposited at a regular time after the deposition of the previous layer of sediments.

There is a second possible mechanism for the formation of the angular pellet conglomerate. Erosion by the current may have cut through several layers of the interbedded deposits and so exposed consolidated muds. Under such circumstances both angular and rounded fragments might be expected to occur in the same sediment. No such conglomerate has been recognised, and in no place has the massive grit been seen to cut deeply into the underlying beds. It is improbable that the poorly consolidated material will have been dispersed and deflocculated by the currents on some occasions but
not on others.

**Interbedded grits and slates.**

Stratigraphically below the conglomerate horizons, or, where these are absent, below the massive grits, are many repetitions of a grit-shale sequence which are considered to be of the greywacke suite. The interbedded grits and slates appear initially to consist of discrete beds of sand and separate beds of slate, but close examination reveals that in the majority of cases there is gradation from sandstone to slate. In some instances, however, very black slates occur without grading to a silty fraction. These non-graded slates are believed to be autochthonous slates, the graded types being due to deposition from a current, probably a turbidity current.

The series of alternations show relatively constant direction of grading from coarse-grained on the northern side to fine-grained to the south. The junction between the base of the coarse sand and the underlying mudstone or slate is well defined and abrupt. The grading is reflected in the physical properties of the bed. The coarser portion is a light grey-brown colour when weathered, and a dark green colour when fresh. This part forms low ridges. The fine-grained material is dark grey when fresh but brown when weathered. This part is marked by small hollows on many exposures. Cleavage occasionally swings in direction as it crosses the graded units, and approaches perpendicularity to the bedding plane in the coarse material.

At the base the grits are often very coarse, with sand grains
not uncommonly reaching 0.75 mm. in diameter. Sorting is poor near the base, but increases upwards with a general decrease in the diameter of the larger grains in the direction of the mudstone component. With the decrease in the size of the maximum grains there is a decrease in the average grain size, and an increase in proportion of material of clay grade.

Grading is rarely uniform and within one large unit of a graded bed there may be many small breaks, in which a relatively muddy layer has been deposited above a coarse sand, and in turn followed by a slightly less coarse sand horizon. The effect is that of a general decrease of size upwards, by a series of steps, perhaps controlled by some minor variations of conditions during the passage of the current. Thus, a relative slackening in the velocity of the current could lead to deposition of a finely grained lamina, and subsequent increase of velocity would allow only coarser material to be deposited. This sort of variation may be studied in detail on some of the ice-polished surfaces.

The individual graded units vary from 1.8 cm to 85 cm in thickness, although the minute individual component laminae may be no more than 0.5 cm thick.

The material of some units of grading does not reach up to coarse sand grain size, and the maximum grain size seen in the field may be only of fine sand grade. Such units may have been deposited from very dilute turbidity flows, the coarser layers from less dilute flows.
It is normal for the coarser grained debris to form at least 50% of the thickness of any individual unit. The finer material is clearly of later settling and may include autochthonous slates in the uppermost horizons. In a few cases the complete settling of the debris from the turbidity flow took place before deposition of the autochthonous black slates recommenced. The very black slates are never more than 4cms in thickness, and frequently contain orange flecks which clearly originated from alteration of pyrite to limonite.

In the coarsest grits the quartz grains form up to 70% of the detritus, but in higher levels of the graded beds there is a decrease of this proportion, with an increase of feldspar. The quartz fragments decrease in size upwards and are still identifiable as discrete grains in the mudstone component. Individual isolated grains also occur within the graded slate fraction, but none have been seen in the autochthonous slates.

The quartz grains are usually angular to sub-angular, and mostly show sweep extinction, but about 15% are clear and appear to be of igneous origin.

The feldspars are principally of orthoclase, but plagioclase is also present. Both types are partly rounded. Sericitisation has occurred in almost all feldspar fragments, and shows distinct preferred orientation in the albite-oligoclases. Generally the potash feldspars are more altered than the plagioclases and some patches composed entirely of sericite may be totally altered feldspars.
Lithic debris includes a few fragments of metamorphic quartzite. All the detritus is set in a matrix composed almost exclusively of chlorite and sericite, but in which some zones rich in ankerite, and others in amorphous silica, occur from place to place.

Large flakes of muscovite occur in the coarser fraction, but have not been recognised in fine grained material, where the less prominent constituents are masked by the sericite and chlorite.

Iron ores are disseminated through the rock, but they tend to be concentrated in shear zones which are seen in some thin sections. The original pyrite is seen in most of the sections, but in weathered areas this has altered to orange-coloured limonite. The presence of pyrite suggests a reducing environment subsequent to deposition, for the pyrite appears to be of secondary origin, since euhedral grains surround included quartz fragments.

Sedimentary bottom structures are not common in the interbedded grits and slates, in which individual thin beds may be traced laterally for great distances.

Grading is ubiquitous, and in most cases indicates younging towards the south. A few reversely graded beds occur in the sequence, but these represent less than 2% of the rocks, and are scattered between uniformly graded beds. On the evidence of grading alone no large-scale folds have been recognised.

Load casts are rare and indicate movement from the east. Some structures which may be load casts indicating younging northwards,
or alternatively, shallow channels and ripple fillings indicating younging southwards, have been seen in the Letterbrock fields between the conglomerate beds. They occur only in one flat exposure and the two alternatives seem equally probable from structures seen in the field.

A section across one flute cast was seen in a small vertical exposure, which indicated a direction of movement either from east to west or west to east.

Some sedimentary sliding has occurred, and detached blocks of sandstone have moved within the slated portion, with balling up of the slates around the end of the sand block. (Fig 10a) A clear example of this shows truncation of the slump features by the base of the succeeding grit layer of the greywacke to the south. The block appears to have moved from an easterly direction towards the west, and is itself graded towards the south.

Dewey (1960) states that on the Letterbrock ridge east of Oughty "the steeply plunging isoclinal folds were only discovered by detailed examination of younging in boulder beds and greywackes." As has been stressed above, the majority of the sedimentary structures indicate a younging towards the south. Isolated examples have been found in which a northward direction of younging is indicated, often in opposition to the indication of immediately adjacent beds.

Detailed mapping of the three-fold division (of conglomerate, massive grit, and interbedded grits and slate groups), is shown in Fig. 8. In this it is clear that the massive grit always occurs to
the south of each conglomerate horizon, and interbedded grits and slates occur to the north of the conglomerates. The complex facies changes, in which massive grits, with or without conglomerates interdigitate with the interbedded grit and slate succession, suggest that there is a genetic relationship between the conglomerates and massive grits, both, or only one of which may be present in the sequence. Dewey (1960) believed that the conglomerates alone were derived from boulder slides from the north-west. It is clear from Fig 8 that the massive grits, which are essentially micro-conglomerates, also had a similar derivation.

The presence of two forms of mud-pellet conglomerate suggests that the influx of the coarser debris from the north was spasmodic, and that it cut into the greywacke assemblage of grits and slates during transport into the basin of deposition. The greywackes appear to have been derived from the east, both on evidence of flow structures, and an apparent increase in slates westwards.

East of the Letterbrock ridge, rocks apparently of the same age as the Letterbrock Conglomerates are seen on Liscarney Hill. They consist of a monotonous sequence of grits and slates of greywacke type, with a few layers of black autochthonous slates. Immediately south of the Silurian junction the grits are very coarse, almost conglomeratic, and near Lanmore Bridge a thin bed of conglomerate has been recognised. In this bed the pebbles show regular orientation with the long axes plunging steeply westwards, suggesting origin from a north-westerly direction.
To the south of the two conglomeratic horizons are a few beds of massive grit, between which are interbedded grits and slates similar to those seen at Letterbrock. Within the sequence of interbedded grits and slates two beds of acid tuff occur at Lis-carney, and one near LanmoreBridge. The intimate relationships of the interbedded grits and slates has made distinction between 'grits' and 'slates' difficult, but in the vicinity of Lanmore it proved possible to map zones of predominantly gritty nature and zones of predominantly slaty nature.

The grits of the eastern area are of similar composition to those further west (Sp. 638). Angular quartz dominates the clastic material (85%), with partly rounded feldspars very subordinate (10%), plagioclase and orthoclase being equally represented. The matrix is composed principally of sericite, with some pale green pleochroic chlorite, and a little ankerite. Heavy minerals present include leucoxene, which may be an alteration product of detrital ilmenite. Small flakes of biotite develop along shear planes oblique to the bedding.

North of the Lanmore Slate quarry, the grits generally appear to be massively bedded, but from the level of the northernmost workings the grits to the south are rarely massive and are usually of interbedded type. The junction of the Letterbrock Conglomerate Group and the Owenmore Group probably occurs at this horizon.

The location of the junction between the two groups in this
area, where the facies of the groups are virtually identical, is necessarily speculative. It has been placed at the top of the highest massive grit horizon for over 300ft. (100m), in the sequence. Thus the boundary between the Letterbrock and Owenmore Groups has been put at the level where the northwesterly source ceases to be of major importance.

The Owenmore Group.

As indicated in the introduction to this chapter, the Owenmore Group is exposed on the southern part of the Letterbrock ridge, on Carrowrevagh Hill, and eastwards into Carrowmore, Lanmore, and Cordarragh North, including the bog which lies between these townlands. The best exposures, are on Carrowrevagh Hill and in the disused slate quarries at Lanmore.

The Group is characterised by thinly interbedded grits and slates of greywacke facies, with a few beds of massive greywacke, some thin tuffaceous bands, and one thin conglomerate. The conglomerate is identical to those of the Letterbrock Group, and the massive greywackes show flame structures and are contorted by prolapsed bedding, all of which suggest a north-westerly origin. The finer sediments, however, continue to indicate an easterly source, with the few linear sedimentary structures running approximately parallel to the present strike. All grading and sedimentary structures indicate younging towards the south.

The bed of conglomerate is 3 ft. (1m) thick when it is first seen and increases in thickness to 8 ft. (2.5m) westwards, where it
it is faulted out. It is directly overlain by a massive greywacke with contorted internal structure similar to prolapsed bedding. Massive greywackes, conglomerates, and tuffs are very subordinate in the sequence. Some subdivision has been achieved by mapping of zones of predominantly grit or predominantly slate.

The thinly laminated grits and slates are very constant in thickness and weathering characteristics along the strike. A few of the more massive layers of eastern origin stand up as ridges.

Absolute identification of any single bed along the strike for a distance of three miles is not possible but five samples have been taken from within 2 ins (5cms) of the base of a prominent bed of grit a few feet south of a bed of tuff. Modal analyses were prepared using a Swift Moving Stage and Point counter, one thousand points being counted for each thin section. The complete analyses will be found in Appendix 1 at the end of the Thesis. The quartz, feldspar, and lithic fragment components were recalculated as fractions of the principal clastic material present. The matrix included sericite, chlorite, and carbonate, where present, and is given as a percentage of the bulk rock total, as are the heavy mineral and carbonate contents. The results are summarized below:

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<th>814</th>
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<td>10</td>
<td>15</td>
<td>14</td>
<td>19.5</td>
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<tr>
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<td>12</td>
<td>4</td>
<td>6</td>
<td>3</td>
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<tr>
<td>Heavy Mineral</td>
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<td>1.1</td>
<td>1.7</td>
<td>2.7</td>
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Specimen Number (West) - Contd. 808 811 814 640 662 (East)

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<td></td>
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<td></td>
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<td>37.7</td>
<td>0.6</td>
<td>-</td>
<td>0.2</td>
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</tbody>
</table>

On the evidence of the five analyses there appears to be a decrease in the proportions of feldspar and heavy minerals, and an increase of matrix and carbonate content westwards. The lithic component shows an apparent westward increase. This may be partly due to the presence of more lithic material of lateral origin towards the west and partly due to an increase in the proportion of mud pellets in this direction. The upper surfaces of some of the massive greywackes are abrupt and suggest that erosion removed the upper part of the bed before consolidation occurred. Such erosion may have been by the turbidity currents which later deposited the finer beds which are being examined. A similar explanation may be given for the increase of heavy minerals in Specimen 808, for epidote, which is relatively common in the rock, is virtually unknown in sediments of eastern derivation, while it is common in rocks from the northerly source.

However, five modal analyses are not sufficient to justify sweeping conclusion concerning the group, but rather suggest lines along which further work may profitably be carried out.

A general increase in the proportion of slates towards the west has been noted in the Owenmore Group by Dewey (1960). This is to some extent supported from Eastern Murrisk, but the change is not great. The proportion of 'predominantly slaty' bands appears to
increase westwards.

The massive grits possess flame or flow cast structures as previously described. Many of these have been sheared during later folding (see Fig. 12a), but the sense of movement is essentially not from east to west but from a northerly direction. The massive grits are very sporadic in occurrence in the sequence, but when present may be traced laterally for at least 1 mile, as exposure permits.

On ice-polished surfaces the finer interbedded grits and slates show good grading indicating a constant direction of younging towards the south (Fig. 12b). Flute casts are rare, but have been seen to the south of the Lanmore slate quarries and indicate an east-west component of movement.

On the south side of Carrowrevagh Hill a thin nodular bed was mapped in which bright green nodules, apparently of fuchsite, were identified in the field. In thin-section this rock is seen to consist of fragments of metamorphic rocks, with some nodes of chlorite up to 0.5 mm in diameter around which are scattered flakes of colourless mica, which may be muscovite or fuchsite. (Sp. 817)

In the fields of Carrowmore exposures of the greywacke yield crystals of pyrite, up to 5 cm. cubes. Many pseudomorphs of limonite after pyrite, and unaltered pyrite crystals have been seen particularly along the southern side of Carrowrevagh Hill. However, not all the orange-flecked rocks owe the flecking entirely to pyrite, for one thin-section reveals the presence of large crystals of secondary
dolomite and siderite within the sand part of the graded beds. It is thought that synchronous deposition of pyrite, introduced perhaps from a volcanic source, and of ankerite, formed, perhaps from pelagic fossil debris may lead to reactions, producing first hygroscopic iron sulphate, and then siderite, the iron carbonate. Development of euhedral rhombs of dolomite with associated siderite has taken place. The secondary origin of the carbonate is shown by inclusions of detrital quartz and feldspar. Very little chlorite is present as inclusions in the carbonates. Magnetite crystals occur both associated with and separate from the dolomite. Disruption of the original sedimentary structures is rare, and the green chlorites appear to be well oriented with respect to the cleavage produced in the f_1 folding.

**Palaeogeography of Owenmore Times.**

Dewey (1960) has suggested that the boulder beds of the Letterbrock Group resulted from slides from a source to the north-west. They may have originated in submarine canyons which crossed the scarp of the Highland Boundary Fault, to the north. He pointed out that flow structures suggest movement of greywackes (and here he refers to the massive grits) from the north-west. He considered that this was improbable since there is a general westward increase of the proportion of slates. From evidence in the Arenig sediments of N. Galway and the Tourmakeady district, Dewey postulated a trough trending NE - SW in the east and S - W in more central Murrisk, a trough into which the boulders were carried.
However, he added (p. 59) that "no axial sediments are exposed at the present day."

It has been shown above that the conglomerates and massive grits do have a north-westerly origin, but the presence of a few flute casts and the westward increase in the slate content of the sediments suggests that the interbedded grits and slates of greywacke facies were of easterly derivation. The statement concerning the absence of axial sediments is therefore unjustified.

Dewey (1962) suggested that certain features are diagnostic of deposits from lateral turbidity flows. These include flame structures and load casts, convolutions and prolapsed bedding, all of which have been recorded in the massive greywacke grits associated with the conglomerates, in both the Letterbrock and Owenmore Groups. In each case they suggest a south-eastward movement of the currents.

Thus there may have been a trough along which dilute probably far-travelled turbidity currents flowed, depositing graded greywacke sequences, between which, autochthonous black slates were deposited during quiescent periods. Periodically lateral turbidity flows from a north-westerly direction brought material from the nearby land to the north-west.

The present work, therefore, may be said to support the views of Dewey (1960) in that the conglomerates are again shown to have been derived from a westerly or north-westerly source, and in the distinction of the interbedded grits and slates as having a separate origin from the conglomerates. The further sub-division
of the Letterbrock Conglomerate Group, and recognition of the genetic relationship of the massive grits and the conglomerates has enabled the facies changes associated with the influx of the conglomerate-bearing arenites to be distinguished. The evidence of a westerly or north-westerly origin for the coarse grits themselves is a further step forward. The distinction that the interbedded grits and slates are of axial turbidites has been shown from field observation.

Dewey (1960) interpreted the structure in the Letterbrock Conglomerate Group as an isoclinal fold. During the present work it has been possible to show a constantly repeated sequence of rock types: - interbedded grits and slates; conglomerates; massive grits; and interbedded grits and slates. The repetition of this sequence throughout the Letterbrock area, in each case with the coarsest representative on the northern side of the sequence, suggests that no folding has occurred. The rocks appear to face uniformly southwards.

The presence of metamorphic rocks which can be matched with the Dalradian rocks of N. Mayo is important for two reasons. Firstly it indicates the nature and composition of the rocks in the source area, and secondly it clearly shows that the Dalradian metamorphism and erosion had occurred before deposition of the Letterbrock Group sediments.

The source rocks were principally metamorphic, and included quartzites, but there may have been some pillow lavas, for jasper pebbles have been seen.
There may have been some basic intrusion, for some dark fragments, possibly altered dolerites, have been seen. Grains with granophyric texture have been seen in thin section. These may have been formed by fusion in the sediments into which the basic intrusions were injected. Alternatively the granophyric grains may have come from an acid granophyre intrusion. The source area of varied rock type was therefore metamorphosed and folded (pebbles with some small folds are present in the conglomerate), intruded, uplifted and eroded before deposition of Letterbrock sediments. Production of a varied gravel suggests that several rock types were being eroded, but rounding of the pebbles is hardly indicative of the length of time which elapsed before deposition. The gravels formed in the rivers and were later swept into the sea and into the E-W trough, either along submarine canyons, as suggested by Dewey (1960), or perhaps moved by the undertow associated with tsunamis. Bridon and Irving (1963) have suggested from palaeomagnetic evidence that the British Isles may have been between latitudes 30° and 20° during the Ordovician period. The sphere of influence of tsunamis today extends over this range of latitude in the northern hemisphere and it is possible that they may have been responsible for the coarser lateral flows. The phenomena causing lateral flows were not frequent, for when they occurred large quantities of accumulated debris from the nearby shore were washed into the deeper water by means of turbidity flows.

Within the Owenmore Series two beds of acid tuff have been
identified on Liscarney Hill, and one to the east near Lanmore Bridge. The cream-weathering fine-grained flinty tuffs are easily recognised. In thin-section they consist principally of quartz with some albite-oligoclase feldspar. A few stains of limonite may have been derived from early pyrite, At least two beds of tuff of more basic composition are present; one has been recognised near the Ordovician-Silurian contact at Lankill, and the other in the bog south of Lanmore and on the western side of Carrow-revagh Hill. In each the rock consists principally of andesine-oligoclase, with some albite. Exsolution of sericite oriented along two crystallographic directions is common, particularly in the more calcic plagioclases. The sericite of the matrix in the slates often shows an orientation parallel to that associated with the second phase of folding in the rock. A few rounded and embayed fragments of quartz are believed to be cognate, although generally smaller than the crystals of feldspar, which are of fairly uniform size, up to 1.5 mm in diameter. Some angular, non-cognate quartz suggests that the ash may have been partly mixed with sediment during deposition. The ash may have settled from a cloud while normal currents were flowing in the sea, thus producing a noticeable intermixing as extrusion of the ash decreased.

Some minor extrusive volcanicity occurred during Owenmore times. Ashes of generally acidic composition were erupted and deposited. Some pre-compactional re-sorting occurred, for not only are the tuffs graded in part, but they also include fragments of lithic material and detrital quartz grains. No inferences concerning direction of origin of the tuffs are made, as the localities where the tuff has been recognized are isolated, and
their thickness varies little along the outcrop of any given bed.

Skeeffry Series.

1. Drummin Group.

The Drummin Group which is badly exposed in C. Murrisk received little attention from Dewey (1960), and as a result is poorly defined. He recognised some flute casts which indicated a southerly origin for the greywackes of the Group. In Eastern Murrisk, the Group is again poorly exposed, but appears to thin eastwards, and according to Dewey's (1960) map, must increase in thickness rapidly westwards in Central Murrisk.

The most westerly exposures of the Group are to the north of the Derrakillew bog, and south of Lissaphuca, the Celtic fort. There are a few exposures south of Carrowrevagh Hill, but no more until east of Lough Nambrackkeagh. To the north-east of the cross-roads at Cordarragh the Group is concealed by Carboniferous sediments, and may be in part cut out along the Carrowkennedy hinge fault.

In the extreme west the sediments are very massive grits with abrupt tops and bases, and no cleavage to indicate the direction of grading. At Derrakillew both grits and slates of greywacke facies are present, again without sedimentary structures.

In the only well-exposed part of the series, south-east of Lough Nambrakkeagh, the Group is composed mainly of thin greywacke grits, but with a few massive grits. The entire sequence in this area is dominated by the presence of autochthonous black, often pyritic slates. There is one feldspathic tuff which contains much secondary albite, set, together with the broken feldspar fragments and a few sericitised slivers of slate, in a
Fig. 13. Slump structure in the Drummin Group.

These two features occur in an ice-polished pavement 100 yds north of point 358, Rooghaun.

Fig. 14. Diapiric structure due to the upward movement of water.
matrix of biotite and sericite. This tuff resembles some of those seen in the Owenmore Group on Carrowrevagh Hill, except that it has a noticeable percentage of apatite.

The black autochthonous slates are very fine-grained and massively bedded. They were once composed principally of altered clay minerals which have given rise to small biotite flakes, together with sericite. Some small apatite and tourmaline crystals are present. There are a few larger fragments of rounded feldspar and angular quartz. The biotites are oriented parallel to the \( f_2 \) cleavage, which in this area is penetrative, producing tectonic ripples on exposed bedding planes. Small crystals of pyrite are visible on fractured surfaces in the field, but most of the iron ores present in this section are magnetite and limonite.

A thin section cut across the boundary between the black slate and the grit immediately to the south reveals an irregular erosional contact. The grit is composed principally of angular quartz, which forms 80% of the detritus, about 10% of feldspar, chiefly plagioclase, and 10% of lithic fragments, including metamorphic quartzite and pellets of sericitised muds, particularly in the lowest layers. There is a little detrital biotite showing pleochroic haloes. The matrix is very fine-grained, and largely consists of sericite and silica, with secondary biotite and chlorite subordinate. Iron minerals are scarce in this sediment.

In the exposures just north of the Cordarragh road at Rooghaun are a series of ice-polished and bleached sections which reveal a series of complex sedimentary structures (Figs. 13 & 14). The sediments at this point consist largely of thin layers of grit interbedded with layers of slates.
Fig. 15. Complex internal structure of a slumped bed. Quarry by road at Roughaun (plan view).

Fig. 16. Thicknesses of graded beds in a sequence from the Lugacolliewee Group Above the high fields at Carrowkennedy.
In Fig. 13 there is an apparent slump structure in which the beds moved downwards from the east towards the west, the slumped block showing many reversed faults, and eventually apparent penetration of the underlying beds to the north. Other reversed faults are associated, and there appears to have been an overall shortening in the length of the bed. Younging appears to be towards the south.

In Fig 14, is a structure which is adjacent to that in Fig 13 and which appears to be an infilled channel which youngs towards the north. Since this directional younging is opposite to that in the surrounding beds, an alternative method of formation has been considered. If younging is to the south then the structure is diapiric, and may have been caused by release of water in the pores as it broke through a capping layer of clay grade material, the upward movement arching the beds upwards. Individual laminae may be matched in the structure and in the undisturbed beds of the margins, so that this interpretation seems probable.

The rocks are largely fine-grained sandstones, and considerable convolution or slumping has occurred in many levels. A series of what initially appear to be false-bedded laminae, truncated sometimes on the north and sometimes on the south, occurs in some fine-grained, yellow-weathering grey sands and black slates. Both the bases and the tops appear to be asymptotic on occasions, and the structures may have developed as a result of differential movements during tectonism. It is more likely that the sections seen are oblique to a series of slump structures, such as are seen in another bed at the top of a virtually infilled small quarry by the roadside at Aoighaun (Fig. 15).
Plate 3. Ice-polished surface showing slump structure in the Drummin Group Rooghaun.

Plate 4. Cutting out of beds by erosion in the Drummin Group, Rooghaun.
This fine-grained bed is no more than 5 cms in thickness, and can be traced for several metres along the top of the quarry. The base of the bed is nearly to the north, for channelling is present, the 'channel' appears to be very shallow, and may have been cut in a direction oblique to the present section. Just above the base of the bed which overlies the channel, the sands show relatively regular lamination for 1 cm., but above this irregularities occur, in which the noses of slumps, which appear to have moved from the east, are seen. Crossed lamination is also present in many places, the truncation of this and all balled-up structures being on the south side. Younging in these beds is towards the south. Currents from a possible northerly or southerly direction may have cut the 'channels' (perhaps shallow flute-casts), which were infilled, the later sediments slumping to form sedimentary nappes. Movement of these nappes may have been from the east.

Grading at this point is confused: in some beds the southern side is finer grained; in others the northern side.

Initial examination suggests that where might be an isoclinal fold in this area, the bedsyounging to the north and south respectively on each limb. No other evidence for this fold is present, and it is believed that in each case the sedimentary structures may be adequately explained by a southward direction of younging.

It is unfortunate that this very interesting series of small cuttings has been partly obscured by a filling of boulder clay. Such features as have been observed indicate that some currents may have flowed from the south, as suggested by Dewey (1960), but slumping certainly occurred from
a more easterly direction.

2. **The Lugaloughan Volcanic Group.**

Dewey (1953) described a total thickness of 170 ft. (52 m) of ashes near Lugaloughan. The tuffs are grey weathering, composed principally of angular crystals of albite feldspar with some andesine-oligoclase, all strongly sericitised. Fragments of quartzite are present set in the sericitic matrix, and in some units quartz dominates the graded beds. Pyrite, often altered to limonite, gives some of the units a red-stained appearance.

Initially this group was believed to be present along the southern part of Carrowreagh Hill, where the rocks have a distinctive red-stained appearance. However in this locality staining is due chiefly to dolomite and siderite, and although the rocks are in part largely feldspathic and probably tuffaceous, the correlation was felt to be inconclusive. Instead a search was made for Dewey's upper unit, a 40 ft. thick fine-grained white tuff.

The only tuff which lies in a position at present considered to be above the Drummin Group, but below most of the Sheeffry Series is a 3' 6" thick acid tuff seen in Sruhaunderrakilliew. It is composed of very fine-grained quartz, with some sericite and chlorite flakes, all of which are oriented parallel to the cleavage. There are included fragments of cherty material which may be pieces of the underlying sediment. In places there are structures which resemble recrystallised shards, and it is possible that this acid tuff horizon was composed of glass shards which became recrystallised after deposition. Below this white-weathering tuff
are thin beds which show some orange flecking due to limonite. This is believed to be the sole exposure of the Volcanic Group in Eastern Murrisk, and it has been recognised at no other locality.

The thinning of the uppermost unit from 40 ft. (12 m) in C. Murrisk to 3 ft. 6 ins. (1 m) in Sruhaunderrakillaw implies a considerable change of facies, and the centre of extrusion of the ashes must have been to the west or perhaps north-west or south-west of C. Murrisk.

Dewey (1960) describes the quartz fragments as cognate, although he adds that they are large and angular. The customary form of cognate quartz crystals in many tuffs, notably those of the Partry Series, is with deep embayments, and rounded, corroded margins. This form of quartz has been seen in some crystals within the feldspathic tuffs in higher parts of the Sheeffry succession. The large angular quartz fragments are usually associated only with the sediments, where they often form over 80% of the detrital grains. In the tuff bands the quartz is often less than 25% of the detritus.

Dewey suggested that the tuffs were emplaced by turbidity flows. During settling the ash fragments became intermixed with the accumulating sediment at some point and may have been instrumental in the initiation of the flows. As such it is not surprising that detrital quartz was deposited in the ash beds, nor yet that in the uppermost beds, where fall-out of ejectamenta was reduced, the tuff beds would be principally of detrital quartz.

Isolated beds of graded grey tuffs occur in many parts of the Arenig succession. They are difficult to distinguish in hand specimen, the
principal criterion for recognition being a characteristic orange flecking and a general lack of quartz, and they can only be determined with certainty in thin-sections.

3. The Lugacolliee Group.

The Lugacolliee Group is composed of a varied group of sediments, with all transitions between graded greywackes and feldspathic ashes, and including darkly coloured slates, and at least one horizon of flag-stones. The absence of any clear sedimentary features poses problems concerning the source of the detritus, but in many places there are fine striations on the bedding planes, possibly indicating an east and west component of transport. The striations may, however, be of tectonic origin.

As a whole the group is extremely complex. Massive beds of greywacke grit up to 20 ft. (6m) thick are composed principally of quartz, with lesser quantities of plagioclase, set in a darkly coloured matrix rich in sericite and chlorite. Heavy detrital grains include tourmaline and garnet, and secondary carbonates are present in many cases. The thinner beds are often composed of ashy grits in which the proportion of plagioclase increases as the rock approaches a true ash. The feldspars are usually in the andesine-oligoclase range, and frequently show exsolution of sericite, oriented along clearly defined crystallographic directions, which reverse from twin to twin. The very fine grained rocks are composed almost exclusively of sericite and chlorite, which are the products of clay minerals. Minute grains of quartz are present. In these finer rocks the development of pyrite is at its greatest. The pyrite oxidises to limonite in the coarser rocks. The cleavage direction is particularly well preserved in the finer rocks, in
which the sericite lies parallel to the cleavage.

At the extreme top of the Group are two 3 ft. thick beds of acid tuff, composed essentially of quartz, but other beds of tuff are principally of feldspar, and have been integrated into the greywacke sequence.

Beds of grits and slate alternate in the succession and often show considerable variation in their lithologies, with silts and sandstones equally intermixed. Lithological varieties are not always continuous along the strike, and in places grit lenses grade into slates.

Immediately above the fields of Carrowkennedy the alternations appear to be relatively constant along the strike, and measurements were taken of the thicknesses of the individual beds of grits and slates. A total of 840 measurements were taken, and the results plotted graphically (Fig. 16) in an attempt to detect any possible periodicity in the sedimentation. This analysis was facilitated by the tendency of the alternating coarse and fine members to form good exposures of some width. In the analysis both single and double band plots were used, in the manner used in varve analysis by the classical method of de Geer (1912). In the double band plot there is a suggestion of periodicity of about 140 bands in width. This periodicity does not appear to be connected with the sun spot cycle recorded by Zeuner (1946) from various parts of the geological column. The factor controlling this sedimentation therefore appears to be independent of control by the sunspot cycle.

Locally elongated cavities have weathered out where calcareous nodules have been deformed and rotated into the plane of the later cleavages.
Above Carrowkennedy veins of quartz which in the rather massive grits towards the top of the Lugacolliewee Group, are associated with iridescent blue and brassy coloured cubes of chalcopyrite and bornite. In a few places weathering has altered some of the sulphide to produce characteristic blue-green flecks on the surface of the veins.

The abundance of fragments of vein quartz along the north face of Carrowkennedy Hill suggests that the Carrowkennedy hinge fault lies relatively close to the present face of the hill, but it was not actually located at any point.

4. The Spink Group.

Dewey (1960) defined the Spink Group as follows:

"The base is taken at T. B. 4, a distinctive flinty cream-weathering tuff ... the Group comprises 2,950 ft of graded beds with seven distinctive tuff beds, used as marker horizons ... Apart from these tuffs, the Spink Group consists of graded ashes and greywackes enplaced by turbidity currents, often bearing a large quantity of limonite as pseudomorphs after pyrite. Calcite is also abundant and frequently occurs as nodular segregations in the greywackes."

Dewey considered the tuffs in great detail but devoted no more attention to the sediments. He states that T. B. 7 and T. B. 8 die out eastwards. Other beds of tuff may do the same, before reaching the western limit of the Eastern Murrisk area.

The Spink Group is very much reduced in thickness on Slieve Mahanagh, and at Carrowkennedy exceeds no more than 1,250 ft. The base is taken as the nearly continuous acid tuff bed 5(A.T.B.5) of Eastern Murrisk.
This bed has been traced along the entire outcrop of the Sheeffry Series from Carrowkennedy to Corveagh. It bifurcates in places but remains parallel to the bedding, and an intrusive origin is believed to be improbable.

Other beds of acid tuff are present, all flinty and cream weathering, and are best displayed beside the road to Tourmakeady at Cordarragh, where, however, faulting is greatly developed, leading to repetition of some beds.

Between the beds of tuff are many alternations of bedded grits and slates. The beds are often 5-15 cms thick. Beds of massive grits are rare in the Group. Some layers of 75-125 cms thickness show load casting at the bases and are graded, with swinging cleavages. The rocks young uniformly southwards, although there are a few reversely graded units, whose tops, however, do not show load casting, in contrast to many of the normally graded beds.

The sandstone part of the alternating coarse and fine beds does not show a chaotic arrangement of fragments. Instead there is a marked dimensional orientation of the debris, and the long axes of grains are arranged approximately parallel to the bedding. The grains, which are predominantly of quartz (63% of the detritus), with subordinate plagioclase feldspar, are subangular to sub-rounded. Considerable sericitisation of the oligoclase feldspars has taken place, and absence of sericite in some places reveals authigenic growths of feldspars. Other detrital material includes flakes of both muscovite and chlorite, each showing compaction strains, and occasional fragments of mud now altered to sericite.

The matrix is composed principally of chlorite and sericite, the flakes oriented parallel to the cleavages in the rock. Large brown patches visible
in the hand specimen are composed of limonitised pyrite, the grains of limonite often encrusting the detritus in the rock. Some cubes appear to enclose crystals of quartz and feldspar, and may be of secondary origin. No feldspathic tuffs have been recognised in the Group, nor any well layered tuffs. Segregations of calcite are present in many of the fine grained sandstones. They are elongate parallel to the cleavage, and may represent thin calcareous beds which have been broken.

At Carrowkennedy the succession, of nearly 500ft. (130m) in thickness, from the Lugacolliwee Group into the Spink Group is well exposed:

10ft. (3m) alternating coarse and fine grits
5ft. (1.5m) brown shales.

Spink Group:
50ft. (16m) massively bedded alternating sediments.
100ft. (33m) alternating coarse and fine grained silts
6ft. (2m) Acid Tuff Bed 5
60ft. (20m) massively bedded laminated siltstones.

60ft. (20m) alternating coarse and fine grained silts.
40ft. (13m) massive grits.

Lugacolliwee Group
75ft. (25m) alternating coarse and fine grained silts.
15ft. (5m) massive sandy silts.
4ft. (1.3m) brown shales.
60ft. (20m) alternating coarse and fine grained silts.
A traverse eastwards along A.T.B.5, which corresponds to Dewey's T.B.4, reveals that this fine-grained, quartz-rich rock is occasionally paralleled by another bed, A.T.B.7, which appears to be discontinuous, although over 6 ft (2m) thick in places. About 400 metres east of point 704, in Keekill, A.T.B.5 increases in thickness from its usual 3 – 5 m. to a maximum of 10 metres, and forms a prominent knoll of flinty material. East of this point the bed is double, with a group of alternating coarse and fine grained silts, intervening between the tuffs. These intervening sediments increase in thickness eastwards until the fold zone is encountered, where a third tuff bed, A.T.B.6, appears in an intermediate position between A.T.B.5 and A.T.B.7. Beyond the fault zone the tuffs are wider apart, and A.T.B.6 is again seen, and despite complications by further faulting it is probable that directly east of the road five tuff beds are present. Neither A.T.B.5 or A.T.B.6 continue far to the east of the road, and the important, almost continuously exposed tuff horizon east of here is A.T.B.7, with A.T.B.8 in close association. A.T.B.8 appears abruptly in place of massive grits along the strike, and rapidly increases to the thickness of 10 ft. Its base infills hollows cut into the surface of the underlying sediments. A.T.B.9, which lies to the south of A.T.B.8, is no more than 5 ft (1.5 m) thick, and continues for no more than 200 metres along the strike.

Both A.T.B.7 and A.T.B.8 continue to Corveagh, where A.T.B.7 splits into two separate tuffs, which diverge eastwards until they are obscured by drift. The one bed, 12 ft (4m) in thickness, gives rise to two beds each 6 ft (3m) thick, with an intervening bed of slate which increases in thickness to at least 15 ft (5m) eastwards. Above this level A.T.B.8, no
more than 5 ft (1.5m) thick at this point, shows some divergence, the slates between it and A.T.B.7 increasing from 18 ft (6m) to 25 ft (8m) in thickness across two fields, A.T.B.6 is also present for a short distance here and is itself very thin. The intervening sediments at all levels (except between A.T.B.7 and A.T.B.8) are darkly coloured slates and siltstones.

The beds of acid tuff, which are for the most part in perfect conformity with the sediments of the Group, have been seen to bifurcate in two places, and on two occasions terminate abruptly on their western ends. Dewey (1960) records abrupt terminations of his T.B.7 and T.B.8, which he believed marked the maximum lateral extent of *nuées ardentes*. He considered that the ashes were deposited only in the restricted localities in which they occur today. Other ashes he considered to be at least partly deposited from turbidity currents set up on a south-north slope from the Connemara cordillera, where the centre of eruption was probably located.

The presence in the lowermost layer of A.T.B.5 of dark inclusions up to 5 cms in length, composed of balls of cherty material, lends support to Dewey's suggestion that turbidity currents may have played a part in the emplacement of certain tuffs. However, while both explanations are adequate for the features described by Dewey, they cannot account for the bifurcation of a single bed of tuff and the intercalation of sediments between the two parts. During the deposition of the tuffs the normally operative sedimentary processes continued elsewhere. If the deposition of the ash did not take place as a single rapid event, as from a *nuée ardente*, but rather as a prolonged settling from a lengthy, perhaps gentle and sporadic eruption,
Fig. 17. Interpretation of the bifurcation of the acid tuff beds of the Spink Group.
then turbidity flows of sediment, some coarse, and some fine, may have occurred before the deposition of the tuff was completed. These flows may have originated in areas unaffected by the fall-out of ash, and in consequence would be completely free of ashy material although deposited during the time of eruption (see Fig. 17).

The lower part of each tuff bed shows laminar jointing parallel to the bedding, but the central parts of the beds are massive and cream-yellow in colour when weathered, but pink and white on freshly fractured surfaces. A.T.B.8 is granular in the extreme east and shows green and black flecks of chlorite and iron in hand specimen.

Direct correlation with the area described by Dewey (1960) is not possible, and the disappearance of certain beds of tuff in both Central and Eastern Murriëk makes the suggested correlation of A.T.B.5 with T.B.4 of Dewey very tentative. An acid tuff to the south of A.T.B.5 on Slieve Mahanagh is very discontinuous and may represent A.T.B.8, which is abruptly terminated near the road, and replaced by a coarse deposit from a turbidity flow. Similar flows may have occurred further west, so giving additional breaches in the bed.

The base of a thin bed of massive grit some 50ft to the south of A.T.B.8 is well exposed and reveals a series of casts of tool marks (Dzulinski and Sanders, 1962, p. 72) - grooves cut into the surface of underlying sediments during movement of a turbidity current. These markings plunge north-eastwards, and indicate an easterly origin of the current responsible for the deposition in this instance. Dzulinski has shown by experiments (personal communication) that the tool marks associated with
turbidity flows are best developed at a distance from the source of the flow, and so the sediments of the flows deposited in the area must have travelled a distance of several miles before deposition.

There is a general thinning of all tuff beds eastwards, suggesting a source of the tuffs somewhere to the west or south-west. This variation is accompanied by a marked westward increase of slate, suggesting that the sediment has principally an eastern origin. The restricted lateral extent of any given turbidity flow may have permitted partial erosion of previously deposited, but unconsolidated, beds of tuff.

5 The Cuilmore Volcanic Formation.

The Cuilmore Volcanic Formation has not been recognised in Eastern Murrisk and may have thinned out and disappeared in C. Murrisk before entering the westernmost part of the area. This suggests a westerly or south-westerly source for the Formation.


The Creggan-a-tiadwar Group consists principally of darkgrey slates interbedded with grits, which show internal sedimentary banding, and associated with occasional thick beds of grey-green ashes. (Dewey 1960).

Sedimentary structures identified by Dewey include ripples, grading, and sandstone dykes. He interpreted small scale folds associated with flame structures within coarser grits as being partly caused by intermittent seismicity.

Dewey (1960) observed that the ripples, which have also been recognised in E. Murrisk, were symmetrical in cross-section, and showed in his illustration (Fig. 18 B) that they have an average wavelength of 10 cms. No
internal micro-stratifications of sedimentary structures were described. The absence of asymmetry he ascribed to formation parallel to the flow of the currents, and he believed that they originated under shallow water.

Sandstone dykes, in which sands moved upwards as sheets rather than pipes were believed to have been formed due to loading by the overlying beds. They may have produced sand volcanoes, or even fissure eruptions of sands since long sheets have moved upwards and often been truncated by higher beds, but none have been found. No sandstone dykes have been recognised in the sparsely exposed outcrop in E. Murrisk. Photographs taken during recent oceanographical surveys have shown symmetrical ripples on the ocean floor at considerable depth. No evidence is available for estimation of the depth of formation of sand volcanoes.

From the presence of all these structures Dewey deduced a shallow water environment of deposition, from which he inferred an infilling of the Murrisk sedimentary basin. However, alternations of coarse and fine grained beds occur intermittently throughout the Sheeffry Series. It is only in the Creggan-a-tiadwar Group that they dominate the sequence, and are sufficiently well exposed to be studied in detail (in the cliffs above Creggan-a-tiadwar in Central Murrisk). There is no clear difference between these alternating sediments and the ones seen elsewhere in the Sheeffry Series. It seems improbable, therefore, that the sediments which are virtually identical to those interbedded with rocks thought by Dewey (p.49) to have been deposited under at least 1100ft of water, are of shallow water origin. There is little evidence to support shallowing of the basin.

In Eastern Murrisk the Group is exposed on Slieve Mahanagh where it is
composed of finely interbedded grits and slates. Grading is common in this area, and is accentuated by the swinging cleavages. Load casting is well developed on the bases of the occasional massive beds of grits and some siltstones. The softer beds beneath are often drawn up to form pseudo-ripples, which plunge steeply down the bedding, in contrast to the true ripples, which are nearly horizontal in plunge orientation. Further east, towards Corveagh, the generally brown-weathering rocks become more massively bedded, and psammitic in composition. In the well exposed sections along a fault line cliff on the northern face of the hill, the Group is seen to have changed radically in nature. In this eastern part the thin slates have virtually disappeared, and the sequence consists almost exclusively of beds of massive grits, up to 12 ft (4m) in thickness, and without intervening slates. The grits are well jointed and white-weathering. The few sedimentary structures are flames indicating a southerly or south-easterly origin. The sediment is very clean washed, rich in metamorphic quartz, and low in clay grade matrix material. It may be some of the first material to be eroded from a newly uplifted area to the south-east, along a continuation of the Dalradian rocks exposed in Connemara today.

In Central Murriak two beds of acid tuffs, T.B.14 and T.B.15 were noted by Dewey (1960). Two tuffs A.T.B.10 and A.T.B.11 have been recognised north of Claddy, Jnd. one, A.T.B.11, in Keelkill, where the bed is granular and crystals with albite twinning are visible in hand specimen. Both are cream-weathering and discontinuously exposed. Neither has been seen east of the road at Cordarragh.

Occasional thin beds of feldspathic tuff are present in the western
part of Slieve Mahanagh and some thin hornstones may be due to deposits of ash.

The palaeogeography of the area during deposition of the Creggan-a-tiadwar Group was probably essentially the same as that during deposition of the preceding Groups. It was as suggested by Dewey (1960). The long-lived east to west trough still survived and along it moved dilute turbidity currents, which deposited thin layers of grits and slates. A dominant westward moving current swept the floor of the trough during periods of non-deposition, and produced longitudinal ripples.

The coarser, white-weathering grits which show flame structures are clearly from a different source, and flowed in from a south or south-easterly direction and represent the first influx of material recognised from a southerly quadrant in the Sheeffry Series.

The location of the boundaries at the base and top of the Group in the Corveagh area is subjective, for the sediments of both this Group and the Banded Group above it are dominated by the white grits, which are virtually identical with those of the Derrylea Group, which overlies them both. It is clear that the term Creggan-a-tiadwar Group is used for the stratigraphical division which embraces two facies of sedimentation.

The Group is thinner in Eastern Murrisk, where it is 1000 ft (310m) in maximum thickness, than in Central Murrisk, where it is 1,750 ft (435m) thick. However, in the Corveagh area the thickness is not known, owing to difficulty of recognising the boundaries of the Group due to the change of facies.
7. **Banded Group.**

At Claddy the Banded Group is about 300 ft (100m) thick compared with a maximum thickness of 350 ft (115m) in Central Murrisk. It is characterised by a uniformly bedded series of greywacke grits, which weather to a brown colour, and thin layers of slates, some of which are black and autochthonous, and others genetically associated with the greywackes. The other important diagnostic character is a total absence of volcanic ashes.

At the base of the more massive grits (up to 25 cms in thickness), load casts are sometimes developed. Pseudo ripple-drift bedding is present east of Claddy, where there appears to be migration of the 'ripples' from the west towards the east. These ripples are asymmetrical, the steeply inclined lamination being towards the east. Detailed examination shows that this is due entirely to variation in orientation of early cleavages as they pass through layers of differing lithology.

As indicated above, there is a facies change to the east, and white grits of the lateral turbidite facies of the Derrylea Group appear to be contemporaneous with the more varied beds which occur further west.

8. **The Derrylea Group.**

The Derrylea Group was stated by Dewey (1960) to be composed of "evenly bedded greywackes, some thick and massive, others thinner, fine-grained, and interbedded with slates." In his detailed account of the sedimentation of the Group he showed it to have originated from turbidity flows, which moved from two directions, east and south. In flows from each of these directions he distinguished structures characteristic of the
mode of deposition. The axial turbidites, of easterly derivation, are identified by the presence of grading, banding and internal discontinuities. Groove casts, and flute casts are also typical. The other type, the lateral turbidites, often show prolapsed bedding, internal contortions, and on the base, overturned flow casts.

The Derrylea Group is exposed in two east-west strips of country. In the north it is exposed from Claddy to Teevinish along the Slieve Mahanagh-Corveagh Hill ridge. To the south of the Erriff tear fault the Derrylea Group outcrops on the slopes and ridge north of Lough Glenewough, but is obscured by bog as far as Croaghrimbeg Hill; exposures are then virtually continuous to Croaghrimcara and Bohaun, where a suite of pillow lavas appears to be partly contemporaneous with the sediments of the Derrylea Group.

In the Teevinish area the Group is at least 4,800 ft (1,480m) thick, neither the top nor the base being seen at this locality. The true thickness is seen in only one place, at Erriff village, where a small exposure of the sediments of the Banded Group occurs near the valley floor. Above this the sediments are all of the Derrylea Group until the junction with the overlying Glenummera Series, which is also seen higher up the hill. The maximum possible thickness is 4,200 ft (1,280m).

The sediments are principally composed of clean washed greywacke grits with little clay, usually very massively bedded, between which are a few thin beds of slates, usually of grey-green colour. The slates contrast with those of the Sheeffry Series, which are usually darkly coloured. In the Lackderg area a red coloured facies occurs, in which rocks of otherwise
typical Derrylea composition are rich in a hematite stain. This may in part be due to the proximity of the Carboniferous weathering surface at this point. One bed of feldspathic tuff is present in this zone.

Where the Group is well exposed, sedimentary features are usually common, and fine detail has been observed in some places. As indicated by Dewey, material from two sources was transported during sedimentation. The easterly source was of lesser influence than the southerly one. On Slieve Mahanagh near Claddy, where the beds are inverted, structures such as tool-marks and elongate load casts are seen, often in three dimensions. Occasional slump structures are present, and the axis of the fold of the sediments is approximately perpendicular to the principal flow direction, i.e. in the sedimentary 'b' direction, approximately north-east and south-west.

A comparison of the structures from place to place along the outcrop of the Derrylea Group shows that the shallow grooves, parallel to the 'a' movement direction of the southern sediments, are present throughout. Slump features perpendicular to this direction have rarely been observed, except in the more southerly exposures, near the top of the Group at Erriff and Croaghrimcara. The sedimentary directions are indicated in Fig 18. Flute casts are long narrow grooves cut into the top of either a sandstone or a slate. When flutes cut into slates have been filled with coarse grits, loading often causes post-depositional penetration of the slates by the grits. When little loading has taken place, the cross-cutting nature of the feature is evident, fine laminations in silty horizons are broken through.
The groove may be terminated, the abrupt termination being in an upstream direction relative to the flow which caused the formation of the feature. In a downstream direction the flute mark may become progressively shallower.

The formation is due to erosion by water, a change from overall laminar flow near the base to minor turbulence in small zones being the controlling factor. The flow of a turbidity current is dominantly of turbulent type, but at the base of the flow movement probably approximates to laminar in type, otherwise considerable erosion of the underlying beds would result in all cases. Where the flow pattern is broken flutes are formed, and the casts of these are preserved to act as indicators of the current direction. Tool marks are discontinuous hollows or dents caused by the impact of fragments of rock debris upon the sea floor during movement of the turbidity flow. These features are essentially groove-like, but tend to be short, and may be deep, prod-marks into the underlying surface. Where the tool responsible for the marks has turned over during movement, irregularly shaped grooves may result. Experiments by Dzulinski (personal communication), in which he passed a fine turbid suspension of plaster of Paris over a soft surface of kaolin, have shown that the proximal zone, near the outfall of the flow, is characterised by flute casts, but that further from the source tool marks and prod marks remain often as the only forms of sedimentary 'a' structures.

Particularly good examples of tool marks occur in the Cladda area, where they indicate a movement from a south-easterly direction in the lateral turbidites. Their presence at this locality indicates that the
origin of the flows was some way from here.

Channels up to 2 ft (60cms) in depth, and 10 ft (3m) in width, and which cut into the bedding, are common in the Croaghirmacara area. Their sides are steep and the floors of the hollows are filled with conglomeratic debris often up to 4 ins (10cms) in diameter.

These features were cut by pebble-laden currents which flowed from an east-south-easterly direction. Such channels originated relatively close to the source of the flow, and the land surface at the time of the deposition of the upper part of the Derrylea Group must have been to the east-south-east of Croaghirmacara.

Prolapsed bedding. Complex internal contortions and sedimentary nappes form deformed ball structures which have been flattened. Such features are typically seen in parts of the succession deposited from lateral turbidity flows in Central Murrisk, and also occur in Cordarragh South. Dewey (1960) considered that the axes of the fold structures were analogous to those in slumps, and lay along the sedimentary 'b' direction, viz. perpendicular to the flow of the current. In prolapsed bedding the axial plane is usually inclined towards the direction from which movement took place.

Ripples. Asymmetrical ripples, spaced widely apart, occur on the top surface of some of the beds of greywacke, below the succeeding slate layers. The ripples are relatively regularly oriented, with their steep side towards the north-east when the dip of the nearly vertical beds is removed. They lie along the sedimentary 'b' direction and are transcurrent to the flutes, grooves, and channels in the Croaghirmacara area.

Ripples are rare except in the Croaghirmacara area, where ripple drift
Fig. 18. Orientation of sedimentary lineations in the Derrylea Group.
(not adjusted for compression)
has been seen, migration being towards the northwest in successively younger beds.

In consideration of the Letterbrock Group, the longitudinal ripples were not considered to be reliable indicators of depth on their own. In the Upper Derrylea Group the presence of channels in association with asymmetrical ripples suggests a relatively shallow water environment of deposition.

The detailed analyses of all the information concerning sedimentary direction in this Group in Eastern Murrisk is given in a series of diagrams in Fig. 18. In the extreme west, at Claddy, the grooves, tool-marks and elongate load casts all indicate movement from a south-easterly direction. One slump structure is perpendicular to this direction. There are a few flute casts which are parallel to the slump feature, but they are in a separate series of beds, and are probably of axial origin.

A similar series of results is obtained from Cordarragh South, where, however, the flame structures and load casts are not truly perpendicular to the grooves which parallel the flow direction. The principal direction of flow at this locality was again from the south-east.

In the Corveagh-Teevinish area a similar south-easterly source is indicated by shallow channels. Here flute-casts of the axial sediments occur, indicating influx of the axial turbidites from an easterly or east-north-easterly direction.

Above Erriff village, where the Derrylea Group outcrops along the steep slopes below Lough Glenawough, slump features are more common. The axes of the balled up structures and of a flame structure are alike, along
Plate 5. Virtually undeformed conglomerate of the Derrylea Group, Croaghrimcara.

Plate 6. Sheared and eroded pebbles in conglomerate of the Derrylea Group, Croaghrimcara.
an easterly direction and indicate derivation from a source more nearly south than previously observed.

By contrast, at Croaghrimcara the lateral sediments have a more easterly origin than previously seen. Shallow channels, grooves and striations indicate an east-south-easterly derivation. Perpendicular to this direction are slump ball-ups, and many small asymmetrical ripples, also thought to be cross-current features. In this most south-easterly area, not only are the channels deeper and more steep sided than in any other part of the out-crop, but the sediments are also coarser in grain size, and thin beds of conglomerates occur in the sequence.

In the exposures of the Claddy-Teevinish area the influence of the axial turbidites is much stronger than in the rocks of Erriff and Croaghrimcara. There also appears to be a decrease in axial importance from west to east, for many of the grit beds of Teevinish are of lateral origin, while their contemporaries to the west appear to be of eastern origin. It is possible that emplacement of the sediments took place in two phases, firstly an influx from the south-east, and later movement of this material westwards down the axis of the trough.

In thin-section the rocks are seen to be partly sorted sandstones and slates. The sands are composed principally of sub-angular quartz, partly rounded feldspars, and lithic fragments set in a clay matrix of silica, chlorite, and sericite.

The quartz, which varies in proportion from 20% to 50% of the rock, shows undulose twinning and granular structure in many cases. The unstrained quartz fragments show partly rounded grain boundaries and are sub-rounded
in shape. Many show trails of very small gas bubbles. Other inclusions are rare, biotite and dumortierite having been identified. Some of this quartz may be of igneous origin, the rest being derived from quartz veins. Such unstrained quartz increases in proportion upwards until at Croaghrimcara it dominates the quartz content of the rock. The quartz of metamorphic origin is generally angular to sub-angular, and in the fine-grained material the quartz fragments occur at the centre of fine 'pods' of sericitic material.

The feldspars, which generally form sub-rounded grains, vary up to 30% of the rock, but throughout most of the sequence form 7-11% of the bulk rock total. In the lowest layers in the Claddy - Teevinish area the feldspars are of albite-oligoclase plagioclase, and of orthoclase. All the feldspars have been altered to some extent, sericite and epidote exsolutions occurring within the fragments in the rock. Most of the feldspars appear cloudy in plane-polarised light. In the highest beds at Croaghrimcara the plagioclase crystals are angular, and the many albite and combined Carlsbad-albite twins show the feldspars to be of more basic composition, An_{35-50}, in the andesine range.

Two forms of detrital mica, muscovite, and chlorite sometimes interleaved with muscovite, are present. Both usually show compaction strains, and the flakes of each lie parallel to the bedding when not buckled or broken by adjacent sand grains.

The lithic material is principally formed of fragments of metamorphic quartzite, with some mica-bearing gneisses high in the sequence. Mud pellets are common in the lateral turbidites, and are present largely in
the form of nodules of sericite and chlorite.

Heavy detrital minerals comprise a small proportion of the rock, and vary in identity. Detrital garnet, sphene, epidote, apatite, tourmaline and staurolite have been observed in thin-sections. Such minerals as dumortierite, and biotite occur as inclusions within large quartz grains. The variety of the heavy minerals increases upwards in the sequence, while their proportion of the bulk rock shows a slight decrease upwards.

The size of the grains comprising the rock varies from place to place and within each individual bed. In many beds, especially the axial turbidites, there is a distinct grading, although in the lateral turbidites grading is present only in the uppermost few centimetres of the beds, which may be 50 - 200cms in thickness.

In the stream section at Cordarragh South the grits are coarse-grained and often micro-conglomeratic. Grains of quartz, up to 2cms in diameter, occasionally show imbrication which suggests a south-easterly derivation. Imbrication is normally associated with shallow water deposits, and the inclination of the grains in this case may be due to later tectonism, in which the grains have become oriented parallel to the cleavage. The micro-conglomerates contain fragments of black chert, metamorphic quartzite, light coloured mica schist, and occasional small fragments of jasper. The lateral turbidites are rich in fragments of slate and grits of similar composition to the rocks themselves, and these are thought to indicate penecontemporaneous erosion, perhaps during movement of the turbidity flow before deposition.

At neither Gladdy nor Teevinish are such coarsely grained beds present,
and the greywackes are rarely more than coarse sandstones. Above
Erriff the Group becomes more coarsely grained upwards, and the rocks, which
lower in the sequence are largely of medium grained sandstones, become
coarse sandstones in which distinctly conglomeratic layers are present.
Again metamorphic material is common, with grits and slates important
among the components.

At Croaghrimcara the exposure is sufficiently good to enable the
study of groups of beds and the changes of their composition along the
strike. From the eastern side of the hill, near Bohaun, to the western side
the rocks, which strike slightly oblique to the road, change in facies from
interbedded conglomerates and grits to slates. In the west the grits con-
tain many slate fragments.

The conglomerates near the summit of the hill contain boulders
commonly 25 cms in diameter, and reaching a maximum measured diameter of
55 cms. Such conglomerates line the floors of channels cut into the under-
lying grits.

The boulders of the conglomerates are composed principally of granites
and quartzite, but some are of jasper and others black chert. They are
often well rounded, and visual estimates of 0.65 - 0.68 were made in the
field on such material. The grits and slates, which are cut away
during formation of the channels, form pellets in the sediment down-
stream of the channels. This debris is present as lenticular fragments of
clay and grit, the ends of which have been pinched and buckled during com-
paction subsequent to deposition. This is the material which becomes
elongated, partly due to sedimentary compaction, and partly due to later
tectonic deformation during shearing of the rocks. The pebbles composed of competent material such as granite rarely show shape deformation, but fracture along the cleavage. Thus different materials subjected to the same stresses react in different ways: some show brittle fracture, others a form of flow deformation. The granite and jasper pebbles were solid and dry during stress, but the sediments were partly composed of water at this stage, and deformation drove out some of the water, and was responsible for the production of the extrayagant elongation in some of the fragments of grit and slate.

During detailed petrological investigation of the sediments of the Derrylea Group the following criteria were used in attempting to correlate the sediments from thin-section:

1) Identity of included fragments.
2) Relative proportions of the included fragments.
3) Relative proportions of detrital material to clay fraction.
4) Grain size distribution in the rock.
5) Roundness of grains in the rock.

The last feature is insensitive. The visual method of analysis suggested by Powers (1953) was applied throughout the entire Arenig succession, and a variation of 0.18 (from 0.26 to 0.44) has been recorded from examination of thin sections (based on 20 analyses). Thus in all the sediments the grains range between sub-rounded and sub-angular in outline.

The relative proportions of detrital material to the clay grade fraction is not of great diagnostic value. In the early stages of movement of a turbidity flow the proportion of matrix material deposited is probably
low. Later the material of clay grade may dominate the assemblage in the areas furthest from the source.

Many turbidites show some form of vertical grading of grain size in the beds. Thus the lowest sections of the beds may be low in clay grade or matrix grade material, while the highest sections in the same bed at the same spot may consist entirely of clay grade material. Thus the factor of grading renders useless direct comparison using this criterion.

The grain size distribution in the rock is again very dependent upon the location relative to the origin of the flow from which the sample is taken. The sorting of the grains is poor at the base, where deposition is from a turbulent flow, but at higher levels in the bed sorting improves.

The identification of the individual grains within the rock is important in that material derived from any one source should be composed of fragments of the same minerals. As the source alters in nature, new minerals appear.

A variation of this type occurs within the sediments in the lateral turbidites of the Derrylea Group. As is seen from the mineralogical analyses in Table 1, the heavy detrital grains comprise a small fraction of the rock. The details given here refer entirely to observations on thin sections of the rock. Although it was attempted to break down the rocks to facilitate examination of the heavy minerals in detail, total disaggregation was impossible and thin section analysis was the only other method of examination undertaken. In the lowermost part of the Group at Claddy, chlorite and muscovite are the only 'heavy' detrital minerals present in the thin sections examined, and they also occur throughout the rest of the sequence. Epidote and apatite both occur as small grains, and have been seen from
Fig. 19 Variations in heavy mineral content of thin sections from the Derrylea Group.

West

East

Based on 22 thin sections.
the southern exposures at Claddy, Lackderg and Teevinish, garnet also occurring in the first two of these localities. All occur commonly higher in the succession, but none are known lower. In the highest levels, above Erriff, and Croaghirmcara, sphene is present in most sections. Sillimanite has been recognised in one thin section from near the top of the sequence at Erriff, but nowhere else.

Biotite follows a different distribution, and occurs at Teevinish and in all of the southern exposures, but not at Claddy or Lackderg.

There is a small variation in the plagioclase feldspars in the sequence. Near the base they are mostly albite-oligoclase in composition, but towards the top some reach the composition of andesine.

Thus on the evidence of 21 thin sections, a thin section of sediment from this Group could be given an approximate stratigraphical position from examination of the identities of the heavy minerals contained. This will also be reflected in the diversity of the contained assemblage of minerals (Fig 19).

The sediments of the lateral turbidites are of demonstrable southerly and south-easterly origin, and they would be expected to reflect any variation in composition of the source area. In the Dalradian rocks of Connemara the general structure plunges towards the east, with rocks of lower structural position and of higher metamorphic grade occurring towards the west. A study of Fig. 19 reveals that the more complex assemblages of minerals occur at lower stratigraphical levels in the west than in the east. This is clearly due in part at least to variation of metamorphic grade of the rocks which acted as sources for the debris. The source for eastern
sediments was constantly of a lower metamorphic grade than that for the westerly sediments. Other minerals, such as sillimanite, may occur at lower levels in the Derrylea Group of Central Murrisk.

The rocks of more complex composition were exposed and eroded at a later time in the east than in the west, and so any mineral species is diachronous in its appearance in the rock.

The relative proportions of such debris as quartz, feldspar, lithic fragments and heavy minerals will depend partly on the ratio of volume to specific gravity of the individual component. Thus, if heavy minerals of large volume are transported, they will tend to settle nearer the source than grains of quartz of equal volume and shape. The sediment would, therefore, show a decrease in the total mass of detritus at any given level, e.g. the base of the bed, from source to the head of deposition.

If simple conditions of laminar non-turbid flow were extant, the deposit should show a steady decrease in the total mass of the detritus along its length from the source, and a similar decrease in an upward direction. Turbulent flow has been postulated by Kuenen and Migliorini (1950) to be responsible for movement before deposition of greywackes. In turbulent flow the settling mechanics are more complicated and sorting due to specific gravity alone has a less pronounced effect. Nevertheless, a broad zonation of the coarser and heavier material near the source, and lighter material with small quantities of heavy minerals further from the source, is to be expected.

Reference to the common constituents of the sediments of the Derrylea Group indicates that much of the magnetite \((G. = 5.2)\) and ilmenite
(G = 4.5 - 5.0), would be expected to settle during the earlier part of
the flow movement, and only later would such constituents as sphene (G = 3.4 -
3.56), epidote (G = 3.25 = 3.5), apatite (G = 3.17 - 3.23) and garnet (G =
3.15 - 4.3) be deposited in bulk. Biotite, muscovite and chlorite (G =
2.6 - 3.1) would settle later, potash feldspars (G = 2.54 - 2.58), plagio-
classes (G = 2.6 - 2.75) and associated quartz (G = 2.65) would be deposited
still later in order of specific gravity. Such a finely divided zonation
will certainly not result from turbidity flows; but a general sequence from
a deposit rich in heavy minerals near the source to a quartz and feldspar
rich deposit away from the source should be found. Factors such as size and
shape, however, influence the hypothetical zonation.

In practice the heavy minerals are present in the southern exposures,
which are not only high in the sequence, but also near the source. Iron
minerals are, however, not so abundant in these high levels as in the
Cladep - Lackderg area, where the heavy silicate minerals are of smaller
proportion. Most of the iron minerals are alterations from pyrite, ilmenite
and magnetite, and are opaque in thin section. Reflected light reveals them
to be principally of leucoxene, with some limonite and a little magnetite.
This apparent concentration in the lower levels may be due to a
difference in the nature of the source, or perhaps due to derivation from
the axial turbidites, which are more common in this part of the sequence.

Briggs, McCulloch and Moser (1963) have shown that the heavy mineral
suite deposited in a sandstone may be greatly influenced by the hydraulic
sorting of particular sizes and specific gravities of these minerals. They
showed that drag coefficient, which partly controls transport, has the same
effect as specific gravity. Sorting of heavy minerals by shape is as
important, relative to size frequency distribution, as sorting by specific gravity."

They considered mathematically the effect for laminar flow only, but clearly settling from turbulent flow will be subject to somewhat similar limitations.

Small differences of shape among angular grains were shown to have a far greater hydraulic effect than small differences among nearly spherical grains. As a result of this they urged that accurate shape measurement be undertaken when minerals are used to distinguish between sedimentary environments or where cosanguinity of mineral suites is used to define petrological provinces of stratigraphical units.

In the Derrylea Group the significance of variation of mineral content has been studied with reference to possible changes in the nature of the source of the detritus. No direct attempt has been made to establish stratigraphical units on the evidence of petrological composition, but some attempt has been given above, to link changes with the source, and so a brief consideration of the effect of shape differences on the minerals will be given.

All the observations have been made in thin sections and it is unlikely that the maximum dimensions or eccentricity of the grains will have been seen. The degree of rounding of the grains varies considerably. Quartz is usually subangular to angular, potash feldspar sub-angular to sub-rounded, and plagioclase feldspar sub-rounded to rounded. The micas are plate-like and generally non-rounded, while the heavy minerals vary considerably. Zircon is always small and well rounded, apatite is usually
sub-rounded, and garnet likewise, but both sphene and the epidotes are poorly rounded and fall in the sub-angular - sub-rounded boundary area. Lithic fragments vary in shape according to their composition.

Although differences exist between roundnesses of the individual components of the sediments, there appears to be an overall increase of angularity up the sequence. This reflects the increasing proximity of the source of the sediments.

In summary it may be said that the three principal factors influencing the distribution of the components in a sandstone are size, shape, and specific gravity.

The relative amounts of quartz, feldspar, and lithic fragments have been studied. Since the lithic material is composed principally of metamorphic quartzite, schists and gneisses, and chert, there has been little post-depositional decomposition. The three components therefore, represent the most stable parts of the rock.

The results of analyses from the Derrylea Group have been plotted using quartz, feldspar, and lithic material as parameters, Fig. 20. There is a distinct trend towards an increase of feldspar and lithic material in the higher parts of the sequence. This partly reflects greater proximity to the source and probable changes in rocks of the source area. All five of the specimens from the Claddy - Teevinish area fall in a group in the region of 80% quartz, 15% feldspar 5% lithic. There are two notable exceptions to the regular linear distribution, namely specimens 621 and 825. Of these, the former is more finely grained than the average rocks examined and the latter much more angular, even the feldspars being angular instead
of the usual rounded to sub-rounded grains. Specimen 825 is associated with a tuff. The approach of 621 towards the feldspar apex is interesting, for there is a pronounced tendency for the detritus of the finer grained rocks generally to be composed of plagioclase feldspars rather than of quartz. This has been observed in fine grained and sediments not investigated by detailed analysis.

Passing reference is made to the increase of feldspar proportion in the finer grained rocks in many stratigraphical papers, and it may be of some significance. Pettijohn (1957) summarised the limited data available concerning feldspar content of sands, and concluded that the feldspar content decreased rapidly in high-gradient streams and slowly in low-gradient streams. McEwen, Fessenden, and Rogers (1959) noted a decreased quartz content with grain size in the Colorado River. Pollock (1961) found higher quartz ratios in coarser sands than in finer sands from the South Canadian River. Hayes (1962), from a study of the sands of the South Platte, Platte, and Missouri Rivers, showed that there was little change in the total feldspar content with decrease of grain size, but there was a distinct decrease in the quartz-plagioclase ratio in the finer material. However, Hayes's results were from an average of samples taken along the 2,500 miles of the rivers, and for this reason are not applicable to the sediments of Murrisk. In Murrisk, the latest turbidites can have moved no more than 30 miles from the south-east, and only the uppermost 4 analyses of Hayes (1962) will be comparable. In these there is a rapid increase in the total feldspar content, but no information on grain size. Clearly the results presented by Hayes are inconclusive. River sands are not the same
as marine sands, but are the only ones for which data is available. The method of deposition from turbulent flow in streams is similar to that from turbulent water in turbidity flows, and results should be analogous.

In turbidites the upward decrease of quartz-plagioclase ratio may be partly due to slight differences of specific gravity between quartz and the feldspar. The presence of cleavages in the feldspars makes the potential breakdown due to mechanical weathering greater than in the quartz. Weathering is considered to be an indirect factor in the distribution. After passage of a turbulent flow, all material in suspension begins to settle. The hydraulic properties mentioned above permit relatively rapid settling of the angular and sub-angular fragments, which are principally composed of quartz. Other material, of similar specific gravity but of better rounded grain shape, is held in suspension for a slightly longer time. At this stage differentiation due to specific gravity becomes important, and again quartz is deposited prior to the plagioclase. The result of this is that quartz dominates the earliest layers, and contains some feldspars, but that higher in the same bed there will be a lower quartz-plagioclase ratio. The principal factor is rounding.

Since the sediments vary in composition from place to place and even within the thickness of individual beds, the problems of their classification are manifold. Clearly it is futile to classify each individual specimen examined, and yet if the compositions of ten samples from the low part of the beds and another ten from the higher parts of the same beds are averaged and compared, they will be termed as different rock types according to most
of the existing methods of classification.

Krynine (1948) was the first author to use triangular diagrams in the classification of sediments. His parameters assigned no place to rock fragments, and classed micas and feldspars under two separate headings. Decay of feldspars produces sericite in many of the thin sections of the rocks from Murrisk, and the problem arises as to whether this sericite is "feldspar" or "mica" in this classification.

Pettijohn (1949, 1954) provided M.L.Q. diagrams in which the parameters are matrix (M), quartz and chert (Q), and labile constituents (L), the latter comprising feldspar, rock fragments and unstable minerals. These include a maturity factor - quartz to labile material, and a fluidity factor - ratio of sand to matrix. He introduced a minimum requirement of 15% clay content for greywackes.

The introduction of a provenance factor, which appears to assume all feldspar to be of igneous origin, and all rock fragments to be sedimentary is doubtful. In Murrisk much of the feldspar is metamorphic and some probably volcanic. The use of a 15% matrix component is again dubious, for the base of a graded bed might thus be a sub-greywacke, only to grade upwards into a greywacke when conditions of deposition of the same bed were quieter.

Gilbert (1954) suggested an arbitrary division based on a 10% matrix content, to split the rocks into two groups, the Wackes, and the Aronites. To each of these was assigned an independant triangle, for which the parameters were Quartz, Feldspar, and unstable fine-grained rock fragments (Q.F.R. diagrams). The material of both of the latter parameters is liable
to break down. Decomposition of material of one of these parameters may take place at a faster rate than the other. Decay of a slate or mudstone to form sericite may be more rapid than alteration of feldspar to form sericite. Such secondary sericite has no place on the ternary diagram and as a result of the decay the sediment could change from being a lithic wacke to a feldspathic wacke solely as a result of diagenetic changes.

Folk (1954) pursued an illusive classification in attempting to define the character of the source area to the exclusion of either the mode of sedimentation or the detailed petrography of the rocks. His parameters were quartz; feldspar and igneous rock fragments; and mica, metamorphic rocks and metaquartzites. They are intended to measure detritus of sedimentary, igneous, and metamorphic origins.

This classification is perhaps the least satisfactory of all those under review, for it not only follows Pettijohn (1954), in classing all feldspar as of igneous origin, but also classes all mica as metamorphic, ignoring granites and granite pegmatites which may contain important percentages of mica. Quartz grains of the first cycle of sedimentation may have been either igneous or metamorphic in origin, and need not have undergone prolonged weathering. Where two or three quartz grains are in contact along deeply sutured margins the problem arises as to whether they are "quartz" or "meta-quartzite".

Packham (1954) considered that classification in the laboratory should only be carried out after sufficient field work had established the nature of deposition of the rocks. In view of this he suggested that two suites of rock based on structures characteristic of "deep" water or "shallow"
Fig. 20. Q.F.L. diagram for 21 analyses from the Sheeffry Series

- Lateral turbidites
- Axial turbidites
- Owenmore Group
- Derrylea Group
water might profitably be used.

Two MLQ diagrams were used. As in most of the previously discussed classifications, the decay of the unstable, labile constituents produces sericite, which is classed as 'matrix'. Movement on the diagram due to this decay could at the most change the composition of a rock from a labile greywacke with high matrix content into a pelite. Slight variations in matrix content do not, however, lead to name variations implying different genera.

This classification embodies less evident faults than the previous ones. Crook (1960) suggested certain modifications to it. He suggested the use of an arenite diagram, for application to rocks about which no information concerning sedimentary structures was available. Presumably this is intended for borehole material. His most useful proposal, however, was a series of name divisions for the labile greywacke, or labile sandstone fields of Packham (1954). These are applied on the basis of a QFR diagram to be used in conjunction with the MLQ diagram. The use of the new terms conveys an accurate mineralogical description with clear genetic significance, although it does not indicate the nature of the source of the debris.

The results of modal analyses of the Arenig sediments of Murrisk have been plotted on QFR and MLQ diagrams, see Figs 20 and 21.

According to the Crook - Packham classification, therefore, the sediments of the Derrylea Group range from dominantly feldspathic sub-labile greywackes near the base to litho-feldspathic greywackes at the top of the succession, in Croaghrimcara, with feldspathic greywackes occurring from place to place in the succession. The lateral turbidites tend to
Fig. 21 M.L.Q. diagram for 21 analyses from the Sheeffry Series.

- Lateral turbidites
- Axial turbidites
- Owenmore Group
- Derrylea Group
deposit litho-feldspathic greywackes, and axial turbidites deposit feldspathic greywackes.

In the rest of the Arenig succession, the rocks of axial derivation are principally feldspathic greywackes and feldspathic sub-labile greywackes. The lateral turbidites in the Owenmore and Letterbrock Groups deposited lithic or feldspato-lithic greywackes.

Each of the diagrams shows that the sediments of the Derrylea Group occupy a different field from those of the rest of the Arenig succession. The Derrylea sediments, which are dominantly lateral turbidites, have a higher sand content (quartz and feldspar fractions) and less constant composition than the axial turbidites. Reference has already been made to the distinct trend line of compositional variation shown in the QFL diagram as applied to the Derrylea sediments. The analyses for the Owenmore Group also show a distinctive trend on the QFL diagram. The envelope for the rest of the sediments of the Arenig succession shows no marked trends of compositional variations, probably due to the small number of analyses in each of the remaining Groups.

In each of the methods of classification discussed above, the decay of labile material to form clay raised doubts on the validity of the divisions established. Cummins (1960) considered the decay to be of fundamental importance in the production of the matrix, and he believed that the proportion of matrix material increases with time. Factors contributory to the breakdown included depth of burial, temperature, and pressure, due to orogeny. Each of the latter increase both the rate of decay and the
Fig. 22 Grain size analyses from the Arenig grits.

Cumulative frequency %

Axial turbidites

Lateral turbidites

Axial turbidites
solubility of the debris.

Cummins published an interesting QFR diagram to show the lack of highly feldspathic Pre-Cretaceous greywackes.

He compared ternary diagrams of particle size analyses of greywackes and other turbidites, with analyses of some modern sands, and those of the same sands, assuming disintegration of 15% of the sand fraction. The resemblance of the two sets of diagrams is clear. Cummins' conclusion that most, if not all, of the matrix was produced by decay of the feldspars and other labile materials, must be treated with caution, for much virtually unaltered feldspar, chlorite, and mica remains in many of the thin sections examined from Murrisk. If decay had been responsible for the production of the matrix, most of these labile fragments would have been removed.

Particle size analysis has been carried out on the Arenig greywackes, measurements being taken from thin sections, since disaggregation of the rock by chemical means proved impracticable. The method adopted is that described for the analysis of the sediments of the Partry Series (see Chapter 4). The results are plotted graphically in Figs. 22 and 23.

Of the ten samples measured, four were from the Owenmore Group, two from the Derrylea Group, and the remainder from the intervening parts of the Arenig succession.

There is a clear distinction in grain size between the lateral turbidites of the Derrylea Group and the three samples of axial turbidites of the Owenmore Group. The cumulative frequency curves of analyses from the two Groups have different gradients, those of the Owenmore Group
Fig. 23 Graphical representation of the Inman parameters of 10 grain size analyses from the L. Arenig sediments.

$L = \text{lateral turbidites}$

$A = \text{axial turbidites}$
being steeper than those of the Derrylea Group.

The plots of the Inman parameters given in Fig. 23 show that the sediments have very similar properties of grain size variations. It is interesting to note however, that only the curves of the lateral turbidites show positive skewness; and that in each case the lateral turbidite analyses lie outside the envelope enclosing the results from the rest of the Arenig succession.

The palaeogeography of Arenig times in the Murrisk area may therefore be summarised as a broad east-west trending trough of relatively deep water which was bordered to the north and south by land on which metamorphic rocks were exposed. In the earliest record, found in the Letterbrock Group, there is evidence of movement of lateral turbidites, and boulder flows from a northwesterly direction, flowing into the trough in which dilute axial turbidity flows ran from east to west. Further up the succession, the lateral turbidites decrease in importance and axial turbidites, interbedded with intermittent bands of acid tuffs, were the only deposits. The upper part of the Arenig succession is represented by the Derrylea Group, in which lateral turbidites derived principally from the south and south-east increase in importance up the sequence. At the top, in Croaghrimcarra, conglomerates are seen. The pebbles of these are well rounded, suggesting that the beds may be directly related to the Mount Partry beds, seen on the south-eastern side of the Partry Mountains, at Derryveenagh. The Mount Partry Beds are composed largely of conglomerates in which the pebbles are very well rounded, and which appear to have been derived from the south-east. This boulder train may mark the location of one of the principal
Plate 7. The pillow lavas of Bohaun.

Plate 8. Bedded tuffs above the lavas at Bohaun.
routes along which the turbidity flows moved periodically. Clearly the presence of boulders indicates increasing proximity to the source, which must have been the early Connemara Cordillers.

Within the upper part of the Derrylea Group in the Sraheen - Bohaun area, are flows of spilitic lavas. The lavas may have partly existed as flows on the sea floor, for in places they are interbedded with grits and slates. They are well exposed beside the road at Bohaun, and have also been observed in the Aille River, to the north of Croaghchrom Lough, where the thin lavas are interbedded with calcareous slates and occasional beds of chert. The rocks form typical massive 'greenstones' in many places.

A regular succession of rock types repeated at least twelve times has been observed. At the base is a thickness of massive pillows with little extraneous material, other than occasional lenses of jasper between the pillows. Above this layer, which varies in thickness from 10 ft (3.3m) to 80 ft (26m), are pillow breccias in which fragments of pillows are surrounded by a largely tuffaceous, epidotic matrix. Again a few pods of jasper occur between the pillows. This layer of fragmental pillows is followed by shaly layers and occasional limestones, which are interbedded with aquagene tuffs. Above the calcareous pale green shales, lies the base of the next sequence of massive pillows.

Immediately south of the road at Bohaun, the pillows reach up to 20 ft. in length, but they are usually 10 - 15 ft (3.5m) long. These massive pillows are green-weathering, gritty rocks, in which there is a complex system of hollows on all weathered surfaces. Most of these hollows are larger than the vesicles, which may themselves reach up to 10 cms in length parallel.
to the direction of maximum elongation in the cleavage. The large cavities are quite distinct from the vesicles, and in conjunction with the outlines of the pillows, give the rock a very grotesque appearance in the field.

The pillows are composed of spilite in which the feldspar laths are of albite, and albite-oligoclase, with many small crystals of colourless epidote, set in a matrix of chlorite and albite.

The epidote and the green pleochroic chlorite are probably alterations of early augitic pyroxenes, but no relics are found, although the granular replacement texture is clear in many places. Opaque iron ores are relatively rare in thin section, although the rock is heavy in hand specimen.

At least three phases of production of plagioclase may be recognised in the rock. The earliest is present as occasional fragments of andesine surrounded by later albite-oligoclase. These earlier two feldspars are often rather cloudy, and later crystals of clear albite may be distinguished in thin section. These later albites are often closely associated with vesicles in which there is often an infilling of epidote. The vesicles lie in greatest profusion around the upper margins of each pillow, and in many cases have become elongated during later tectonic activity. They are usually empty, but some contain pale pink crystals of calcite, and occasionally epidote is concentrated in the cavities. The amygdales of these two calcic minerals may indicate that albite replaced an earlier calcic feldspar, the sodium replacing calcium in the crystal lattice. Some of the calcium may have come from breakdown of calcic pyroxenes of the original spilitic
The pillow breccias consist of fragments of pillows and small whole pillows, rarely exceeding 35 cms in length, set in a green tuffaceous matrix. Immediately above the massive pillows there is little matrix, but it increases in proportion up the sequence until the individual pillows are completely isolate. These pebbles of lava show empty vesicles, usually of uniform orientation due to later elongation in shearing. The epidote-rich matrix is often a deeper green colour than the pillows, which are more resistant to weathering, and stand out from the exposed surfaces. The lighter coloured pillows often have series of cracks crossing them, but these are believed to be of later tectonic origin. In shape the isolate pillows are globular or at least partly spheroidal, indicating general absence of explosive eruption. Some angular fragments do however, occur, suggesting that some explosive activity took place during eruption. Explosions of this kind have been described by Washington (1909) who observed the submarine eruption of 1891 near Pantelleria. He described hot bombs moving across the surface of the sea, buoyed up by gases in the vesicles. The 'bolts' as he termed them, exploded after a time, and the fragments sank. Carlisle (1963) has suggested that, if there was an accompanying extrusion of pillow lavas, many of the small, vesicular pillows would rise to the surface and shatter irregularly during the eruption. This may be the cause of the angular fragments which occur within the pillow breccia, but most of the included fragments are of complete isolate, spheroidal pillows.

Throughout the sequence, between the massive pillows and also among the isolate fragments in the pillow breccias, occur small lenses of jasper...
which are clearly contemporaneous with eruption. In three places distinct beds of jasper, reaching a maximum of 10ft (3m), in thickness, have been seen: in the Aille River north of Croaghcon Lough; beneath the bridge at Sraheen School; and directly north-west of the unconformity at the base of the Partry Series, above the fields in Bohaun South. These occurrences of the jasper are clearly associated with the slate-rich part of the sequence, where slates are interbedded with green, shardic tuffs. The jaspers occasionally show a form of weak banding, revealed in thin section as layers of coarser and finer grains of silica in the chalcedonic matrix. More frequently however, the cherts show a nodular texture. In thin section this is seen to be composed of series of pink coloured concentric layers forming irregular concentric nodules around a centre of clear silica within which are developed small flakes of specularite. The pink colouration is due to finely disseminated hematite. The fresh iron ore minerals have a regular distribution in the centres of the nodes in rocks where no shearing has occurred, but where such shearing has taken place the iron is concentrated in the zones of finely-grained silica and is principally in the form of hematite. In the occurrence near the unconformity with the Partry Series, some of the jasper has been injected into the surrounding sediments and is distinctly cross-cutting on Croaghrimcura Hill. Remobilisation of the iron has taken place, probably associated with the injection, so that it is now present as large segregations of specularite around which the small flakes of hematite have intergrown with silica to form a border. In some layers where shearing is intense, the iron is represented by minute octahedra of magnetite which occur in the very finely grained cherts. No radiolaria
have been seen in these cherts.

The aquagene tuffs, which occur intermittently throughout the sequence, may have been composed of shards, for one thin section shows rhombs of dolomite in which strange prolongations extend from the crystal edges, producing shapes reminiscent of shards. This suggests that the original glass shards may have been replaced by later dolomite. In other thin sections the tuffs show broken crystals of albite-oligoclase, and fragments of epidote, all set in a matrix of sericite.

In one instance corroded crystals of volcanic quartz with rounded, and deeply ambayed outlines are seen set in a rather nodular sericitic rock. Two possible explanations for the texture of this rock have been considered. Firstly that the fine-grained fragments of tuff may have coagulated during flight, perhaps due to contact with rain, and fell as mud pellets, which accumulated on the sea floor as a nodular layer. Alternatively there may have been flocculation of the fine tuff as it entered the water directly from the eruption and this would again lead to a nodular deposit. Of the two tentative explanations, the former appears preferable.

On the eastern end of Croaghrimcara Hill the conglomerates described as part of the sediments of the Derrylea Group contain occasional angular fragments of pillows. The frequency of occurrence of these decreases westwards. The distribution of the fragments suggests that the conglomerates and their related turbidites were in part contemporaneous with the extrusion of the pillows. The extrusive volcanic rocks may therefore, be regarded as a facies of the Derrylea Group.

Since the bedding is obscure in these rocks, their true thickness is
not known, but the volcanic facies is exposed for about one mile, from the Carboniferous rocks at Sraheen to the fields of Bohaun. The thickness in which volcanic rocks are known in the succession is estimated at a minimum of 3,500 ft (1020m) in the upper part of the Group. Their lateral extent is obscured by bog in the west but they are present in the Aille River north of Croaghcrom Lough, and extend eastwards in to Bohaun, where they are overstepped by the Partry Series.

Although Geikie (1897) first recognised the rocks as pillow lavas, it was Gardiner and Reynolds (1909) who recognised the identity of spilites to the east of the Partry Mountains. There spilites identical to those of Bohaun, though much less extensive, occur in the Shangort Beds.

Dewey and Flett (1911) defined the spilitic suite of rocks, as spilitic pillow lavas, and tuffs interbedded with mudstones, limestones, and radiolarian sediments. Gilluly (1935) outlined the principal considerations concerning the origin of the spilites. Turner and Verhoogen (1951) further indicated that such considerations hinge largely on geochemical investigations. Since no geochemical analysis has been undertaken on these rocks no examination of the origin of the spilites, or of the possibility of soda metasomatism will be given.

Perhaps the most extensive bibliography was given by Middleton, (1950), who described a spilite suite from Devonshire.

Submarine lavas and tuffs are characteristically found in the sediments deposited towards the end of the sinking and in-filling of a geosynclinal trough. Their association with the upper part of the Derrylea Group, and its partial equivalent, the Shangort Beds east of the Partry Mountains
may herald the end of rapid sinking, and a change of the type of sedimentation would be expected in the Glenummera series. The eugeosyncline which had existed in Murrisk throughout much of the Arenig appears to have reached the stage of old age, and a quieter form of sedimentation ensued during the Llanvirn.
CHAPTER III.

THE GLENUMMERA SERIES.

The sediments of the Glenummera Series are exposed sporadically along a narrow outcrop, which extends in an east-west direction to the south of the Derrycraff River (see Map).

The rocks were originally assigned to the 'Glenummera Slates' by Theokritoff (1951), who worked in the Leenane district. Stanton (1953) demonstrated that the dominantly slaty rocks stretched as far west as the Atlantic coast, and outcropped on each side of the Mweelrea syncline, to the north of Killary Harbour. He also discovered a fauna containing trilobites, brachiopods, gastropods, and lamellibranchs and which suggested a Middle or Lower Ordovician age for the deposits.

Stanton (1953) believed that there were perfect conformable junctions between the 'Sheeffry Grits', the 'Glenummera Slate' and the 'Mweelrea Grit'. McKerrow and Campbell (1960) demonstrated that on the southern limb of the syncline the Glenummera slates are progressively overstepped by later sediments, which they believed to be part of the 'Mweelrea Grits'.

On the northern limb of the syncline, the conformable relationship between the Mweelrea Group and the Glenummera Series is demonstrable as far east as the Letterreeneen fault. Beyond this, in the Glennagashleeny, Bohaun, and Lough Shee areas there is a distinct break at the base of the overlying sediments of the Partry Series. This break is believed to be due to overlapping of the sediments of the Mweelrea Group and Glenummera Series by those of the Maumtrasna Group (the upper part of the Partry Series). It is believed that the breaks, both here and on the southern limb of the syn-
cline, are due to the same cause, an unconformity within the Partry Series, and not to one at the base of the Series. (See Chapter 4).

The base of the Glenummera Series is seen to the west of Lough Glenawough, above Erriff village. There is an apparently conformable sedimentary junction, and the transition from the Sheeffry Series to the Glenummera Series is marked by an increase in the proportion of slate in the upper part of the succession.

The term 'Glenummera Series' has been introduced by Dewey (1962, Proceedings of the Geological Society of London), and although the definition has not yet appeared in print, it is (personal communication) synonymous with the previously used 'Glenummera Slates'.

Towards the base of the succession in the Glenummera Series, thin beds of sandstone identical petrographically and in sedimentary structures (principally grading) to sandstones of the Derrylea Group occur sporadically. In the upper part of the Series, however, the sandstones interbedded with the slates are identical to those of the overlying Mweelrea Group. The Glenummera Series, therefore marks a transitional stage between deep water turbidite facies, and a shallow water, current bedded sandstone facies.

As indicated by the earlier name, the Glenummera Series is dominantly of slates, with occasional very subordinate layers of sandstone. From place to place thin beds of conglomerate occur near the top of the succession.

The slates are generally very fine grained and are composed principally of birefringent flakes of mica-like clay minerals, with some minute crystals of silica set into the ground-mass. There are occasional coarser grains composed of angular fragments of quartz and feldspar.
0.05 mm in diameter, and are arranged in layers parallel to the bedding.

Within the very fine grained material are occasional euhedral crystals of dolomite, which show no regular orientation of the crystal faces and edges relative to the shear planes in the slates. This dolomite may have formed after the last phase of tectonism. Some of the dolomite is centred on small grains of limonite, which appear to have a form of chambered arrangement and may have been of organic origin. None of these are recognizable as identifiable fossils. Irregular masses of the finer grained clays are of markedly smaller grain size than the immediately adjacent slates. These zones often cut across the bedding and may represent bioturbation of some form.

Heavy minerals occur sporadically in the slates, and it is thought that they are principally of secondary origin. Tourmaline showing authigenic overgrowths has been seen in thin section. Iron ores are chiefly limonitic, but a few large grains of magnetite are present. In hollows beside the magnetite grains are clusters of crystals of secondary albite which grew in a position which was probably relatively sheltered during later shearing. Pyrite also occurs from place to place, although this has often rusted where exposed to weathering.

In many cases the rock has been intensely cleaved, and slip-strain cleavages are present in some thin sections. The micas have been broken along well-defined planes nearly perpendicular to the bedding.

Stanton (1953) recorded the presence of a conglomerate in the Glenummera Series. Near Lough Glenawough the conglomerate layer reaches over 50 ft (15m) in places, and extends along the line of cliffs on the slopes above Erriff.
village for at least 1,500 ft. At Lough Glenawough pebbles up to 10cms in diameter occur set in a matrix of blue-green slates. The pebbles are usually isolated without contact with their neighbours. They are composed mainly of fragments of yellow or white cherts, quartz and a few pieces of granite. At the base of the conglomeratic layer, lenses of coarse green sands occur. No marked orientation of the pebbles was observed in the field.

The sandstones which occur in thin beds throughout the sequence vary in composition according to their stratigraphical position. Towards the base, by the long well in the cliffs above Erriff, they are petrographically identical to the uppermost turbidites seen from the Sheeffry Series above Erriff. The sandstones are coarse grained and are composed mainly of angular and sub-angular fragments of quartz. Feldspars (andesine oligoclase) are less abundant than the quartz, and the grains are more well-rounded. Lithic fragments are principally of metamorphic quartzite and muscovite-schist, but also include siltstone and mudstone, while the heavy detrital grains indicate presence of epidote, chlorite, and ilmenite in the source rocks.

Staurolite has been recorded from one thin section of sandstone from near the base of the Series, above Erriff. There is some clay material although it is in no high proportion. Secondary iron minerals present are limonite, leucoxene, and magnetite, the latter occupying voids in the rock.

The grits towards the top of the succession, immediately west of Lough Glenawough are of the same composition as those of the
Mweelrea Group. About 80% of the grains are of angular fragments of quartz, about 60% of which show strained extinction patterns. Many of the quartz grains are free from gaseous inclusions, but needles of tourmaline are not uncommonly observed. Again the feldspars, andesine-oligoclase (An$_{15-30}$), are highly sericitised, and exsolutions of epidote occur. The lithic components are chiefly of metamorphic quartzite and muscovite schists, with some slates and mudstones. Detrital muscovite, chlorite, and biotite are present, and grains of epidote and sphene also occur. The secondary iron ores are limonite, hematite, and leucoxene, which are alterations of early magnetite and ilmenite. Carbonate is common, and comprises up to 12% of the bulk rock total. It is sometimes anhedral, but usually is present as euhedral, rhombic crystals of dolomite.

Modal analyses of sandstones of the Glenummera Series are given in Appendix 1. Plotting the analyses of MLQ and QFR diagrams reveals that the lowest sandstones are closely connected mineralogically with those of the Sheeffry Series, and the highest sandstones with those of the Mweelrea Group (Fig. 54).

The ratios of quartz to feldspar, or quartz to labile constituents are the same in the upper Glenummera Series as those for the sandstones of the Mweelrea Group, and in the lower Glenummera Series as for those of the turbidites of the upper Derrylea Group. The propinquity of results is best displayed in the MLQ diagram, in which there is partial overlap of the envelope of the Glenummera Series with those of both the Derrylea and Mweelrea Groups.
The upper sandstones resemble the Mweelrea Group in their high proportion of quartz in the detritus (80% as against 60-65% in the Sheeffry Series), the presence of partly oxidised flakes of biotite (common in the Mweelrea Group but unknown in the Sheeffry Series), and the importance of coats of iron on the detrital grains.

Sedimentary structures have rarely been observed in Eastern Murrisk. In the Aille River, at the entrance to Glen Mask, there are apparent sedimentary striations which plunge gently north-eastwards. The striations appear to indicate movements of a current from the east. They may however, be parallel to slumps running down a depositional slope. Slumping is seen in polished sections in the stream bed, but gives no indication of derivational direction.

No sedimentary features have been observed in the exposures of the Glenummera Series along the Derrycraff River between Lough Glenawough and Derrinkee.

The conglomeratic bed above Erriff Village (53° 39' 47" N, 9° 32' 25" W), is problematical in that the well-rounded pebbles are isolated within a very fine-grained matrix of slates. The two appear to have been deposited simultaneously, although there are no minor features to show this. Dewey (1960) has suggested that the 'lenses of gravel' which were also recorded by Stanton (1953) represent the localised courses along which flowed turbidity currents to feed the deeper basin to the north. This explanation is unsatisfactory in that it does not account for the low proportion of sand in the matrix, which is dominated.
by slate. A similar slate-matrix conglomerate occurs north of Glen Mask, \(53^\circ 40' 03'' N, 9^\circ 28' 18'' W\). This may not be a true part of the Glenummera series, but it lies below the base of the Mweelrea Group, and between the principal faults. In most conglomerates the matrix material is coarsely grained. In cases where isolate pebbles occur in a silt or clay matrix, many workers have postulated the existence of ancient glaciations. This is thought improbable in the present instance, for no evidence of striated pebbles or glaciated pavements exists at this level. Further, palaeomagnetic data suggests (Irving and Breiden 1963) that the area was located within tropical latitudes during this time. The alternative, that the pebbles were transported with plant debris carried to sea from the land is not applicable during the Ordovician Period, for plants had not yet colonised the land.

A conglomerate in which pebbles are surrounded by a clay matrix may have been produced by diagnostic changes. If, for instance, the matrix has been dominantly composed of feldspar, subsequent decay might have produced a clay. No relics of feldspar occur in these sediments, and grains of feldspar which have not undergone extensive alteration exist in the sandstones nearby in the sequence. Bioturbation may have partly changed the sediment by comminution of the fragments after deposition. This, however, would tend to throw the pebbles into closer proximity to each other. Any post-depositional re-sorting would remove material of clay grade first.

Provided weathering has been active for long enough to break down most of the rock debris to near clay grade, mud flows may have formed on the land. These flows may have swept into the sea, carrying with
Plate 9. The basal bed of the Fartry Series resting unconformably on top of the Glenummera Series, Glennagashleeny.

Plate 10. Pebbles within the highly cleaved slates of the Glenummera Series, Lough Shee.
them the gravel debris from the mouths of the rivers. This mechanism could lead to low sand content, and could have moved the debris large distances from their source.

Another conglomerate which occurs at the top of the Glenummera Series, in the only exposures at water level, at Lough Shee, also has groups of pebbles within a slate matrix. At this position which is immediately below an unconformity, it is thought that the pebbles, which are identical to those of the Partry Series conglomerates, may have been allowed to work their way down into the clays by a process of a gentle movement of the underlying soft rocks by wave action, so that the clays oscillated slightly from side to side. A direct analogy of this is seen off the Essex coast today, where pebbles of flint are being worked down into the surface of the London Clay where it is exposed on the intertidal flats.

It is possible that at some stage during the deposition of the Glenummera Series a similar gentle lateral movement was possible some way down the sequence. Where pebbles, derived no doubt from streams, were available, they might have been mulled into the clays. As such they may also have been isolated. The conglomerates near L. Glenawough are nearly 50 ft (18m) thick and may represent a period of prolonged mulling, but it is doubtful if the wave actions could inject pebbles for more than a very few feet into the underlying sediment. If the stage of clay deposition was followed intermittently by deposition of gravels, and accompanied by mulling, then a thick deposit of conglomerates in which the matrix is dominantly pelitic might result. Such a method of deposition involves periodic emergence of the sea bed, or at least periodic shallowing to the depth of wave-base. This
mechanism may have been at least partly responsible for deposition of these intermittent conglomerates in the Glenummera Series.

Dewey (1960) recorded one tuff bed, T.B.21, in the Glenummera Series. This has not been recognised in the slopes above Erriff, and is obscured by the terraces above Derrinkee. However, it reappears beneath the road bridge across the Aille River at the entrance to Glen Mask.

The tuff is intermediate in character, and consists of at least nine individually graded units. It is composed essentially of highly sericitised angular andesine-oligoclase feldspars set in a fine-grained matrix of sericite, with some small flakes of white mica, and a little carbonate. In some layers there is much carbonate. Unaltered iron ores are present, in the form of magnetite, but many of these have been altered to limonite. The graded units show an upward increase in the abundance of red flecks, due to oxidation of iron ores during weathering. Some syn-depositional slumping occurred, and the slumped masses have since settled, later joints cutting across the closures. It is not possible to determine whether the slumping took place before cooling has been completed.

The perfect conformities between the turbidites of the Sheeffry Series regarded as of deep water facies, and the Glenummera Series and that with the shallow water sandstones and conglomerates of the Mweelrea with the Glenummera Series suggest that the Glenummera Series may have been deposited in a position intermediate between the deep and shallow water.

Within the Glenummera Series are thin beds of grit, as described above.
Fig. 24. Orientation of TB 21 with respect to the Mweelrea Group, the Glenummera Series, and the Derrylea Group.

Fig. 26. Variation of inclination of the depositional slope with facies changes as indicated by TB 21.

Fig. 28. Increase in depth of water corresponding to 4000 ft. of deposited sediments in the Glenummera Series.
The grits near the top of the Glenummera sequence are petrographically identical to the sandstones of the western facies of the Partry Series, viz. to the overlying Mweelrea Group. Towards the base of the Glenummera Series, however, the grits are virtually identical to those of the Derrylea Group of the Sheeffry Series. Thus within the Series it is possible to recognise the influences of both the deep and shallow water, although the blue-green slate surrounding the grit horizons appear to be constant in composition.

Since the individual grits of the upper part of the Glenummera Series are identical to those of the Mweelrea Group which overlies the slate sequence, the question arises as to whether the two rocks may have been partly deposited at the same time. In other words the lowest part of the Mweelrea Group may be a facies of nearer shore deposition than the uppermost part of the Glenummera Series, the junction between the two being diachronous. Such a suggestion could only be confirmed by the presence of time marker horizons, which fortunately, are present in S.W. Murrisk.

Dewey (1960) observed that T.B. 21 and I.B.1 (of McKerrow and Campbell, 1960) were equivalents. The former occurs within the Glenummera Series, the latter near the base of the Mweelrea Group. The two individual tuffs are seen to be parts of the same tuff to the west of Lough Nafooey.

The extrusion of thin partly welded tuffs is a short-term phenomenon, and the tuff, therefore, forms a good time plane which may be used as a datum. Other welded tuffs occur within the Mweelrea Group and these also represent time planes which may be used as alternative datum planes.

Comparison of the position of the first tuff (T.B.21 - I.B.1) shows that above Lough Nafooey it is 130 ft above the Mweelrea - Glenummera junction.
Fig. 25. Isopachytes for sediment between tuff beds and the Mweelrea-Glenummera boundary.
In Central Murrisk, however, it is 1300 ft. below the junction, and at Glendarvock it reaches the maximum recorded distance of 1,700 ft. below the junction. This is a clear demonstration that the change of rock type from slate to grit is diachronous. (Fig. 24).

Since the slate sequence is intermediate in position between shallow and deep water environments, it is thought possible that the slates may have been deposited on a slightly steeper slope than the other sediments. The growth of the deposits in a seaward direction may have permitted sands and muds to be deposited in very close proximity but at the same time.

If the surmise concerning a change in the inclination of the slope is correct, then it should be possible to prove this from a knowledge of thickness of sediment between the tuff and the junction of the two sediments. The welded tuff MT1 is known to be 400 ft. above the base of the Mweelrea Group at Loughanshee, 350 ft. west of L. Glenawough, 200 ft. at Glendarvock, 450 ft. north of Lough Nafooey and 600 ft. in Joyce Country. By the use of a series of three point diagrams it is possible to construct isopachytes for the sediments of Mweelrea facies below the tuff, but above the Glenummura Series. (Fig. 25). This is inclined towards the north at a slope of 1 in 95 to the junction between the series. This inclination represents a minimum slope, for minor sedimentary discontinuities occur in the Sandstones.

It is also possible to construct isopachytes for the sediment of the Glenummura Series above T.B.21 and thereby deduce that the slope on which this deposition occurred was much steeper than before, about 1 in 18 also to the north. The change of thickness of slate between the tuff and the boundary marking the change of sediment type gives an indication of the inclination of the depositional surface on which the tuff rests relative to the change from
Fig. 27. Inclination of the tuff beds relative to the facies change boundary.
slate to grit deposition. There is clearly a change in the angle of the depositional slope from a minimum of 1 in 95 in the Mweelrea Group to 1 in 18 in the slates, relative to the same plane (Fig 26). The minor discontinuities in sedimentation in the sandstone facies may increase the 1 in 95 angle slightly. The effects of post-depositional compaction in the sediments will be greater in the slates than in the sandstones, and so the angle calculated in the slates must be regarded as a minimum value. Thus the differences in the original inclinations of the slopes may have been different from those calculated above, but they will have been of a similar order of degree.

A continuation of the examination of the Partry Series using this same method reveals that the floor on which M.T. 2 was deposited was inclined at 1 in 36, but M.T. 5 is inclined at 1 in 9 in the opposite direction (towards the east), Fig 27. An examination of the tuffs within the sandstone and conglomerate sequence reveals that there was probably a considerable amount of penecontemporaneous erosion in the shallower water nearer the source. There was clearly a differential component of sinking of the basin on the location of the greatest thickness of accumulation of debris.

The rapid increase in inclination of M.T. 5 relative to the facies change boundary results from the thickening of the sediments in association with the first Mweelrea Slate bed, in the Ben Creggan - Glendavock area, where it seems that sinking was at its greatest.

The orientations of the isopachytes for the different parts of sedimentary sequence examined vary. In the earliest case, T.B.21 - T.B. 1, the isopachytes have a nearly east-west trend. For higher levels these lines
show a swing to a north-east - south-westerly direction, and for M.T. 5 are of a north north-east - south south-west trend. This may be partly a reflection of the changing source area, but more probably indicates the direction of maximum sinking, which remained on the site of the Murrisk trough in which the Sheeffry turbidites had been deposited previously.

The concept has been introduced that the sandstones and slates are partly contemporaneous. This is important in the consideration of the ages at which deposition of the rocks occurred. The Sheeffry Series is known to be of Arenig age. Stanton (1953, 1960) found a varied fauna in the Glenummera Slates, but it was insufficiently definitive to give a date more precise than Lower or Middle Ordovician age. Some fossils are known from slate beds in the Mweelrea Group, and these indicate a possible Llandeilian age, certainly much later than Arenig.

The lower grits of the Glenummera Series are turbidites connected with those of the Sheeffry Series, (see Fig 24). They may have been deposited low down the slope on which accumulation of the clay took place. Thus the lowest part of the Glenummera Series particularly in the area nearest the source will be contemporaneous with the Sheeffry turbidites. They may therefore be of upper Arenigian age. The uppermost grits in the Glenummera Series are identical to those of the Mweelrea Group, slates some way up the sequence of which may be Llandelian. Hence the uppermost part of the Glenummera Series may be the equivalent of Lower Llandelian in age.

Thus the sedimentary divisions established in these rocks are essentially facies changes. The absolute time planes are arranged at a slight angle
to the facies changes.

No individual tuff horizon can be traced from the Mweelrea Group through the total thickness of the Glenummera Series and into the Sheeffry Series, and so no direct age equivalence between the two extremes of sedimentation has been proved in the field. T.B. 21 has been seen at the Aille River bridge, where it is only 1,300 ft from the base of the Glenummera Series. If further exposures existed to the north east of the Partry Mountains it should theoretically be possible to find T.B. 21 within the turbidite facies.

The maximum known thickness of the Glenummera Series is about 4,000 ft. Since the plane of deposition is inclined at an angle of 1 in 18 to the top of the succession, it is possible to calculate that, provided the slope was relatively uniform, it marks an increase of a maximum of 3,200 ft in the depth of water at which deposition occurred. The increase of depth must have been less than this, for the calculation assumes no inclination of the depositional slope of the Mweelrea Group sediments.

In the above calculations information has been used only from the area to the east of the Maam faults. It has been shown by Stanton (1953, 1960) that syn-depositional movement took place along these faults, and that the downthrow was towards the east. A section drawn across the fault from East Lugmore to Ben Creggan shows an eastward thickening in the slates of the Mweelrea Group. It is thought that the faults may have been inclined at an angle slightly steeper than that of the slope on which deposition of the clays took place. In such a position the accumulated clays would be
expected to increase in thickness of the downthrown side.

The forces controlling movement along the faults are not known. It is suggested that they may be related to movements in the underlying basement of Dalradian rocks.
CHAPTER IV
THE PARRY SERIES

The rocks of the Parry Mountains, form a thick series of red beds consisting largely of sandstones and conglomerates. As a result of recent work Dewey (in press) has suggested a grouping of the rocks of the Parry Mts. into one large series, the Parry Series, composed of two parts, an upper, or Maumtrasna Group, and a lower, Mweelrea Group.

Interbedded with the sandstones and conglomerates of the Mweelrea Group are several horizons of welded tuffs. These have now been traced from the Atlantic coast north of the entrance to Killary Harbour along the strike for a distance of 25 miles. For convenience they are referred to as M.T. 1, 2, 3, 4, and 5.

In the extreme west Stanton (1953) traced five tuff bands, but demonstrated that two of them join, to form one double tuff band (M.T.3 and 4) further to the east. Dewey (1960) further demonstrated that MT 2 dies out eastwards, so that in the westernmost part of Eastern Murrisk the four horizons of welded tuff are MT 1, MT 3 and 4, and MT 5.

The tuff bands form excellent marker horizons along which it has been possible to compare changes of facies throughout the Mweelrea Group, (see Fig. 55).

The bounding horizon between the Maumtrasna and Mweelrea Groups is taken as a high-level tuff band, MT 6, located high on Maumtrasna.

Although a sixth and a seventh tuff horizon have been recognized in E. Murrisk, these are too low stratigraphically to be the lateral equivalents of Dewey's MT 6. If they are not equivalent, the entire part of the
Partry Series cropping out in the E. Murrisk area is of the Mwoelrea Group.

In E. Murrisk the varied sediments of the Partry Series include some conformable and some unconformably above the Glenummera Series. The lithology of the Group varies greatly from slates, through sandstones and conglomerates, and includes both welded and non-welded tuffs.

Stanton (1953) recorded a flaggy lithology at the base of the Group in S. W. Murrisk, and Dewey (1960) noted that this occurred only at Erriff in C. Murrisk, whilst in E. Murrisk, at Kinnewry only, have flags been observed.

Although slate horizons are much more common to the west, only one notable pelitic layer has been recorded in E. Murrisk. This occurs above Glen Mask, and in close association with the Lettereeneen fault, and is probably part of the Glenummera Series.

Stanton was able to demonstrate the existence of a syncline in the west of Murrisk, and McKerrow and Campbell (1960) have identified the existence of the southerly limb of the same fold in Joyces. Country (Fig 29). In E. Murrisk no synclinal axis is seen west of the Lettereeneen fault, where the beds dip fairly uniformly towards the south-east at about 45°. East of the fault most of the beds dip north-westwards at low angles, and it is only on the northern escarpment slope of the Partry Mts., in the Bohaun area, where the beds dip south-eastwards to any extent. It appears therefore, that the syncline is broken across by this major fault. The southern limb may have been brought into direct contact with the northern limb along the break. On the northerly limb of the syncline, a minimum thickness of 9,500 ft has been recorded near the Lettereeneen fault, whilst
Fig. 29. Known outcrop of the Partry Series of Mayo and North Galway

Incorporating work by Stanton, McKerrow & Campbell, Dewey, and McManus

Scale 1:126,760
on the southerly limb no more than 5,500ft of sediments are exposed in the Glen Saul area. This latter section maybe seen near the fault, where swing of the strike, variation of angle of dip, and minor faulting all occur.

Truly red beds are seen in the west, and north-east of B. Murrisk, with an intervening zone in the Tonnesaile-Glennagashleeny area, where the rocks have a grey-green aspect. The colour in this intervening zone is due to proximity of a large supply of water, which inhibited oxidation during deposition. The presence of many sedimentary structures indicates that deposition occurred under water. The red beds are not aeolian in origin.

The boundary between the Glenummera Series and the Mweelrea Group follows the northern scarp of the Partry Mts. as far as the Lettereeneen fault, beyond which it cannot be located. In the Glennagashleeny area powerful faulting complicates the boundary, which further east resumes a line parallel to the mountain front. On the eastern side of the Partry Mts, in the north, the Partry Series sediments are overlain by Carboniferous deposits, but further south are seen to rest unconformably upon earlier horizons: Gardiner and Reynolds (1909, and 1910). In the south-west of the area some faulting parallel to the mountain front is seen and this largely controls the limit of Partry Series deposits visible today.

For convenience of description in all stages of examination of this Series a division has been made along the Lettereeneen fault. The notable sedimentary change which occurs at the fault may be due to the presence of a different sedimentary Group on each side of the fault, or alternatively, to change of facies from east to west, with an intermediate
zone cut out by the faulting. Interpretation of this change by either of these alternatives is equally possible.

Dewey (personal communication) has shown that the Partry Series is composed of two parts, the upper, Maumtrasna Group and the lower, Mweelrea Group. A tuff band, MT 6, which is continuous in Central Murrisk, marks the junction between the two Groups. On the southern limb of the syncline the Mweelrea Group oversteps the underlying beds and is in turn overstepped by conglomerates of the Maumtrasna Group, along the base of which is a discontinuous tuff horizon. Dewey has stated in discussion that he believes the Maumtrasna sediments to have completely overstepped the Mweelrea Group at L. Nacorralea.

The position of the boundary between the Maumtrasna and Mweelrea Groups in the sides of the Owenbrin valley is not known. Lack of time prevented extension of mapping in this direction and no published work shows the location of the boundary. It is possible, however, that the Maumtrasna Group may not continue east of the Owenbrin River.

At the base of the conglomerates in the cliffs of Glen Saul, a discontinuous bed of welded tuff occurs, and other exposures of welded tuff are seen further north, in Derryveeny townland, and above Træanlaur. A non-welded, andesitic tuff is known at the base of the Partry Series in Bohaun South. It is thus possible that the eastern end of the Partry Mountains are occupied by sediments of the Maumtrasna Group.

To the west of the Lettereeneen fault the Mweelrea Group of E. Murrisk may be traced southwards to the lip of the Owenbrin valley. No tuff horizon high up the sequence has been found, the rocks continue to dip

Plate 12. Diffuse conglomerate of the eastern facies of the Partry Series, Bohaun Hill.
southwards and no synclinal axis is seen. This sequence of rocks passes upwards from a current-bedded facies with intermittent conglomeratic horizons into a medium finegrained slightly current bedded, red sandstone. East of the fault at Glen Saul there is an abrupt change to conglomerates with interbedded sandstones. A similar change is seen to the east of the faulted block at Glen Mask. Throughout the eastern facies, there is an increase of frequency of conglomerates in an easterly and south-easterly direction. These conglomerates are believed to have been proluvial deposits, laid down on alluvial fans which spread north-westwards, from the Connemara Cordillera. In front of a zone of high level fans the current bedded facies of sandstones may have been deposited in shallow eater. Evidence to justify these conclusions will be presented later in this chapter. Periodically pyroclastic flows covered the lower parts of the deposits, forming welded tuffs, but at places above the level of the top of the tuffs no evidence of their existence would be found. Apart from a basal andesitic tuff at Bohaun, and one non-welded horizon at Kiltarsaghaun, no other tuffs are present in the eastern facies. Thus the absence of tuffs in the east may be entirely due to non-deposition due to different elevation of the rocks during deposition. The welded tuffs below the base on the south-eastern side of the mountain may be associated with the period intervening between deposition of the Glenummera Series and the younger sediments. No unconformity exists between the Glenummera Series and the Mweelrea Group on the northern side of the Partry Mts, but there is a marked unconformity on the southern side, between the Maumtrasna Group and the underlying sediments.
For convenience the rocks from the east of the fault will be referred to as of the "eastern facies" and those from the west as the "western facies".

**Current Bedding.**

Current bedding is seen occasionally in the sandstones of the low horizons of the Series at Tonnasaile. This becomes more frequent higher in the sequence along Sruffaunnaagreeve and above Glen Mask, and is ubiquitous to the west of the Lettereenen fault. In the western area, the inclination of the foreset beds indicates that the currents flowed predominantly from the south-east, but further east the foresets show much more irregularity in their orientation. This may be due to different environmental conditions during deposition.

The current bedding observed in the Mweelrea sediments is exclusively of the festoon type, Knight (1929). This type of bedding is characterised by concave surfaces. Ideally such cross-bedding should give paraboloid intersections with the plane of truncation, but this plane has not been observed in the field. Similarly the plan of the bottom surface has not been seen in the field, and it has not been possible to observed any ripples which it may have developed on it. The individual laminae at any one point will be controlled in orientation not only by the current, but also partially by the configuration of the hollow which is being infilled. Asymptotic bottoms and clearly truncated tops are ubiquitous. Torrential bedding, in which the cross-stratification is parallel from top to bottom of any individual unit, has not been observed.

Each is represented by a single cross-stratified unit. The individual
Fig. 30 Intersection of bedding planes and false-bedding

Fig. 31 Extreme variation of current-bedding attitude. Tonnasaille.

Fig. 32 Asymmetrical channel from Derryvaeny.
laminae are graded, from a coarse quartzo-feldspathic base, up into finer material in which iron oxides predominate. Due to the red colouration, this upper part of each lamina is prominent, despite the fact that it may only occupy one tenth of the thickness. Thus, whereas near the Lough Naweelon the beds may be 20 cm. thick, the inclined laminae reach a maximum of 3cms. The entire cross-bedded pattern is made clear by magnetite-rich layers, which are rarely more than 0.5cms in thickness. At the base of the false-bedded units the bottom-set is again accentuated by the presence of magnetite concentrations. These probably resulted from the winnowing out of the less dense minerals. (Plate 11).

The inclination of the foresets is always at a low angle, and never exceeds 30°. Truncation of the foresets by the base of the succeeding sandstone is normally very clear and gives the direction of younging. This criterion indicating way up is particularly important in the rocks immediately adjacent to the Letteresenee fault at Glen Mask, where many of the beds are inverted.

West of Lough Glenawough the beds dip at 48° towards 1460, while the false bedding dips at 15° towards 130°. This is shown in stereogram, Fig 30. The two planes intersect along a line which is perpendicular to the direction of flow of the current responsible for the deposition. Removal of the effects of folding indicates that the current flowed from approximately south-east. Other results from similar pairs of readings indicate that low in the sequence at Lough Glenawough the currents flowed from a southerly direction - in the 145°- 155° range of bearing, while at higher levels a more easterly influence becomes apparent, with bearings of 130°- 150°.
Because of the concave nature of the false bedding the intersection is not necessarily perpendicular to the flow of the current, but an average of many readings would prove so. The variation may therefore be due to this alone.

Whereas throughout the whole area the majority of the foresets of the festoon bedding indicate the current to have travelled from south-east to north-west, occasionally there is a reversal of the inclination of the foresets, but this is rare.

In the east, between Tonnasaile and Derryveeny, the sandstones show variations in the orientation of the foreset beds. The intersections of many of the planes suggest a current movement from 90° (Fig 31). At nearby points in one bed, the festoons indicate movement of water in almost opposite directions — to the north-west, and to the south-west. This is interpreted as the result of movement of water overflowing outwards from a run-off channel.

At a high stratigraphical level in the Mweelrea Group, where the succession is dominantly sand, the current-bedding becomes very pronounced. In the west, a few pebbles occur in the inclined laminations.

Channels

Shallow channels are developed in many localities, with their most complex development in the Derryveeny — Tonnasaile area. Much of the evidence concerning the nature of the channels is incomplete due to poor exposures.

In E. Murrisk a two-fold division of channel types may be recognised: —

a) Shallow channels, reaching a maximum of 1 metre in depth, up to
5 metres in width, and showing gently sloping sides, with a maximum inclination of 20°. These may be seen in all areas. Most of the shallow channels appear to run approximately east-west. The channels cut down through the sandstone horizons in the current-bedded grit facies. In the west of the area they may be lined with occasional pebbles, but in the east they may be infilled completely by conglomerate.

In the stream section of Glenmagsheeney, two shallow channels infilled with conglomerates are seen cutting into a grit horizon. One of these trends along 86°. South-east of the watershed, two further examples of this type occur aligned along 106°.

In one instance in Derryveeney townland, the channels cut into 'imbricated' conglomerates. The channel shows an asymmetry which appears to be controlled by the imbrication of the conglomerate, producing a relatively gently sloping north-western bank, and a steep south-easterly one (Fig 32). This asymmetrical channel has 110° bearing, and is 4 metres wide. It has an infilling of coarse conglomerates, with cobbles up to 15 cms in diameter, showing a completely chaotic arrangement of their axes.

These two 'channel' types may result from trough bedding (Allen 1963), the asymmetry being seen in axial profile, a symmetrical section occurring perpendicular to the current flow.

b) Steep sided channels up to 1.5m in depth, the sides being irregular in shape and at angles of inclination up to 90°. These channels are infilled with coarse conglomerates. They have been recognised in Eastern Murrisk only near the hairpin bend on the mountain road.

Several such channels occur in close proximity in the stratigraphical
Fig. 33. Reinterpretation of Dewey's shallow channels as festoon type of current-bedding.

Fig. 34 (a). Apparently inverted current-bedding due to origin as sand bar deposit.

Fig. 34 (b). Two series of festoon-bedding superposed.

Section A

Section B

Fig. 34 (c). Groove cusps truncated.

Fig. 37(c) of Dewey (1960).

Fig. 34 (b). Pebble-bearing lens of Glennagashleeny.

Section through festoon bedding as shown in b.)
succession. This arrangement suggests that some regular stream flowed in this rather restricted position for a considerable period of time. No trace of such channels has been observed elsewhere by the author, although Dewey, (1960) described similar phenomena in Central Murrisk.

Further channels, which cannot be assigned to either of these classes, are seen cut into the uppermost surfaces of MT 6 and MT 7 at the waterfall of Glen Mask. One of these runs obliquely to the present section and cuts down 2 metres into MT 6. Another channel was observed in the top of MT 5 west of L. Glenawough, but again the trend of the channel cannot be ascertained.

The presence of channels eroded in the surface of the welded tuffs shows that after deposition of the tuff erosion was renewed. All streams were strongly rejuvenated, and scoured the surface of the newly deposited tuff, removing much of its volume before subsequent re-establishment of conditions amenable to the deposition of sandstone.

In Central Murrisk Dewey (1960) recognised two types of channels. The first similar to type (b), and the other, which he illustrated (Fig 37 c) and described as possessing: - "gently inclined sides and being shallow, often with concentrations of coarser psphitic material in the centre." His illustration may equally be interpreted as festoon current-bedding, (see Fig 33).

The orientations of the axes of the shallow channels of the eastern area are variable, and directions of 80°, 86°, 90°, 106°, 110°, and 131° have been recorded. The channels of the second type have a clear 120°
bearing. Thus it may be that the powerful streams flowed along the south-
easterly direction, whilst others less powerful, controlled perhaps by some
other factor, such as the slope of the surface on which deposition was
taking place, were able to flow only in a more easterly direction.

Although many of the streams follow roughly parallel courses, there
is a $40^\circ$ variation of bearing between them. The degree of parallelism is
remarkable when the great variation introduced in meandering in river val-
leys is considered. Only the shallow channels appear to show characteris-
tics of meandering, as indicated by the structure of the material filling
the channels. These features may, however, be formed by trough bedding,
in which the anti-dune migrates upstream, and has a steep upstream slope
but gently inclined downstream slope.

South of the mountain road, the sands infilling a channel show
apparent inversion of the direction of facing of the current bedding.
This is interpreted as the deposit on the slip-off slope in a meander,
similar to that described by Evans (1959) in the sediments bordering
creeks in the Wash. The "bottom sets" are almost perpendicular to the
base of the channel, the inclination decreasing upwards (Fig. 34 a).
The presence of the clearly identifiable channel in the conglomerates here
and general undisturbed nature of the surrounding sediments indicate
absence of inversion of bedding.

The steep-sided channels appear to have been cut by more powerful
streams than the type of channel described above. The steep sides
suggest that rapid partial post-depositional lithification of the
sediments may have occurred, otherwise the very steep sides of the channels
would show collapse features. However, this is not the only possibility.

There may be some control of the steepness of sides on the depth of
the cross-section of the channel by the layer into which incision occurred.
Shallow channels have been observed in the tops of sandstones and conglomerates of all concentrations, but the steep sided channels have only been recorded cutting into grit horizons.

The shallow, slightly asymmetrical channels may be due to a form of
trough bedding, but the deep steep-sided channels almost certainly mark the courses along which swiftly flowing streams cut into the soft underlying sediments.

It is impossible to state categorically whether there is an increase
in the number of channels up the sequence. Similarly it is not possible to define any migration of the centre of the run-off waters, although the centre itself was in the Derryveeny - Treanlaur zone low on the eastern side of the Partry Mts., and appears to have remained near the mountain road throughout the sequence. No other concentration of channels has been recorded in E. Murrisk, although many individual, rather isolate, channels have been observed in all parts of the Series.

Conglomerate and sand lenses.

A complete variation from lenses of grits within conglomerates to lenses and trails of pebbles within thick regularly bedded grits. The lenses appear to be genetically related to the channels and are seen in almost every large exposure.

The most easily identified lenses are those less than 15 ft. in extent, for exposure imposes limitations on the size recognised. Many
lenses have their long axes approximately parallel to the direction of flow of the currents, in the range 102°-135°. Imbrication of the pebbles of the conglomerate lenses indicates derivation from a south-easterly direction.

Above the sill on Tonnasaile a 6 metre thick bed of conglomerates contains a lens (1.5 metres thick) of sandstones, with the foresets gently inclined towards 150°. The top of this lens is channelled by the conglomerates. Other isolated sandstone lenses are seen. These are usually thinly bedded and are without false-bedding of any sort. Two mechanisms of formation are believed to have been active in the deposition of the lenses: -

a) The intermittent lenses of pebbles between two well-bedded grit horizons are believed to be due to concomitant erosion and deposition. Such lenses show well-imbricated pebbles of south-easterly derivation, and the long axes of the lenses tend to be along an easterly direction.

b) Lenses of sandstone or grit within conglomerates may indicate small areas of relatively still water within an area of generally swiftly moving water. The resultant lenses are small, no more than 2 metres in width across the current direction, and rarely 3 metres parallel to it. Frequently they are cross-bedded to a minor extent in a direction transverse to the main current direction, indicating that an unusual direction of movement of water is probably a controlling factor in their deposition.

Such lenses are able to accumulate in areas of quiet water perhaps protected by levées of other natural banks, where the finer grains are able to settle out instead of being carried further away with the more
rapidly moving water.

Totally isolated lenses of pebbles are also found, with their axes parallel to the current trend. They often line hollows in the bedding planes of grits (Fig 34 b) The complete reason for this is not understood, but it is believed they may be due to some form of braiding of a stream bed, in which small banks of pebbles tend to accumulate.

In a down-current direction the sedimentary changes are almost as rapid as in a transcurrent direction, with grit lenses appearing, reaching a maximum thickness of 25cms., and disappearing in a 20 metre section. Many beds are observed to thin in a westerly direction.

Virtually every coarse-grained bed which is traced in a down-current direction becomes finer in grain size, and a generalisation that conglomerates give way to grits in a north-west direction holds true from S.E. to N.W. across the mountains at Glennagashleeny, but this is far from true of the entire length of the Partry Mountains.

Ripples

Nolan (1876), in the Memoir of the Geological Survey of Ireland, recorded the occurrence of only one ripple mark in the sandstones of the northern end of the Partry Mountain range, above Maumeen. Although he specified the locality, this ripple has not been located by the author.

No unequivocal ripples have been identified in E. Murrisk, and alternative methods of origin may be suggested for all known occurrences.

A few structures which may be ripples on sand bars have been identified in cross-section only. They are lenticular bodies of medium grained sand. In wave length they never exceed 8 cms. No internal structure
of cross-bedding has been observed in the sections seen in the field. At only one locality, in the stream south-west of the mountain road, were more than two successive ripples or lenses observed in the one horizon. These ripples, without exception, lie parallel to the main direction of current movement (85°-120°). This orientation is anomalous for normal ripples, but longitudinal ripples (parallel to current direction) have been described by Evans (1960), from the recent sediments of the Wash. Such ripples are formed by powerful streams flowing down the meandering creeks into the Wash during the ebb tide. The ripples run across the slip-off slopes of the meanders and form in any deposits exposed to the powerful currents. An analogous condition of deposition may have been in operation in E. Murrisk.

Minor tectonic warping produces a gentle rippling appearance in the flagstone horizon in the stream above Kinnawry. A polished section of one of these ripples shows the regular layers of differing grain size being uniformly warped in a truly concentric style of folding. These are distinct from the above type of ripples, and no sedimentary ripples are present at this locality.

Other bedding structures.

Structures such as 'candle flames' and hollows which are cut into the upper layer of a bed, have been identified only from cross-sections, and consist always of sand in sand.

West of the high mountain road a candle-flame structure 3 cms high is present at the base of a medium-grained grit horizon which overlies a coarse-grained bed of sandstone. This candle-flame is inclined towards the west, as are other, similar structures in the Glennagashleeny-Derry-
veeny area. In each case the flames are formed between an overlying layer of medium-grained sandstone and underlying coarse-grained sandstone, which is more common in the Group as a whole. These inclined structures may signify a westward flow of water.

In some layers of diffusely conglomeratic grits, shallow hollows up to 1 cm deep and 3 cms in width, infilled with sand occur at the base, cutting into the layers of angular grit beneath. The groove casts are oriented along 95°- 110°; and are believed to have been formed as a result of the scraping of pebbles along the bottom of a stream bed during movement of the water.

The red iron layers which emphasize the current bedding, also show up hollows which may have been grooves of some type. Their cuspatate form is shown in Fig. 34(c), and several such hollows may be superposed, all running along a south-westerly direction, suggesting that they may be grooves formed parallel to the flow of the current. The form of the truncated superposed cusps give an additional criterion for determining the direction of younging in the rocks, and is well-developed in an environment in which current bedding is typical, as high near Sruffaunnagreeve, in the western facies.

No mud cracks have been observed in the sediments of the Partry Series.

Orientation of organic remains.

In the stream above Dennewry, the fine-grained yellow flag-stones show partings of dark shale. The shale partings show yellow markings believed to be organic in origin. They consist of streaks or rod-like bodies, up
to 6 cms in length, which superficially resemble graptolites and commonly show some degree of parallelism of orientation along 80°- 90°. The smaller bodies, up to 1 cm in length, have a random distribution.

The alignment may reflect the direction of the currents during the deposition of some of the layers, for not every shale parting shows preferred orientation of the remains. It is consistent with the directions of other orientated features.

The Pebbles of the Partry Series

a) Introduction.

In the Partry Series there are all gradations between sandstones and very coarse conglomerates. East of the Lettermoreen fault the conglomerates are particularly abundant, but on the west side, they are much less frequent. Many conglomerates show little interstitial material. The pebbles of the conglomerates vary greatly in composition, size, roundness, sphericity, and shape factor. Many show a two-fold orientation which can be studied in the field, namely the orientation of the longest axis of the pebbles (in terms of azimuth and plunge), and the orientation of the intermediate axis. Each feature will be considered in an attempt to evaluate its significance.

b) Previous accounts of the conglomerates.

The only previous description of the conglomerates was by Nolan (1875) as "pebbly grits and sandstones of a purple or green colour, sometimes very coarse and containing good sized pebbles and blocks, chiefly of red granite, felstone, mica-schist, and jasper." No further details of the conglomerates were given.
Stanton (1953) in S. W. Murrisk showed that the Mweelrea rocks there contained conglomeratic material, and identified small fragments of metamorphic rocks, including a fine-grained quartzite, pieces of muscovite gneiss, biotite schist and jaspers, and the lesser frequency of gneiss, sandstones, black slates, and vein quartz. Dewey (1960) noted a rather similar distribution of material in central Murrisk and attempted to correlate many of the pebbles with a possible source area to the south. Both Stanton (1953) and Dewey (1960) point to the Connemara Cordillera, or an eastward extension of it, as a source of the metamorphic gneisses, schists and quartzites. Dewey further suggested the presence of a granite some distance away, evidently associated with the Dalradian rocks. Nearer to the area of deposition he demonstrated a belt of lower Arenig volcanic material which he considered as a source of the jaspers.

c) **Composition of the pebbles.**

The variation of the composition of the constituent pebbles is very great and the following types have been identified:

- Black and green slates,
- Green, grey, pink and yellow sandstones,
- Black, green, and white chert,
- Red jasper,
- Brown, green, grey, pink, purple and red 'felsites', some of which are welded tuffs.
- Pink and purple tuff from the Mweelrea Group,
- Green non-welded tuff,
- Garnetiferous gneiss,
Biotite schist, sometimes with garnet, sometimes highly siliceous,
Muscovite schist.
Amphibolite,
Metamorphic quartzite, sometimes fine grained,
Pink and grey granites,
Pink granite porphyry,
Pink and white vein quartz.

There is a general trend towards a high proportion of locally derived material near the base decreasing upwards, while constituents of metamorphic origin increase in proportion upwards. This trend is particularly clear on the eastern slopes of Tonnasaile. Initially the area east of the Lettereeneen fault will be considered.

At the base, the contact of the rocks of the eastern facies of the Partry Series, and the underlying Shangort Beds and 'felsites', is exposed in two stream sections (Gardiner and Reynolds, 1909). Directly above the base the rocks of the Series contain many fragments of non-welded green volcanic rocks, black chert, green grits, and 'felsites', similar to those of the underlying beds, together with occasional pebbles of metamorphic quartzites, gneisses and schists. This zone of predominantly local material is approximately 50 ft thick, above which there is a steady increase of metamorphic material.

Within the lowest part of the conglomerates, the rather siliceous matrix has a blue-green colour, due to fragments derived from the green
source rocks which occur below the unconformity in this area; but the
colour rapidly changes and takes on a red aspect, even before the pebbles
themselves have become of fully foreign origin.

Throughout the next 200 ft, there is a steady increase in the propor-
tion of metamorphic materials, biotite gneiss, muscovite-schist, meta-
morphic quartzite and biotite gneiss, until these predominate. This
dominance of metamorphic material continues through the remainder of the
sequence. Granite pebbles have rarely been recorded, and then only
between 600 and 800 ft above the base in northern Tonnasaile.

Further south-west, along Sruffaunnagreeve and above Glen Saul, there
is an exposure of the lower part of the succession in which locally derived
material also predominates. The base of this section is nowhere exposed.
The upward sequence into a zone of dominance of metamorphic pebbles is
again seen. This is accompanied by an influx of granite and granite-
porphyry boulders, which are much more common here than further north:
approximately 300 ft above the base, the granitic material forms a high
proportion of the detritus. Ascending higher in the sequence the propor-
tion of granitic components decreases so that the upper 400 ft of sediments
directly east of the Lettereneeen fault consist mainly of metamorphic con-
stituents.

West of the Lettereneeen fault, only the lowest part of the sequence
is conglomeratic, and here the pebbles are usually present in very thin
layers, often only 10 cm. in thickness. These pebble layers line the
bases of the shallow channels and the many disconformities which occur
west of Lough Glenawough, and are also often associated with the inclined
Fig. 35 (a) Diffuse conglomerate

Fig. 35 (b) Pebbles and related false-bedding W. of L. Glenawough.

Fig. 36 Multiple reversed grading from Glennagashleeny
planes in the ubiquitous false-bedding (Fig. 35b). The composition of the pebbles shows less variation in the west, and is strikingly different from that of the deposits of the eastern facies. The metamorphic constituents are relatively rare, and then mainly seen in the east, near the Letterroneen fault. The majority of the pebbles are of welded tuff derived largely from the beds MT 1, MT 5 and 4, and MT 5, which lie within the series. The importance of these as sources of debris may be demonstrated by the manner in which conglomerates virtually cease a short distance stratigraphically above MT 5. The newly deposited tuffs covered the surface in the lower parts of the source area, but above the top of this tuffaceous layer streams in the highlands still flowed along the uppermost parts of their old valleys. Initially rapid aggradation occurred on the top of the newly deposited rock, but further downstream erosion of the tuffs occurred. Associated with the extrusive vulcanicity were upward and downward movements of the crust, which led to rapid downcutting of streams into the surface of the tuff. Pebbles of the tuffs were carried downstream, to be deposited as megaclasts surrounded by sands in the current-bedded facies. With burial of the tuffs their importance as a source ceased.

Granitic material, occasional jasper, and black chert occur from place to place in the west.

The one common factor of virtually constant distribution over the area is jasper, the blood-red pebbles of which occur sporadically at all points from east of L. Glenasough to Derreenascooba.

The present work confirms many of the suggestions of previous workers (see section (b)). The existence of a granite, or more probably of several separate granites within the general area of the metamorphic complex is again clearly demonstrated. These may be the Galway or Oughterard granites. The presence of a few pebbles of pegmatite suggest that this granite may not have been entirely due to metamorphism but intrusively. In part at least. Decrease in the frequency of occurrence of granitic fragments in a northward direction, (and the currents of the streams carrying the debris are known to have been largely from the east or south-east), and may indicate that the granites lay in a southerly direction, rather than a south-easterly
The absence of pebbles of non-welded tuffs and clasts in the lower parts of the succession on the western outcrop contrasts sharply with the eastern outcrop of the deposits of the Partry Series. This demonstrates the entirely local nature of this material. The virtual disappearance of locally derived debris in higher horizons suggests that the belt of Lower Arenig and Llanvirn rocks to the east may have been buried by Partry Series material at an early stage in the depositional cycle. Dewey (1960) attributed the blood-red jaspers to the easterly belt of volcanic rocks, but it is noticeable that the jaspers are ubiquitous and so very probably not of such origin. Red jaspers are known from the Dalradian rocks of Clare Island, to the west (Phillips, personal communication) and it is possible that the Dalradian rocks in the source area would likewise contain jaspers. Jasper is a very hard and stable rock type which is able to be transported over long distances without being broken down. It is commonly found in a second- or third-cycle of deposition. Thus the jaspers of Mayo may not be of local origin and may have been reworked from earlier conglomerates elsewhere.

Two forms of vein quartz, pink and white respectively, have been recorded from the northern part of the Tonnasaille-Bohaun ridge. The pink material has not been seen elsewhere, but the white to translucent quartz vein fragments are widely spread over the outcrop of the eastern facies of the Partry Series.

d) Size of the Pebbles.

The deposits show many alternations of conglomerates and sandstones, beds of pebbles being irregularly distributed throughout the stratigraphical column. There is no simple overall systematic variation in the size of the pebbles. Along the eastern front of the Partry Mountains there is a general increase in size from north-east to south-west. In 300 ft. along are beds in Ghennagashlonecny the size of the pebbles decreases from 8-12 cms. to 2-5 cms. in a north-westerly direction.

The conglomerates may be divided into three types with regard to pebble distribution: (1) concentrated: in which each pebble
Fig. 37. Sequence low in course of Sruffaunnagreeve.

many cycles

14

13

12

11

10

9

8

7

6

5

4

3

2

1

fracture zone

fault

fault

lowest level by farmhouse

10 metres

Coarse conglomerate

Diffuse conglomerate

Grit
is in contact with several adjacent pebbles, and there is little interstitial material (2) diffuse:- the pebbles having no contact with their neighbours, being totally surrounded by sand. (3) rafted:- in which case "rafts" or "slabs" of grit up to 1.5 metres across are intermixed with poorly sorted pebble debris.

Due to difficulties of extracting individual pebbles, it was not possible to measure size on a volume basis, and comparison of size of the longest diameter in random sections of the conglomerates, as seen in natural exposures has been attempted.

Low on the eastern side of the Partry Mountains, in the Shangort, Treanlaur and Burryveeny townlands, many repetitions of conglomerates occur with few intervening grit beds. Reversed grading of the pebbles is common, reaching a maximum size of cobbles 10-15 cms. in diameter, while the degree of concentration, defined as the number of contacts with neighbouring pebbles, remains constant and high. Again in a low stratigraphical position along the course of Sruffaunmagroo reversal of grading occurs, with pebbles increasing upwards from 1.5 cms. to boulders 20-35 cms. in diameter in one b.d. This important sequence is shown in Fig. 37.

The feature of reversed grading is not restricted to the easternmost exposure, but also occurs in Boham and Glennagashleeny (see Fig. 35, and Plates 13 and 14), and again high in the succession at Lettereeneen, but has not been observed west of the major fault.

A tendency towards a bimodal size distribution is particularly common in the 'concentrated' type of conglomerate, in which pebbles of two modes are abundant but few of intermediate sizes are found. At Shangort a coarse bed shows frequency maxima at 5-10 cms. and 16-22 cms., with little material between these sizes. The western slopes of Tonnasaile, where some of the finest exposures of these conglomerates occur, show two maxima, at 1-4 cms. and 10-14 cms., and at a lower horizon, in the gorge west of the road, the maxima are 1-4 cms. and 12-15 cms. Further west, at Garangerra a similar duality gives 1-2 cms. and 6-10 cms. in diameter. Once more this feature is widespread east of the Lettereeneen fault but has not been noted west of it.

A constant ratio of 1:4 between size of the most common pebbles and the maximum size of pebbles at any one horizon, occurs at all
Plate 13. Reversely graded, concentrated conglomerate, Glennagashleeny.

levels in the conglomerates.

At Shangort the lower part of one bed shows many pebbles between 4 and 5 cms. and a maximum pebble size at this level of 22 cms. At Troonlaur, east of the road, two zones in the same reversely-graded bed show frequency maxima at 5-8 cms. and 10-15 cms., with greatest fragment sizes at 20 cms. and 40 cms. respectively. Again, on the eastern side of the mountain at Derryveeny, readings of 5-6 cms. and 20 cms. are recorded. The same ratio is observed in Glen Mask, where maximum frequency lies in the 8-12 cm. range with largest boulders of 30 cms. diameter, and the relationship is maintained on the watershed between Glen Mask and Derryveeny, where the average size of the boulders is 30-40 cms. and the maximum recorded diameter is 125 cms.

'Rafts' of grey-green sandstone up to 150 cms. in length, apparently isolated in a well-imbricated bed of pebbles 1-7 cms. in diameter, occur in Bohaun South, in Tonnasaile east, (east of the mountain road), and Derryveeny. The rafts are always composed of sandstones similar to those interbedded with the conglomerates, suggesting that some form of contemporaneous erosion was taking place. This is supported by the occurrence of channels and scour and fill deposits, which indicate that the water cut rapidly into the earlier sediments and washed out large blocks of the debris without breaking them. Shattering and rounding of the raft material did not occur in some cases for otherwise the rafts would not have been preserved. The intermittent movement of powerful currents is implied, not always restricted to well-defined channels, but capable of eroding previously deposited sandbanks.

The "diffuse" conglomerates (Fig. 35a, Plate 12) occur principally in the western and south-western parts of the Partry Mountains, and are particularly well displayed in the Glen Saul valley, along the lower reaches of the Sruffaunnagreevo. Sub-rounded pebbles and cobbles 5-10 cms. in diameter are frequently present, completely surrounded by angular sand. Professor Sutton (personal communication) has suggested that these "diffuse" conglomerates bear close resemblance to the Lower Torridonian sediments of Scotland.

The beds of "diffuse" conglomerates vary in thickness but in the Suffaunnagreevo section they are frequently thicker than the
Plate 15. Coarse concentrated conglomerate of eastern facies beside Sruffaunnagreeve.

more concentrated types of conglomerate, and two beds 23 ft. (7.3 m.) thick have been recorded. This form of conglomerate is the central member of a sequence which is repeated 16 times in the lowest 400 ft. (120 m.) of this section. The sequence may be as thin as 15 ins. (38 cms.) or as great as 27 ft. (11.2 m.), and embodies the following subdivisions:

- **very coarse, concentrated conglomerate**
- sandstone proportion decreases upwards.
- **fine-grained**
- **diffuse conglomerate**
- **pebble-bearing sandstone**
- **sandstone**

This sequence indicates an increase of grain size from the base to the top, pebbles attaining a diameter of 20 cms. at the top of the bed. It further shows that the "isolate" conglomerates occur almost entirely in reversely-graded deposits.

It is noticeable that the sequence so well displayed in the Suffaunagrave section is not seen throughout the Partry Mountains area, for along the sections by the mountain road extensive "diffuse" conglomerates do not occur. Instead the sediments are entirely of concentrated conglomerates and grits, the grading from the one to the other being more rapid and without an intervening diffuse stage.

The increase in pebble size implies an increase in the capacity of the current to move material of large dimensions. Beyond this initial observation two interpretations of the origin of the sediment are given:

1. There was a constant increase in the power of the stream. Only sand was transported and deposited by the earliest currents. An intermediate period followed, during which both sands and occasional pebbles, derived perhaps from pre-existing gravel banks, were deposited as "diffuse grit" and "diffuse conglomerate". Ultimately coarse, concentrated conglomerates resulted from the most powerful streams which moved much debris from the headwaters of the valleys. Since no decrease of grain size is seen above the very coarse material, there was either a rapid decrease in the volume of run off, or the coarse pebbles had completely covered any sand material, preventing it from being carried by the streams during the period of slackening of run off.
(2) During run off, build up similar to that described above took place, but much of the water, instead of flowing on the surface may have seeped into the underlying sands.

No vegetational cover existed on land during the Ordovician and for erosional purposes the environment was a desert, perhaps semi-arid in character. In semi-arid areas the seepage away of water is a typical phenomenon and downward movement of water washes sand size material lower into the fresh deposits, in effect concentrating the conglomerates above (from which interstitial material has been removed), with a central zone in which virtually a sand enriched conglomerate exists, composed of scattered isolated pebbles completely surrounded by sand.

The second alternative involves a more basic assumption that the former and entails a consideration of the climatic conditions. It has been observed above that the diffuse conglomerates and reversed grading are not entirely linked. These phenomena may have been produced in differing locations with regard to the main centres of run off, greater seepage occurring in areas of lesser run off. Thus by L. Knocknagower huge boulders of 150 cms. diameter represent a central position in a run-off stream while westwards along the strike the same bed in Letterenceen is much less coarse-grained and diffuse horizons appear.

Perhaps the only generalisation which can be made concerning the conglomerates is that there is an increase in frequency and thickness of the pebble-bearing horizons in a south-easterly direction, and clearly indicates an approach towards the source area.

e) Imbrication:

Throughout the Partry Series sandstones and conglomerates imbrication of the pebbles occurs with remarkable regularity. The long axis of the pebbles show an inclination towards the east or south-east. In some horizons in Glennagashleeny a similar arrangement of the long axis of grains of very coarse sand has also been observed. The inclination of the axes is variable: but in the east is frequently between 12° and 28°, while in the extreme west of the area rarely exceeds 5°.
Fig. 38. Cross-sectional area of the ends of pebbles from Glennagashleeny.

Fig. 39. Imbrication of pebbles in the Eastern facies of the Partry Series.
Very coarse conglomerates rarely show any imbrication, and similarly with fine-grained conglomerates, but imbrication is very pronounced when the pebbles vary in size, with 5 cm. - 20 cm. maximum dimension predominating. In the diffuse conglomerates, where a few pebbles appear to float in the sands, imbrication is poor if developed at all, and it appears that the density of packing of the pebbles may or may not exert some influence on the degree to which imbrication is developed. However, as the density of distribution of the pebbles increases, so does the degree of imbrication, until a maximum is reached where virtually all the pebbles are in contact with neighbouring pebbles. The degree of imbrication is thus dependent on sorting. Where sorting is poor, size variation is great, and degree of imbrication is great.

The orientation of individual pebbles occasionally shows some degree of control by shape: the larger, more bulky end of non-rounded pebbles shows a downward position. In the field this "end orientation" is a general feature of the eastern facies. Measurements taken on one exposure west of the Glennagashleeny road are represented graphically in Fig. 36. In any inclined pebble, two mutually perpendicular measurements were taken approximately 1 cm. from each end, and each at right angles to the long axis of the pebbles. The lengths of the two axes of the cross-section at the upper and lower ends of the pebbles are taken to give an areal representation of the cross-sections of the pebbles. For convenience it is considered to be rectangular in shape and the assumption is made that the area is proportional to the weight of the one end relative to the other.

Shape factor appears to have some connection with imbrication, and it is noticeable that imbrication is distinct where shape factor is high, but less pronounced where the pebbles are more nearly equidimensional. The higher the degree of sphericity, the less well is imbricated the resultant sediment (Fig. 39).

Conglomerates in which the intermediate axes are both sub-parallel or sub-perpendicular to the bedding planes exist in Murrisk. In each case where this occurs the heaviest end of the pebbles is towards the east.

The first detailed account of imbricate structure was given by
Becker (1693). He considered the relationship between the structures and the currents which formed them from a mathematical viewpoint. He asserted that a pebble in a stream of water, but not in contact with the sides or bottom of a channel would become orientated so that the shortest axis lay parallel to the direction of the flow, thus not only presenting the largest cross-sectional area, but also enabling it to fall through the water and tip over so that it could come to rest dipping upstream. Twenhofel (1932, p.36) considered that other causes acted: "slab shaped particles may turn over and over until the downstream end becomes higher than the upstream, when a condition of stability is attained". (In other words, in the opposite direction).

Cailleux (1945) conducted an intensive survey on pebbles of ancient and modern deposits and concluded that imbrication of high inclination (15°-30°) were fluviatile, while low inclinations (2°-12°) were of marine origin. He observed that the angle of imbrication increased with greater contact between the pebbles.

The change of degree of isolation is believed to be due to variations in essentially the same continuous depositional process, as described in section 2.

The derivation of the work imbrication is from "imbricatus" (Latin), meaning 'overlapping like roofing tiles.' This gives a guide to the inclination of the axes and also the proximity of pebbles to one another. Some doubt arises as to whether the term may justifiably be used when no overlapping occurs, more especially in the very diffuse conglomerates where pebbles are isolated in sandstones.

Since the inclination is constant in direction and the degree of isolation is variable it does not appear justifiable to introduce any new terms to describe the inclination of the axes of semi- or totally isolates pebbles, but the significance of the term imbrication will be increased if accompanied by a phrase to indicate degree of concentration or isolation of the pebbles in the conglomerate.

The very regular direction of imbrication in the conglomerates of the eastern facies indicates currents flowing from the east and southeast. The angle of imbrication, as suggested by Cailleux indicates "shallow water environment of deposition," while the end orientation suggests that the currents were swift flowing. These
a) 100 pebbles from Glennagashleeny
b) 100 pebbles from Glennagashleeny
c) 50 pebbles from Glennagashleeny
d) 33 pebbles from two adjacent bedding planes
   100 ft above M.T. 3 & 4. W. of Loughanshee.
e) 50 pebbles from Glennagashleeny
f) 50 pebbles from Tomasaile high road.
g) 50 pebbles from Glennagashleeny
h) 50 pebbles from Shangort stream.
j) 50 pebbles from Treanlaur stream.

Fig. 40 Rose diagrams to show orientation of long axes of pebbles in the bedding planes of Partry Series conglomerates.
three features alone give no indication as to whether the sediments are marine, lacustrine, fluviatile or terrestrial.

f) Orientation of the long-axis of the pebbles.

Random distribution of the axes of pebbles is virtually unknown in this Series. Normally there is a clear direction of preferred orientation of the major dimension of the pebbles in the conglomerates. The orientation of the long axes of 500 pebbles, mainly from the eastern facies of conglomerates but including 50 from west of the Lettermeneen fault, has been measured and plotted in the form of rose-diagrams. An equal area 7.5 cm stereographic grid system was employed using a scale of 5° to one measurement. Individual measurements were grouped into 10° classes and the class total plotted at the median for that class.

The rose-diagrams indicate that the major direction of flow of the current was approximately 120°-130°, but that there is usually a subsidiary maximum can become dominant. The observations for this were taken from the base of a conglomerate bed in the stream above Treanlaur village. While the basal layer shows the 80°-90° maximum there is a distinct swing of the long axis towards 120° as the higher layers are reached within this one conglomerate bed.

The other observations were taken from the upper part of conglomerate beds in various parts of the area. Measurements of the direction of major axis orientation at 80°-100° and in higher zones as 120°. Intermediate angles occur above the sill at Tonnasaile and in the stream of Derryveeny (116° and 108° respectively).

Weak orientation at 30°-40° was noted above Treanlaur, roughly perpendicular to the habitual orientation but still showing the usual imbrication direction, indicating that another type of current was in operation at times during the deposition of the group. However, this is an isolated example in one bed which can be traced for half a mile by this characteristic.

The figures of the rose-diagram show the wide spread of maximum readings, often (Fig. 40(a)) occupying a 70° spread about the mean. This is the expected spread including experimental error in reading the directions present. The mean itself is still pronounced as a
result of the method of plotting and connection of the point readings.

The deviation in directions may partly reflect the angle into which the smaller pebbles slide when brought into contact with the rounded upstream ends of larger, more stable pebbles. There is a sliding off round the end which rotates the major axis through about 30º in many cases.

The pebbles vary greatly in size, and are known from 1 cm. to over 100 cm. At the extremes of size, preferred orientation is poor, and shows development where pebbles are in the 5 cm.-20 cm. range. The lower parts of many conglomerate beds show small (1-4 cm.) well rounded pebbles with high sphericity, grading upwards to cobbles (10 cm.-25 cm.), relatively ill-rounded, and of low sphericity.

The feature of reversed grading is seen in virtually all beds of the conglomerate and a maximum of six repetitions of reversed grading in conglomerates are seen at one locality in Glencassleeny with no intervening sandstone horizons (Fig. 36). At the base and top of each band there is a poorly developed preferred orientation which becomes more pronounced towards the centre of the bed.

Previous workers have been divided into two sharply contrasted schools of thought as to whether the long axes of the pebbles were parallel or perpendicular to the current direction. Pettijohn (1957) observed that Jones (1922), and Murray and Schlee (1955) considered them to be parallel to the flow, while Hunziker (1930), Tienhofel (1952), and Fraser (1935) supported the opposite opinion.

It would appear to depend on the type of flow and the strength of the currents. The author's observations indicate that the long axis directly down the imbrication angle, i.e. the maximum slope of the pebbles usually lies along their longest axis, suggesting that the currents, in this instance at least, flowed parallel to the longest axis of the pebbles.

The apparent swing of orientation of the long axes rise to several possible interpretations:

1) The earliest, well rounded pebbles were influenced by some property of the underlying sands causing them to adopt their initial orientation and only later, when the sands had been completely covered could the pebbles assume the more usual orientation. This seems
Effect of varying $R$

Change of azimuth of resultant current

$$\frac{R}{K} = \tan \phi$$

b) Effect of varying $R$

Fig. 41. Influence of two interacting currents.

To give 50° deflection $R = 1/6K$ to $R = 2K$ is required variation

50° variation
improbable as the repeated conglomerate beds of Glennagashleeny, where no intervening sandstones occur, also show the swinging orientation direction.

2) The regular flow of water from an easterly direction in many small channels may account for regularity of orientation of the axes. Spreading of water from the channels as run off increased would certainly lead to different orientation, of the axes, but this would be more random in type and not regular as in the Mweelrea conglomerates.

3) The source of debris may be a north and south ridge to the east. Storms moving from north to south along the ridge could produce a nearly flow of runoff waters from east to west, and as the centre of rainfall moved further south the flow relative to the stationary point would become more south-east to north-west. This alternative attributed the dual maxima of size of pebbles to a two-fold nature of the eastern ridge, and differing size of pebbles to variations in the proximity of the sources. This is not considered the probable explanation.

4) The apparent variation of direction of the depositing currents may be due to variation of the strengths of two interacting currents. In this a relatively constant offshore current of 'regional' status is assumed to have uniform direction and strength, while the strength of the currents due to runoff water varies. The interaction of the currents produces a resultant current which swings in direction with variation of the strength of the runoff current, as illustrated graphically in Fig. 41(a). No conception of any continued separate movements of the individual currents is implied, but a combined action giving the resultant movements. A build up of strength of the run-off current could account for a swing from 80° to 130°.

The earliest flood water has little power and is easily deflected into the direction of the 'regional' current, but when a large volume of run-off from high in the catchment area, arrives at the shoreline it will have much momentum gained by conversion of potential energy during the descent in the stream valleys. This momentum will carry the coarse debris forward into the 'regional'
current before friction and gravity cause it to slow down, depositing the load. Continuous increase in the power of the stream leads to a gradual swing in orientation of the deposited pebbles, and a decrease should be accompanied by the reverse.

The area of such oscillation of orientation should be rather restricted, and suggests a location in a piedmont position.

Reference to Fig. 41 (c), shows that a variation of $50^\circ$ in the direction of flow of the currents, as produces a swing from $80^\circ-130^\circ$ can be produced by variation of the runoff current from one-eighth to double the strength of the 'regional' current. Such fluctuations are easily envisaged, and a variation of from half to four times the strength of the constant current. e.g. a drift current of 4 knots influenced by a varying current from 2-16 knots would provide the observed swing of long axes.

For convenience the effects have so far been considered with reference to two mutually perpendicular interacting currents, but there is no justification for this assumption and the angle between them may be acute or obtuse, but it can still be shown that the direction of the resultant current is dependent upon the strength of the run-off current.

\[ B \sin C = V \sin a \]
\[ B^2 = K^2 + V^2 - 2KV \cos c \]
\[ V^2 = K^2 + B^2 - 2KB \cos a \]
\[ \cos a = \frac{K^2 + B^2 - V^2}{2KB} \]

substituting for $B^2$
\[ \cos a = \frac{K^2 + (K^2 + V^2 - 2KV \cos c) - V^2}{2KB} \]

\[ \cos a = \frac{K - V \cos c}{B} \]
substituting for $B = V \sin a$

$$\sin c$$

$$\cos a = \left( \frac{K - V \cos c}{V \sin a} \right)$$

$$\cos a \sin a = \frac{\sin c \left( K - V \cos c \right)}{V}$$

Since $K$ and $C$ are constants the angle $a$ is dependent upon the length of $V$ and hence upon the strength of the run-off current.

It is suggested that the area may have been one of piedmont deposition. If this is correct then the two maxima of pebble size frequencies may be partly due to reworking of earlier gravel deposits higher in the valleys. The well-rounded material is easily available to the earliest run-off waters and only later, when power has increased, can large angular fragments be moved. Reworking of the earlier gravels continued with newly eroded and transported material may be responsible for the two maxima.

This alternative assumes deposition in shallow water.

5) Reworking of early gravels of a piedmont plain may account for the high degree of sphericity observed in many of the pebbles and cobbles. Deposition from such a source would lead to accumulation of pebbles in lenses of restricted size. It appears that some larger scale process would need to be invoked, perhaps the flowing of many small streams, all migrating in the same way, for all would be unrestricted by vegetation and should have been influenced by the same conditions. Continued uplift of the source would be necessary to maintain both the supply of clastic material and to permit depth of accumulated debris to increase.

6) Coriolis effect is not thought to be the causative factor since this is effective only on large scale phenomena, and implies constancy of environmental conditions.

The significance of the change of orientation of the long axes of the pebbles is not fully understood. The author believes that a piedmont or near-piedmont environment of deposition was responsible for the type of sediment and the fluctuations observed in it. A piedmont environment in semi-arid conditions, perhaps leading into
shallow water, could allow variation of azimuth due to any one of several of the above mentioned methods. A similar semi-arid environment has been quoted in deduction from the section concerning distribution of pebbles.

\( g \) Orientation of the median axis

The median axes of the pebbles of the conglomerates are normally arranged in a position sub-parallel to the bedding planes, but occasionally especially on the slopes of Tonmasaila, zones of over 10 metres lateral extent are seen in which the median axes are sub-perpendicular to the bedding planes. In such locations with very few exceptions the orientation is constant and varies little from the vertical.

The feature has been recorded in layers of relatively coarse conglomerates, in which pebbles up to 15 cms. in length and with median axes over 8 cms are common. The lack of observations of this phenomenon in finer grained material may be due to either non-occurrence below a certain limiting diameter, or because the orientation is less noticeable in smaller material.

No record of the sub-perpendicularity of median axes to the bedding has been encountered in records examined by the author. It is believed that whilst in many basins deposition occurred from a single inflowing stream, in S.E. Murrisk the deposition was from several nearly parallel streams in close proximity. Where no interference between currents occurred, then the 'normal' sub-parallel arrangement of median axes resulted, but where two currents approached and coalesced the consequent increase in turbulence caused the median axes of the pebbles to become inclined towards a vertical position. The currents were powerful, for, as has been noted above, large cobbles are tilted.

For currents to retain a high velocity either the angle of the slope on which deposition is taking place is high, or land is relatively close. The incidence of several nearly parallel neighbouring streams each with swift flow is typical of a piedmont area of deposition, within a few miles of a mountain front.
h) **Roundness**

The pebbles of the conglomerates of Eastern Murrisk vary from poorly rounded to well-rounded, often with the extremes intermixed.

The visual comparison scales of roundness introduced by Krumbein (1941) during work on recent gravels, have been applied to a selection of photographs representative of most of the area. It was not possible to separate and examine individual pebbles, for the well-cemented conglomerates do not easily release discrete pebbles, and so laboratory work from photographs was necessary in place of direct field analysis. Although Krumbein states that the method of visual comparison should be applied to the maximum projection plane of the pebble, this has not proved possible in these ancient conglomerates, and a random selection of projections has been used. Variations of the attitude of the photograph with respect to bedding will introduce certain systematic errors. In a plate-like pebble the end section may be relatively well-rounded, while the side section is less well-rounded. Since many of the pebbles of the Partry Series are not truly spherical and show a regular orientation, it is clear that a section oriented across the current direction will indicate better apparent rounding in the pebbles than in a section parallel to the current direction. Whenever possible the photographs used in the analysis were of sections parallel to the current.

The use of photographs introduces a further error, that of distortion of outline due to shadow effects, and to partly eliminate this the photographic negative was projected on a wall-screen, from which all observations were made.

Since the same method of analysis has been applied to all of the examples, the systematic errors have been applied to all equally. Although direct comparison with the results of Krumbein are not possible, comparisons amongst the figures themselves should be valid.

Comparison of results obtained by the vertical comparison method have been compared with the Wadell (1932) method involving measurement of the radii of the corners, and the two show little discrepancy, so the more rapid, visual method was used for all samples.
Fig. 42. Roundness of pebbles in the Partry Series conglomerates
# TABLE 2

Results of Roundness Computations.

<table>
<thead>
<tr>
<th>Location</th>
<th>Roundness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below the mountain road, on east side (S. Stream section)</td>
<td>0.52</td>
</tr>
<tr>
<td>Treanlaur stream 350' contour</td>
<td>0.52</td>
</tr>
<tr>
<td>Treanlaur stream 500' contour</td>
<td>0.52</td>
</tr>
<tr>
<td>Above Derryveeny field, by fault</td>
<td>0.54</td>
</tr>
<tr>
<td>Bohaun Hill</td>
<td>0.53</td>
</tr>
<tr>
<td>Sruffaunnagreeve</td>
<td>0.55</td>
</tr>
<tr>
<td>Sruffaunnagreeve</td>
<td>0.55</td>
</tr>
<tr>
<td>Sruffaunnagreeve</td>
<td>0.58</td>
</tr>
<tr>
<td>Glennagashleeny low by stream (W. of it)</td>
<td>0.55</td>
</tr>
<tr>
<td>&quot; &quot; &quot; &quot; (E. of it)</td>
<td>0.55</td>
</tr>
<tr>
<td>&quot; &quot; &quot; &quot; (50' higher)</td>
<td>0.57</td>
</tr>
<tr>
<td>&quot; &quot; by high road wall</td>
<td>0.62</td>
</tr>
<tr>
<td>Glen Mask, above furthest houses</td>
<td>0.57</td>
</tr>
<tr>
<td>&quot; &quot; on northern scarp of mountains.</td>
<td>0.58</td>
</tr>
<tr>
<td>&quot; &quot; above waterfall</td>
<td>0.58</td>
</tr>
<tr>
<td>Ridge W. of L. Glenawough</td>
<td>0.60</td>
</tr>
<tr>
<td>Corrie W. of L. Glenawough</td>
<td>0.61</td>
</tr>
<tr>
<td>&quot; &quot; &quot; &quot; (100' higher)</td>
<td>0.61</td>
</tr>
<tr>
<td>Below unconformity, at Loughanshee, in slates</td>
<td>0.71</td>
</tr>
<tr>
<td>&quot; &quot; &quot; &quot; Derryveeny</td>
<td>0.72</td>
</tr>
<tr>
<td>&quot; &quot; &quot; &quot; Garangerra River junction</td>
<td>0.72</td>
</tr>
<tr>
<td>&quot; &quot; &quot; &quot; Farm yard, Derryveeny W.</td>
<td>0.73</td>
</tr>
<tr>
<td>&quot; &quot; &quot; &quot; &quot; &quot; &quot; &quot; &quot; &quot;</td>
<td>0.76</td>
</tr>
</tbody>
</table>
Pebbles from a total of 25 exposures of conglomerates were examined, 20 belonging to the Partry Series, and 5 from the Mt. Partry Beds, which are conglomerates overlain unconformably by the conglomerates of the Partry Series and distinguished in the field by a greater pebble roundness than in the overlying conglomerates. Only rarely was it possible to measure more than 20 pebbles with satisfactory accuracy, and the statistical significance of the results will be less than is desirable.

The data obtained is presented on Table 2, and on map Fig. 42. There is an increase in the degree of roundness from 0.52 in the south-east, to 0.61 in the north-west, the western facies.

Pebbles of variable composition were measured, but mainly these were confined to granite porphyry, gneisses, welded tuff, and jasper. A study of any one constituent was not undertaken, although jasper, black chert, and granite porphyry, each of which is distinctive, might yield interesting results. The problem of low frequency of occurrence, or even of total absence of pebbles of any one composition in many localities imposes severe limitations on the use of individual pebble types.

As early as 1888, Bonney, who observed the pebbles of Alpine streams, noted that roundness increases downstream, and that even high in the courses of mountain streams this difference is noticeable within a few miles of the source. Later observers, notably Barrell (1925) and Wadell (1932) confirmed this, and Wadell suggested a method of calculating roundness of individual pebbles, from the radii of the corners.

Krumboin, in investigations of the river gravels of the San Gabriel (1941), and Aroyo Seco (1942) canyons, showed that the only reliable systematic variation of character of the pebbles was roundness. A method essentially similar to that of Wadell (1932) was given in the 1940 paper, followed in 1941 by a visual method of analysis. Powers (1954) published an alternative set of visual aids to comparison of roundness measures, but the reduced variation is less sensitive and does not apply so clearly to the Partry Series conglomerate study.

Barrell (1925, p.336) quotes Sternberg (1875) as having derived
an equation from which, knowing the average weight of pebbles at two known points, it is possible to deduce the distance travelled by a pebble from its source to the point of deposition:

\[
\frac{W_I}{W_O} = e^{-\lambda x}
\]

Krumbein (1941) rediscovered this exponential relationship as applied to roundness:

\[
\frac{P_I}{P_O} = 1 - e^{-\lambda x}
\]

Plumley (1946, p. 566) believed that the roundness was partly proportional to the power of the distance the pebble had travelled, and gave a general equation:

\[
\frac{P}{PL} = 1 - e^{-r(x)n}
\]

The introduction of the additional variable renders the Krumbein (1941) equation obsolete, but in the present work the further unknown quantity complicates the findings greatly for little effect on the end result, since it is the order of magnitude of the distance rather than the distance with which the study is concerned.

Sarkisian and Klimova (1955) derived an equation essentially similar to that of Krumbein, without the Plumley modifications:

\[
\frac{P_o - P}{P_o - P_i} = e^{-d_s s}
\]

The average roundness of the San Gabriel gravels approaches an asymptote as the distance from source increases, and the use of this asymptote enabled Krumbein (1940) to estimate the value of \( P_o \). The Partry Series pebbles do not show this part of the curve for the same parameters, and the asymptote must lie above 0.61, so that the value of \( P_o \) may be placed at a minimum of 0.65, and more probably lies between 0.70 and 0.75.

Only the results obtained from east of the Lettereenen fault have been used in the calculations, although the limiting position of the asymptote for maximum roundness has been taken from the highest figures obtained, near L. Glenawough.

Taking the four fixed points of well-known roundness and of known distance apart in the direction of the current (deduced from the current bedding above), it is now possible to calculate the
values of both \( \lambda \), the coefficient of rounding, and \( X \), the distance of Treanlaur from the source.

When \( P_0 \) is 0.65

\[
\begin{align*}
\frac{0.52}{0.65} &= 1 - e^{-\lambda x} \\
0.2 &= e^x \\
x &= \log 0.2 \\
x &= 0.05951 \quad (a)
\end{align*}
\]

Subtracting (a) from (b)

\[
\begin{align*}
4\lambda &= -0.0254 \\
\lambda &= -0.00638
\end{align*}
\]

Substituting for \( \lambda \) in (a)

\[
\begin{align*}
X &= 0.06931 \quad (b) \\
X &= -0.00813
\end{align*}
\]

Similarly, using other results.

When \( P_0 = 0.75 \)

\( x = -14.8 \text{ miles} \)

When \( P_0 = 0.70 \)

\( x = -9.3 \text{ miles} \)

When \( P_0 = 0.65 \)

\( x = -8.5 \text{ miles} \)

In either case the result indicates that the source was within twenty miles of the area of deposition, for this \( X + 0 \) position corresponds to a location in the stream above Treanlaur. This would place the source in the general area of Ballinrobe - Kilmaine, the whole of which area is now covered by later, Carboniferous sediments.

The results obtained must be regarded with considerable caution for there are several uncertainties in the calculation, but it is believed that the results will be of about the correct order of magnitude.

Thus it is believed that an area of metamorphic rocks and granites existed in the Ballinrobe - Kilmaine area in the M. Ordovician.

i) Sphericity.

The sphericity can only be accurately assessed when complete pebbles are available for examination. This is not the case in the conglomerates of the Partry Series, but some observations may be made.
Sphericity is ideally represented by the ratio of the surface area of a sphere of the same volume as the pebble to the actual surface area of the pebble, and is unity for a perfect sphere. Not all of the debris begins with the same initial sphericity, for when rocks of different composition are broken they characteristically produce differently shaped fragments.

Mica-schists, gneisses, slates, and some welded tuffs tend to produce slivers, or plates of low initial sphericity, whilst granites, quartzites sandstones, and certain welded tuffs fracture to give a higher initial sphericity. This factor alone renders examination of the Series as an entity complex.

Theoretically, the sphericity of any one constituent should increase in the direction of the current, but the only striking changes in the sphericity take place in a vertical section through individual beds. At the base of the reversely graded beds in particular, the small pebbles show a high degree of rounding and high sphericity. Higher horizons in the same bed show more angular, less spherical fragments.

There cannot have been any great changes in the location of the source of material in each of the many repetitions which are seen, and the change of sphericity may be due to different duration of time spent by the pebbles in stream of moving water between erosion and deposition. Thus the earliest deposited material may have undergone a lengthy history of erosion, abrasion, and deposition on gravel banks, before arriving at the present position, while later material, high in the bed, may have been derived from the same source, but carried the whole distance and deposited in one movement, thus undergoing less wear due to a lesser time or exposure to abrasion.

No detailed study of the variation of any single constituent, which might indicate systematic changes of sphericity through the Partry Mountains, has been attempted.
The Petrology of the Sandstones of the Partry Series.

The sandstones, which lie between the conglomerate beds, and form the greater part of the Series, vary from coarse to very fine grained. They are sometimes current-bedded, though occasionally totally devoid of cross-bedding. The aspects to be analysed are firstly, variation in the size frequency distribution, with the accompanying analysis of the sorting and other parameters of the sediment, and secondly, variation of the mineralogical composition of the rock, and its relation to grain size differences.

Size analysis.

The cementation makes disaggregation of the sandstones for sieve and pipette analysis impracticable. Thin section analysis was therefore undertaken, and grains of quartz only were measured. The thin sections were cut perpendicular to the bedding planes and current direction so that control was introduced, to eliminate the effect of orientation of the grains, which would produce biased results in some random sections.

The method adopted, of measuring quartz grains only, differs in several respects from the two standard methods used in the study of recent sediments. Sieve analysis deals with the entire sediment, clay, heavy minerals, lithic material, and feldspars, as well as the quartz. The results are partly controlled by the shape of the particles under analysis, the smallest diameter being the controlling factor. The clay grade fractions are more easily analysed by pipette methods. Although small in dimension, this fraction may include the heavy minerals, which, despite their size, and due to their higher densities, should normally be considered with the sand fraction.

Examination of the quartz fraction only means that, while a true overall picture of the size of material in the rock is not obtained, a very accurate representation is achieved for the major component of the silt-sand portion of the rock. Study of the mineralogical analyses in Section 4 indicates the proportion of the sediment to which the analysis refers. The size distribution of feldspar debris is essentially the same as for quartz.
<table>
<thead>
<tr>
<th>Micrometer</th>
<th>Slide 865</th>
<th>Slide 916</th>
<th>Number of grains per group. 250 grains total per slide.</th>
</tr>
</thead>
<tbody>
<tr>
<td>readings</td>
<td>100</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>195 - 295</td>
<td>295</td>
<td>395</td>
<td>495</td>
</tr>
<tr>
<td>305 - 405</td>
<td>415</td>
<td>515</td>
<td>615</td>
</tr>
<tr>
<td>315 - 415</td>
<td>425</td>
<td>525</td>
<td>625</td>
</tr>
<tr>
<td>325 - 425</td>
<td>435</td>
<td>535</td>
<td>635</td>
</tr>
<tr>
<td>335 - 435</td>
<td>445</td>
<td>545</td>
<td>645</td>
</tr>
<tr>
<td>345 - 445</td>
<td>455</td>
<td>555</td>
<td>655</td>
</tr>
<tr>
<td>355 - 455</td>
<td>465</td>
<td>565</td>
<td>665</td>
</tr>
<tr>
<td>365 - 465</td>
<td>475</td>
<td>575</td>
<td>675</td>
</tr>
<tr>
<td>375 - 475</td>
<td>485</td>
<td>585</td>
<td>685</td>
</tr>
<tr>
<td>385 - 485</td>
<td>495</td>
<td>595</td>
<td>695</td>
</tr>
<tr>
<td>395 - 495</td>
<td>505</td>
<td>605</td>
<td>705</td>
</tr>
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<td>405 - 505</td>
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<td>715</td>
</tr>
<tr>
<td>415 - 515</td>
<td>525</td>
<td>625</td>
<td>725</td>
</tr>
<tr>
<td>425 - 525</td>
<td>535</td>
<td>635</td>
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</tr>
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<td>435 - 535</td>
<td>545</td>
<td>645</td>
<td>745</td>
</tr>
<tr>
<td>445 - 545</td>
<td>555</td>
<td>655</td>
<td>755</td>
</tr>
<tr>
<td>455 - 555</td>
<td>565</td>
<td>665</td>
<td>765</td>
</tr>
<tr>
<td>&gt; 555</td>
<td>675</td>
<td>775</td>
<td>875</td>
</tr>
</tbody>
</table>

Table 3. Distribution of grain size measurements.
### TABLE 4

**Inman parameters of Earty series sediments.**

<table>
<thead>
<tr>
<th>No. of specimen</th>
<th>$\phi$ Median diameter</th>
<th>$\phi$ Mean diameter</th>
<th>$\phi$ deviation measure</th>
<th>$\phi$ Skewness measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>295</td>
<td>2.9</td>
<td>2.9</td>
<td>0.65</td>
<td>0</td>
</tr>
<tr>
<td>862</td>
<td>3.08</td>
<td>2.88</td>
<td>0.88</td>
<td>-0.33</td>
</tr>
<tr>
<td>880</td>
<td>2.54</td>
<td>2.64</td>
<td>0.74</td>
<td>+0.23</td>
</tr>
<tr>
<td>891</td>
<td>2.84</td>
<td>2.90</td>
<td>0.78</td>
<td>+0.08</td>
</tr>
<tr>
<td>892</td>
<td>3.4</td>
<td>3.33</td>
<td>0.78</td>
<td>-0.10</td>
</tr>
<tr>
<td>894</td>
<td>2.95</td>
<td>2.9</td>
<td>0.65</td>
<td>-0.08</td>
</tr>
<tr>
<td>887</td>
<td>3.15</td>
<td>3.0</td>
<td>0.75</td>
<td>-0.02</td>
</tr>
<tr>
<td>1004</td>
<td>2.85</td>
<td>2.85</td>
<td>0.85</td>
<td>0</td>
</tr>
<tr>
<td>1005</td>
<td>3.2</td>
<td>3.1</td>
<td>0.6</td>
<td>-0.17</td>
</tr>
<tr>
<td>1008</td>
<td>3.15</td>
<td>3.05</td>
<td>0.8</td>
<td>-0.13</td>
</tr>
<tr>
<td>1108</td>
<td>2.74</td>
<td>2.68</td>
<td>0.93</td>
<td>-0.07</td>
</tr>
<tr>
<td>1120</td>
<td>2.85</td>
<td>2.75</td>
<td>0.8</td>
<td>+0.13</td>
</tr>
<tr>
<td>1121</td>
<td>2.4</td>
<td>2.5</td>
<td>0.8</td>
<td>+0.13</td>
</tr>
<tr>
<td>1131</td>
<td>2.64</td>
<td>2.73</td>
<td>0.94</td>
<td>+0.09</td>
</tr>
<tr>
<td>1140</td>
<td>2.50</td>
<td>2.56</td>
<td>0.78</td>
<td>+0.07</td>
</tr>
<tr>
<td>1144</td>
<td>2.41</td>
<td>2.61</td>
<td>0.65</td>
<td>+0.30</td>
</tr>
<tr>
<td>1014</td>
<td>2.8</td>
<td>2.8</td>
<td>0.85</td>
<td>0</td>
</tr>
<tr>
<td>1047B</td>
<td>3.18</td>
<td>3.0</td>
<td>0.8</td>
<td>-0.23</td>
</tr>
</tbody>
</table>
Fig. 43 Plots to show variations in the distribution of more than 100 grains.
The thin sections were mounted on a microscope with traversing stage as used in conjunction with the Swift Point-counting mechanism. The stage controlled the line along which the measurements were taken, and ensured that no duplication of measurements occurred. The diameter measured in this study was defined as the maximum intercept through the various grains, parallel to the direction of traverse. All resolvable quartz grains in the field of view were measured, using a micrometer eyepiece.

The method of measuring the diameter of grains parallel to an arbitrary line is believed to be preferable to measuring the largest diameter in the section of the grains concerned. As observed above, sieve analysis is based on the dimension of the smallest diameter. The distribution of diameters observed in thin section will not indicate accurately the true grain diameters, as few random sections will pass through the centre of the grain. Krumbein (1938) gave an equation to correct the observed values so that an estimate of the true diameters could be made. Friedman (1958) used a correction curve which may be applied after construction of the cumulative curves for the observed distribution, to enable consideration of the results in the same terms as for sieve analysis.

A standard number of 250 grains was measured in each of 20 thin sections taken from sandstones collected from most of the area occupied by the outcrop of the Partry Series.

Plotting 100, 160, 210, 260, 320, and 360 grains measured from slide No. 846 and 100, 150, 200, and 250 grains from slide No. 1014 shows that there is little difference between successive cumulative frequency curves based on more than 200 grains (Fig. 43). A standard number of 250 grains was therefore measured in each section, partly to decrease statistical error, and partly to reduce the considerable time involved in taking larger numbers of measurements. The readings were arranged into groups of 10 graduations of the micrometer scale, and plotted as conventional cumulative frequency curves. On to this scale, equivalents of metric and phi readings were plotted, and from these latter
E. or W. signifies origin east or west of the Lettereneen fault.
Cumulative frequency distribution curves of grain size analyses in the Partry Series.

Fig 4.8: Results plotted against metric scale.

Fig 4.9: Results plotted against phi scale.

phi values corrected for sieve analysis.
Fig. 47. Grain size frequency in the Pamily Series.

- W. of Lettereeeneen fault only
- E. of Lettereeeneen fault only
- Common to both sides of the fault
values statistical analyses of the results carried out. The original data are given in Table 3 and the subsequent analyses in Table 4, plotted on graphs of Figs. 44,45,46 and 47.

This method of analysis has advantage over sieve analysis in that the inter-grade interval is small, and detailed curves can be produced, in which virtually the entire length of the curve is accurately known, and speculation concerning what happens between known points is reduced to a minimum. The interval plotted was 0.014 mm throughout the range 0.04 mm to 0.5 mm; thus including most of the sand grade and the uppermost part of the silt fraction. Below 0.04 mm the quartz grains were not resolved under the low power of the microscope on which the measurements were carried out.

**Presentation of results.**

The results are presented graphically as histograms, Fig. 44, and as cumulative curves, Fig. 45. The data were analysed statistically using the method of moments, to give the arithmetic average, standard deviation and median. From these a calculated maximum grain size may be obtained, outside which no more than 0.3 % of the material should lie (arithmetic average plus three standard deviations). These statistical methods, however, assume a unimodal distribution and a lack of skewness in the distribution of the grain size frequencies. Examination of the frequency curves indicates that there is a considerable skewness involved here, and these analyses using the lengthy method of moments are not as accurate as at first hoped, but nevertheless can be used with reservations.

A far quicker method of obtaining results of some significance was given by Trask (1932) in which he obtained several fundamental measures to describe the characteristics of the distribution - the mean and median, which represent the average size of the grains; the sorting, which serves to indicate the spread of the readings; the skewness, and indicator of the degree of symmetry of the curve; and the kurtosis, which indicates the peakedness of the curve. In this method readings are taken direct from the curve and used to compute the results.
It is generally accepted that natural granular substances obey a log normal law, and Hatch and Choates (1929) and Wentworth (1929) introduced the use of logarithmic moments for their analysis. Krumbein (1936) made a further notable advance with the introduction of the phi notation, in which phi represents the negative logarithm to the base two of the diameter of the particle in millimetres (\(\phi = -\log_2 \text{diameter}\)). Again moments are available for the analysis of the curves, but the simplified methods introduced by Trask (1932) are still applicable to the phi curves.

Inman (1952) examined methods of analysing data and suggested the use of the 16th and 84th percentiles in some cases, and the 5th and 95th percentiles in others. He measured the median and calculated the standard deviation, kurtosis and two measures of skewness; the second of these uses the extreme measures of the tails of the distribution. In sieve and pipette analyses the tailing effect in the cumulative frequency distributions suggest that some errors of readings may occur where the curve and the percentile lines are nearly parallel. In preference to the use of 5th and 95th percentiles, where this error is potentially greatest, the quartiles have been used in the second series of calculations. The parameters involving the 16th and 84th percentile are a statistical improvement on those suggested by Trask (1932) in that they enable nearly 70% of the graph to be used in place of the former 50% of the data.

There are clear objections to the Inman parameters, for, while considering a very small volume of rock, as in the thin section analysis undertaken, the entire curve for the quartz grains may be obtained (except for the most small fraction). With a larger volume, especially if the material is very coarse, considerable difficulties might result in achieving even the 16th and 84th percentiles. Unimodal curves are ideal for this method, but, the results for the Partry Series are at least biomodal if not polymodal in many instances. Again this detracts from the value of the Inman parameters. Folk and Ward (1957) suggested a further series of parameters to enable analyses in the parts of the distribution not covered adequately by the Inman parameters, and dealing largely with the tails of the curve in the extremes of the distribution. Clearly, for reasons already
given, reliance cannot be placed in the extremes of the distribution of the data for these analyses. It is interesting to note that despite these further modifications, the only factors of significance appear to be skewness and kurtosis (Mason and Folk 1958). Nevertheless it is important to attempt to convert the masses of data into a more intelligible form, and in the absence of more adequate analytical methods, those suggested by Inman have been applied to the data for the Partry Series.

The frequency distribution histograms were constructed and show that, in all but one sample, there is a wide spread about the central mode, but there is often a secondary mode in the 0.25 - 0.3 mm range, much less important than the main peak, which occurs at 0.075 - 0.1 mm in most cases (Fig. 44). The exception is fine grained in the hand specimen. It is noticeable that the peakedness of the distribution is more pronounced in samples taken from the western facies than in those taken from the east.

The problems involved in the super-position of two populations of grain sizes may be resolved in two ways. Firstly, the straightforward interaction of two currents which flow in different directions, and bear debris of different sizes, can produce anomalies in the resultant deposits. Secondly, a form of post-depositional movement of the finer particles by the movement of groundwaters can produce an anomalous result. It is not possible to distinguish between the two anomalies by grain size measurements alone, although the latter mechanism is doubtless capable of producing a greater percentage of clay grade matrix material, as would be reflected in computations of the mineralogical composition of the rock. Since no clay grade material has been measured, it will not be possible to speculate on the lines of Doeglas (1946 and 1951) concerning additions of material outside and sand grade.

The cumulative frequency distribution curves plotted against either metric or phi scale bases; figs. 45 and 46, appear to show no significant differences with the exception of specimen
Fig. 48 - Graphical representation of the Inman parameters of the sediments of the Partry Series.

- Western facies
- Eastern facies
846. The curves vary in gradient, regularity and size of the tail, but none of these variations appears to be linked with particular positions from which the samples originated. Fig. 46 shows the plotting of the results of the cumulative curves on an arithmetic probability scale, which enables the results to be compared with those of Doeglas (1941, 1946, and 1950). Once again much reliance is placed in the extremities of the distribution for the sake of interpretation.

These probability curves are all sub-parallel and nearly straight, with a slight suggestion of convexity in the coarser grades, and slight concavity in the finer material. It is noticeable, however, that the point of inflection of the curves always lies in the 2.5 phi - 3.5 phi range, i.e. in the range 0.1 mm - 0.2 mm.

Irregularities of these curves are not sufficiently large to render valid speculation concerning additions to, or subtractions from, the original sediment after the style of Doeglas (1941). A sediment which has been deposited as the result of a single act of deposition, such as the topmost layer of wind-blown sand on a dune, shows a true log-normal distribution (Bagnoli 1941). Such sediments, in which no later addition of material, by reworking, or seepage of water throughout the sediments has occurred, are rare. All other sediments show deviations from the log-normal distribution, and a skewness is observed in the curves. Direct addition of material to an original sediment leads to the preservation of part of the original log-normal curve. Such irregularities of curves are reflected only when the entire range of the sedimentary components have been analysed. This has not been undertaken for the sediments of the Partry Series, and so no such speculation will be given.

The values of phi median diameter, phi mean diameter, phi deviation measure, and phi skewness, have been calculated as indicated by Inman (1952). The results are presented in Table 4. These values were plotted one against the other, see Fig. 48.
Fig. 49. Comparison of analyses with those of Davies (1962)

Eastern facies
Western facies
The initial plotting of these data shows little significance of relationships between the parameters, but when a larger series of scales is use, corresponding to those used by Davies (1962) in his analyses of the Recent sediments of Gibraltar Point, then the results from the Partry Series appear to plot in a close distribution, and a clear indication of linear relationships is observed. Fig. 49.

The phi median diameter - phi deviation measure relationship, gives an approximately linear distribution along a deviation of 0.75 phi; with a maximum spread of 0.25 phi on either side of this on the deviation scale, and extending from phi median diameter of 3.7 phi to 2.2 phi.

The phi median diameter - phi skewness curve is a pronounced linear function in which the phi value is lowest (2.4 phi) for strongly negatively skewed curves, and highest (3.7 phi) for strongly positively skewed values.

The phi deviation measure - phi skewness curve is less strongly linear and plots as an inequidimensional zone of slightly elongate outline. There is a slight suggestion that the phi deviation measure is lower for high negative skewness values than for high positive values.

A comparison of these results with those of Davies (1962) indicates some overlap of the distributions of points, and a limited parallelism in the case of the phi median diameter and skewness curves. The very marked convergence of Davies's plots of phi median diameter and phi deviation measure towards a value of 2.75 for the phi median diameter is not reflected in the analyses from the Partry Series. The results from the Partry Series, however, plot to give a well defined zone which can be recognised in each of the analyses.

The linear relationship between phi median diameter, and phi deviation measure (a function of the sorting) is a well known feature, widely reported in analyses. The other two linear trends have been reported by Davies (1962) and Shepard (1961) and are to some extent confirmed from the Partry Series.
Fig. 50. Analyses plotted against three perpendicular axes.

1 Western facies
2 Eastern facies
3 Forebeach
When the analyses are considered as groups representing analyses on the two sides of the Lettereeneen fault separately, distinct trends appear. In the phi-median diameter - phi deviation measure plot, the trends each show a convergence towards a median diameter of 2.5 phi. In the skewness - phi median diameter plot, the two trends are approximately parallel. In the skewness - phi deviation measure plot, however, distinct trend lines are difficult to discern, but they apparently occur at 0.75 phi deviation and skewness of -1.

The features described in sections 1 and 2 indicate that the deposits to the east were of shallow water origin, possibly sub-aerial, while those to the west were deposited under a permanent cover of shallow water.

Comparison of the trend lines north those of Davies of (1962) shows that with progressive advance towards marine conditions the curves of the sediments in the phi median diameter - phi deviation measure graph go from negative to positive gradient. The results from the eastern area, of shallow water origin, plot very close to those of the forebeach deposits of Davies, but the results from the west show marked differences of orientation of the trend lines.

Since all three of these pairs of analyses plot as linear regressive trends, the three in combination, plotted against rectangular, Cartesian co-ordinates should give a plane of regression. Fig. 50.

The application of the results of both Davies and Shepard to triaxial rectangular co-ordinates indicates the existence of many planes, the orientation of which varies with the depositional environment under examination. The significance of these planes of regression, on which the sediments of any one environment appear to lie, is not known, but it may have some meaning in the evaluation of conditions of deposition of ancients sediments, and the usefulness in determination of facies is evident. For instance, the angles of inclination of the plane may show systematic variations with the strength of the currents operative
Fig. 51. Skewness-sorting relationships of river and beach sands (after Friedman).

Skewness

Standard deviation (sorting)

- river sands
+ beach sands.
○ Eastern facies
● Western facies.
during deposition, to nearness of terrestrial, or deep water environment. A systematic study incorporating all available data could usefully be made.

Friedman (1962) analysed many sands of beach and river origins and showed a distinct break between the two fields of distribution when the skewness is plotted against standard deviation. In Fig. 51 the analyses of the Partry Series have been plotted against these parameters and lie within the field of distribution of river sands rather than beach sands. Analyses of the eastern facies appear to be more clearly of fluviatile affinity than those of the western facies, which approach more closely to the beach sand distribution.

The various analyses applied to the sediments of the Partry Series suggest that they are of shallow water origin, probably fluviatile or fluvio-marine.
Comparison of the analyses with those of Davies (1962) immediately reveals an apparent correlation of the sediments of the Partry Series with his forebeach deposits. The sedimentary structures described earlier show no characteristics of a beach environment of deposition, and so an impasse is apparently reached. The results of Davies (1962) have, however, been obtained from measurement of settling velocities and not sieve analysis. Corrections have been applied to the present analyses to equate the optical analyses with those of sieve analysis.

Friedman (1962) used computations based entirely on mechanical analysis by sieves, and would have obtained a different distribution for the same sands as analysed by Davies (1962). Clearly Davies' forebeach deposits, without correction for sieve analysis, would, according to the Friedman (1962) analyses, be classes as river sands.

The interpretation of the sands from the results given above as being of fluvio-marine, or fluviatile origin is based largely on Friedman's (1962) analysis, coloured by the evidence of sedimentary structures. It is believed that the sediments were carried by rivers draining the Connemara Cordilleræ, and which deposited their loads near the coastline. The sands are therefore principally of fluviatile character, and beach forming processes may have had little time to become established before the deposits were buried.

This study of the sediments of the Partry Series, therefore demonstrates the difficulty of recognising ancient environmental conditions of deposition from thin section analysis alone. The grain size analyses given above are so inconclusive that, without recourse to a study of sedimentary structures, no reliable conclusions can be reached.
**TABLE 5**

Mineralogical analyses of sandstones of the Partry Series

<table>
<thead>
<tr>
<th>Quartz</th>
<th>Feldspar</th>
<th>Muscovite</th>
<th>Biotite</th>
<th>Lithics 1</th>
<th>Lithics 2</th>
<th>Iron</th>
<th>Clay</th>
<th>Chlorite</th>
<th>Leucite</th>
<th>Heavy</th>
<th>Slide No.</th>
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<td>6.0</td>
<td>8.8</td>
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<td>1.0</td>
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<td>-</td>
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<td>-</td>
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<td>0.3</td>
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Lithics 1 - Metamorphic and igneous
Lithics 2 - Sedimentary
Sedimentary Petrography

The most important component is quartz, which occurs both in strained and unstrained grains. Feldspars, both orthoclase and plagioclase, often highly sericitised, are set together with the quartz in a cement of clay with some siliceous material. Lithic components vary in identity and importance. All of the fragments may be coated to varying extents by thin layers of red iron oxides.

Quartz.

A genetic classification given by Krynine (1948) places quartz into three principal origins; metamorphic, igneous, and vein. All three of these types have been recognised in E. Murrisk. By far the most abundant type is metamorphic quartz, characterised by undulose and strained extinction. It often occurs in clusters of crystals, between which the margins are heavily sutured. Inclusions of chlorite and occasional muscovite are frequent in this metamorphic quartz.

The next most abundant type of grain is plutonic, or igneous quartz characterised by single grains with straight extinction, and with very few vacuoles or inclusions. Outlines of the grains are frequently deeply corroded, as are the phenocrysts in the welded tuff horizons.

Vein quartz, recognised by the abundance of vacuoles and composite to undulose extinction, is difficult to distinguish from metamorphic quartz, except in large grains. The vacuoles may be filled with liquid or gas. This type of grain is infrequent in the rocks of Murrisk, although it is more common in the Maumtrasna Group, in which pebbles of vein quartz occur in the conglomerates.

An analysis of the distribution of the three basic types of quartz has been attempted. The general absence or difficulty of recognition of the third type has forced a two-fold division to be used: metamorphic and igneous quartz. A Swift moving-stage point counting mechanism ensured no repetition of measurements, and 500 points on quartz grains were counted for each slide.
Fig. 52 Ratios of metamorphic and non-metamorphic quartz.

Metamorphic quartz

% 90
70
50

Non-metamorphic quartz.

Eastern facies
Western facies.

Fig. 53. Secondary micas in a hollow in a quartz grain.
The results obtained from examination of 20 slides are shown graphically in Fig. 52. The linear relationship is to be expected, for the curve may be expressed by the equation \( x + y = 100 \), since the two parameters represent the respective percentages of the two varieties of quartz.

Towards the base of the sequence in the east there is a high proportion of igneous quartz. In this area the underlying beds are composed largely of non-welded tuffs, and 'felsites' or welded tuffs, and these have clearly acted as a source of debris.

The beds associated with the welded tuffs in the west again show a less marked high percentage of igneous quartz. In these the large, corroded crystals are clearly phenocrysts derived from the welded tuffs, indicating derivation of material from the interbedded deposits of tuffs.

Despite the variation of the relative abundances of igneous and metamorphic quartz, at no stage has the proportion of metamorphic quartz been observed at less than 50%. This constantly high proportion of metamorphic quartz is indicative of the importance of the relatively nearby area of metamorphic rocks acting as a source, but now no longer exposed.

**Feldspars.**

Plagioclase and potash-feldspars occur in varying proportions in the sequence. A few grains of microcline have been observed, but in only one thin section. The plagioclase has a constant composition in the andesine-oligoclase range, as indicated by extinction angles of the frequent albite twins. Zoning of the feldspars is rare, and then mainly in the potash-feldspar.

Near the base of the sequence the proportion of feldspar in the rock is low, approximately 5% of the bulk rock total. The proportion increases up the sequence at Tonnasaile until it ranges between 18% and 22% on the crest of the hill. West of the Lettereeneen fault the proportion of feldspar is more constant, between 11% and 15% (with one exception, 20% above the tuff bands in the Glen Mask waterfall).
Sericite, epidote, and calcite are seen within plagioclase crystals, the first two being clearly exsolution products in many cases, showing distinct preferred orientation. Sericitisation has occurred in most cases as a late stage metamorphic alteration, and in the few zoned plagioclase crystals it is the calcium rich layers which show the greatest alteration. Grains of highly sericitised feldspars tend to be better rounded than non-sericitised material.

The relationship of the carbonate alteration to the feldspar is believed to be a post-depositional feature.

Sericitisation may be partly a diagenetic feature, for in many examples the clay matrix material is seen to impinge upon the highly sericitised feldspar crystals. The alteration of the original feldspars to sericite, and then to illite is believed to have occurred in some instances, perhaps due to post-depositional chemical reactions.

Authigenic overgrowths of clear, secondary albite occur on many of the usually cloudy grains. The overgrowths show little sericitisation, due to their highly sodic composition, which does not possess the chemical constituents for the formation of the potash-rich sericite.

Although recognition of the feldspars in thin section is facilitated by use of the sodium cobaltinitrite and barium rhodizionate stains, these were not used on the material from the Partry Series. The twinning, cloudiness, and exsolution products serve as reliable diagnostic characteristics. When these are absent distinction from quartz is established by means of differences in refractive indices.

Lithic Components.

The proportion of lithic material in the rock varies in the same way as the pebbles in the sandstones and conglomerates. Both lateral variation, and upward variation through the sequence, are great. West of the Lettereeneen fault the lithic fragments comprise between 1% and 7% of the bulk rock composition, whilst east of the fault the proportion is often much higher, beginning at 26% near the base, and commonly being over 12%.
The variety of composition is not as great as has been recognised in the pebbles of the conglomerates, but this is believed to be a sampling deficiency. Towards the base in the east the proportion of fragments of sedimentary origin is very high, but this decreases as metamorphic material becomes more abundant higher in the sequence.

Metamorphic quartzite is particularly frequent, and is easily recognised by the pronounced suturing of intergranular contacts. Muscovite-schist, with clear foliation direction, occurs as small nodules. In some cases the muscovite is seen altering to chlorite. All gradations from muscovite-schist to chlorite-schist are found.

Non-metamorphic rocks include sandstones, siltstones, slates and cherts. In thin section the cherts differ radically from the 'felsites', to which they sometimes bear a superficial resemblance.

'Felsites' clearly are welded tuffs, and large corroded phenocrysts may be seen in some lithic fragments.

Spilitic material, and a darkly coloured fragment of a basic igneous rock suggest that some intrusive activity had occurred in the area before the deposition of the Mweelrea Series.

**Micas.**

Three principal representatives of the mica group are found as detrital material. Flakes of muscovite are frequent. In some flakes alteration to chlorite is seen in zones parallel to the cleavage planes. This alteration may develop so far that virtually no original muscovite remains, and flakes composed entirely of chlorite are common. Such alteration occurred before deposition, for both partially altered and totally altered flakes show strain polarisation due to compaction. This feature is not preserved by post-compactional replacement. The author believes that this indicates some retrogressive metamorphism in the source area from which the flakes were derived.

Flakes of detrital biotite, showing compaction strains, and sometimes altering to chlorite, occur sporadically. Their
occurrence points to early post-erosional deposition, for biotite decays rapidly.

Further alteration is seen in a few of the biotites and some of the chlorites, with the production of opaque, black flakes of hematite. The iron oxides show a preferred orientation along the cleavage direction. A similar alteration has been observed in biotites within the welded tuffs, where oxidation under heat was thought to have produced the hematite.

Some chlorite flakes show patches of white, opaque, leucoxene.

The proportion of all the detrital micas in the rock ranges up to 10%, and is normally over 3%. Chlorite is usually slightly more abundant than muscovite, and biotite is rarely present as more than three flakes per thin section. No marked differences in either composition or proportion of the micas occur on the two sides of the Lettereeneen fault.

Secondary micas, such as sericite, are common in the feldspars, and may be present in the clay grade material. Small plates of a highly birefringent mineral are apparent under high power and these are believed to be some form of hydro-mica, probably of diagenetic origin.

The clay minerals occupy the limited intergranular spaces and comprise up to 9% of the bulk rock total. As has been stated above, the material of clay grade is too small to be resolved under the low power of the microscope (x 10). Under high power (x 40) the clay material is seen to consist of plates and needles of varying birefringence. Absence of equipment suitable for more precise examination of these minerals renders any identification tentative.

Small plates, and occasional fan shaped groups of small flakes of bright birefringence colours are believed to be hydro-micas or illites. The birefringence is too high for any member of the caneloite Group (e.g. kaolinite), which show similar modes of occurrence. These flakes occasionally grow from a centre such as a hollow in the outline of a quartz grain (Fig 53), suggesting that these minerals are diagenetic.
Pale green, pleochroic flakes, and grains of higher relief than the hydro-micas, are diagenetic chlorites. Occasional small amorphous masses of similar material may be chlorite produced by alteration of fragments of detrital clay pellets. Secondary chlorites also act as cementing material between many of the grains, and may be responsible for the green colouration of the rock in some areas.

No clearly detrital clay minerals have been recognised in the generally siliceous materials. All of these may have been altered to illite or chlorite in diagenesis. No x-ray photography was undertaken to identify these minerals due to difficulty of separation.

There is a noticeably lack of carbonate material of either primary or secondary origin in the sediments. The only carbonate material recorded was in the form of probable breakdown products from feldspar. The presence of epidotes, occasional garnets, and one diopside, indicate that calcium minerals were present in the source area, but the absence of carbonate reflects a general lack in the Dalradian source rocks. In Connemara today few bands of true marble or limestone are seen in the metamorphic rocks.

**Heavy detrital minerals.**

As indicated above, breaking down of the rocks to reveal individual grains was not possible, and the following observations are from thin section analysis only.

There are few heavy minerals in the sandstones. The non-opaque ones include apatite, diopside, epidote, garnet, sphene, and zircon; the opaques include ilmenite, magnetite, and hematite (which may not be entirely detrital).

Epidote, in the form of zoisite and clinozoisite has been widely recognised in thin sections of the rocks to the west of the Lettereeneen fault, and is also present in some sections from the eastern area. Epidote is a calcium mineral mainly of metamorphic origin, and is clearly derived from the sparsely calcic metamorphic rocks of the Connemara cordillera.
Garnet occurs in two places relatively high in the sequence west of the fault, and had been seen nowhere else. This may indicate that the rocks bearing minerals of progressively higher grades of metamorphism were being exposed at later times in the erosional history of the source area.

Sphene is present low in the succession west of the fault. Since this may be of either igneous or metamorphic origin, it is not of great diagnostic value.

Zircon is found in many sections on both sides of the fault. It is an igneous mineral which owing to its physical resistance, may survive to become second or third cycle detritus. The occurrence of zircon is not unexpected for granitic material is common in the pebbles of the conglomerates. Zircon is also preserved in many metamorphic rocks of sedimentary origin, and has been seen in thin section of one chlorite schist in the present area.

Apatite has been recognised in one thin section from west of the Lettereen fault.

Diopside, a calc-silicate mineral, is present in one thin section from the east of the fault. Calc-silicates are not very abundant in the Dalradian rocks exposed in Connemara.

Although biotite cannot strictly be classed as a heavy mineral its distribution as detritus is interesting. It occurs as isolated flakes very low in the western sequence, but is relatively common high in the Tonnasaile sediments.

Iron minerals.

The heavy detrital grains and their subsequent destruction show several interesting features.

Magnetite is locally abundant as small octahedra and as irregularly shaped fragments, the concentration probably being due to derivation from the volcanic horizons. Elsewhere it is present as small grains, the margins of which show much alteration to secondary hematite.

Outside the local areas of high magnetite content, ilmenite is generally more abundant than the magnetite. The ilmenite is more stable than the magnetite, but much of it has been altered to white
opaque leucoxene. This is particularly noticeable in the rocks high in the Tonnasailo area, but is less commonly observed to the west of the Lettermoneen fault. The leucoxene forms up to 1% of the bulk rock total in some instances.

Hematite is present as black flakes of specular iron, which gives a red and black appearance in reflected light. Such flakes are probably detrital.

The identity and genesis of the secondary iron minerals present a complex problem which is intimately connected with the colouration of the rocks, and involves not only original conditions prevailing during deposition but also the subsequent conditions in those rocks.

The Partry Series deposits of the west and the rocks of the extreme north-east of the Partry Mountains constitute a true red bed sequence, but the Tonnasailo area and the southern side of most of the Partry Mountains are occupied by drably coloured beds, and even green beds. The colouration reflects the changes in the secondary iron minerals.

In the west hematite and goethite are present in the truly red beds, while in the north-east hematite alone has been recognised. In the central area around Glennagashleeny much of the drabness is due to a decrease of hematite, and increase of both goethite and chlorites, until ultimately in the green horizons above Treenlaur no goethite is present, the only diagenetic iron minerals present being chlorites.

In the west the red colouration is derived mainly from the hematite which is present as thin coatings to the grains of quartzo-feldspathic material. The coatings of iron oxides were derived from breakdown of such minerals as magnetite, which is plentiful in association with the volcanic rocks. Partial breakdown of ilmenite, the titanium content of which serves to produce leucoxene, releases iron for the formation of limonite (goethite), which in turn dehydrates to hematite. Very little unaltered detrital chlorite or biotite is known from the western area, doubtless due to breakdown of the minerals and removal of the iron by oxidation. Some of the colouration is taken from goethite, which is a minutely granular oxide
found in the matrix of the rocks and associated with the secondary micas.

Since the rocks in the west are of relatively uniform colouration throughout, the pigmentation was probably not connected directly with the conditions extant during deposition, but rather caused by later chemical activity. There are two alternative methods of pigmentation. Either the iron was carried in colloidal solution by groundwaters and deposited as coatings around the grains, or the ferric iron was a true chemical solution which was precipitated as ferric oxide round the grains, thus cementing them. No direct cementation of the grains by the hematite is known. The uniformity of the distribution precludes a third alternative, that the iron was brought in as coating on the detrital grains. It suggests some chemical action, associated with intermittent movement of groundwaters, and with intervening periods of aeration to permit oxidation of the iron coatings previously deposited.

In the west the red staining is early post-depositional, for a thin coating of hematite, similar to that seen on associated quartz grains, has been seen around one magnetite grain. This indicates that solution of the magnetite had not progressed to an advanced stage before deposition of the surrounding coat.

In the completed process of the hematitasation, all goethite should become dehydrated to give hematite, but this has not occurred in the west where the rocks are still quite porous.

In the north-east, however, above Kiltarsaghaun and Tawnynagry the red pigmentation is entirely due to hematite, and goethite has been observed in thin sections of this material. The hematite exists as coatings and discrete flakes within the clay matrix, and again may be diagenetic. The greater development of the hematite here may be partly due to the finer grain size of many of the sandstones in this area. The abundance of hematite is seen in the hand specimen, for hammer marks reveal the characteristic streak colour.

A possible method of distinguishing between the Ordovician early post-depositional red staining and stain associated with the Pre-Carboniferous peneplain lies in the palaeomagnetism of the beds.
Theoretically each should reflect a different palaeomagnetic latitude. However, unaltered ilmenite is still present in the rocks of the north-east, and this ilmenite would retain its Ordovician magnetic field. Later hematite, which has a much weaker intensity of magnetisation, would thus be masked by the magnetism of the original sedimentary or minerals.

Directly east of the Lettereeneen fault the beds have a grey-green aspect, marked by a high proportion of diagenetic chlorite and general absence of hematite, whilst some goethite is present as finely disseminated grains in the matrix. Amorphous inter-granular masses of chlorite are common. In the central area, around Glennagashleeny, the beds are drab in colour, and differences exist between succeeding beds, apparently due to variation of chlorite and goethite content. Lack of alteration of the biotite and chlorite flakes in this region indicates that the chemical processes and intense oxidation which occurred to the west did not develop here.

The area of non-oxidation is also that which shows many channels in the sequence, suggesting a large quantity of water running across the surface, and probably a high sub-surface water table. A high water content in the rocks immediately after deposition produced a reducing environment, ideal for preservation of the chlorites and biotites in their unaltered condition. Later reactions led to alteration and total removal of the iron from the magnetite and ilmenite. The iron may have been redeposited in the few horizons in which goethite is still preserved. It is true that the abundant coarse conglomerates are associated with the drab and green beds, and may have served as active aquifers for some time after deposition.

There is thus an intimate association between the colouration of the beds and post-depositional environmental conditions. The sediments deposited under conditions in which thorough oxidation occurred appear to have been relatively unsaturated by groundwaters and developed into hematitic red beds. Sediments associated with reducing conditions of constant hydration produced drab or green beds. The nature of the original sediment influences this secondary...
alteration, for conglomerates and open-work sandstones permit easy passage of water whereas the more compact grits of the west are less amenable to this.

Although there are authigenic overgrowths on some of the feldspars, the overgrowths at no point impinge on other crystals to become cemented. Cementation of the sandstones is mainly achieved by the agency of diagenetic clay minerals. These minerals occupy the intergranular voids, and often form a cheveux de frise texture where the minute flakes slightly overlap the margins of the crystal fragments. Micas, illites, and chlorites are the principal minerals of this cement. Occasionally the thin coatings of hematite, and isolated goethite grains are important in the cement, but no direct cementation of crystal debris by the iron oxides alone has been observed.

No pressure-solution boundaries between sand grains are known.

A study of a sandstone suite such as that of the Partry Series would be incomplete without an attempt to classify the sediments according to some well-established system. A full discussion of the methods of classification of a sandstone has been given in Chapter II, and so only a few points will be discussed at this stage.

Krynine (1948) used a compositional triangle with the parameters Quartz or chert; Micas and chlorite; and Feldspar and Kaolinite. According to this system the sandstones may be regarded as Arkoses, near the Orthoquartzite boundary.

Application of the Quartz, feldspar, matrix diagram of Pettijohn (1954) places the rocks of both east and west of the Lettereeneen fault in the Feldspathic Quartzite field. Those of the eastern facies frequently lie almost on the boundary between the Arkose and Feldspathic Quartzite fields, whereas the western facies material is generally more rich in quartz and lies within the Feldspathic Quartzite field.

Packham (1954) divided sandstones into two suites, of deep or shallow water origin, as distinguished by sedimentary structures. According to this classification the sandstones of the Partry Series are feldspathic sandstones.
Cummins (1960), in a study of greywackes and turbidites, used triangles in which each sandstone is divided into fine sand (0.05 mm - 0.25 mm in diameter), coarse sand (over 0.25 mm in diameter), and silt and clay matrix (diameter below 0.05 mm). Certain subsidiary statements concerning the size relationships between the various component minerals of the sands must be made before consideration of this method is undertaken.

The fragments of feldspar generally follow the same grain size distribution as the quartz detritus. The lithic material, however, does not conform strictly to the above analyses, and appears to be independent in size variations. There is a general agreement in size between all components of sand grade in the rock, and this is used in analyses of the rock. The proportion of the matrix has been determined during the course of petrological investigations, and the relationships between the three parameters are easily calculated. There is a well marked resultant cluster towards the apex for fine sand in a position which would lead Cummins to conclude that little if any disintegration of the original sand grains has taken place. In fact, the location corresponds closely to that for "normal sands" (Cummins, 1960, pp 67-68).

A sandstone may be classed further with regard to textural maturity, from characteristics of the grain compositions and their shapes. The majority of the samples examined from the Partry Series contain over 5% of clay grade material. The deductions from application of Cummins (1960) method above indicates that little alteration has occurred, but some diagenetic decay of feldspars and micas may have produced a slightly higher proportion of clay material than was originally in the rock. In many cases the clay proportion is sufficiently high to justify estimating that at least 5% of detrital clays are present.

According to Folk (1951) the sandstones, therefore, represent an immature stage of development, the diagnostic features being a content of over 5% of detrital clay, high proportion of fine grained micas, and angular to sub-angular grains in the sand grade material, which
**TABLE 6**

*Analyses of the Partry Series Sediments.*

<table>
<thead>
<tr>
<th>Quartz</th>
<th>Feldspar</th>
<th>Lithics</th>
<th>Matrix</th>
<th>Labiles</th>
<th>Quartz</th>
</tr>
</thead>
<tbody>
<tr>
<td>894</td>
<td>79</td>
<td>15</td>
<td>6</td>
<td>11</td>
<td>25</td>
</tr>
<tr>
<td>862</td>
<td>58</td>
<td>28</td>
<td>14</td>
<td>7</td>
<td>42</td>
</tr>
<tr>
<td>1008</td>
<td>57</td>
<td>28</td>
<td>15</td>
<td>10</td>
<td>35</td>
</tr>
<tr>
<td>1120</td>
<td>69</td>
<td>24</td>
<td>7</td>
<td>5</td>
<td>38</td>
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<tr>
<td>1131</td>
<td>61</td>
<td>6</td>
<td>33</td>
<td>9</td>
<td>39</td>
</tr>
<tr>
<td>1004</td>
<td>63</td>
<td>23</td>
<td>14</td>
<td>9</td>
<td>41</td>
</tr>
<tr>
<td>891</td>
<td>78</td>
<td>15</td>
<td>9</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td>890</td>
<td>69</td>
<td>26</td>
<td>4</td>
<td>9</td>
<td>39</td>
</tr>
<tr>
<td>887</td>
<td>65</td>
<td>21</td>
<td>13</td>
<td>9</td>
<td>34</td>
</tr>
<tr>
<td>880</td>
<td>80</td>
<td>15</td>
<td>5</td>
<td>12</td>
<td>23</td>
</tr>
<tr>
<td>846</td>
<td>77</td>
<td>21</td>
<td>2</td>
<td>18</td>
<td>29</td>
</tr>
<tr>
<td>295</td>
<td>76</td>
<td>17</td>
<td>6</td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>
Fig. 54(a) Combined MLQ analyses for the Owenmore, Sheeffry, Glenummera, and Partry Series.

Fig. 54(b) MLQ analyses of 14 specimens from the Glenummera and Partry Series.
should be poorly sorted.

The sandstones of the Partry Series, therefore may be classed as immature feldspathic sandstones which increase in "arkosity" upwards through the sequence.

The composite results of mineralogical analyses given in Chapters II, III & IV are plotted in Fig. 54.

The axial turbidites of the central part of the Sheeffry Series are believed to have been deposited a relatively great distance from the source. Various lines of evidence have been given in Chapter II to justify the conclusion that the lateral turbidites of the Derrylea Group were deposited nearer the source of the sediments. Few analyses are available from the Glenummera Series, and although both Stanton (1953 and 1960) and Dewey (1960) believed that they were of relatively deep water origin, the presence of conglomerate beds, and slump structures in many places may indicate some form of shallow water environment of deposition. The sediments of the Mweelrea Group, which comprise the 'Western facies' of rocks studied in the Partry Series are of shallow water origin. They were deposited near the source, and may have been intermittently above sea level, during accumulation of the welded tuffs. The Maumtrasna Group, often of coarsely conglomerated sediments is believed to be of fluvio-marine or very nearly terrestrial origin.

In Fig. 54, which is an MLQ diagram, the sediments show a distinct movement towards the Quartz-Labile boundary as they approach the source. In other words, the sediments deposited further from the source have a higher proportion of matrix. The quartz-labile component ratio is relatively constant, at about 3:2. Despite the constancy of this ratio, the sediments were not all derived from the same source, although, for the most part the metamorphic rocks of Dalradian age acted as the principal source of debris.

Two totally different types of sedimentation have been recorded during the present examination of the rocks of Murrisk: turbidite deposition in deep water (in Chapter II); and current bedded sandstones of shallow water (in Chapter IV). Nevertheless, all the sediments appear to show a systematic variation of petrological composition which may be independent of the conditions of deposition.
<table>
<thead>
<tr>
<th>No. of specimen</th>
<th>ω : M : F</th>
<th>Metamorphic : igneous quartz</th>
<th>Median φ</th>
<th>Deviation φ</th>
<th>Skewness φ</th>
</tr>
</thead>
<tbody>
<tr>
<td>862 (w)</td>
<td>70.1:10.3:19.6</td>
<td>74.2 : 25.8</td>
<td>3.08</td>
<td>0.88</td>
<td>-0.22</td>
</tr>
<tr>
<td>846 (w)</td>
<td>61.9:22.7:15.3</td>
<td>69.0 : 31.0</td>
<td>2.95</td>
<td>0.65</td>
<td>-0.07</td>
</tr>
<tr>
<td>890 (w)</td>
<td>63.5:12.4:24.1</td>
<td>77.8 : 22.2</td>
<td>2.54</td>
<td>0.74</td>
<td>+0.13</td>
</tr>
<tr>
<td>887 (E)</td>
<td>67.4:10.5:22.1</td>
<td>84.0 : 16.0</td>
<td>3.15</td>
<td>0.75</td>
<td>-0.2</td>
</tr>
<tr>
<td>894 (W)</td>
<td>73.4:13.2:13.4</td>
<td>69.0 : 31.0</td>
<td>2.95</td>
<td>0.65</td>
<td>-0.07</td>
</tr>
<tr>
<td>880 (W)</td>
<td>71.7:13.0:15.2</td>
<td>77.8 : 22.2</td>
<td>2.54</td>
<td>0.74</td>
<td>+0.13</td>
</tr>
<tr>
<td>295 (W)</td>
<td>71.9:12.6:15.5</td>
<td>81.0 : 19.0</td>
<td>2.9</td>
<td>0.65</td>
<td>0</td>
</tr>
<tr>
<td>1004 (E)</td>
<td>64.6:11.3:24.1</td>
<td>75.6 : 26.4</td>
<td>2.85</td>
<td>0.85</td>
<td>0</td>
</tr>
</tbody>
</table>
sediments appear to show a systematic variation of petrological composition which may be independent of the conditions of deposition.

Pettijohn (1949 and 1954) believed that the MLQ diagram gave an indication of the nature of the source area. From the results presented above it is seen that the MLQ diagram clearly gives an indication of the distance of the location of deposition of the sediment from the source area.

The nature of the source area may be reflected in the diagram, but since all of the sediments were probably derived from the Dalradian meta-sediments, variations would not be detected on an MLQ diagram.

Variations of the nature of the source area should, however, be reflected in the QFR diagrams. However, the analyses for most of the sediments under consideration lie in a relatively constant zone on the QFR diagram. The presence of occasional beds of tuff in the succession may cause analyses for the immediately overlying beds to deviate towards either the quartz or feldspar apex, according to the composition of the tuff. The constant and location of the distribution of analyses on the QFR diagram based on 49 thin sections is not surprising, for as has been stated above, the source varied little in nature during deposition of the sediments. The only really good indicators of change are the heavy minerals, which increase in variety up the Arenig succession but are relatively stable during the deposition of the Partry Series.
Depositional Environment of the Partry Series.

It has been suggested in sections 1 and 2, that the environment of deposition may be similar to that of a piedmont. This certainly applies to the eastern facies, where the deposits bear a great likeness to the proluvial deposits in Strakhov (1957).

Nikolaev (1946) and Chantzer (1948) used the term 'proluvium' to include both fine and coarse material of alluvial cones, the word being of genetic significance. Gvozdetsky and Mouratov (1948) examined the extensive proluvial formations of the Khazaout valley in the Caucasus, and observed that the temporary streams of dry areas are characterised by their murky waters. The more water falls, the greater the amount of mud in suspension, the higher the specific gravity of the stream, and the greater the ease with which sand, pebbles, and boulders are transported. Blocks of over 30 cms are easily moved. On arrival at the plain, the stream expands into many beds to give a fan. The speed of flow drops, part of the water evaporates, part filters into the soil, and part runs off to form season lakes. Paplov (1950) examined facies changes on such fans in Central Asia, and noted that the size of the proluvial material decreases in the direction of movement of the currents, and in composition it approaches a clayey soil with intervening beds of sand and gravel. Due to speed and temporary nature of the proluvial currents, sorting of the formations deposited by water near the mountains is poor, and blocks and pebbles may be disseminated irregularly in a clayey ground mass.

Paplov further stated that the thickness of proluvial formations may reach several hundreds and even thousands of metres. The width of the zone may reach 100 Km and its extent along the mountain front may be hundreds of Kilometres.

The complex variations of deposits of sandstones and conglomerates in the eastern facies of the Partry Series show many features of very shallow water deposition (see sections 1 and 2). The almost total lack of sorting in some of the horizons may typify the deposits described above as proluvium. Thus much of this Series may have been partly sub-aerial in origin.
Under dry climatic conditions proluvial formations always contain finely dispersed calcite and occasional gypsum. This is certainly not true of either eastern or western facies of the Partry Series, in which the absence of calcium minerals, particularly carbonates was noted in section 3. No mud cracks have been observed and it appears that the rocks were not deposited in a hot semi-arid environment, but rather under conditions sufficiently cold for no carbonates to develop, and possibly quite humid in nature. In Pre-Devonian times, the absence of a protective vegetation cover on the continental surfaces would have led to easy run off of any precipitation, so that proluvial processes would not have been restricted to dry climates.

The waters of the run-off streams were turbid, but analysis of the mineralogical composition of the eastern facies of the Partry Series shows a low clay fraction, which suggests that tendency towards aggregation or flocculation was not present or active during deposition at least in which clay was the active member. Clay nodules are very rare between the sand grains.

The differences between the two types of sediment on each side of the Lettercrossan fault have been stressed, but there are similarities, particularly in composition. Nolan, in the Memoir of the Geological Survey of Ireland noted that the contained pebbles in the conglomerates of the Tonnasaile area are similar to those further west, at L. Glenawough, and on this evidence considered the rocks of the two areas to be approximately contemporaneous if not exact lateral equivalents. The contained pebbles are certainly of identical composition and clearly came from the same source, but the essential difference between the rocks of the two areas is one of proximity to the source.

An aeolian origin for the current bedding is precluded by the presence of layers of pebbles up to 10 cms in diameter, parallel to the false bedding laminations.

Further west, in central and south-western Murrisk, Stanton and Dewey have shown the presence of slate horizons; Stanton (1953) noted that the Mweelrea Slate beds reach up to 700 ft. in thickness
individually. They thin from west to east on each limb of the Mweelrea syncline and also from the northern to the southern limbs of the syncline. He attempted no further subdivision of the slates, but concluded from the thickness variations that the land acting as a source area lay to the south-east.

Dewey (1960, p.140), after a detailed study of the 2nd Mweelrea Slate horizon pointed to the existence of several layers of turbidites within the one band. He concluded that each of the slate bands of western and central Murrisk represents a sudden retreat of the "deltaic front", with associated slumping from the margins of the deposits. The well graded grit beds are typical of turbidite deposits, which have not been recognised outside the slate horizons. This interpretation may be correct but it should also be held in mind that currents resulting from flash floods are turbid currents which could produce well graded turbidite layers without the necessity of great changes in environmental conditions.

The changes of facies and sediments in the Partry Series from place to place in the whole of Murrisk are represented diagramatically in Fig. 55. The evident decrease in total thickness in an eastward direction may be in part due to local discontinuities. It is certainly partly due to the complete absence of the sediments of the Mweelrea Group from the area east of the Lettereenoon faults. It is noticeable that the sediments in this eastern area are principally conglomerates, whereas further west sandstones and slates dominate the sequence.

The important conclusion reached on page 137 that the western facies of the Partry Series was under a cover of shallow water during its deposition, is significant in the consideration of the Mweelrea Tuff horizons. These welded tuffs lie between current-bedded sandstones. In the west both Stanton (1953) and Dewey (1960) have shown a basal layer of sillar materials which thickens north-westwards. Dewey considers this to indicate a deepening of the water in this direction, the sillar being necessary to build the sea floor up to water level before welding of the tuffs could commence.
Welding of tuffaceous material is widely believed to be a subaerial feature, and has nowhere been recorded from a marine environment. It is possible that extrusion of the tuffs may have been accompanied by associated temporary lowering of the sea-level, but no evidence for this is known.

In the introduction to this chapter, note was made of the discontinuous tuff horizon which lies at the base of the eastern facies of the Partry Series. Each of these isolated patches of tuff may be remnants of the one tuff horizon, or they may represent remnants of various tuffs deposited on an erosion surface before the advance of the coarse proluvial formations. The variolitic lava of south of Croaghriomara Hill may be the only surviving fragment of more extensive flows.

Some of the conditions extant before deposition of the Partry Series may be deduced. In the south-east the Mt. Partry Beds are coarse conglomerates while in Glennagashleeny and for the entire northwestern side of the Partry Mts. the Glenummera Series is represented by slates, fine-grained sandstones and occasional beds of tuffs. The two facies are not necessarily of the same age and no direct connection can be seen between them. Marine erosion, or at least erosion by water, occurred at the top of the Glenummera Series. Pebbles up to 10 cms in diameter have sunk into the uppermost metre of the slates (see Chapter III. It is believed

No bedding is visible in the Glenummera Slates above the pebbles, for all small-scale sedimentary features are obscured by intense cleavage. It has been suggested in Chapter III that the pebbles may represent an intertidal zone.

The well-rounded boulders of the conglomerates of the Mt. Partry Beds may represent the location of outflow of a stream into the shallow tidal zone which extended across the Bohan-Glenmaglashleeny - Lough Shee area before the onset of sedimentation of the Partry Series. The boulders are large closely packed, very well rounded, and lie in beds of rather restricted lateral extent.
The Age of the Partry Series.

As stated in chapter III, the Glennummura Series of S.W. Murrisk have yielded a fauna of probably Llanvirnian age. The Partry Series lies unconformably upon the limestones of the Tourmakeady Beds at Shanvallyard. These fossiliferous limestones are being studied by Prof. A. Williams.

The Partry Series rests on each of these fossiliferous rocks and is clearly later in age. Stanton also located a trilobite - brachiopod fauna, believed to be of Llandovery - Caradocian age, in the slate bands of the Partry Series in S.W. Murrisk.

No further fossils were found in C. Murrisk by Lawley (1960), who showed that the tuff bands provide excellent means for lateral correlation. No new identifiable fossils have been found during the present investigation, but fragments of possible algal origin occur in the flagstones of Kinnewry. Use of the tuff bands for correlation has again been made, but the tuffs do not continue to the east of the Lettereenen fault, and so no clearly demonstrable age equivalence is possible in this area. It is possible to surmise that if the beds are of different facies only across the fault then those of eastern facies will also be of approximately Llandovery age.

The entire series of rocks represents a coarse facies of sedimentation associated with the mountains of the Connemara Cordillera which lay to the south and south-east of the present outcrop. A general analysis of available data concerning Ordovician palaeomagnetism has been given by Breiden and Irving (1963). These compilations, indicate that during the Ordovician, Western Ireland occupied a position at approximately latitude 20°S, and appears to have approached the palaeomagnetic equator during the Silurian. The axis of the British Isles appears to have been about NW - SE. The Dalradian rocks in this part of Ireland are known to have been undergoing erosion in the L. Arenig (Chapter II). Thus during the L. Ordovician, the mountain source may have been subjected to subtropical conditions of weathering, provided that the disposition of climatic zones was similar to that of to-day, and were of similar breadth of latitudinal extent.
This subtropical environment of weathering must have acted for at least 20 million years between the Uppermost Cambrian and the Llan- deilian, at which time deposition occurred. During this time any cover above the metamorphic rocks of the mountains was removed, and rocks of at least garnet grade of metamorphism exposed by erosion. This suggests that active down-cutting of the mountains was in progress as a result of which the very deep lateritic soils found in many tropical areas of today may not have developed. Evidence of the presence of laterites on the old source rocks would have in the presence of Kaolinite, a very stable clay-mineral, in the red bed deposits. None has been recognised and laterites may not have been present. This absence of laterites may be due to the ruggedness of the terrain, since the time period available for the development of laterites appears sufficiently large.

The problem of whether the deposition took place under arid or humid conditions remains.

Bernard (1963) has shown from the work of Milankovitch that "the thermal zonation of climate over the surface of the earth is a reflection of the latitudinal zonation of insolation climate." Many cosmologists and meteorologists consider that variation in the solar radiation constant during geological time has been negligible. The climatic zones of the Ordovician may certainly have been broader or narrower in latitudinal extent than today, but were still arranged in bands approximately parallel to the equator.

To-day a belt of south-easterly trade winds is located in latitudes 10°S - 25°S and may have been similarly operative during the Ordovician. The Connemara Cordillera occupied a position astride the path of any such winds and at 45° to the equator preventing passage of the winds to the northern side of the range, in which the deposits of Murrisk were accumulating. Thus, while the mountains may have been eroded by precipitation from these winds, the material on the northern flanks was deposited in a rain-shadow of semi-arid or arid environment.
The Mweelrea Volcanics.

Interbedded with the sandstones and conglomerates of near-shore or deltaic facies of the Mweelrea Group in Eastern Murrisk are several horizons of welded, dacitic tuffs, first recognised as being welded by Stanton (1953). These have been traced from the Atlantic coast for a distance of 25 miles almost to Croaghrimbeg, where they are faulted and inverted so that the trend of their outcrop runs southwards into the Owebrin Valley. For convenience the tuff bands are referred to as MT 1, 2, 3, 4 and 5, as did Dewey (1960).

The most consistent feature of the tuff bands in Murrisk is the erosion at the top of each band, so that the complete thickness is never seen. Further west, however, Stanton records the inferred complete thicknesses near Oughty Craggy. Moreover, although the basal contacts are rarely seen, it is evident in the field that the tuffs were deposited on an irregular surface, for they fill in earlier channels. In the field the exposures in the Mweelrea tuff bands are marked by a notch or hollow at the base of the band followed by rather massive cliffs with columnar jointing. This conceals the base of the tuff bands, and although both Stanton and Dewey have recorded the presence of a sillar layer at the base of both MT 1 and MT 3, none has been observed in Eastern Murrisk.

The welding is recognised in the Mweelrea tuffs from the deformation and rounding of the extremities of the shards, no longer angular as in normal vitro-clastic tuffs. The rock shows no bedding or sorting, but there is some overall grading to each band.

Mweelrea Tuff Band No. 1.

The westernmost exposures are in the Aillebaun corrie floor, in the bed of a stream which cuts through a 25 ft. cover of drift, but towards L. Glenawough the tuff is well exposed on the intervening ridge. Here the basal zone is represented by a recess, and at no point is the contact of tuff and underlying sandstone seen.

The hard, purple rock has a brittle, almost flinty fracture, and generally occurs as a steep cliff line with columnar jointing.
Joints are sub-parallel and sub-perpendicular to the base of the bed, and in the absence of bedding, are used for superficial division of the band, as at L. Glenawough: (53°39'27"N. 9°32'00"W.)

- 1 ft. intensely broken, weathered surface.
- MT 1: 8 ft. massive tuff with columnar joints
- 18 ft. minimum thickness
- 4 ft. tuff closely fractured by sheet jointing.
- 5 ft. massive tuff with sheet jointing; base not seen

Within the massive, highly welded section, with columnar joints, the weathered surface of the rock shows many angular and elongate fragments of pumice, up to three inches in diameter. Flattening of the pink pumiceous inclusions is characteristic of all the tuff horizons, and probably occurred while the tuff was still hot. Pumice fragments are flattened even in non-welded tuffs in Iceland (G.P.L. Walker, personal communication), but Martin (1959) considers that collapse and flattening increase with progressive increase of welding. Clearly the major factor here is load pressure, but higher temperature in welded tuffs may also have some influence.

East of L. Glenawough MT 1 is hidden beneath bog and talus but reappears west of Loughanshee, from where it is well exposed until the stream separating Glenmask and Derrinkee townlands, beyond which, in common with the other tuff bands, exposures terminate against a fault. The moorland east of the stream is covered with blanket bog with a few exposures of tuff but precise identification of these is impossible. Faulting produces further complications on the northern wall of Glenmask, where MT 1 is cut out, but it reappears on the southern wall of the valley and has been traced into the Glensaul Mountain area east of point 1462, and beyond into Lettereeneen, where it is cut out by faulting before reaching the valley of the Owenbrin River.

Throughout its entire length MT 1 is remarkably constant in thickness. Stanton (1953) records it as 20 ft. thick near the Atlantic coast, Dewey (1960) records a maximum of 40 ft. south of Lough Tawnyard, whilst in Eastern Murrisk it varies between 18 ft. and 29 ft. in thickness.
Penecontemporaneous erosion, produced an irregular upper surface to the tuff, which is overlain by false-bedded sandstones with pockets of conglomerate composed entirely of tuff pebbles. No deep channels have been seen at this horizon.

Although Dewey records no shards from this horizon, specimens from L. Glenawough show a few very angular devitrified and recrystallised shards, from the non-welded or poorly welded portion of the tuff. Eutaxitic structure is absent, but there is some preferred orientation of the smaller plagioclase phenocrysts. Further east, beyond Loughansheo, the shard content of the upper zones rises to more than 25% of the rock.

The lower and central zones of this tuff bed are relatively rich in phenocrysts, (30% of the bulk), whereas the uppermost part has only 22%. This reduction indicates a very coarse and gentle overall grading in the tuffs.

Mweelrea Tuff Nos. 3 and 4.

Fine exposures of this band are seen astride the ridge to the west of L. Glenawough, and it is only here that the truly composite nature of the band can be demonstrated in Eastern Murrisk. Elsewhere exposures are poor and the two horizons cannot be distinguished. Erosion certainly occurred between the deposition of the two beds, for high on the ridge of Glenawough the upper surface of MT 3 is deeply weathered. East of the lake, where the duality ceases to be apparent due to poor exposures, one of the two horizons may disappear, but for convenience the tuff will be referred to as MT 3 and 4.

The basal zone is not seen, and in the Aillebaun corrie is marked by a distinct spring line. The rock is rather massive, of purple to deep green colour, and joint surfaces show thin red veins within the tuff, referred to by Dewey (1960) as "tuffisite". Reynolds (1950) used the term "tuffisite" to describe the rock filling a narrow vent through which passed gas under medium pressure, near the centre of extrusion of a tuff flow, the rock containing fragments of the material around the conduit cemented as a breccia by tuffaceous material. It does not seem justifiable to use the
term for these narrow veins, of maximum width 0.5", which are distinctly cross-cutting to the flow lamination structures and may mark the paths taken by small streams of gas escaping from the tuff after deposition. There is no evidence of any brecciation of the welded tuff material and no evidence of a later infilling of younger tuffaceous material. They are believed to be late in origin and may be hydrothermal.

On the north side of the Glenmask valley the lowest exposures have a green tinge in the granular tuff, but the tuff becomes harder, and pumiceous inclusions progressively more deformed upwards, whilst the colour reverts to purple. Some partings are coated with limonite and weather to a yellow-rust coloured oxide up to 0.1 inches deep. The tuff may become lilac coloured, and even develops a distinctive white patina through which protrude the quartz phenocrysts.

When struck with a hammer the tuff gives a ringing sound, and fractures in sub-conchoidal fashion with small splinters.

MT 3 and 4 rests on different facies along its outcrop; to the west as far as Glenmask, and to the north side of Glenmask, it rests on reddish-brown sandstones, in which it infills depressions; near Glensaul Mountain it is very much reduced in thickness and lies directly on green slates.

The upper surface of the tuff is also irregular and channels occur, often infilled with lenses of current-bedded red sandstones, and conglomerates, the pebbles of which are derived exclusively from the tuff.

\textbf{Mweelrea Tuff Bed No. 5}

Unlike the other tuff bands, which are usually associated with gullies or depressions on the surface around L. Glenwauough, MT 5 forms a well marked cliff on the western side of the lake, the cliff being best developed in the massive columnar-jointed zone. Subdivision on the basis of joint pattern is again possible, and in the uppermost parts some possible rudimentary devitrification spherules are seen. The upper surface of the tuff is an erosion surface which has caused the rock to become deeply weathered, with the
Fig. 56. Nodular structures in welded tuff at top of Glen Mask waterfall. (looking north-east)

Fig. 57. Interpretation of facies changes in the Lower Owenduff Group of C. and E. Murrisk. (after Dewey).
quartz phenocrysts set in a soft, earthy matrix. In the upper part of the tuff band the pumiceous material increases greatly in quantity, suggesting that the original top of the tuff was not very much above the present eroded upper surface.

Curved jointing, possibly reflecting irregularities in the underlying surface, has been observed in MT 5. Nodular weathering in the lower, massively jointed part of the band, with nodules up to 6 inches in diameter, is seen in this band in the Aillebaun corrie.

This band is the most variable in thickness of the three tuff horizons of Eastern Murrisk, varying between 26 ft. and 75 ft. in one half mile laterally in the Aillebaun corrie. Elsewhere it reaches a maximum of 85 ft. to the east of Loughanshee.

Although it is thinner and inverted on the northern side of Glenmask, it is still over 40 ft. thick. Without doubt MT 5 continues on the southern ridge towards Glensaul Mountain, before being faulted out along the Lettereenen Fault.

Mweelrea Tuff Beds No. 6 and 7.

A traverse westwards along the north wall of Glenmask valley from the top of MT 5 reveals further sandstones and conglomerates, and two additional previously unrecorded tuff horizons. Both are thin, having a maximum thickness of 5 ft. and 12 ft. respectively, and continue into the main cliff of the spectacular waterfall, where their inverted relationships are demonstrable.

MT 6 is pumice-grey in colour, and is strongly jointed both parallel and perpendicular to the base; at the crest of the falls forms a distinct ridge in which a nodular structure is present. (Fig. 56 Plate 17.) Large nodules, up to 2 ft. 6 inches across and tapering slightly upwards suggest a possible relationship to inverted pillows, although the accepted mode of origin of the rock as a cloud of hot gases and tuffaceous material militates strongly against this. The feature may be an enlarged version of the nodular weathering observed in the Aillebaun corrie further west.

Directly above this surface is the fractured and weathered zone of tuff characteristically found immediately below the over-
Plate 17. Nodular weathering in welded tuffs at the top of Glen Mask waterfall.

Plate 18. Pebble-filled channel cut into inverted welded tuffs at Glen Mask waterfall.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>Densities (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>847</td>
<td>2.56 &amp; 2.53</td>
</tr>
<tr>
<td>848</td>
<td>2.56</td>
</tr>
<tr>
<td>849</td>
<td>2.52</td>
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<tr>
<td>850</td>
<td>2.56</td>
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<tr>
<td>851</td>
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<td>852</td>
<td>2.62</td>
</tr>
<tr>
<td>853</td>
<td>2.59</td>
</tr>
<tr>
<td>858</td>
<td>2.64 &amp; 2.60</td>
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<td>859</td>
<td>2.67</td>
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<tr>
<td>860</td>
<td>2.60</td>
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<td>861</td>
<td>2.45</td>
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<td>863</td>
<td>2.59</td>
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<td>864</td>
<td>2.60</td>
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<td>877</td>
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</tr>
<tr>
<td>1092</td>
<td>2.80</td>
</tr>
<tr>
<td>1093</td>
<td>2.66</td>
</tr>
</tbody>
</table>

**MT1** Glenawough

**MT3**

**MT4**

**MT5**

**MT6** Glenmask waterfall
lying conglomerates, and into this surface erosion has cut deeply, especially along the joints, indicating that the tuff was fully cooled and jointed before subsequent erosion and deposition. (Plate 18).

Between MT 6 and MT 7 occur 10 ft. to 15 ft. of sands and coarse conglomerates rich in tuff fragments. Above these lies MT 7, without siller base, but being lighter in colour, and weathering nodular and white. This tuff horizon rests on an irregular surface, is no more than 8 ft. thick, and is eroded at the top. Both MT 6 and MT 7 are higher in specific gravity than the other three Mvaelrea tuff horizons, 2.6 - 2.8 as against 2.45 - 2.6.

To the south the tuff beds appear to coalesce on the southern wall of the Glenmask valley, the actual junction being obscured by bog.

In the extreme northeastern part of the outcrop of the Partry Series, at Kiltarsaghaun are three bands of non-welded shardic tuffs. The southernmost of those cream-weathering, hard blue rocks is 10" thick but the second, more northerly tuff reaches 30 ft. in thickness but thins westwards. The northern tuff is of no more than 20 ft. in thickness.

This is a shardic tuff in which undeformed shards show their typical Y and T shapes, and are recrystallised to silica showing neither pectinate nor granular structure. Phenocrysts form a high proportion of the bulk of the rock and are mainly of quartz and unstrained plagioclase (Andesine-Oligoclase An_{25-40}) which is usually sericitised. The phenocrysts rarely exceed 0.25 mm. in diameter. Non-volcanic material includes fragments of metamorphic quartzite, discrete grains of strained quartz and a brown basic 'spilitic' rock. Heavy minerals are not common but include epidote and zircon.

Secondary minerals are represented by albite and calcite. The brown basic inclusions which appear to be spilitic have also been observed in thin sections of MT 1 and there may be some degree of lateral equivalence or the occurrence may be fortuitous.

In the area immediately south-east of Croaghrimcar a Hill, two
further rock types, each of volcanic origin, are present, each connected with the sediments of the Partry Series.

East of the stream, the foot of the hill slope shows a 1.5 metre (5 ft.) thick layer of non-welded andesitic ash in which discrete angular particles up to 1 cm in diameter are found in association with undeformed, but highly sericitised, shards. A deep red colouration results from an early stage of homatisation, for regular iron-rich layers are broken by later tectonic features. This agglomerate, which may be traced laterally for 200 metres. At the other localities to the south-east the base is marked by a tuff. The tuff may be a time-equivalent of welded tuffs to the west, or the non-welded tuffs to the north-east.

It is believed by the author that this tuff horizon rests upon the Glenummera Series and is either basal to the eastern facies of Partry Series or represents a deposit dating from the intervening period. If it is the equivalent of either of the previously recorded tuffs it implies some diachronality of the grit facies.

In the H.M. Geological Survey of Ireland Memoir, Nolan states that the tuff is represented by a "basal felstone" overlain by an agglomerate. No 'felstone' (the term applied by Nolan to welded tuffs) has been recognised by the author, and no welding has been seen in thin section.

In the centre of a wide expanse of bog south of Croaghrimara hill a few exposures of red grits occur, associated with another isolate 'felstone' horizon. Thin sections show the rock to closely resemble a variolite, but the small laths of plagioclase, instead of being truly radiate in structure assume near perpendicular orientation, and all laths show buckling as though formed as a flow structure. The rock is uniformly fine-grained and no welding of any kind is seen. This small exposure therefore, represents a form of andesitic flow. It is apparently low in the eastern facies of the Partry Series despite the isolation of the exposures both by bog and by the clear presence of sediments. Some outpouring of lavas may have occurred as well as explosive eruptions during the lower part of Mweelrea times.
Petrography.

The intratelluric or phenocrystic material consists largely of quartz and plagioclase feldspar with a few crystals of orthoclase and microcline, all of which were formed before eruption.

Quartz phenocrysts are sub-rounded in outline and show deep embayments now filled with recrystallised siliceous groundmass, as though formed due to partial resorption by the magma. The crystals themselves are clear and unstrained, although lines of liquid inclusions or gas bubbles are very common. Fractures, probably essentially connected with the extrusion itself, frequently occur.

The quartz phenocrysts are commonly between 1 mm. and 3 mm. in size reaching a normal maximum of about 5 mm. in diameter. This places them astride the ash-lapilli range of pyroclastic material as indicated by Williams, Turner and Gilbert (1954), straddling the 4 mm. boundary between the two grades as defined by them.

Although they are relatively large the quartz crystals usually make up less than 10% of the total bulk rock.

The feldspar phenocrysts are predominantly of zoned plagioclases which vary in composition from An$_{40}$ to An$_{20}$ i.e. in the andesine-diopside range. Cores of the phenocrysts, which commonly show oscillatory zoning with corrosion contacts at the boundaries of some zones, are rarely more sodic than An$_{42}$, and remain virtually unaltered by the later sericitisation which affect the outer, more sodic rims.

Occasionally the outer rim has been torn away from the core of the plagioclase indicating considerable force at some stage in the history of the crystal, probably during extrusion, when many crystals became fractured or broken.

The few microcline crystals are thought to have been derived from the margins of the vents from which the flows were extruded.
Three micas are found in the tuff—phenocrysts of biotite and muscovite, and the secondary alteration product, sericite. Biotite crystals are normally associated with chlorite and magnetite, and tend to be pale green in colour. In many cases the biotite is partly replaced by the chlorite and magnetite, the latter frequently occupying well-defined layers in the mica structure. Isolated mica flakes are entirely replaced by iron ores in MT 5. Long, thin, and generally unstrained muscovite flakes appear to increase in proportion upwards through the individual layers of tuff. Virtually all the feldspar crystals show sericitisation to some extent, more especially in the sodic portions of the Oligoclase range. Individual sericite crystals are small and show no marked preferred orientation.

Stanton (1953) records the presence of hornblende, but no unaltered amphiboles have been seen in the rocks of E. Murrisk. Pseudomorphs of carbonate, chlorite, and iron ores probably after hornblende are seen. One section shows a perfect amphibole-shaped outline to a new secondary crystal of calcite in which one of the original amphibole cleavage directions has been inherited.

Apatite crystals are found throughout the tuff bands, but are particularly common in the upper zones.

Euhedral zircon grains enclosed by brown haloes are not infrequent in the tuffs. The presence of both zircons and apatites suggest that some considerable differentiation and probable settling out of early minerals had occurred within the magma chamber prior to extrusion.

The groundmass which forms a very large proportion of the rock consists of chlorites, silica, and minute particles of iron ore. Suspended within this matrix are the shards, important in the identification of the rock as a tuff. The silica matrix is of deuteric material, probably formed while the tuff-sheet was cooling.

Devitrified, recrystallised, and often deformed shards are present in all the tuff bands. Pectinate structures are present, in which the fibres perpendicular to the boundaries of the shards vary from very fine to coarse in thickness.
Low in MT 3 the pectinate structure is particularly well developed. In all cases the central cavity of the shard is filled with secondary feldspar, perpendicular to which fibres develop in the silica-glass material of the shard.

The shards are best examined under reduced ordinary light, for under crossed nicols they become indistinguishable from the remainder of the silica and dust matrix.

None of the original glass remains unaltered; it is always devitrified and re-crystallised to form the silica of the groundmass material. High within MT 5 the shards retain a pale brown colour, but this colouration is rare in the series as a whole and elsewhere shards are represented by colourless crystalline material.

In the lower and central parts of MT 5 the shards curve around the major phenocrysts.

Replacement of the shards by calcite is seen in all stages from unaltered through partial to complete replacement, individual shards being replaced by an aggregate of calcite grains. The characteristic shape of the shards is still visible after such replacement.

Iron ores occur in two forms, as fine grains of primary origin disseminated in the dust matrix, and as larger, later nodules frequently associated with carbonates. The former are very minute and are of both magnetite and hematite, variations in the relative proportions of which lead to differences in the purple to brown colour of the bands. Manganese oxides may also influence colour variations. The larger frequently well-rounded but occasionally six-sided sections of ore are probably of secondary origin. These nodules attain a maximum of 1 mm in diameter, but are usually smaller. The secondary nature is demonstrated firstly by the replacement of carbonate by iron; the carbonate itself replaces silica of the 'matrix'; and secondly by association with 'zones' of phenocrysts -- with a concentration of iron well above the average for the rock, indicating routes along which iron-bearing solutions migrated leaving trails of small magnetite crystals, even
in the lowest parts of the tuff band MT 1. This secondary iron may be of the same age as that replacing the micas as described above, but there is no direct evidence of this. Red stained patches of hematite are common in the rock, and many phenocrysts have a thin layer of hematite around them.

All thin sections of the Mweelrea Tuff bands examined show secondary carbonate, chlorite and feldspar. As has been previously stated the carbonate, which is entirely calcite, replaces the shards and amphiboles, but also certain of the chlorites. Some calcite, occupying areas with well-defined outlines, may be filling vesicles in the tuff. Some albite rimmed with chlorite probably likewise fill vesicles. Occasionally irregular replacements of the silica of the groundmass are seen.

The albite always appears fresh and clear in ordinary light but as it is known to survive sericitisation it may not be very late in origin.

Occasional centres or nodes of development of feldspars, often partly sericitised, occur scattered within the matrix material, and bear close resemblance to rudimentary radiolites. If these are truly secondary feldspar then they are early post-depositional in origin, whereas the albite vesicle fillings were much later.

There were two periods during which the secondary minerals could form; firstly while the tuff was still hot (i.e. within a few years of emplacement) when tridymite, quartz and feldspar were deposited; and secondly during later folding on a regional scale, when carbonate, chlorite, iron ore and possible sericitisation occurred.

Lithic inclusions occur in the lower parts of the tuff bands. They are usually of slate and sandstone or individual sand grains, but the tuffs also include a few basic rocks, composed of many small feldspar laths set in a dark matrix in which the later hematite developed.
<table>
<thead>
<tr>
<th>No. of section</th>
<th>MT 1</th>
<th>MT 3</th>
<th>MT 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>5</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Phenocrysts</td>
<td>31</td>
<td>23</td>
<td>13</td>
</tr>
<tr>
<td>Mica</td>
<td>0.8</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Lithic material</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Apatite, Zircon, Epidote</td>
<td>1.2</td>
<td>1.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Groundmass</td>
<td>19</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>Groundmass Matrix silica</td>
<td>31</td>
<td>43</td>
<td>25</td>
</tr>
<tr>
<td>Magnetite</td>
<td>8</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Carbonate</td>
<td>0.4</td>
<td>1.8</td>
<td>2.8</td>
</tr>
<tr>
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<td>Secondary feldspar</td>
<td>2</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>Secondary chlorite</td>
<td>-</td>
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</tr>
</tbody>
</table>

The table represents modal analyses (volume per cent) made on thin sections of Mweelrea tuffs. Two thousand points were counted in each instance.

The figures are correct to the nearest 1% where possible. These results indicate that the tuffs are of similar composition, minor variations occurring within the individual horizon, and from band to band.
The rock fragments, feldspar and quartz of MT 1 show a decrease in proportion upwards, indicating a gradual grading through the bed, the proportions varying from 38% to 22%. MT 3 has up to 40% fragmental material, whereas MT 5, which in the field shows more pumiceous material, shows maximum content of 22% fragments. With this there is a concomitant increase in a vertical direction through MT 1 in the combined totals of shards and matrix silica (to which the shards change with increase of recrystallisation) from 31% to 51%, whilst the other tuff horizons are more constant in composition, MT 3 with 20% and MT 5 with 34% - 42%.

Variations of micas, and the apatite, zircon and epidote groups are small and irregular, but secondary albite is slightly more abundant in MT 1, and calcite in MT 3.

In thin section the tuff bands appear to be coarse crystal tuffs in which intratelluric crystal fragments of quartz and plagioclase are set in a fine-grained, highly siliceous matrix. Throughout most of the bands devitrified and recrystallised shards are present, and in the lower portions evidence of welding of these shards occurs.

Shards are the result of disintegration of a vesiculated magma. They are angular in outline but their long axes assume a sub-parallel arrangement. Non-angular particles in the tuff also show sub-parallelism which is detected as a streakiness under reduced ordinary light, and known as eutaxitic structure.

The shards were hot and plastic, though very viscous, when emplaced, and near the base of the tuff band load pressure was great enough to overcome the high viscosity and deform them. In place of the usually angular extremities the shards develop rounded, smoothed and often interlocking limbs. There are seen towards the bases of all the tuff horizons. Retained body heat, and load pressure are thought to combine to produce this welding of the shards; no reheating is envisaged.

Boyd (1961) uses the term "pyroclastic flow" to describe material from eruptions in which fragmented lava buoyed up by escaping gas
is emplaced at high temperature as rapidly moving flows or avalanches of fine particles of viscous melt. Such material is believed to be moving under the influence of gravity, and to have retained sufficient heat to permit deformation and welding of the included shardic material. This is a clarification of the term introduced by Gilbert (1938) and subsequently used by Williams (1941), MacGregor (1952) and Aramaki (1957).

"Pyroclastic flow" is used in preference to the term "ignimbrite" introduced by Marshall (1935) to describe rocks "formed from material that has been ejected from orifices in the form of a multitude of highly incandescent particles which were mainly of a minute size", since much confusion has occurred in recent years, with the result that the use of the latter term now carries secondary implications not originally intended by Marshall.

The Mweelrea tuffs of Murrisk are welded in the sense that Boyd (1961) used the term "welded tuff" to refer to tuffs in which shards and fragments of pumice have been deformed and welded at high temperatures so that the rock is indurated.

Aramaki (1957) considered a "pumice flow" as the least viscous form of "pyroclastic flow" and to be derived from a "fully frothing mass of magma". Characteristically it contains rounded pumice and ash fragments of similar composition and which vary in size and frequency within a single flow. Great areal extent is typical of this "pumice flow" type of deposit, with over 10 cubic kilometres of material extruded. Such features are typical of the Mweelrea Tuff bands of Murrisk.

Throughout all the Mweelrea Tuff bands pink inclusions of pumiceous nature are visible in hand specimen. These have been flattened, probably very soon after deposition, whilst the tuff was in the process of being welded, so that they lie parallel to the general eutaxitic structure. High in the tuff bands the pumice fragments are still flattened, indicating that they are readily crushed, presumably due to their high porosity. Deformation is great, with inclusions of less than 0.2 inches thick (in a vertical sense with respect to bedding) exceeding 4 ins. in length.
and $\frac{3}{3}$ ins. in breadth. This is largely due to load pressure in each band, as seen high in MT 5 where deformation of inclusions is markedly less. In this case the dimensions are reduced to $0.2$ ins. in height, by $0.4$ ins. length and $0.3$ ins. breadth.

Movement of the tuff from the original vent to its present site may have influenced the major direction of elongation of the pumiceous material. The long axis lies along $140^\circ - 160^\circ$ in many cases, producing a distinct lineation in the rock. This is either parallel to the flow direction, $f$, or perpendicular to $f$, there being no field criteria to distinguish between them. Flow is probably laminar either along $140^\circ - 60^\circ$ or along $50^\circ - 70^\circ$, of which the former is considered the most probably direction of movement. Large plugs of "Felsite", lithologically similar to the Mweelrea tuffs are known in the Tourmakeady district, where they cut through the older rocks (Gardiner and Reynolds, 1909).

Stanton (1953) first pointed out the similarity between the rocks of the Tourmakeady district and the Mweelrea Tuff bands, and Dewey (1960) expanded on this, noting the continuation of the line of intrusions into Joyce's Country further south.

McKerrow and Campbell (1960) consider a possible vent for the extrusion of the Mweelrea Tuff bands to be located near Curraghrevagh, on the shores of Lough Corrib. The location of this vent relative to the exposures in E. Murrisk is along a bearing of $150^\circ - 160^\circ$. This is closely parallel to the direction along which the pumiceous debris is elongated in MT 5, suggesting that the vent may indeed have been the source for this bed.

Both "intrusive" and "contemporaneous" felsites (Gardiner and Reynolds 1909) are very similar lithologically to the welded Mweelrea Tuffs in the field, and the "contemporaneous felsites" show columnar jointing in the quarry beside the high road at Treanlaur. However, in thin section they show no deformation of the sherds in welding and have a markedly higher content of phenocrysts than the Mweelrea Tuffs. Nevertheless, they do show elongation of included fragments, along $80^\circ - 97^\circ$, a very different direction from those of L.Glenawough.
Dewey (1960) believed that the 'felsite' masses were possible feeders to the vents from which the Mweelrea Tuffs were extruded. This may be true of the Brown Felsite intrusion of Derassa described by Gardiner and Reynolds (1909), but recent field work has shown that the other 'felsite' masses could not have acted in such a capacity.

In the Derryveeny river cliff section the westernmost "intrusive felsite" of Gardiner and Reynolds (1909) is seen to lie as a sheet upon coarse conglomerates of the Mt Partry Beds, and is a granular tuff bed. In the stream above and west of Tournakeady Lodge the 'felsite' is overlain by Partry Series grits of Tomnsaile, and although cut out by faulting, this position intermediate between the Partry Series and older beds is maintained into Treamlour, where the bed disappear possibly due to pre-Mweelrea erosion.

The 'felsite' of Tournakeady Lodge and Smithy Bridge was regarded by Gardiner and Reynolds as contemporaneous with the Shangort Beds and lies clear of the boundary with the Partry Series.

The main "Green Felsite Intrusion" of Derassa is overlain unconformably by a series of blue-green quartz-rich grits, which rest in hollows in the surface of the 'felsite'. This quartz-rich grit appears to be basal to the Tomnsaile grits, which conglomerates, which are, therefore, later than the intrusion.

There is one very thin layer of 'felsite' in the northern side of the Glen Saul Valley, known only in two localities where it does not exceed 6 ft in thickness. This lies within the lowest part of the exposed rocks of the Partry Series.

The 'contemporaneous felsite' of Gardiner and Reynolds lies below the Llanvirn Limestones of the Tournakeady Beds, and the second 'felsite', of Derryveeny and Treamlaur lies above the limestone. The position of the latter horizon, which is clearly a tuff, along the boundary between the Partry Series and the Shangort Beds gives it an uncertain age, for it might be the latest event in
Shangort history, the earliest in the Mweelrea, or alternatively of an intermediate age, unconformable to both groups. The discontinuous nature suggests that it is of pre-Mweelrea age and that pre-Mweelrea erosion may have cut it away, or alternatively it may mark the northward limit of the pyroclastic flow responsible.

The 'Brown Felsite Intrusion' of Derassa is the only one not seen in direct contact with the Partry Series and so this may have acted as a feeder for the Mweelrea Tuffs. However, both Dewey (1960) and Stanton (1953) have shown that the Mweelrea Tuffs tend to die out eastwards and it seems that a source further south-west and towards Joyce's Country is more probable than one in the Tourmakeady district. Fenner (1923) suggested that, as in the Valley of the Ten Thousand Smokes, welded tuffs may originate from several vents at the same time, thus permitting a greater volume to be extruded than through one orifice. Certainly the region west and south-west of L. Mask could constitute such a zone of crustal weakness.

The felsites below the base of the Partry Series at Treanlaur and Derryveeny show pumice elongated along 80°-100°. These cannot have been derived from the Curraghrevagh vent, but must have come from a vent further north, possibly now submerged beneath Lough Mask or even obscured by Carboniferous rocks to the east of the Lough.

Some of the felsites of the Tourmakeady district of similar age to, and the lateral equivalents of the tuff bands within the Glenumera Slate Series.

In the literature concerning welded tuffs, virtually all the authors consider their origin to be as mëés ardentes, yet no historical mëë is known to give a welded tuff. This may be due to the occurrence of most known historical mëë deposits on small islands such as the West Indian arc. Doubtless much ejected material fell into the sea, and this restriction of the area of deposition to the immediate vicinity of the vent may be responsible for the absence of any observed welding.
MacGregor (1946), in a criticism of Cotton (1944) states that ".... it is characteristic of the nuées of the West Indies that they are in a loose and unconsolidated state. Nobody has ever described welded or agglutinated tuffs ("ignimbrites") as products of nuées ardentes in the West Indies".

The proportion of gas as indicated by the shards must have been extremely high, and some similar form of eruption must have been responsible for their origin.

Most of the gas was lost during lithification and cooling, with the result that very few vesicles survive in the rock. The effect of the gases is to promote crystallisation of the glass material, so the devitrification of these tuffs was probably an early feature. The presence of the gases also leads to reaction with the earlier formed, and now solid minerals of the tuff, giving decay of the amphiboles and micas. It is notable that infilled vesicle cavities are present in all thin sections of the rock, but in no case exceed 2% of the bulk rock total. In the changes accompanying the cooling of the tuff, steam was probably the main catalytic agent. Relatively thin clear zones exist around the larger intratelluric fragments, and these may be due to an early autopneumatolitic process.

Many of the spherical light-pink bodies high in MT 5 resemble devitrification spherules of some kind which have been preserved although the rock is now totally devitrified and recrystallised. This suggests that devitrification and recrystallisation took place in two stages, first an early post-depositional phase of devitrification, and a later one which entirely altered the rock whilst preserving the early alteration spherules.

A position close to the basal section permits relatively rapid loss of heat, and a probable production of a glass. After congelation the rock probably took several tens of years to cool down from about 800° to normal surface temperature, and devitrification proceeds rapidly at such temperatures.

Towards the base of the tuff bands, and especially in the sillar tuff sections of Dewey (1960) and Stanton (1953) lithic fragments
and sand inclusions are not uncommon. Marshall (1953) considered this a criterion for distinguishing between ignimbrites on the one hand and normal submarine vitro-clastic tuffs and lavas on the other, for neither of the latter disturb the surface on which they rest. All of these tuffs are the products of explosive eruptions, and pieces of pre-existing rocks could be expected to be blasted out from the walls of the vents. The existence of small grains of microcline in the tuff support this theory, but the presence of slate and sandstone fragments point to disturbance of the underlying sediments in the manner envisaged by Marshall.

The presence of basic material, rich in small feldspar laths has been remarked upon above. The laths vary in composition, many being largely albitic, whilst others are more in the andesine-labradorite range, suggesting that both spilites and andesites are represented. They are quite different from the acid-dacitic welded tuffs in which they lie and may be either derived from the country rock adjacent to the vent, or they may be more directly connected with the eruption in that this basic material may have been responsible for the explosive activity. Insertion of basic material at high temperature into a magma chamber of acid material rich in volatiles would, by superheating this material, cause rapid evolution of gases, and lead to an explosive eruption.

No basic fragments have been identified from the Mweelrea sediments which the tuffs are emplaced and this precludes these sediments as a possible source for the fragments.

Martin (1959) proposed a two-fold division of ignimbrites on lithological grounds. The welded tuffs of Murrisk fall into his heterolithic category, in that they show zones of varying lithology, different joint types and some eutaxitic structure. Microscopic lithological variations are largely superficial in the Murrisk welded tuffs, for they appear to be microscopically petrographically identical. Differences between the extrusive and lithoidal-glass zones and the lithoidal welded zone have largely been removed by later geological processes during tectonism.
Whereas the Recent welded tuffs of New Zealand show specific gravity in the range 1.4 - 2.4 (Martin 1959), those of Murrisk range from 2.45 - 2.80, probably due to infillings of the pore spaces, although the higher iron ore content may have a small effect. The results of measurements on specimens from the Mweelrea tuffs are shown in table 5. In no case was the basal sillar tuff examined.

As shown by Dewey (1960) three major types of jointing are typical of the welded tuffs: columnar, sheet jointing (parallel to thin bedding), and tectonic joints. The first two are due to processes directly related to the cooling of the tuff, whilst the third is much later, perhaps late Caledonian.

Characteristically the welded tuff base is not seen in E. Murrisk but the lowermost portion seen shows joints both parallel and perpendicular to the bedding, the former predominating. This zone is highly fractured and gives way to a thicker, more massive section with only sheet jointing, and this in turn to very massive tuffs with columnar jointing, by way of a thin transition zone, highly broken, with both types of joint. The original upper surfaces of the tuff have nearly everywhere been removed by penecontemporaneous erosion, but on the Partry Mountains, above Loughanshee, MT 5 shows a 5 ft. layer, overlying the mains columnar zone, in which both columnar and sheet jointing are developed.

The sheet joints are prominent features due to release of load pressure by later erosion. The rock has a horizontal 'grain' due to parallel elongation of the tuff particles and this probably guided later jointing when load pressure was decreased.

The columnar joints were produced during the long period of cooling of the tuff, permitted by the basal zone which acted as an insulator to retain the heat.

Curved joints occur at two localities west of L. Glenawough but there is no apparent regularity in their attitude. It was thought that these might be due to irregularities in the sub-tuff surface as described by Tomkeieff (1940), similar to features in
the basalt lavas of the Giant's Causeway, but the orientation of the
curved joints of Murrisk is rather different. Instead of paralleling
the base and basal irregularities, these joints begin subparallel
to the top of the bed and swing to a position perpendicular to the
base of the bed, several feet above the base. These are not small
features, but are up to 8 ft. from limb to limb and do not appear
to be due to large inclusions in the flow, nor yet to hummocks
of the underlying sandstone protruding into the flow.

It has been postulated above that sheet jointing is a result
of the type of 'grain' in the rock. These curved joints may represen-
t irregularities in the original 'graining' along which
 cracking has occurred. Such irregularities of flow are breaks
in the normal laminar flow, where turbulence of some form develops,
possibly due to sudden undulations in the underlying surface.
Nevertheless there is no constance in the examples seen, and this
suggests that the joints are in no way connected with regular
flowage. No abrupt undulations of the underlying surface have been
observed.

In the upper massive part of MT 5, on the ridge 200 yards
north of point 1768, the axis of curvature is inclined gently
eastwards, is slightly oblique to the strike and is 'open' in an
up-dip direction. Here later columnar joints cross the curved
joints indicating that actual folding is not responsible for curving
these joints. The other locality, 300 yards west of this, and
still in MT 5, shows a joint steeply oblique to the bedding. The
direction of curving is markedly different from that of the other
example, for it is now gently inclined southwards and 'faces'
downwards.

The tectonic joints are regular, as over the whole of this part
of Murrisk, being near-vertical along a north-south direction. They
swing in proximity to the Erriff tear fault, which is a Post-
Carboniferous feature, and so may ante-date it. Further, they lie
perpendicular to the main axis of the syncline of Silurian rocks to
the north and are thought to be directly connected with the folding
movements, of late Caldonian age.
Intrusions into the Partry Series.

On Tonnasaile Hill a sill of olivine dolerite 50 metres thick is intruded between beds of coarse grained sandstone. It is present in the cliffs above the northeast of the mountain road at the watershed between Glennagashleighy and Treanlaur, and is poorly exposed. To the east, however, it is seen in deep scars which have been cut into the eastern flank of the mountain slopes, where the sill is deeply weathered and easily eroded. The sill forms the face to the cliffs for about a mile from south to north and its presence is indicated by a belt of rich grazing. At the southern boundary of the Gortbunacullin townland the intrusion is obscured by a thick cover of peat. To the north of this point is the Tremanagh fault north of which the sill reappears in the Gortbunacullin stream (stream ‘H’ of Gardiner and Reynolds 1909), below the junction with its tributary. Here the sill forms a hard surface at which level the river has been held in its downcutting. Lateral erosion has produced a river cliff 25 metres in height at this point.

The discordant nature of the sill is seen in the west of the Gortbunacullin stream section, where it cuts across the bedding before it is faulted cut, and also on Tonnasaile, where the beds overlying the sill are progressively wedge out in a westerly direction. There is a close field resemblance between the rock of the sill and of a dolerite dyke recorded in stream ‘H’ by Gardiner and Reynolds (1909), this dyke occurring below the unconformity which is basal to the Partry Series.

Nolan (1876) described a small exposure of a dyke low on Tonnasaile Hill, but this has not been located during the present investigations.

The earliest and only previous description of the sill was by Nolan (1876) who gave the detailed structure as "the lower part tuffoid, above that amygdaloidal, then tuffose, while the upper part is compact but shingly. Adjoining the conglomerate that overlies the melaphyre, there appears to be a small sheet of trap. The melaphyre is a nearly horizontal bedded mass, and apparently is interstratified with the Upper Silurian rocks".
Reference to Teall (1888) reveals the three possible definitions of 'melaphyre' which existed at the time when Nolan was writing. Of these it appears that Rosenbusch's interpretation (1872) is the one referred to: "Pre-tertiary massive rock composed essentially of plagioclase, augite, and olivine, together with a certain amount of interstitial matter". This corresponds to the composition of the upper and lower parts of the sill, which today would be classed as a dolerite.

The quarry recorded in the Memoir of the Irish Survey (1876) in which the sill was exposed is no longer visible and examination is only possible in the gullies on the eastern side of Tonnasaile. Weathering of the lowest parts is so intense that no unweathered material was found even after excavation. Large blocks of the lower part of the sill shatter under a light blow from a hammer. The surface of the rock is covered in nodules 0.5 - 1.0 cm. in diameter, and composed of pyroxene crystals through which penetrate laths of plagioclase feldspar.

In thin sections the lowermost part of the sill is seen to be an olivine-dolerite which has an intergranular texture. Early phenocrysts of plagioclase are of bytownite, An 80, and show extinction angles of $45^\circ$, while later small laths are of andesine, An 35-45, of smaller extinction angle. The large, sometimes untwinned, feldspar phenocrysts show undulatory extinction, which reflects a change of composition outwards from the core. Zoning is seen and corrosion followed by overgrowths of later feldspar is common. The major mafic minerals are olivine and pigeonite, the former often intensely fractured and associated with opaque iron ores and other alteration products. Occasionally the latest pyroxenes and laths of feldspar to cool show an ophitic relationship.

Cutting across the dull brown and green-coloured rock of the lower dolerite are a few veins of lighter colour reaching up to 10 cm. in thickness. Such veins are essentially horizontal in orientation, and are composed of coarse ophitic dolerite from which olivine is absent. The plagioclase crystals again show two stages
Plate 19. Chilled top of sill at contact with Partry Series sediments. Tonnasaile.

Plate 20. Regular banding shown by nodules of natrolite near the top of the sill on Tonnasaile.
of development with a clearly marked boundary between the two zones. The most basic plagioclases identified were of composition An$_{60}$ and vary to An$_{40}$, in comparison with An$_{80}$ and An$_{40}$ of the surrounding non-ophitic material of the sill. The pyroxene is again pigeonite and there is very little interstitial material.

In these white veins there are small zones of replacement of the feldspars with development of analcime and bundles of thin fibres of natrolite, probably alterations produced during a late stage of cooling of the sills.

The lower olivine dolerite is 25 metres in thickness and above it is a leucocratic layer, often highly nodular, above which is a second layer of olivine dolerite, some 15 metres in thickness.

Towards the top of the upper dolerite the rock becomes fine grained, and shows a drastically chilled margin, dark green in colour, very fine-grained and broken by many joints parallel to the margin of the sill (Plate 19).

Below the immediate vicinity of the chilled margin there is a distinct layering in the rock, with a repeated grading upwards to a zeolite assemblage, rich in natrolite (Plate 20). Between the light coloured zeolitic bands, which are up to 5 cms. in thickness, the rock retains its dark green colour, and the while nodules of zeolite are very much reduced in size and frequency.

At one locality the succession from the margin downwards reads:

- 5cms. intensely chilled margin
- 1cm soft white zeolitic layer
- 22cms dark green dolerite
- 5cms zeolite rich horizon
- 20cms dark green dolerite

The alternations continue for at least a further 400 cms in this widely spaced orientation and then become more closely spaced giving a distinct appearance of bedding.

The nodules of zeolites are composed of radiating fibres of natrolite, and reach a maximum observed diameter of 3cms.
The size of the zeolite nodules increases upwards to a zone of high concentration above which there is an abrupt reduction of size and frequency.

Above the top of the sill cavities occur in the sandstones, and some of these have been infilled with well-formed crystals of chabazite. This occurrence is clearly associated with the proximity of the hot sill and may have been partly caused by the migration of hot gases into the surrounding rocks.

Nolden (1876) recorded an amygdaloidal sector to the sill, but did not identify the zeolites concerned, and it appears that this is the first identification of the zeolites associated with the sill.

The central zone of the sill occupies a maximum of 5 metres in thickness. It is light coloured, more solid than the dolerites above and below, and has a nodular appearance. Thin sections from this central layer are remarkably varied, and appear to be xenoliths of granites and various sandstones. One such thin section shows quartz, much potash feldspar and some altered mica flakes: another, individual grains of fractured quartz, some plagioclase feldspar, and altered micas set in a fine-grained matrix.

Comparison of the composition of the leucocratic nodules in this layer with the conglomerates in the sequence into which intrusion has occurred, reveals great similarities.

The matrix of the conglomerate was originally clearly a sandstone, for discrete quartz and feldspar grains occur within the rock, often with thin authigenic rims discernable in thin sections. This sandstone matrix of the conglomerate shows microgranophyric and granophyric texture in specimens from the central layer of the sill.

The granophyric areas show an interesting texture, in which euhedral crystals of plagioclase twinned on the Albite and Carlsbad Laws and elongated parallel to the twin planes occur. These apparently acted as centres around which developed the granophyric intergrowth of quartz and plagioclase. The existence of
euhedral crystals of plagioclase is not known in the same sandstones outside the 'raft', and they may have developed in the rock during the earliest phases of thermal metamorphism, perhaps using some of the clay mineral fraction as constituents. They may represent overgrowths on earlier fragmental feldspar grains. The newly formed crystals appear to have acted as centres around which the intergrowths developed rather than being incorporated in the grenophytic textures.

Whereas in the sandstones well clear of the sill the proportion of strained quartz is high, in the rock in which grenophytic texture is present the quartz crystals all show uniform extinction. This may be due to the effect of heating on the strained quartz. Small veins of quartz, however, still show differing crystal sections along their length, although where they meet large quartz crystals they are in optical continuity with them. The veinlets were thus earlier than the thermal metamorphism.

During the development of the grenophyre, as revealed from material in the centre of the raft, the material of the clay matrix developed a cherty texture. The formerly open structure of the sandstone, in which intergranular spaces were considerable, disappears and is replaced by a completely cemented mosaic of quartz and feldspar grains, with a few oxidised detrital biotite flakes between them.

In the original sandstones many of the grains show the irregular extinction of metamorphic quartz, but at this earliest stage of development of the grenophyre the heating was sufficient to cause all the quartz detritus to melt and recrystallise so that all of the grains show uniform extinction. In other words the structure of the quartz grains achieved regularity due to heating and melting.

Between many fragments of plagioclase "bridges" of secondary plagioclase grow, and between the quartz grains, similar overgrowths of quartz occur, like authigenic overgrowths in sandstones.
There is a tendency for early development of micro-granophyric texture in fine grained siltstones in which small fragments of quartz and feldspar are initially intimately intermixed. In such a rock distinct overgrowths occur as large feldspar crystals, which, together with quartz crystals, become centres for outgrowth of granophyric texture.

It is therefore suggested that the central zone of the sill may represent a discontinuous raft, or large xenolith, of conglomerate of the Partry Series which sank into the molten rock during intrusion. Thus the great variety of textures and compositions recorded in this zone may be explained by differing degrees of thermal metamorphism.

It is noticeable that in thin sections of the granophyric sandstones there is a low proportion of clay material in the interstices. It is possible that migration of such elements as potassium, magnesium, calcium and sodium occurred during thermal metamorphism, and that some of these components were partly responsible for the composition of the zeolites of the upper dolerite. The migration was probably associated with the dehydration of the sedimentary raft, the water escaping as superheated steam and passing into the sill above the raft. Rising gas bubbles were clearly responsible for development of amygdales, but the reason for the 'layering' of the amygdales is not known.
CHAPTER V.
SILURIAN STRATIGRAPHY

Silurian rocks occur in two belts in the Mayo-Galway area of Lower Palaeozoic rocks, namely in the Croagh Patrick Syncline, and in a strip of country stretching from south of Killary Harbour in the west to Lough Mask in the east. McKerrow and Campbell (1960) demonstrated the existence of two unconformities in the upper part of the Lower Palaeozoic succession near Lough Nafooey. The first is at the base of the Lower Owenduff Group, and the second separates the Upper and Lower Owenduff Groups. Gardiner and Reynolds (1912) examined the fauna of the south-eastern area and described the rocks as Llandoverian.

Stanton (1953) discovered fossils at Cregganbaun, on the southern limb of the Croagh Patrick Syncline, and believed the rocks to be of Llandoverian age. Williams (in McKerrow and Campbell, 1960) considered the fauna of the Lower Owenduff Group to be Upper Llandoverian, and Dewey (1960) extended this age to the Lower Owenduff Group of the Croagh Patrick Syncline. However, Williams (in Anderson, 1960) believed that the rocks of the Upper Owenduff Group were of the Upper Llandovery or Wenlock. The presence of the basal unconformity suggests a Wenlockian age.

On the southern limb of the Croagh Patrick Syncline the rocks of the Lower Owenduff Group vary in lithology. Dewey (1960) observed that the Lower Owenduff Group is overstepped at Oughty by the Upper Owenduff Group. At Oughty the Lower Owenduff Group consists of 20 ft of current bedded sandstones of easterly origin. Further west, however, the rocks become conglomeratic, and then change abruptly to dark slates. In the Cregganbaun district, previously mapped by Stanton (1953), Dewey (1960, p.150) observed 500 ft of sandstones and slates above a thin basal conglomerate, but lying below the conglomerate which marks the base of the Upper Owenduff Group.

In the southern syncline McKerrow and Campbell (1960) demonstrated that the basal breccias of the Lower Owenduff Group rest directly on a deeply stained surface of Connemara Schists. The overlying sediment shows an increase in the slate content in a north-westerly direction.
McKerrow and Campbell (1960) suggest that the Connemara Schists acted as a landmass which extended at least to the south-west of Killary Harbour. They believed that the northward increase of slates indicated an approach to open sea conditions. Dewey (1960) interpreted the facies changes of the northern syncline as indicating a near shore environment in which banks or bars of sand and gravel were built up by a westward moving longshore drift, and behind these clays accumulated in the protected lagoons.

In Eastern Murrisk the Lower Owenduff Group reappears towards the eastern end of the Letterbrock ridge, where it is represented by 40-50 ft of black slates. The contact of these with the underlying Arenig rocks is nowhere exposed, and no basal conglomerate has been recognised. The slates are best exposed in a small cutting used as a sheep shelter, beside the path to the ridge from the Drummin road (N53°43'23" W9°35'22"), and recur in the path below a bungalow north of the bend in the road (N53°43'26" W9°35'00"). They are black, very thinly bedded, intensely cleaved, and often heavily stained by iron. There is no evidence of current bedding in any of the thin silt layers in the slates. The Lower Owenduff Group is exposed in no other part of Eastern Murrisk. The slates may mark the presence of a further lagoon of the type suggested by Dewey for the accumulation of slates to the west.

The absence of deposits of the Lower Owenduff Group between Oughty and the eastern end of the Letterbrock ridge may be partly due to the presence of the Letterbrock Slide along the junction of the Silurian and Arenig rocks in this district, but it may also be an original feature. If the sand banks and bars built out from an irregular shoreline developed an Arenig rocks then at some point the section revealed by the present topography may cut through onto the original land surface, into a position where no deposition of the Lower Owenduff Group took place. There is an unconformity at the base of the Upper Owenduff Group, and considerable erosion has been seen at this level during fieldwork in the Oughty area. The Upper Owenduff Group may have completely overstepped the Lower Owenduff Group to the east of Oughty. Exposures are not continuous in this region, and the rocks may be present but unrecognised to the west.
### Fig. 58. Equivalents used by Dewey and Anderson.

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<tr>
<td>Massive current bedded Group</td>
<td>Owenwee Group</td>
<td>Knockladda Psammitic Group.</td>
</tr>
<tr>
<td>Current bedded and slumped Group</td>
<td>Lough Nacorra Group</td>
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<tr>
<td>Mixed Group</td>
<td>Fiddaunarinnia Group</td>
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<tr>
<td>Interbedded pelitic and psammitic Group.</td>
<td>Oughty Group</td>
<td>Cregganbaun Pelitic Group.</td>
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<tr>
<td>Green slates</td>
<td>Pollanoughty Group</td>
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<tr>
<td>Cregganbaun Quartzite</td>
<td>Cregganbaun Group</td>
<td>Croagh Patrick Quartzitid Group</td>
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<tr>
<td>Cregganbaun Conglomerate</td>
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of the present mapping area. Where they occur in the area studied there is usually a distinct break of slope on their southern margin.

Thus, while it is not possible from the evidence in Eastern Murrisk to substantiate more fully the palaeoecology suggested by Dewey (1960), the presence of black slates in eastern Letterbrock may without difficulty be interpreted by invoking the conditions which he suggested. (Fig. 57) The pebbles of white quartzite, of northern origin (Dewey 1960, p. 148) were probably transported by rivers and carried to the sea some way east of the present outcrop. Longshore drift carried the pebbles, together with jasper-rich sand debris from further east (possibly the Charlestown area) westwards to achieve an intermixing of debris from the two sources.

The Upper Owenduff Group

The rocks of this Group rest unconformably on an eroded surface of the sediments of the Lower Owenduff Group at Oughty. They consist principally of sandstones, with slates in varying proportion throughout the sequence.

Stanton (1953 and 1960) referred to the rocks as the Cregganbaun Series. Dewey (1960) applied the term Upper Owenduff Group to the same sediments. He continued the use of the terms 'Cregganbaun Conglomerate' and 'Cregganbaun Quartzite' of Stanton (1953) for the lowest parts of the Upper Owenduff Group. Anderson (1960) proposed an independent name, 'the Croagh Patrick Quartzite Group' which is named after the occurrence on Croagh Patrick, where the quartzites reach their maximum development, and are probable facies equivalents of higher members of the sequence as well as the quartzite of the southern limb.

Dewey (1960) introduced a list of purely descriptive terms for the rocks (Fig. 58). He later (1962, still in press at the time of writing) gave these same divisions locality names (see Fig. 58). The newly named groups are better stratigraphical divisions than the previous ones, for the international principles of stratigraphic nomenclature have now been followed. He rightly proposed a series of terms to replace the very broad divisions given by Anderson (1960). The descriptive terms used by Dewey (1960) will be used in this thesis.

The equivalents of the divisions used by Anderson (1960) and Dewey (1960 and 1962) are given in Fig. 58.
Dewey (1962) introduced the term Croagh Patrick Series, which is the synonym of the Upper Owenduff Group as applied in the northern, Croagh Patrick syncline. The term 'Upper Owenduff Group' has not been used in the sense of a time division only, for it is used to describe a sequence of rocks in the southern syncline. The term has nowhere been used as a reference for a division of time. The introduction of a fresh term to refer solely to the sediments of the northern syncline, therefore seems justified. Under these circumstances it appears doubtful whether the term Lower Owenduff Group should be applied to the rocks of the Upper Llandovery below the basal unconformity of the Croagh Patrick Series. Perhaps these rocks should be referred to as of the Lower Croagh Patrick Series. The time equivalence of the Croagh Patrick Series and the Upper Owenduff Group is accepted.

At this point attention must be drawn to the existence of two villages by the name of Boheh, both of which lie within the bounds of the Croagh Patrick Syncline. The first is referred to by both Stanton (1953) and Dewey (1960), and lies to the west of Lough Gill. The second is on the Westport-Leenane road, one mile north of Liscarney. Whenever the name Boheh is mentioned without qualification in this thesis, it is the eastern village to which reference is intended.

1. **The Cregganbaun Conglomerate** (Lower Cregganbaun Group)

The basal conglomerate is nowhere exposed in Eastern Murrisk. West of Oughty it has been described by Stanton (1953) as consisting of many pebbles concentrated together, with as little as 10% interstitial material. He stated that the pebbles were of white quartzite, jasper, quartz porphyry, spilite (?), dust tuff, and felsite. Stanton also recorded that the pebbles had been deformed and elongated during folding. Dewey (1960) suggested an easterly derivation of the debris, and likened the conglomerates to modern beach deposits. He recorded deformation of the pebbles. Anderson (1960) considered that the conglomerates extended as far east as Moher Lough on the
southern limb of the syncline. This is not true: the only conglomerates present here are of the Letterbrock Conglomerate Group, part of the Areng succession.

2. The Cregganbaun Quartzite Group. (Upper Cregganbaun Group)

The Cregganbaun Quartzite has been recognised on both limbs of the Croagh Patrick Syncline in Eastern Murrisk. It is thickest in the north, (1250 ft. maximum), but on the southern limb it ranges from 400 ft. in thickness on Liscarnay Hill to 600 ft. at Letterbrock. On the southern limb the Quartzite runs eastwards as far as Lankhill, where the strike swings to a northerly direction before exposures cease in the Knappaghbeg area. On this limb the rocks are rather impure, grey coloured quartzites near the base, passing upwards into massive white thickly bedded quartzites in which there are only occasional darker layers of feldspathic grit. Towards the top regular thin beds develop in the light coloured quartzite, which however, often weathers to a pale green or cream colour, due to the presence of chlorite or biotite. Current-bedding is very sparse on the southern limb, (one observation) but appears to indicate movement of currents from east to west. No grading has been observed in these rocks.

The Quartzites of the northern limb run from Aghamore in the west to Cooloughra Bridge in the east. The bedding is inverted on this limb, as shown by the occasional current bedding (two observations). Towards the base of the succession the quartzite is massive and very white, but very thin (1 mm.) darkly coloured layers rich in biotite and chlorite increase up the succession and also become more common towards the east. In this area east of Lough Creggan the beds are thinner and occasionally grey in colour. They are generally about nine inches (23 cms.) thick. Current bedding is present, but considerable deformation has occurred in the rock. Nothing is known concerning the compression in the rock and so no interpretation of these structures can be given other than that currents appear to have flowed from the east.
In thin section the quartzites of the southern limb are seen to consist of well sorted grains of quartz (75%), with minor amounts of K-feldspar, and albite-oligoclase plagioclase. In the more 'impure', grey layers, the plagioclase feldspars become more abundant. There is a noticeably high proportion of heavy detrital mineral grains (2%-4.5%), composed of tourmaline (which shows authigenic overgrowths), zircon, rutile, ilmenite, anatase, and corundum (sapphire). The minor constituents are set in a mosaic of metamorphic quartz.

The rocks of the northern limb are less well sorted. There is a greater variation in the size of the quartz grains. Heavy minerals are less abundant, and also less evident, due to the greater proportion of biotite and chlorite in the metasediments.

The rock is characteristically intensely cut by quartz veins. On the southern limb, in the northern slopes of Liscarney Hill, the quartz veins occupy up to 40% of the rocks. On the northern limb they may occupy still more of the rock. The veins are usually parallel to the bedding, but also cross the bedding in low angle planes on the northern limb. Sigmoid tension gashes infilled with terminate crystals of left handed quartz are also common in the quartzites. The vein quartz varies in colour from white to pink, orange, yellow, and green. The association of intense veining with the Quartzite probably reflects the proximity of faults to each limb of the syncline, for the Highland Boundary Fault bounds the northern limb, and the Letterbrock slide the southern.

3. The Green Slate Group (Pollanoughty Group)

Along the southern limb of the syncline the Cregganbaun Quartzite Group passes upwards into a sequence of blue silts interbedded with thin brown sandstones. These passage beds are up to 50 ft. thick, and are well exposed in small quarries east of Liscarney, and again on the Letterbrock ridge. The more slaty layers have a rich blue sheen, due to reflections from the chlorite flakes of which the layers are composed. The chlorite flakes frequently show abrupt buckling where
they are folded to give a lineation parallel to the axial plane of the second series of folds in the rock. Between these blue layers, the brown sandy layers reflect a combination of quartz and calcite in the rock. The bedding is particularly easy to discern in this passage zone, but decreases in clarity upwards into the fine grained green and purple slates. The slates at least 300 ft. thick on Boheh Hill, are highly cleaved, and it is only where the occasional thin beds of interbedded sandstone occur that the dip of the intensely folded rocks is seen. The slates weather to a delicate shade of pastel turquoise, or to a dull purple colour, in bands parallel to the axial plane cleavage of the rock. The weathering colour varies with the limb of the fold, southward facing limbs having a green colour, northward facing limbs purple. This may be related to the different orientations of chlorite flakes on each limb, for chlorite, with a little biotite is the principal constituent of the slates. The best development of the Green Slates is seen in the exposures of Boheh Hill.

A few calcareous segregations occur in layers near the base of the slate sequence in the eastern part of Boheh Hill, but they have not been recognised in the Green Slates of Letterbrock. These segregations are present as ovoid hollows which line the bedding and are elongated along the tectonic a direction in the axial plane cleavage of the second phase folds.

On the northern side of the syncline the rocks immediately overlying the quartzites show a gradual increase in clay content, and remain highly siliceous for the entire equivalent succession, as far south as the laminated siltstones and sandstones of Aghavarr. In the small quarry by the roadside west of Lough Craggan the rock is a well laminated, siliceous semipelite. (laminae up to 0.25 ins. thick). The rocks are nowhere green or purple slates but are always black semipelites. The equivalent succession is thinner (250 ft. maximum) on the northern limb than on the southern limb of the syncline. In the northern limb a few hollows of calcareous
origin occur in the extreme east, low in the sequence.

4. **Interbedded pelitic and psammitic Group (Oughty Group).**

This Group consists principally of sandstones and siltstones. Above the purely slate-rich group is a series of passage beds in which thin, fine-grained sandstones of green and grey colouration are interbedded with slates and siltstones. The sandstones are relatively competent beds, and have formed open rather concentric folds, in contrast to the slates between them, which have been intensely folded. Current bedding indicating movement of a current from the west towards the east has been seen in sand layers of the central isolate rock of the crest of Boheh Hill. There is some channelling here, indicating movement of water along a north-westerly line.

On the northern limb, the succession again shows siltstones and sandstones, in a rather flaggy succession of laminated rocks which fracture to a blue-grey colour. The occurrence of distinct sandstones between the pelitic bands gives the rock the appearance of being part of a sub-greywacke sequence. Grading has not been observed in these beds. This group is only exposed in the western part of the northern limb at Aghamore and the Owenwee River.

Dewey (1960) recognised several layers of cream coloured ashes in this Group, but none has been recognised during the present mapping.

Towards the top of the sequence in Boheh Hill ovoid cavities resulting from erosion of calcareous nodules occur in layers along the bedding, and elongated along the axial planes of the folds. Similar cavities have been seen at high level in the dry gap to the west of Aghamore Hill.

5. **Mixed Group (Fiddaunarinnia Group)**

The interbedded siltstones and sandstones pass upwards through about 50 ft of green and purple slates, seen in Tawnynameeltoge (Midgofield) townlands before they yield to a series of continuously interbedded sandstones and slates. Differential weathering in such beds enables the dip to be easily determined, and the occasional current bedding in the

Plate 22. Oversteepened current bedding in the Lough Nacorra Group, eastern Owenwee.
thin (6" thick) sandstones indicates the direction of facing in the rocks. In the higher parts of this succession the rocks are almost all sandy but are characteristically fine-grained.

The sandstones of this Group are well sorted, the grains usually 0.1-0.2 mm. in diameter. The thin interbedded laminae very slightly in their colour and composition, the chlorites and micas being the principal variables. Individual thin laminae are continuous over wide exposures although there is a tendency for the thicker beds to be lenticular.

The Mixed Group has not been recognised on the northern limb of the Croagh Patrick Syncline.

6. Lough Nacorra Group

The Lough Nacorra Group is exposed in Eastern Murrisk along the northern slopes of the Letterbrook ridge, and in the heart of the Croagh Patrick syncline, in the Owenwee area. It is nowhere exposed on the northern limb of the syncline in the area mapped.

The rocks are generally pale grey-green in colour in hand specimen, but in thin section they are seen to consist principally of quartz, with lesser amounts of sericite, chlorite, and biotite. Plagioclase and K-feldspars are very subordinate. The schistosity is not apparent in thin section, but a few of the sericite and chlorite flakes are oriented parallel to the axial plane cleavage. The sandstones are usually fine-grained, and composed of angular and sub-angular, often well sorted sand fragments. As the sorting improves, the sedimentary structures increase in complexity, particularly in the more finely grained rocks.

The bedding units in the rock vary in thickness, and often reach 3-5 ft (1-1.6m). Due to the nature of the exposures, (often ice-polished pavements), a truly three-dimensional examination of the sedimentary structures is rarely possible, and so with few exceptions, all the structures have been recognised in two dimensions only.
Fig. 59 Sedimentary structures in the U. Owenduff Group.

- **a)** Current bedding slightly steepened.
- **b)** Contorted lamination.
- **c)** Streamers
Current bedding occurs in the coarser sandstones. In the southern limb of the syncline the foreset beds are commonly inclined at $30^\circ-50^\circ$ to the plane of truncation, and as such have been slightly oversteepened by shear folding (Fig. 59a). In the hinge of the fold, however, the angle between the foresets and the plane of truncation varies from $20^\circ-140^\circ$, again due to tectonic activity. These effects will be described at greater length in Chapter VI.

On the southern limb observations show that the direction of derivation of the currents was not systematically from either the east or the west. In the region of the axis of folding the currents most frequently appear to have flowed from the north towards the south. The truncated foresets indicate the direction of facing of the rocks throughout the syncline.

Since many of the current-bedded strata are up to 3 ft. thick, it is thought that these beds may have been deposited from migrating mega-ripples.

Occasionally scouring has been observed at the base of a current bedded unit, hollows several inches deep being eroded into the underlying sediment. Such scour, later infilled by false-bedding may result from the formation of trough bedding. (Allen 1963).

Dewey (1960) recorded 'dragged bedding' from the false-bedded horizons. This is best described as a series of kinks which break the continuity of a cross-bedded unit of rock, producing an appearance similar to that of a minor fold within the bed. Since the features tend to have a random orientation compared with the extreme regularity of the tectonic features, they are clearly not related to the folding. They were formed during post-depositional and pre-lithification slumping within the rock. The kinks are generative in that they begin as small displacements, increase to pronounced drags, and then decrease in effect until they die out. The movement occurred when the rocks were in a plastic state, for no breaking of the laminae has been seen. The slip effect may have been in a direction down the depositional slope of the individual bed. The cause may have been
overloading of a slightly unstable accumulation of sand, it may have been initiated by seismic activity, or even by extra large waves whose influence extended more powerfully to a greater depth than the normal waves.

**Contorted lamination** is seen in the fine-grained, well sorted sandstones (Fig. 59b). The structures are extremely complex. As a general rule in any one bed the structure of the 'convolutions' increases in complexity upwards. The warping of individual laminae is easily traced. Such complex internal structure may be present in a bed no more than 3 ft. (1 m.) thick, while the beds above and below are undisturbed. The tops of the many irregularly arranged laminae are often truncated by the base of the succeeding sandstone.

In a few layers the upwarped laminations have been seen to rupture very thin cappings of slate, with the result that broken fragments of slate have been forced up into open cusps. The broken slivers of slate have an irregular appearance, although many have later been elongated parallel to the axial plane cleavage during folding. Slate cappings are, however, rare in Eastern Murrisk, and the often very sharp folds are present in perfectly laminated sandstones.

**Streamers.** Tight isoclinal anticlines are separated by gentle rounded synclines. These are seen consistently in sections at right angles to each other across the bedding. The anticlines commonly have amplitudes of 6-8 inches (15-20 cms.) whereas the wavelength may be no more than 2-3 inches (5-8 cms.). The fine laminations may often be traced virtually undisturbed around the anticline (Fig. 59c). There is no apparent reason why any particular layers should be so folded, nor yet why the one beneath it should be the one on which a decollement should develop. The features are clearly due to an extremely plastic form of flowing, and since they are truncated by succeeding beds, they are evidently of very early post-depositional age.

The sharp anticlines and open rounded synclines are different from the convolute structures which occur in some
of the beds. The latter features generally have open rounded irregular 'antiforms', and may have been produced by bodily movement of the sediment of the bed. The former imply no mass movement of the bed, but rather, movement within restricted parts of the bed.

Dewey (1960) referred to the sharp anticlines and open synclines as 'slop structures'. He noted (p. 160) 'the folds appear to be randomly oriented, since they can be observed on joint faces in many different directions'. This is interesting for Dewey appears to envisage a distinct fold in which two limbs, the hinge, and a direction of plunge could be determined. He believed (p. 60) they were 'formed at the top of a pile of water-laden sediments, whose pore pressure near the surface was reduced by agitation'. Reduction of pore pressure in such a manner would release a stream of water in an upward direction, and allow it to escape from the crests of the folds.

The important observation, made in both Central and Eastern Murrisk, that the folds appear to have the same shape in all sections perpendicular to the bedding suggests that the water moved upwards in zones of restricted lateral extent, and probably nearly circular cross-section.

The actual manner of upward flow and escape of the watery is open to doubt, for in no instance has the crest of an anticline been observed in a breached condition. (Many but not all are truncated by later bedding planes). It is possible that as the water forced the sediment upwards the bounding layers were stretched and the grains simply moved apart, thus permitting the water to percolate outwards from the crestal area of the structure, without rupturing the layer.

Since these features are developed in well-sorted fine grained sandstones, they may be related to the thixotropic nature of the original sand. Ackermann (1948 p. 20) has suggested that thixotropy is greatest in well sorted sands of less than 0.2 mm grains. The average size of the grains in the Lough
Nacorra sediments with these strange structures is 0.1-0.15 mm. Thus the sands may have been quick when deposited and only became stable with release of the excess water in the pore spaces.

Selley et al (1963) have described somewhat similar structures from the Torridonian sandstones. The largely diapiric antiforms were believed to be due to the migration of pore waters, and were given the name 'streamers'. This picturesque term has been used in Eastern Murrisk for a similar process which is believed to have been responsible in their formation. These structures were again recorded only from well sorted, fine grained sandstones.

As noted above virtually all of the sedimentary structures show modification by later tectonic activity. It must be stressed that initial examination suggests that many of the above mentioned structures are of tectonic origin. However, the sedimentary structures are generally irregular, or certainly not developed along the directions of the axial plane cleavage which is a dominating feature of certain horizons.

7. **Massive current bedded Group (Owenwee Group)**

The massive sandstones exposed along the Owenwee River in the central part of the Croagh Patrick syncline are of rather flaggy nature. In the field thin, darkly stained parting planes parallel to the bedding cross the otherwise rather massive sandstone. In thin section the rock consists principally of angular to sub-angular grains of quartz, which have not been well sorted. Plagioclase and K. feldspar are present but form no more than 5% of the bulk rock total. Occasional dark brown coloured smears of biotite are present, usually parallel to the bedding, or early lamination. Pale green chlorite is present as flakes, some parallel to the bedding but some arranged along a late schistosity which is not visible in the field. This plane of schistosity is followed by flakes of muscovite, and is evidently parallel to the axial plane of the second phase of fold. Magnetite epidote and zircon are some of the heavy detrital minerals identified in the rock.
Deformation of the rocks is slight, and current bedding has not been drastically reoriented as in other parts of the Croagh Patrick Series. In the Owenwee Group some localities indicate that currents flowed from east to west, others show a southward movement of the water.

**Palaeogeography of the Upper Owenduff Group (Croagh Patrick Series)**

During deposition of the sediments of the Lower Owenduff Group it is believed that a shore line existed to the north of the present exposures and that the very varied assemblage of rocks between the Arenig greywackes and the Upper Owenduff Group may mark offshore changes of facies. It has been stated above (p. 233) that the slates may mark lagoons, sandstones, sandbars and conglomerates gravel banks. The longshore drift appears to have flowed from east to west.

After deposition of the Lower Owenduff Group uplift and tilting was accompanied by erosion, so that today the Lower Owenduff Group is very poorly exposed, along the southern margin of the syncline. The Cregganbaun Conglomerate was deposited on an irregular surface of the partly eroded Lower Owenduff Group. At Oughty, for example, boulders of the conglomerate rest on eroded stacks probably near an old shore line. The conglomerate is thickest in the west of Murrisk, and thins eastward on both limbs, until at Letterbrock in the south, and at Belclare in the north, the conglomerate dies out. This line from Belclare to Letterbrock may mark the limit of the area to the west may have been above sea level, as land, on which no deposition occurred, or the pebbles were not carried that far eastwards. Conglomerates may have been deposited in this area and since completely removed by erosion. Of the three possibilities the second and third are more likely than the first, and the second may be explained by the continued action of the westward currents of longshore drift (which had been noted previously in the Lower Owenduff Group).
The Cregganbaun Quartzite may be in part contemporaneous with the Cregganbaun Conglomerate. Dewey (1960) has demonstrated that, on the southern limb of the syncline, the quartzite-conglomerate boundary is diachronous in the west. This is probably true of the top of the quartzite both in the east and the west. The more impure quartzite to the east, is probably a lateral equivalent of the pure quartzite in the Letterbrock-Sughty area. The quartzite thins from the northern limb (1250 ft) to the southern limb (600 ft) in Eastern Murrisk. This general increase of thickness from south to north has been seen in most parts of the syncline. Mr Margretts (personal communication) has observed the thickening, to the west of Croagh Patrick, from 900 ft in the south to nearly 1500 ft in the north. As in Eastern Murrisk this is accompanied by a decrease in the variation of the beds within the quartzite to the north.

Variations in thickness of the Cregganbaun Quartzites occur along each limb of the syncline. On the southern limb, in the east the quartzite is 400 ft thick at Liscarney, 600 ft between Letterbrock and the western Boheh, where, by means of a syndepositional fault the quartzite increases to 2,500 ft, only to thin again westwards to 1200 ft at Cregganbaun and 1000 ft at Lough Nahalto. On the northern limb in the extreme east the quartzite is 600 ft thick, and this increases to 1250 ft at Aghamore. Anderson (1960) recorded over 2,000 ft of the quartzite on Croagh Patrick itself, and this thins to 1500 ft west of the summit. The very great thickness of quartzite in the western Boheh area is anomalous to the overall pattern of sedimentation, and there is a general thickening towards the central part of each limb. At all stages, however, the quartzite of the northern limb is considerably thicker than that on the southern limb.

In the upper part of the quartzite both in the extreme east and the extreme west of the syncline silts and slates are interbedded with quartzites. There is a distinct facies change from a central quartzitic lithofacies to marginal impure quartzites, suggesting that currents may have been less powerful in these areas.
In the extreme east on each limb calcareous nodules are associated with the beds immediately above the quartzite and it is possible that these may represent elementary forms of limestone being deposited in quieter waters.

Observations on current bedding directions both in Central and Eastern Murrisk suggest movement of the waters from the eastern or north-eastern quadrant to the western or south-western one. The thickening of the sediment towards the north suggests that the source of debris may have been in that direction, and that the centre of movement of this debris ran in a south-south-westerly direction across the area. It is therefore suggested that the relatively well sorted sands were derived from a river which flowed into the basin of deposition from the land surface of Dalradian rocks at the north-north-east of Croagh Patrick. Currents associated with longshore drift may have partly resorted the debris and so indications of the east to west movements occur today in the rocks.

The siltstones mentioned above mark the change from the Quartzite lithofacies to the Green Slate lithofacies. This change took place over a longer period of time in the east and west than in the centre, where it is relatively abrupt.

The deposition of fine grained slates over most of the northern basin clearly indicates either a change of depth of the water in the basin, or a distinct swing in the direction in which the debris was moved. Of the two alternatives the first appears to be most likely in view of the later sedimentation. It is noticeable that while slates were being deposited on the southern limb of the syncline, siliceous semi-pelitic rocks were accumulating on the northern limb. It appears, therefore, that the northern limb may have been submerged to a lesser depth than the southern one at this time.

Following the deposition of the generally fine grained Pollanoughty Group, the coarser sediments of the Oughty Group appear to mark a return to a shallower environment of deposition. Occasional current bedding suggests that currents may have
flowed from west to east at some time during deposition. Over much of the area sandstones, siltstones and calciferous sandstones were laid down in thin beds. The conditions appear to have been fairly stable at this time. The Fiddaunarinnia Group was similarly deposited under relatively stable conditions, which suggest that the basin was slowly becoming shallower.

The Louth Narorra Group clearly represents a fairly shallow water environment of deposition in which the sandstones are strongly current bedded. Many of the sandstones were probably laid down at about the position of the wave base, and consequently are truncated before deposition of horizontal laminations. Other well sorted fine grained sands were reactivated from time to time with release of pore waters from the quicksands and formation of streamers. The current bedded sandstones in some instances appear to represent migrating megaripples, another shallow, almost intertidal zone phenomenon. Scour and trough bedding are other manifestations of shallow water.

The currents appear to have flowed from a north-easterly direction again and were strong. It is possible that some emergence of the earlier deposited parts of the Upper Owenduff Group was taking place at the margin of the basin of deposition at this time.

The less well sorted sands of the Owenwee Group show less evidence of the action of strong currents, and they may represent a further deepening of the basin. Insufficient exposures have been examined in this Group to justify attempting reconstructions of environmental conditions during its deposition.

The sediments of the Croagh Patrick syncline therefore represent material carried into the basin of deposition from a land surface almost certainly of Dalradian rocks. The principal debris appears to have come from a north-easterly direction, and it is suggested that the valley to the north-east of Newport, between Croaghmoyle and the Nephinbeg range, may have had its origins at about this time.
Since the study of the sediments presented in this Chapter represents the most recent examination of the northeastern part of the Murrisk Palaeozoic sediments it is considered that the sediments should now be reviewed in light of what is known of the Silurian and in particular, the Wenlockian sediments elsewhere in Ireland.

In the syncline near Lough Nafooey the Upper Owenduff Group is represented by a basal conglomerate, followed by 3600 feet of graded greywackes and siltstones. The coarse greywackes grade from conglomerates to slates, and the bases of the less coarse deposits show flame structures overturned towards the west, indicating movement of the turbid flows towards the west. Coarse greywackes are apparently deposited near their source, for large boulders require much energy for transportation. Flame structures and complex internal structures observed by McKerrow and Campbell (1960 p. 39-40) are characteristic of lateral turbidites (Dewey 1962). The greywackes therefore suggest that there was some land mass or island of some kind to the east, from which the flows originated.

McKerrow and Campbell (1960) believed, however, that a landmass existed to the south and southwest of the syncline during deposition. Certainly a basal conglomerate is present but there are virtually no facies changes in the sediment comparable to those of the Croagh Patrick Syncline, where there is good evidence for approach towards a northern shoreline. The Connemara Schists are present to the south of the Louth Nafooey Syncline, but there is no reason to suppose that they were above water level throughout the Wenlock. Dewey (1960 p. 163) also believed that the sediments thinned rapidly southwards against the Connemara Schists. In the absence of field evidence for this, and of facies changes, the assertion is open to doubt.

In the Slieve Aughty area of Co Clare the sediments are principally grits and slates with a graphitolic fauna, but to the south of this, in the Slieve Bernagh - Silvermines Mountains
area a mixture of shelly and graptolitic faunas are associated with a succession of conglomerates and grits of fairly shallow water origin. No information is at present known concerning direction of derivation of this material. At Cloaghger Head, on the Dingle peninsula the sediments are again shallow, with a shelly fauna, but conglomerates are not important here (Harper, 1948).

Clearly, therefore, a land mass existed between Clougher Head, and North Galway, but did not extend much further east than the eastern limit of Galway Bay, for the Slieve Aughthy sediments are not principally of shallow water facies.

The land mass to the east of the Lough Nafoocy syncline may be a remnant of the mountain range which was actively being eroded during deposition of the Partry Series, in which case the mass may have been located in the Tuam area, and was probably an island of some sort (St. Patrick's Land).

Charlesworth (1960) has shown a succession of 6000 ft of Silurian rocks in the Curlew Mountains of eastern Mayo. Here he recognised the equivalents of the Lower Owenduff Group as including a basal conglomerate, thinly bedded, coarse grained sandstones, and a limestone, followed by fine-grained sandstones thinly and irregularly bedded. He gave no details concerning evidence for derivation of the sediments in the upper pebbly and micaceous sandstones, which he believed to be of Wenlockian age. Since these deposits are of similar age to the Upper Owenduff Group, and contain in the lower part a marine fauna of Upper Llandovery age, it is clear that the Silurian basin of deposition extended at least as far east as the Curlew Mountains. (Dewey believed it to be more restricted - his fig. 40). At Charlestown the deposits generally represent a relatively near shore environment of sedimentation, and a shelly fauna occurs in Upper Llandoveryian below the Wenlockian.

The nearest exposures of Silurian rocks to the north-east are in the Lisbellaw area of Fermanagh, some 60 miles away
Fig. 60. Palaeogeography of the Wenlock of the northern part of Ireland.
where the rocks are of Llandoverian age. Here again coarse conglomerates with well rounded boulders lie within a sequence which is principally of mudstones (Harper and Hartley, 1938). The boulders have been compared with rocks in the Dalradian of Tyrone and Donegal, to the north. Clearly these sediments mark an inflow of material from a nearby land surface. Since these surrounding sediments are fine-grained and have a graptolitic fauna, it is assumed that the conglomerates were deposited as a result of some temporary outflow of material from a source in the northern region. At Pomeroy (Harper and Hartly 1938, p 82) the succession is of mudstones and gritty flags, again of intermediate to shallow environment of deposition.

Further south in the Longford, Down, Drogheda area the sediments are of deeper water facies, with a graptolitic fauna. At Balbriggan Gardiner (1899) also records grits and slates with Wenlockian and Valentian graptolites associated with lavas and ashes.

Thus the palaeogeography of the central and northern half of Ireland during the Wenlock may be summarised as a land mass of Dalradian rocks to the north, from which flowed rivers into a shallow marginal sea which became steadily deeper southwards. A major river flowed into the sea to the north east of Clew Bay, bringing coarse sediments. An island, near Tuam, also composed principally of metamorphic rocks acted as a source from which flowed turbidity currents in a westward direction, indicating that this basin of the sea deepened westwards. On the two sides of the Tuam island were located deep seas, which were probably linked both north and south of it by shallow ridges. To the south of the Murrisk basin, in the general area of Galway Bay lay another land mass, to the south and east of which the basin deepened, and shelly faunas gave way to graptolitic ones. (Fig. 60).
CHAPTER VI

Structure

Introduction

The major structures present in Eastern Murrisk are the eastern end of the Mweelrea syncline, and the eastern end of the Croagh Patrick Syncline. The northern limb of the Mweelrea syncline dips at about 45° towards the south-southeast west of the Lettereeneen fault. To the east of this break the rocks appear to represent the southern limb of the syncline, for they dip gently north-westwards. North of the outcrop of the Partry Series the rocks of the Glenummaera and Sheeffry Series southwards at increasing inclinations until they are nearly vertical in the Carrowrevagh area. Dewey (1960) recognised a tight anticline in the Owenmore Series to the east of Oughty, but this has not been recognised in Eastern Murrisk. The Croagh Patrick Syncline is represented by nearly vertical, northward facing sediments on the southern limb, and overturned southward facing sediments on the northern limb. Two large slides are believed to be associated with this syncline; the first, along the southern limb, marks the junction of Silurian and Arenigian sediments, and the second, near the axis of the syncline at Knappaghbeg, marks a dislocation which brings the rocks of the northern limb at least two miles east of the nose of the syncline further south.

Two principal phases of folding have been recognised and several episodes of minor movement are also reflected in the rocks as cleavages, faults and joints. Since the rocks vary greatly in lithology they reacted differently to the deformations, and structures related to the various phases of movement are preserved in separate localities. In some areas however, evidence for three phases of deformation is present.

First phase of folding ($f_1$).

Dewey (1960), in a detailed account of the structure of the Oughty-Letterbrock area demonstrated the existence of
early folds which plunge steeply westwards, and are related to a steeply southward-dipping slaty cleavage. He showed that pebbles in the Cregganbaun Conglomerate had been elongated along this cleavage, which contains the tectonic \( \mathbf{a} \) direction of the first phase of folding. The open anticline and syncline of the Oughty area were shown to pass eastwards into the underlying Ordovician sediment, where isoclinal folds of the same age are present.

One isoclinal is present to the east of Oughty, but no evidence exists for its presence further east, in the Letterbrock area, where all the rocks face southwards. The sharp isoclinal fold may therefore be along the regular east and west striking rocks in the Ordovician sediments. Similarly, no evidence has been seen in Eastern Murrisk for the continuation of the syncline to the south-east of Oughty. It is suggested that the two folds may be generative, and that the varying tightness of folding on the two sides of the unconformity may be due partly to the different initial orientations of the beds undergoing folding; (the Silurian rocks were nearly horizontal before the first phase of folding, whereas the Ordovician rocks were steeply inclined), and partly due to variation in the response of rocks of different lithology to the same tectonic stress. Much of the movement may have been taken up by bedding plane slip, and shear slip along the slate layers.

Dewey measured deformed pebbles in the Cregganbaun and Letterbrock conglomerates. The Cregganbaun Conglomerate is not present in Eastern Murrisk, and no deformed pebbles have been seen in the Letterbrock Conglomerates. He believed all deformation of the pebbles to be due to the \( f_1 \) folding, and showed that the \( \mathbf{a} \) tectonic direction plunged at about 40° towards 100°. He stated that compression in the \( \mathbf{ac} \) plane was 60% on the limbs of the folds, but that this decreased to 20% in the hinges. The plunges of the axes of the \( f_1 \) folds vary, while the tectonic \( \mathbf{a} \) direction remains constant, so the \( f_1 \) folds are not always parallel to the tectonic \( \mathbf{b} \)
Structures associated with $f_1$ occur in the northern part of Eastern Murrisk. They are best developed on the Letterbrock ridge, but also occur on Boheh Hill, Carrowrevagh Hill, and on the Slieve Mahanagh ridge.

The Croagh Patrick Syncline owes its present outline to the first phase of folding, for the later fold movements were oblique to the axis of the syncline. The principal axis of the syncline in Eastern Murrisk plunges along $90^\circ$, and the minor folds associated with this phase of movement generally plunge westward along a similar bearing.

The axes of minor folds, $l_1$, show a considerable variation in their angle of plunge. In the Letterbrock and Cordarragh areas they plunge at $30^\circ$-$70^\circ$ westwards, but at Carrowkennedy and Carrowrevagh the plunge is $10^\circ$-$20^\circ$ towards the north-west and west respectively. The folds are relatively tight, and the hinges are well defined. The amplitude is low and the wavelength of the folds rarely exceeds 3 ft. (lm.). The minor folds are clearly early structures, for the second axial plane cleavage, $S_2$, cuts across them in some places in the Letterbrock area.

The axial plane cleavage, $S_1$, of the early structures always dips steeply southwards, and strikes roughly east-west. It is best seen in the Cregganbaun Quartzite at Letterbrock, where it looks like a plane of schistosity.

Parallel to the $l_1$ axes of folding are lineations, resulting from a preferred orientation of chlorite flakes. These lineations are preserved on the limbs of the $l_2$ minor folds. They are usually more steeply inclined than the later folds.

The poles to $S_1$, at any one locality are roughly $80^\circ$ from the plot of the $l_1$ structures at the same locality. This may be the result of later tightening of the features during compression associated with the second phase of folding.

At the northern end of the Partry Mountains, minor folds of variable plunge are seen. The overall structure of the
Fig. 61. Stereographic plot of $F_1$ structures.

- Plot of plunge of minor folds.
- Poles of axial plane cleavage

Location of the folds.
B Bohaun  Ck Carrowkennedy  Cd Cordarragh
Cv Carrowrevagh  K Kiltarsaghaun  T Teevinish

The envelope near the poles to the cleavages marks the average position of $L_2^c$. 
Partry Mountains is controlled by the open concentric $f_2$ fold of the Mweelrea syncline. The fold is characterised by the absence of cleavage in the sandstones of Eastern Murrisk although an axial plane cleavage develops in the slates of the Glenumbera Series.

In the Kiltarsaghaun area, the end of the Mweelrea syncline is marked by a series of minor crumples, of very open style, and without an axial plane cleavage. A similar group of folds is present in the Bohaun area, where the sandstones form open folds, while the slates beneath are intensely cleaved along a plane which dips steeply southwards, and appears to be parallel to the $S_1$ structures of the Letterbrock area. The analysis of the folds of both Kiltarsaghaun and Bohaun are shown in Fig. 61, where they occupy a fairly restricted area on the stereographic net. The close association of the folds with the $S_1$ axial plane cleavage at Bohaun suggests that the open, minor folds, are connected with the principal phase of $f_1$ folding, during which the Mweelrea syncline was formed.

At Teevinish a large, open $f_1$ fold is present, complete with $S_1$ planes and $S_1$ folds which plunge eastwards at $35^\circ-50^\circ$. These folds are also shown on Fig. 61. The folds of Teevinish and Kiltarraghbaun occupy two curving fields within the eastern sector of the net. The $f_1$ folds from the Carrowkennedy, Letterbrock and Corrarragh areas have also been plotted. All the $f_1$ folds appear to lie on a small circle which is arranged at $75^\circ-85^\circ$ from the pole of the axial plane cleavage, $S_1$, at each locality. The poles to $S_1$ show a small spread, possibly due to later movements.

The folds may have been produced in the $ab$ plane, and subsequently moved from it during the $f_2$ folding, in which case each lineation will have moved through the $a_2$ direction to reach its present location.

Alternatively the folds might have been produced in the axial plane of the fold i) by variation of the attitude of $a$ and $b$, or ii) by differential movement along the $a$ direction.

Dewey (1960) has shown that the tectonic $a$, $b$ and $c$
Fig. 62. Minor folds associated with $F_1$ and $F_2$

a) North of Cordarragh, $S_2$ cleavage on $F_1$ minor fold.

b) Rooghaun, shear folds on $F_2$ cleavages.
directions for this phase of folding were constant throughout central Murrisk.

In Eastern Murrisk there are no structures which could be used to determine the \( a, b, \) and \( c \) directions of this phase, the conglomerates used by Dewey (1960) are not present further east. If the constant tectonic directions were maintained into Eastern Murrisk then variation of the attitudes of \( a \) and \( b \) could be discounted as a causative mechanism.

A third possibility, which could only explain part of the variation, is that the beds had already been thrown into different positions before the minor folds developed. This could account for the plunges at Kiltarsaghaun, Bohaun, Teevinish, Cordarragh and Letterbrock, but could not explain the gently westward plunging folds at Carrowkennedy, where the beds are inverted but steeply inclined.

The difficulty in understanding how the variation could be produced as an \( f_2 \) feature arises from the fact that over much of the area the orientations of \( a_{12}, b_{12} \) and \( c_{12} \) are known. The axis around which any movement would have had to occur during \( f_2 \) is the \( c_{12} \) axis, the direction of maximum compression.

The reason for the spread of the \( l_1 \) structures along the small circle is not understood.

In the Ordovician rocks minor folds of the first phase have been recognised at Lanmore, Carrowkennedy, Corveagh, Teevinish and Croaghrimbeg. These folds all have steeply southward dipping axial plane cleavages, and there is always an anticlockwise sense of rotation (Fig. 62). Later cleavages \( (s_{12}) \) cut across the folded rocks and are seen to cut the early cleavage. Thus throughout Eastern Murrisk there is evidence of an apparent rotation, a movement of the northern area towards the west relative to the south. In the more massive grits of the Derrylea Group at Claddy quartz veins are associated with this phase of rotational movement.

**The Second Phase Folds**

The effect of the second phase of deformation is most pronounced in the Boheh-Owenwee area, where the generally
Fig. 63. Different styles of folding in adjacent beds of pelite and psammite on Bohel Hill.

(Drawn from photograph taken looking down the plunge of $F_2$)

-thickness perpendicular to the bedding

\[ \text{psammite} \]

\[ \text{pelite} \]

\[ \text{thickness parallel to the cleavage} \]

a) in psammite

\[ 6'' \]

b) in pelite

\[ 10'' \]

a) in psammite

\[ 4'' \]

b) in pelite

\[ 4'' \]
Fig. 64. Orientation of 'eyed' folds from the Tawnynamelltoge area.

(Drawn from photograph)

N
S

psammite
pelite

S
S

Schematic representation
Plate 23. Difference of style of folding in slate and siltstone, Boheh Hill.

Plate 24. Complex surface patterns due to folding in slates, Aghamore Hill.
rather pelitic rocks have been very closely folded. Movement appears to have taken place along planes parallel to the axial plane cleavage, with the result that similar folds of shear type have been produced.

Where pelitic and psammitic layers are interbedded they are seen to have reacted differently to the stresses, the psammites being folded in a nearly concentric style, whereas the pelites between them have been thrown into similar folds. This may be demonstrated by measuring the thicknesses of the beds parallel to the axial plane, and perpendicular to the bedding planes. In the psammites the latter gives a nearly straight line graph, as in concentric folding. The pelites give a straight line graph in the other direction. Some measurements of these were made in the field, and are presented in fig. 63. Details of the style of shear folding are also given in this figure.

Characteristic of this stage of folding in the Croagh Patrick Syncline are westward plunging folds in the east, and eastward plunging folds in the west, with a steep northward dipping axial plane cleavage. Outside the Croagh Patrick Syncline the northward dipping cleavage, S₂, is commonly seen, and often cuts across earlier, f₁ structures, and is clearly not related to them.

In the Croagh Patrick Syncline the bedding in the pelites is frequently displaced along the axial plane cleavage, and occasionally are drawn up along these planes, so that they penetrate the overlying psammitic layers. In the Tawnynam-eeletee area exposures are seen in which the eye-shaped sections are seen where the crests of the very small minor anticlines pierce thin layers of psammite. The resultant pattern shows a double orientation of the 'eye' structures, in which the 'eyes' lie along narrow zones parallel to f₂, with the long axes of the elliptical sections parallel to this direction. The minor axes are also arranged in rows which plunge northwards across the face at an inclination of 15°. (Fig. 64). These minor axes may be related to the
Fig. 65 Ellipsoids of deformed calcareous segregations.
earlier fold series. Alternatively, the minor planes on which the eyes lie may be related to the $s_{2a}$ strain-slip cleavage.

Dewey (1960, p.181) showed that the second series of movements led to variations in the orientation of $l_{1a}$, and $l_{1c}$. He further stated that $l_{1b}$ and $l_{2b}$ (the axes of intermediate stress) appeared to have been constant in direction during both phases of movement in the Oughtly Letterbrock area. At no point did he indicate what evidence had been used to locate $l_{2b}$. This axis has since been found to plunge gently westwards on the Letterbrock ridge instead of eastwards as in the area examined by Dewey.

The orientations of the principal axes of stress during the second phase of folding may be found in two ways:

1) Direct observation of the deformed calcareous segregations which appear to have been distorted during the second phase of folding (and lie near the axial plane cleavage), indicate the $a$, $b$ and $c$ directions at that time. The deformed segregations occur in many parts of Eastern Murrisk (see Fig. 65). There is no evidence of any early $f_1$ deformation of the segregations, which may have formed during the interval between the two phases of movement.

All three axes may be measured in cases where several sections are visible due to jointing. The ratios of the lengths of the axes have been calculated and the strain ellipsoid constructed from these.

The $a$ axis ($L_{2a}$) is usually steeply inclined, plunging at about $80^\circ$ eastwards, but is occasionally at a lower angle, down to a minimum observed inclination of $55^\circ$ and reaching maximum observed inclination of $87^\circ$. The axis plunges towards an average bearing of $84^\circ$ (16 readings). The $b$ axis ($L_{2b}$) plunges gently ($10-20^\circ$) towards a bearing of $260-280^\circ$, and the $c$ axis, ($L_{2c}$), is nearly horizontal in a north-south direction. Thus the $a$, $b$ and $c$ axes of $f_2$ appear to be fairly constant in orientation in Eastern Murrisk.

The flattening of the ellipsoid is greatest in highly pelitic rocks in the Croagh Patrick Syncline, and least in the
Fig. 66 Intersection of $l_1$ lineation and $S_2$ axial plane cleavage to show the location of $l_{2a}$
Fig. 67. Structural map of the Owenwee-Letterbrock area.

- --- $t_1$ minor folds
- --- downward-facing $f_2$ folds
- --- upward
- --- cleavage

Axial trace of syncline

Owenwee

Letterbrock

Scale six inches to the mile

Stereographic net showing the plots of the $f_2$ fold axes in the areas shown.
sandstones of the Derrylea Group at Claddy.

2) The axes of stress may also be calculated from the highly folded rocks of the Croagh Patrick syncline. The lineations \( l_1 \) parallel to the axes of the folds of the first phase of movement have been deformed by later folding, and measurement of the variation of plunge and azimuth of the lineations reveals the former trend of the \( f_1 \) folds. The intersection of the great circle containing the poles of \( l_1 \) with the great circle of \( s_{2} \), the axial plane cleavage, lies along the axis of the second phase folds. (\( L_2 \)). This is shown graphically in fig. 66. \( L_2b \) and \( L_2c \) are mutually perpendicular and \( 90^\circ \) from this point. Since \( L_2 \) obtained by this method is located in a position virtually identical to that obtained by the other method, the locations of \( L_2b \) and \( L_2c \) are probably also in similar locations.

In some cases clay pellets have been elongated in the plane of the slaty cleavage, parallel to the axial planes of the second folds. It is clear from the orientation that such pellets are seen in the plane containing both \( a \) and \( b \) axes of the same strain ellipsoid. Unfortunately, these deformed clay pellets are rare and it is not possible to compare the degree of deformation with the orientation of the cleavage, which is everywhere steeply inclined towards the north. Knill (1960) noted a systematic variation in the deformation connected with changing orientation of the cleavage in a series of phyllites at Kilmelfort in Argyllshire. It is not practicable to compare the \( ab \) sections of the deformed calcareous segregations described above, for their change of shape is closely connected with changes in the lithology of the turbidites in which they occur.

It is clear from a comparison of figs. 66 and 67 that the axes of the second phase of folds were not formed parallel to \( L_2b \), for while \( L_2b \) is relatively constant in orientation over the area, the fold axes, \( L_2 \), vary in plunge amount and direction. In the Letterbrock area the folds plunge eastwards, whilst in
the Boheh-Liscarney area they plunge gently westwards. A traverse from Boheh Hill towards Owenwee reveals an increase in the inclination of the bedding, and also in the plunge of the main folds \((12)\). In the field it is clear that there is a connection between these two features, for where the bedding is steep and at a high angle to the \(S_2\) axial plane the angle of plunge is great where the strike of the bedding is at a low angle to \(S_2\) than the plunge is less. The variation in plunge is seen in fig. 67, where the inclination of the \(1\) lineation increases along the axial trace of the syncline with approach to the western margin of Eastern Murrisk.

In the Letterbrock area the folds increase in plunge in an eastward direction, and for some way no second phase folds are seen. This appears to mark the area in which \(12\) has a nearly vertical plunge, and the movement was probably taken up in bedding plane slip, for beyond this zone (in the Glinsk area) the minor folds plunge steeply westward, the inclination decreasing further to the east.

Accompanying the change of direction of plunge of the folds is a change in the direction of facing of the minor structures. Facing was defined by Shackleton (1958) thus: 'A fold faces in a direction normal to its axis, along the axial plane, and towards the younger beds'.

In the western part of the Letterbrock area the rocks as whole face northwards; the minor folds plunge gently eastwards, and face downwards. As the plunge increases to the vertical, the rocks face westwards, and at Liscarney the minor folds face upwards. Along a similar line, on the axis of the Croagh Patrick Syncline, the rocks at Boheh face upwards, but an increase in the inclination of the fold axes leads them to face westwards in the Owenwee area (see Fig. 76).

It is therefore apparent that the direction in which the minor folds face on any major structure depends on the initial orientation of the beds in the structure. The beds of the Croagh Patrick Syncline in Eastern Murrisk had been previously tightly folded during the \(f_1\) movements, and later
Fig. 68a) Detail of structural mapping on Boheh Hill.

Fig. 68 b) Minor f2 fold of similar style from Boheh Hill.
movements were superimposed on structures of varying attitudes. The axial planes $S_2$ and plunges of the folds $l_2$ are oblique to the main axis of the Croagh Patrick Syncline, and so have been demonstrably superimposed on the previous structures. It is this superposition which has led to the variations in the direction of facing of the folds.

Anderson (1960) believed that the major swing of the southern margin of the Croagh Patrick Syncline in the region of the Corvock granite was due entirely to the presence of this pre-regional metamorphic granite acting as a stable block during deformation. Dewey (1960), however, considered that the granite represents the latest phase of orogeny, and considered it to be later than the fourth phase of cleavage seen in Central Murrisk. Later (Dewey and Phillips, 1963) he postulated that it was coincident with a fifth phase of movement. No examination of the granite was undertaken during the present investigation but it seems probable that the granite, which resembles the Galway granites, may be of similar age to these, which are known to be about 365 million years old. (Giletti et al. 1961). If so the Corvock granite is probably much later than the principal foldings in the area.

The arc in the southern margin of the syncline east of the Corvock granite may, however, be partly an $f_2$ feature, for the margin recovers its more northerly position to the east of Letterbrock, where the $f_2$ minor folds are best developed. This is aided by the presence of post-Wenlockian dextral faults, each of which shifts the junction towards the north.

During the mapping of Bohoh Hill the structure of the nose of the syncline was found to consist of several anticlines and synclines of $f_2$ age, on which the related minor folds formed $S$, $W$, and $Z$ shapes, with the aid of these features three separate synclinal axes were identified, each running parallel to the second phase folds. The minor folds are tight (fig. 68) and show compression of up to 70% on the limb. In the pelites they are all true shear folds in which small flakes of chlorite have developed, parallel to the axial plane cleavage. As
Fig. 69a. Unfolding of current bedding oversteepened along $S_2$ cleavage.

b) as seen in the field.
mentioned above the early \( \ell_1 \) lineation is folded over the \( L_2 \) axes. The lineation swings into a nearly parallel orientation at the hinge of the \( L_2 \) folds, but diverges from it on each side. Thus the angle of divergence between \( L_1 \) and \( L_2 \) decreased to zero at the hinge but reaches 50° on the limbs. This is entirely due to the shear folding.

The orientation of the strain ellipsoid has already been discussed. The shearing and compression have a marked effect on sedimentary structures which have been observed in the hinge area near Owenwee. Here false bedding has been observed in thin beds of sandstone which have been tightly folded during the second phase of movement. The angle of divergence between the foreset beds and the plane of truncation has been seen to increase from 20° on one limb to approximately 90° at the hinge, and continue to increase to 140° on the other limb. (Fig. 69). In this case all movement was parallel to the \( S_2 \) axial plane cleavage.

In the Owenwee area the rocks of the Lough Nacorra Group show a systematic derivation from a northerly direction (observations on current bedding). The lineation formed by the intersection of the foresets of the false bedding, and the bottomsets has been observed in many places, and always plunges fairly steeply westwards between the extreme bearings of 250° and 290°. This is a small spread of observations, and apparently represents a constant direction of derivation. In this area, however, the tectonic \( a, b \) and \( c \) directions for the second phase of folding are known (from deformed calcareous segregations) and the amount of compression may be easily calculated. The spread of the sedimentary lineations has been plotted on a stereographic net and arranged on the great circle of the average dip in the restricted area under investigation. (Fig. 69b).

Ramsay (1961, p.89) has described the method used in unfolding the lineations. The deformation on the \( ab \) and \( ac \) planes was initially removed, and as a result of this the lineations moved on paths through the \( a \) direction to their new location on the reoriented circle of the bedding plane. After removal of the plunge of the folds the lineations
are arranged in a rather more restricted arc near the margin of the grid. Now, however, the principal correction, for deformation in the bc plane remains to be applied. Since some of the intersections lie on each side of the b axis, removal of the compression (80%) has the effect of dispersing the field of the lineations, and the resultant readings are spread between 212° and 325°. This large spread is more in the order expected from varying currents flowing from a northerly direction. The effects of the first phase of folding remain to be removed. Since the inclination of the bedding after removal of the f₂ features is very low the corrections applied are small. Dewey (1960) has indicated that L₁ was constant in orientation in Central Murrisk. The lineations have been moved to the edge of the grid through the L₁ direction and this reduces the spread a little, to 221°-318°. The amount of compression during the first phase is not known and the complete correction cannot therefore be applied to the readings. Nevertheless it is clear that the lineations would have a wide spread, indicating that while the currents appear to have flowed from the north, some also flowed from the north-east, and others from the north-west. Thus although in the field the sedimentary structures appear to have flowed from the north-east, and others from the north-west. Thus although in the field the sedimentary structures appear to indicate a very constant flow of the currents, considerable errors could be made if the effects of folding were not taken fully into account in their interpretation.

The effect of change of volume of the calcareous segregations on the values of compression is small. In those at Owenwee the volume change is no more than 1%, but it rises to 10% in the Slieve Mahanagh area.

On the northern limb of the syncline there is field evidence of only one phase of folding in the Aghamore-Couloughra area. The tight folds in the politic quartzites may be either first or second phase features, judging from field evidence alone. They are shear folds with well developed axial plane cleavages which dip gently northwards. The association of similar folds with an axial plane cleavage suggests
that the folds may be second phase rather than first. The pres-
ence of flakes of chlorite developing along the axial plane cleavage
supports this view. The minor folds face southwards, for the strat-
igraphical succession is inverted in this area.

The axial trace of the Croagh Patrick Syncline is known in the
Owenwee-Boheh area, but to the north in Knappaghmanagh the ground
is completely drift-covered. The rocks of the northern limb,
when they reappear, extend several miles beyond the eastern limit
of the southern limb. The northward termination of exposures of the
southern limb occurs along an abrupt cliff marking the northern side
of Boheh Hill. This cliff is believed to lie along a fault which
runs parallel to the axial trace of the early structures. The
fault appears to have developed at the same time as the $f_1$ movements.
A similar fault marks the southern margin of the Silurian rocks. It
is frequently marked by quantities of vein quartz. The southern
fault has been buckled during the $f_2$ movements. The faults, and
the $S_1$ structures, appear to have been contemporaneous, and as such are
slides (Bailey, 1910) they have been termed the Knappaghmanagh
and Letterbrock slides respectively. (Fig. 67). It appears that
on each fault there was considerable translation of the rock in a
clockwise direction. This is the opposite sense to that recorded
in the $S_1$ folds of the Ordovician rocks to the south. The nose of
the Croagh Patrick Syncline on Boheh Hill preserves the same anti-
clockwise sense of rotation as seen to the south. At no point further
east has the southern limb been seen, but it is probable that it
resumed its eastward trend to the north of Knappaghmanagh, and that
all traces of the rocks have been removed during glaciation. Faulting
along the slide may have cut out some of the beds.

Between the line of the Knappaghmanagh slide and the Aghamore-
Couloughra ridge the rocks have been completely folded back so that
the northern limb is now inverted, although dipping northwards at a
moderate angle.

*The $f_2$ folding in the Partry Series.*

The rocks of the Partry Series form a major syncline in which
the axial trace swings from west-northwest and east-southeast north
of Kilary Harbour to north-east and south-west in the East of Murrisk.
Fig. 70. Untilting sedimentary lineations from the Partry Series.

B great circle of the bedding
A removing a plunge of 10° to the east
C " " " " west

b) Long axes of conglomerate from the eastern facies.
   Variation 100°-140°.

a) False-bedding in sandstone from the western facies.
   Variation 55°-85°.
Dewey (1960) who examined slates beds which preserve early cleavages, believed the syncline to be an \( f_2 \) structure. This is not in conflict with any evidence from Eastern Murrisk. In the Lough Glenawough area the structure appears to plunge gently westwards, but to the east of the Lettereeneen fault it plunges gently northwards.

The sandstones and conglomerates of the Lough Glenawough area have been thrown into an open concentric structure in which no axial plane cleavage is apparent. In the sandstones of the western facies current bedding is present, and in the conglomerates of the eastern facies the pebbles often show a clear alignment of their long axes. In Chapter IV (a.v.) these features were used to indicate a south-easterly direction of derivation for the sediments. To reach this conclusion it was necessary to unfold the structures and find the orientation of the features before the \( f_2 \) movements.

The procedure followed is as described by Ramsay (1961 p.85) for plunging flexural folds.

a) The intersection of the great circles of the foreset laminations and the bedding plane forms a lineation which varies from place to place. An average bedding plane was used and the extremes of variation of the lineations plotted on this. The syncline plunges gently to the west-southwest near L. Glenawough, and a maximum inclination of 10° of the axis was taken as representative. The plunge of the fold was removed and the tilting subsequently removed from the beds. The intersection lineations at this stage moved along small circles and indicated a spread of from 60°-80°. Since the lineation is essentially along the sedimentary 'b' direction, the currents flowed from between 150°-170°, viz., from the South-southeast. (Fig. 70a).

b) In the eastern facies the long axes of pebbles lie along 110°-140°. A similar method of correcting for the plunge of the fold (gently northwards at Glennagashleeny) and tilting of the beds has been used, with the result that the sedimentary 'a' direction is known to have been in the arc 100°-135° - indicating an east south-easterly derivation for the sediments, (Fig. 70b).
Strain-slip cleavages.

Minor cleavages later in origin than the principal foldings occur in many parts of Eastern Murrisk. Dewey (1960) demonstrated the existence of two pairs of cleavages, $S_3^a$ and $S_3^b$, $S_4^a$ and $S_4^b$, in Central Murrisk. These have also been recognised in Eastern Murrisk. Their characteristics are:

- $S_3^a$ - gentle northward dip and northward sense of rotation.
- $S_3^b$ - steep southward
- $S_4^a$ - gentle southward northward
- $S_4^b$ - steep northward

Dewey and Phillips (1963) referred to the pairs as $f_7$ and $f_8$ structures. The cleavages are of restricted distribution over the whole of Murrisk, and the number developed at any one locality varies.

The cleavages $S_3^a$ and $S_3^b$

The $S_3^a$ cleavage is widely developed. It occurs on Slieve Mahanagh, Boheh Hill, the slopes above Erriff, and in the Creaghrimbeg-Glennagashloeny area. At Slieve Mahanagh the shallow cleavage gives rise to small monoclinal structures in the interbedded grits and slates. Movement along the cleavage planes has produced shear folds of northward rotation in the Cordarragh area, north of the cross roads. In places the $S_3^a$ cleavage is seen to cut through the $S_2$ cleavages where they curve through graded turbidites. The $S_3^a$ cleavages are distinctive in their orientation, and lack of curving in the graded beds. The presence or absence of curvature in the cleavage varies with the type of cleavage, and may be controlled by the nature of the cleavages developed. In slaty cleavage the cleavage planes are relatively close together, and the texture of the rock exerts an influence on the run of the planes. In strain-slip cleavage the cleavage planes are separated by thin strips of rock which may have a cushioning effect which prevents the texture of the rock from modifying the run of the boundaries of the microlithons. The smaller amount of energy available is used in moving the microlithons rather than individual grains.

On Boheh Hill the $S_3^a$ cleavage is represented by shears which cut through the $S_2$ planes and break them into small segments up to

Plate 26. Intense quartz veining in the Creggan baun quartzite.
1 cm thick. This $S_3a$ cleavage is uncommon in the northern part of the area.

The slates of the Glenummera Series provide an ideal lithology for the development of cleavages, and along the slopes above Erriff and at the entrance to the L. Glenawough corrie the rocks have been intensely cleaved. $S_3a$ is present here, and is cut by a major cleavage, $S_4a$. Again in the slates of the Glenummera Series, the $S_3a$ cleavage occurs in the stream on the eastern flank of the Glennmaghleeny Valley. Here the intense $S_3a$ is accompanied, for the only known time in Eastern Murrisk by $S_3b$. Dewey (1960) stated that this $S_3b$ cleavage was rare in Central Murrisk, and indicated its occurrence in an area west of Derryilra, where only $S_3a$ cleavages have been seen during the present work.

The cleavages $S_4a$ and $S_4b$.

The two cleavages $S_4a$ and $S_4b$ occur together in the slates of the Glenummera Series above Erriff, where they are demonstrably related to each other. In places they occupy a position along the axes of small conjugate folds, which indicate the sense of movement on each cleavage.

Cleavage $S_4a$ is widely developed in the Letterbrock, Corveagh, Lanmore area, where it forms a few small folds, but generally it puckers earlier cleavages. It is present in the small quarry on the Drummin road (N53°43'06" W9°35'09") and also beside the road at Rooghaun (N53°43'10" W9°31'53").

The Glenummera Series is broken by this cleavage along its whole outcrop from Erriff to Croaghrimbeg, but again associated folds are rare.

The $S_4b$ cleavage is present in the Glenummera Series of Erriff and Croaghrimbeg, but is best developed in the slates between the lateral turbidites of the Claddy Bracklagh area. Again no true folds are related to the cleavage, but slip in a northward sense of rotation occurs in most places. In a few exposures $S_2$ and $S_4b$ occur and the rock is broken into thin wedges by the pencil cleavage effect.

The orientation of $S_4b$ varies from place to place. Usually it dips steeply southwards, but in rather restricted areas it becomes
vertical or even steeply northward dipping. Where it dips northwards, (in the Glenummera Series) conjugate folds are associated with the orthorhombic pattern produced.

Dewey (1960) described the strain-slip cleavages in detail and showed that they may be distinguished from the earlier slaty cleavages in thin section as well as in the field. He pointed out that the strain-slip cleavages occur as part of a pair of fractures on which the sense of rotation is constant, whereas in the slaty cleavage rotation is always towards the hinge of the major fold. For further detailed description the reader is referred to his work.

The strain-slip cleavages develop at an acute angle to the direction of the principal compression, which direction is believed to bisect the angle between the two cleavages, and must theoretically be perpendicular to the intersection of the two cleavages. It is not necessarily at right angles to any folds produced by movement on the cleavages. The strain-slip cleavages cut pre-existing cleavages and bedding planes, which are often arranged obliquely to the direction of compression. Folds developing on these surfaces will clearly be oblique to the stresses causing the movements. Thus folds produced during the development of strain-slip cleavages are not reliable aids in deciphering the stress directions.

In Eastern Murrisk the stress directions are approximately as shown by Dewey (1960 Fig. 72). The principal axis of compression during the formation of $S_3a$ and $S_3b$ plunged at a moderate angle ($50^\circ - 60^\circ$) towards the north, whereas during formation of $S_4a$ and $S_4b$ it was inclined towards the south at a slightly greater angle ($55^\circ - 70^\circ$). The folds in the Glenummera Series.

Dewey (1960) indicated that the folds in the Glenummera Series were attributable to two modes of formation. The earliest folds, he believed, were due to drag and bedding plane slip at the base of the Partry Series. These drag folds were accompanied by small thrusts and faults. The second mode of origin of the folds was related to strain-slip cleavage, and led to the development of monoclines and conjugate folds, as described above.

In the area above Erriff the slates of the Glenummera Series
underwent much dislocation during the $S_3$ and $S_4$ phases of movement, but there remains evidence of pre-$S_3$ movement, for the $S_3a$ cleavages cut contorted quartz veins in the sandy parts of the series. The quartz veins are sometimes sigmoid in shape, and indicate an upward movement of the sediments of the Partry Series relative to the Glenummera Series. Clearly this movement was pre-$S_3$. There are minor thrusts within the Glenummera Series, but these are rare in the upper parts of the Series, adjacent to the base of the Mweelrea Group. It appears that any early rotation accompanied by dragging, thrusting, and bedding plane slip took place well within the confines of the Glenummera Series. This may reflect greater ease of slip within the slate sequence, although Dewey (1960) recorded the slipping near the top of the Glenummera Series.

In the Loughanshee area, the upper part of the Glenummera Series is free from slipping, dragging, and thrusting, and only the $S_{4b}$ cleavage is well developed here. However, a fifth, $S_5$, cleavage develops towards the east, and this is parallel to faults which run into the Lettereeneen fault complex.

In Glen Mask the green slates appear to be of the Glenummera Series. An examination of the bedding reveals that the rocks within the fault block have been inverted. The cleavages, however, have maintained their relationship to each other and to the bedding, with the result that $S_{3a}$, $S_{4a}$ and $S_{4b}$, are still recognisable. Conjugate folds related to $S_{3a}$ and $S_{3b}$ are present. The $S_{4a}$ cleavage is associated with small monoclinal structures which show a southward sense of rotation. This cleavage is itself broken into sharp chevron folds along a later fracture, an $S_5$ joint drag feature, which dips approximately parallel to the fault. However, $S_5$ fractures are not common. There are many minor planes of slipping, faulting and thrusting in this area. Some may be related to rotation of the Mweelrea Syncline, but most are connected with the principal faults which bound the isolated block of slates.

In Croaghrimbeg the few folds are monoclinal drags associated with the $S_{3a}$ cleavage.

Quartz veins.

During the first phase of folding, $S_1$, quartz was injected along the axial plane cleavage in some places on Slieve Mahanagh. This quartz
Fig. 71. Late stage fracturing of two series of quartz veins.

1. Injection across the bedding.
2. Injection parallel to the bedding.
3. Fracture along f, cleavage.
4. Strain slip cleavage.
is in thin sheets almost parallel to the bedding.

The $S_2$ movements led to folding of the quartz along the $S_1$ axial plane cleavage. Such folds have been seen at Claddy, and at Corveagh, where measurement of striations on the veins reveals that they now lie along a great circle centred on $l_2b$.

Towards the end of this phase of folding quartz was injected into the axial planes of the $S_1$ monoclines, the quartz forming in gashes no more than 3 ft (1 m.) in length, and up to 6-inches (15 cms.) in width. These gashes are sometimes drawn into the $S_2$ axial plane direction.

The completion of the folding was followed by injection of quartz along nearly vertical planes in a north-south direction. These veins lie approximately along the $ac$ plane of $f_2$ and cut the earlier veins. The north and south trending veins are themselves broken by nearly contemporaneous east-west quartz veins, which lie near the $ab$ plane of the folding. Extending from the east-west veins are some minor north-south veins of the same age.

All phases of quartz injection are clearly seen in the grits of the Derrylea Group in the Claddy area, where quartz of the final stage has been broken by the $S_{3a}$ cleavage. Subsequent movement along the shear planes of the $S_{3a}$ cleavage has displaced the quartz veins so that now the veins are present as isolated fragments bounded by cleavage planes (Fig. 71).

In the areas immediately adjacent to most of the early faults vein quartz is characteristically present. The individual veins are often open tension gashes, sometimes of sigmoidal profile, and often containing open cavities with well terminated crystals of left-handed quartz.

In the Ordovician rocks of Letterbrock, the open quartz veins have a later deposit of cream-coloured dolomite crystals. A few veins of pink calcite occur by the roadside at Boheh, and these are probably the result of migration of calcareous material within the rock.

Faults and joints.

Three phases of faulting and jointing were recognised by Dewey (1960) in Central Murrisk. He rightly associated the joints and faults
Fig. 72 Map of the Lettereeneen fault zone in Glen Mask.

Scale six inches to the mile.
as being formed by the same movements. The three phases were:

1. Dominantly northwesterly trending dextral faults, with some northerly sinistral faults.

2. The Erriff phase, of north-easterly trending, dextral tear faults, which gave associated conical folds.

3. North-westerly trending, Maam tear faults, which phase is virtually absent in Eastern Murrisk.

Phase 1.

The outcrop of the western facies of the Partry Series in the area of Lough Glenawough is broken by many small faults, mostly dextral, with a north-westerly trend, but with some sinistral faults which trend east of north. Associated with these faults and parallel to them are shear joints, nearly vertical in orientation, like the faults. The faults of this phase have also been recognised in the Croagh Patrick Syncline, and along the Slieve Mahanagh-Corveagh ridge, where the north-south sinistral component is dominant. The two components of shear are each represented by joints. Some of these form trains of open gashes in joint-zones rather than major cracks.

Phase 2.

A phase of faulting intermediate in time to the first two recognised by Dewey (1960) has been seen in Eastern Murrisk. This is the movement related to the Lettereenen fault block (see Fig. 72). The boundary faults trend northwest-southeast, but minor dextral faults of phase 1 type, associated with faults of similar orientation, are present within the faulted zone. The rocks of the Mweelrea Group and the underlying Glenanemra Series have been overturned and rotated through 60°-90° in this block. Bedding showing some disturbance of orientation has been observed in the Cross River, and this may indicate a swing of the faults towards a more westerly trend. It appears that the block has been in some way rotated between the two fault planes. The mechanism responsible for the production of this structure is not known. It could be produced by a hinge-like movement along an axis plunging at 50°-60° towards the south east. The rotation would still require additional slip movement along the faults to attain the
Stereographic net to show the swing of the joints with the bedding.

Fig. 73 Swing of beds and joints at Teevinish

- Bedding
- Joint
- Carboniferous
- Derrylea Group

Scale six inches to the mile
present orientation. There is, however, no evidence of any folding movement in the rocks of the 'hi.ge' area.

It appears that the axial trace of the Mweelrea Syncline has been displaced northwards by well over a mile along the sinistral eastern fault of the zone. Although the Lettoomeen fault zone ante-dates the Erriff faults, there is no evidence of a continuation of the feature to the north of the main tear fault. It is possible that the swing of the strike of the beds in the Toevinish area is related to this faulting, but it is some eight miles to the east, and the sense of the movement is not coincident in each case. Lateral movement on the Erriff fault is only one mile in Central Murrisk and it seems impossible that it should be so large only a few miles to the east. It is believed that the stresses were dissipated in the Glenummera Series, into which the western fault is known to swing.

Phase 3.

The second phase of Dewey (1960) was the Erriff fault phase. He showed that the main fault was essentially a dextral tear movement, and that in the Houstons' Bridge area it produced a downward facing conical drag fold. Dewey believed that movement on the fault was at 20° down towards the north-east.

In Eastern Murrisk the same Erriff fault is exposed at two localities, where shear planes parallel to it suggest that the fault plane dips northwards at 50°-65°. There can be no doubt that during the initial movements on this fault a dominantly lateral translation took place, nor that this produced a swing of the bedding and joints near the fault. In Eastern Murrisk the bedding and early shear joints of the Toevinish area show a marked swing (Fig. 73) where they are clearly located on small circles related to an axis plunging steeply north-eastwards. The structure is that of a cone facing upwards, and as such is the exact counterpart of the structure at Houstons' Bridge. The early joints in the Toevinish area are in the distinctive couplet seen over much of Eastern Murrisk, one long NW and the other more nearly north-south. This swing of these two with the bedding is a clear feature.

Parallel to the Erriff fault, and contemporaneous with it are the Corrowkennedy-Corveagh fault and the Clew Bay fault. There may
Plate 27. Jointing in the sandstones of the Oughty Group, Aghamore.

Plate 28. Detail of jointing and quartz veining, in the Oughty Group.
be a fault of similar age to the south of the Black Mountain area, for in this area the boundary of the Carboniferous outcrop is displaced in the same way as it is along the faults. Each of the faults of this phase was initiated in pre-Carboniferous and post-Wenlockian times, and subsequently reactivated after the Lower Carboniferous, for they all throw Carboniferous sediments against older rocks. Few joints are developed in conjunction with this series, only a few shears in the immediate proximity of the fault planes.

The Erriff and Carrowkennedy faults are partly hinge faults in that there was a greater vertical displacement in the east than in the west. It is believed that during the pre-Carboniferous movements a small rotation was associated with the tear. Post-Carboniferous movement was principally vertical.

Phase 4.

The third phase of faulting in Central Murrisk was that of the Maam dextral tear faults of north westerly trend. These faults had been initiated during the Ordovician as syn-depositional features. No representatives of this phase of shearing have been recognised in Eastern Murrisk.

Phases 5-6.

A fifth and sixth series of movements occurred at least partly before deposition of the Carboniferous rocks. These are the faults of the Glennagashleeny-Tonnasaile area, which cross the Partry Series, but have been truncated by the sub-Carboniferous surface.

The fifth phase has an ENE trending sinistral component, and an ESE trending dextral component. Joints are associated only with the ENE trending faults which have downthrows of up to 400 ft. towards the north. The ESE component has a small throw, and is rarely associated with jointing.

The sixth phase is marked by large NNW dextral movements associated with NNE trending sinistral movements. They are best seen in the Glennagashleeny area, and these faults have given rise to the col now followed by the road across the Partry Mountains. Although these faults were of pre-Carboniferous origin, there has been continued post-Carboniferous movement on the NNW component, again in a dextral sense.
Plate 29. The valley along the Highland Boundary Fault, looking east, with Black Mountain on the right.
Post-Carboniferous movements may be recognised from the displacement of the sub-Carboniferous surface. In the eastern part of the Partry Mountains these faults are principally north-south, and of vertical downthrow towards the east. They control the eastern margin of the outcrop of the Partry Series, and have themselves been broken by renewed dextral movement along the NNW direction. These NNW trending fractures are prominent features in the Derryveeny-Carrangerra area. Also of Post-Carboniferous age hinge movements took place on the Erriff, Carrowkennedy and Clew Bay faults. Dewey and McKerrow (1963) have suggested that the latest movements on the reactivated Erriff and Maam faults were of Tertiary age. This seems probable for most of the faults, but some still more recent movement may have taken place along the Glennagashleeny fault on which there is a fault line scarp to both the north and south of the watershed. The movements on the Erriff, Carrowkennedy, and Clew Bay Faults are discussed in Chapter XI. It should, however, be noted that the Clew Bay fault is itself displaced by small north-east trending faults to the south of Westport.

The Highland Boundary Fault (Bailey and Holtedahl, 1936) runs in an east-west direction across Eastern Murrisk, where it is associated with a serpentine intrusion. On the northern side of the fault both Upper and Lower Dalradian rocks occur, while on the south side inverted Wenlockian rocks are adjacent to the serpentine. Dewey and Phillips (1963) have suggested that the earliest pre-Ordovician movement on the fault had a large downthrow towards the north, and that it was a normal fault. They further considered that injection of the serpentine took place at this time. Dewey (1960) suggested that the fault may have formed a southward facing submarine escarpment from which boulder slides moved in a southerly direction. These sediments have since been shown to have been derived from the north west and the fault may not have had such importance during the deposition of the Owenmore Series. Nevertheless some boundary near the line of the Highland Boundary Fault appears to have delimited the Arenig basin of sedimentation. During the Silurian period the sediments were derived principally from a source to the north of Murrisk,
probably a Dalradian mountain range. Downwarping towards the south probably occurred throughout Ordovician and Silurian times. Thus allowing accumulation of the debris in the basin, which is confined principally to the south of the fault line.

During the post-Wenlockian folding evidence of both vertical and horizontal movement have been recorded from the serpentine (see Chapter VII). During these movements nearly horizontal east-west joints developed. It is probable that the latest major movements were associated with the close of the post-Wenlockian folding, although post-Carboniferous faults cross the serpentine marking very late minor movements after the fault had ceased to be active.
Metamorphism

Although Dewey (1960) described the sedimentary succession and folding of the southern limb of the Coragh Patrick syncline, at no stage did he discuss the metamorphism which has occurred in the rocks. Nevertheless he consistently referred to the rocks as pelites, semi-pelites and psammites, and clearly recognised that metamorphism had occurred.

Anderson (1960 p.273) described muscovite and chlorite parallel to structures of the first phase of folding. He recorded some biotite but believed it to be sporadic in occurrence. During the second phase of folding he showed that sharp folding of the earlier schistosity was associated with growth of chlorite along the axial planes of the new folds.

In Eastern Murrisk the earliest metamorphic minerals recognised in the rocks are: muscovite, biotite, and chlorite, as flakes usually parallel to the bedding directions. The biotite is not present when calcite is present in the rock. The second phase is again seen to be associated with intense shearing of the rock in the Owenwee-Boheh area, and muscovite, and chlorite develop parallel to the second folding is again associated with shearing, biotite developing in some localities, chlorite in others. Again this reflects presence of calcite or epidote. Biotite and epidote appear to be stable, as do chlorite and calcite or or chlorite and epidote, but biotite and calcite have not been observed together in these rocks.

In the Tawnynameeltoge area fresh flakes of biotite grow across the folds of the second phase, implying a third phase of metamorphism not recognised elsewhere.

Outside the Croagh Patrick Syncline the rocks are all of a low grade of metamorphism, chlorite being developed in most places.
CHAPTER VII
THE SERPENTINE INTRUSION.

Symes (1876) gave the first description of the serpentine which occupies a belt of country stretching from Louisburgh in the west to three miles east of Westport. He examined the rocks in a railway cutting to the east of the limits of the present area, where he noted that the deeply weathered, often sheared and fractured green rock contained many veins of picrolite. He considered that distinct 'beds' of steatite rested on the surface of the serpentine, which, in turn, he believed to be pseudomorphing sedimentary rock.

Bailey and HolteAsha (1938) considered that the serpentine body was intruded along the line of the Highland Boundary Fault.

Anderson (1960) demonstrated that faults cut across the serpentine belt, and noted a sinistral movement on each of the eastern ones. However, he failed to recognise the two principal faults which cut the belt in the area under discussion.

Dewey and Phillips (1963), in an analysis of the tectonic features of Mayo, demonstrated nine phases of movement which effected both the rocks to the north and the Highland Boundary Fault zone itself. At no point in their discussion, however, did they consider the interesting problem concerning the age of intrusion of the serpentine.

The serpentine occupies a belt of country which is a maximum of half a mile in width, and runs for three miles in an east-west direction across the area mapped.

The southern boundary of the serpentine is marked by a well developed scar, along which runs a valley, often flat-floored, and frequently marshy. This is clearly a fault, which may be traced from the main Westport-Ballinrobe road, Ll01, two miles south-east of Westport, as far as the Owenwee River. For most of its length it is a clear topographical feature, dividing the serpentine from the Silurian Quartzite to the south. On the northern side is a second, less pronounced, hollow, often associated with intensely fractured and sheared serpentine.

In the field it is possible to recognise three types of serpentine, a sheared and foliated type, a nodular variety, and massive, deeply coloured serpentine.
a) **The sheared serpentine** is characterized by a shaly appearance. Many closely spaced and parallel fracture planes break the rock into small layers, which are very deeply coloured. The weathered surface is often red and is marked by the small octahedra which protrude through the encrustations of lichen. This type is found largely on the northern side of the intrusion, and appears to show evidence of intense movement after completion of cooling.

b) **The nodular variety** is often closely associated with the sheared or shaly serpentine. Individual masses of unbroken, deeply coloured serpentine form nodules and nearly vertical rods, which are surrounded by the shaly serpentine which appears to have suffered considerable cataclasis. This variety is particularly well seen at Balclare.

c) **Massive serpentine**, crossed by many small veins of picrolite and chrysotile, forms the backbone of the ridge which marks the presence of the intrusion. This variety is the commonest in the area, and is often rich in iron, as indicated by red weathering colour, and higher specific gravity. The massive serpentine is usually deeply coloured. The rock, although massive in character, is very much broken by veins and irregular joints. There is often evidence of nearly horizontal movement, marked by slicken-sides.

East of the T71 road, zones rich in talc have been mapped within the serpentine. These zones run obliquely across the belt, from south-west to north-east. The rocks rich in talc are soft to the touch and disintegrate readily on hammering, but nevertheless form marked crags along their outcrop. By a rapid and gradational transition the talc zone gives way to solid serpentine within 15 ft (5m) of rock. The rapid changes and the orientation of the zones, oblique to the run of the belt, suggest that they may be associated with faults. This is further supported by the presence of planes, perhaps shear planes, dipping steeply and striking along the talc zone.

In both the east and west much quartz occurs in the form of pods within the ultra-basic rock. This could be due either to an injection of a late stage segregation of silica, or as a segregation of the quartz from a generally silica-poor medium. However, since there are
several evident quartz veins within the black rock, it is probable that the pods are related to the veins.

**Petrography.**

The serpentine is composed principally of antigorite and serpophite, the fibro-lamellar crystals of the former comprising a meshwork around the cores of the latter. The two minerals form a uniform background to the rock, in which are set occasional nodes of antigorite, pseudomorphing either olivine or pyroxene crystals. The texture of the antigorite in the pseudomorphs is much more compact than in the rest of the rock. The orientation of the antigorite, along two directions arranged at about 70° to each other may be a reflection of stresses present in the rock during the formation of the minerals.

Crossing the background of serpentine minerals are a few veins of chrysotile or picrolite, in which the fibres are arranged not perpendicular to the margins, but at angles varying between 40° and 80° to them - often nearly parallel to the antigorite directions. The ramifying systems of veinlets which cross the surface of the rock rarely exceed 0.25 ins (0.6 cms) in thickness. Some larger veins reach up to 3" (8 cms) in thickness, and are composed of picrolite, identified by its green colour, columnar habit, and brittle fibres. Some of the smaller veins have flexible fibres of chrysotile. Many of the veins show zones and cracks across the columns, parallel to the basal plane of the vein, giving a striped appearance to the green rocks.

In some cases, particularly in specimens from the eastern part of the outcrop, highly birefringent flakes of talc occur. They are clearly later than both the antigorite and serpophite, for they cut across the plates of the former. In the eastern part of the outcrop the talc increases in proportion, and is often associated with intense veining in the rock. Talc sometimes partly replaces picrolite veins, but also appears to line distinct shear planes. The occasional isolate crystals of talc show curved twin planes.

Superposed on the talc crystals, especially those filling late shear directions, are replacements of carbonate. The carbonate is sparse in the western area, but it becomes extremely abundant in the rock of the talc rich zone in the east. Since many of the crystals are
euhedral, it is clear that they are not composed of calcite. Staining, using alizarin red and potassium ferricyanide in dilute hydrochloric acid (Evamy 1963) has shown that the carbonate is a ferroan dolomite, and not a magnesite as is common in some serpentine.

In the field it was observed that the rock produced deflections of up to $20^\circ$ in the compass reading, and this is due to the presence of magnetite and chromite. Both of these minerals have been distinguished from reflected light from thin sections of the rock. The iron and chromium spinels occur both as large euhedral crystals, and in fine, well-defined planes which cross the rock in close association with talc or carbonate-filled shears. The close association with the alteration products may indicate that the ores are late in origin. Certainly where the rock is little altered the iron and chromium ores are large and isolate, though reduced in proportion. In many cases the opaque ores have a core of red-coloured material, which forms a solid centre, and around which the margins have a spongy appearance.

Specimens of the rock from the talc-rich area were polished and examined under an ore-microscope. The principal ores present were identified as magnetite and chromite, with a little pyrite.

The early chromite grains have suffered cataclasis, and have all been overgrown by later euhedral magnetite. This magnetite is quite fresh and shows very little alteration to later hematite or maghemite. Small veins of magnetite in the cores of chromite appear to have been produced by infilling, although occasional serrated margins between the minerals suggest that metasomatic replacement occurred in some cases. Normally, however, the margins are straight. Overgrowths of magnetite on chromite have often been reported as due to deuteric reactions, but Dr. A.B. Millman (personal communication) has stated that in this particular case the overgrowths are abnormally extensive and in this respect the rock is quite novel.

Euhedral grains of magnetite without cores of chromite also occur in the rock. Some contain traces of pyrite, which also exists freely as disseminated grains in the groundmass. The pyrite is clearly an unaltered early stage ore.
Messrs. R. Bollin and R. B. Tate undertook optical spectrometry on crushed samples of the magnetite portion of the rock. In the analyses it was found that the fraction examined contained 0.2%–0.3% of chromium, 0.1% of manganese, and about 0.05% of cobalt. Traces of copper and arsenic also occur in the magnetic proportion of the rock. Clearly the serpentine might form a useful supply of nickel, chromium or cobalt in the zone south-east of Westport, but exploitation of such a small deposit would probably not be economical.

In attempting to ascertain the age of the intrusion itself, and the age of development of the area, it is important to consider the movements which can be connected with those of surrounding areas. It is believed that the initial intrusion occurred in the mid- or late Ordovician and that later reinjection took place after the Silurian.

The vertical nodding, associated with the sheared and nearly mylonitised northern side of the serpentine intrusion, is the earliest feature preserved directly in the rocks. Clearly this indicates a vertical movement of the serpentine relative to the Dalradian rocks to the north. It may have been this horizontal movement of the rock after cooling had been completed (for granulisation is a post-solidification feature) which produced the effect of a downthrown southern side to the fault.

The Silurian rocks to the south show the development of pronounced horizontal rods, indicating that after the folding of the Silurian strata, during the late Taconic movements, a tear component acted along the fault. This was approximately parallel to, and may have been simultaneous with the formation of the Kippagwendedagh and Letterbrock slides. Both of these slides were probably formed during the late Caledonide movements (Read, 1961), or approximately the age of the Silurian–Devonian time boundary.

The vertical movements must have preceded the horizontal ones for the rods of the former are dislocated and fractured whereas those of the latter are virtually unbroken.

Evidence of joints, veins, and low angle thrust planes within the serpentine indicates that there were further subsidiary thrusting movements.
None of these three early movements is associated with the later development of steatite from the serpentine.

Later oblique cross-faults break the serpentine into a series of offset blocks, associated with which are distinct zones of weakness where many shear planes developed. Such zones of weakness are the sites of later alterations of the serpentine to talc-dolomite rock.

The movements on the faults were virtually completed before the deposition of the Carboniferous sediments.

The steatitization of the serpentine along the zones of shearing is believed to be due to the action of groundwaters, charged with carbon dioxide and calcium oxide. Such waters may have commenced their reactions soon after, or during deposition of the Carboniferous limestones. The Carboniferous rocks rest uncomfortably upon all the older rocks, and in the east of the outcrop of the serpentine, they were probably not more than a few feet above the serpentine as seen today, probably much less.

Hess (1933) regarded steatitization as a hydrothermal alteration, and he suggested that, at low temperatures and pressures, reaction between serpentine and carbon-dioxide produced talc and magnesite. In the presence of calcium oxide dolomite would be produced. However, in Eastern Murrisk the talc generally appears to be earlier in origin than the ferroandolomites. At higher pressures, induced perhaps by deeper burial, talc is readily converted into dolomite (Turner and Verhoogen, 1951, p. 495-6).

Since this is a low temperature phenomenon there is a little doubt that the alteration is due to proximity of the Carboniferous unconformity, and percolation of liquids down from this surface.

The origin of the ores may be in part connected with alterations to talc and ferroandolomite. In each case the minerals are associated with ores. Both are associated, the talc in particular, with alterations from picotite and chrysotile. If the original deep green vein silicates contained more iron and chromium than could be taken into the talc or dolomite lattice, then the free metal ions would form the spinels. With continuation of the alterations, the amount of free iron in the rock increases. It is suspected that in some cases the nickel spinel, trevorite, may also have formed in this zone of alteration.
The observation of Symes (1876) that the steatite was banded is, therefore, a reflection of the nearness of the unconformity at the base of the Carboniferous rocks to the point at which his observations were made. Elsewhere the steatite is confined to zones of weakness along which percolation of groundwater was possible.
CHAPTER VIII

THE DALRADIAN ROCKS.

The Dalradian rocks occupy a strip of country between the northern side of the serpentines and the fault which brings Carboniferous Limestone to the surface along the valley followed by the railway, south of Westport. With the exception of the cuttings along the railway, the Dalradian rocks are very poorly exposed.

Symes (1876) noted that the rocks are foliated approximately parallel to the bedding. He recognised the following divisions in the Louisburgh-Westport area:

1. Schistose beds, with layers of quartz.
2. Compact schists.
3. Massive green and purplish serpentinous beds.
4. Thin band of schist.
5. Massive Quartzites. Beneath the schistose beds he also observed black slates.

Kilroe (1907) gave a more definitive sequence, established from the metamorphic rocks of North Mayo. This sequence, in order of decreasing age was:

1. Mica schist with beds of fine conglomerate,
2. Boulder deposit, limestone, and graphitic and mica schist, and

Dewey (1961) identified Upper Dalradian greywackes, graded conglomerates, cherts, limestones, and pillow lavas from the outcrop on Clare Island and along the southern shores of Clew Bay. Where Dalradian rocks occur immediately "south of the Highland Boundary Fault" he noted that they were of high grade, Lower Dalradian age.

Dewey and Phillips (1965) suggested that both Upper and Lower Dalradian rocks are present in the corresponding zone to the west of the area under discussion. There the Upper Dalradian metasediments are represented by rocks of chlorite-biotite grade, whereas the Lower Dalradian rocks are amphibolites and muscovite-garnet schists.

The part of the Dalradian succession which outcrops in Eastern Murrisk is dominated by the sheared micro-conglomerates of the Westport Grits, to the south of which occur phyllites, black slates, and light-coloured semi-pelitic rocks. The first three rock types are of the Upper Dalradian and have a north-easterly to north-north-westerly dip. In the west, some biotite-rich schists have been seen in the Belclare
townlands, adjacent to the serpentine, and it is believed that they represent part of the Lower Dalradian succession, for they occur in close association with the serpentine, and may be separated from the rest of the Dalradian rocks by a fault. These Lower Dalradian rocks dip towards the north-west. The Highland Boundary Fault in this area is represented by several sub-parallel faults, between which are the Lower Dalradian high grade meta-sediments (Dewey 1961).

Immediately north of the southerly fault line the rocks are well-laminated, grey-weathering, blue semi-pelites. In thin section these are seen to consist principally of quartz and albite-oligoclase feldspars, with muscovite and biotite subordinate. The micas are mainly colourless, but pale green chlorite and brown biotite lie in an irregular fabric, which later movements have disturbed to give curved plates of mica. Biotite flakes are few, and generally associated with the iron ores. Epidote is widely distributed in the rock as small crystals, but in places it develops as knots, which may represent replacements of early garnets. There appears to have been a form of rotation of these knots, so that the component epidote and chlorite crystals are oriented across the present foliation. No direct traces of any garnets have been found in the rock, but it is possible that they may have disappeared during retrogressive metamorphism. The presence of politic and gammitic layers probably indicates original sedimentary differences, and heavy detrital minerals such as sphene and rutile are present. Calcite is common in the quartz-rich layers. It may be a late alteration, for it fills veins in the rock, and these are associated with concentrations of iron ores. They may be post-Carboniferous alterations, associated with similar alterations in the serpentines.

A distinct sequence of structural and metamorphic events is detected in the semi-pelites:

1. Deposition as a sediment.
2. Regional metamorphism
   a) development of epidote and quartz
   b) growth of garnets and micas
   c) rotation of garnets with included epidote and chlorite
   d) retrogressive metamorphism and disappearance of garnets.
3. Shearing and growth of biotite along shear planes.
Fig. 74 Conjugate folds in the Dalradian rocks of Carrownalurgan

a) Sketch from field note-book.
Looking north-east.

b) Analysis of the stress axes
Regional dip

\[ \theta_{P_{\text{max}}} = 53^\circ \]
\[ \theta_{P_{\text{min}}} = 37^\circ \]
axial planes
P_int

P_{\text{min}}

\[ P_{\text{max}} \]

P_int

c) Relation of stress axes to bedding.
4. Tight folding with some small micas developing parallel to the axial plane.

5. Minor shearing of the biotite-filled shear plane in the opposite sense to the folding.

6. Fractures along the axis of folding.

7. Growth of calcite along fracture planes.

In the field some exposures of this rock show distinct 'eyes' of quartz around which are developed thin films of chlorite, suggesting retrogressive metamorphism of the rocks.

To the north of the semi-polite a black slate band is exposed in a small quarry in Carrowmalurgan, one mile south-south-east of Westport.

In hand specimen the black slates are seen to be composed of black, apparently carbonaceous layers, between which are fine bands of quartz grains. The surface of the black slates is often weathered yellow, and in many cases an iridescent sheen indicates the presence of thin layers of pyrite. Symes (1876) records that this black slate was formerly examined as a possible source of coal.

The slates have been folded and where quartz rich layers are interbedded with the black slates a system of conjugate folds (Johnson 1956) is developed (Fig. 74 a); but beneath these, where quartz layers are very much reduced the rocks are tightly folded and suggest an east-west compression. In these latter folds the axes plunge along a direction intermediate between those of the conjugate folds.

The surface of the black slates is marked with fine lineations which trend 100° - 120°. These lineations antedate the conjugate folds and are folded round the axes of this system.

The orientations of regional dip for the locality, and axial planes of each of the pair of folds have been plotted graphically on a stereographic net (Fig. 74 b). Ramsay (1962) has pointed out that movement which produces the folds is due to failure along two conjugate shear planes. These two planes intersect along the direction of intermediate stress, \( P_{\text{int}} \). In the one example which was observed in Eastern Murrick \( P_{\text{int}} \) also corresponds to the intersection of the plane of regional dip with the two shear planes. Thus the orientations of \( P_{\text{max}} \) and \( P_{\text{min}} \), and the axes of maximum and minimum stress can be determined. It is
evident from the orientation of the folds that \( P. \ max \) lies very close to the bedding (see Fig. 74 c). As a result of this orientation it is clear that the two fold sets should be approximately parallel, a fact which is almost borne out by field evidence. There is certainly very little discrepancy between readings of the plunges of the axes of individual folds in the immediate vicinity.

The principal movement involved in the production of these folds, \( P. \ max \), was oriented near the bedding and acted at about \( 35^\circ \) upwards from the north. This is probably associated with thrusting, which is obvious beyond the west of the area mapped, and on this evidence, may cross the Eastern Murrisk area, although nowhere easily recognised on the surface.

Kilroe (1907 p. 158) suggested that the metamorphosed grits had been thrust over the mica-schists on the northern side of the Croagh Patrick range. To the north of the slates are siliceous phyllites, in which quartzose layers alternate with micaceous layers. In neither bands are crystals sufficiently large to be discerned by the naked eye. These phyllites lie on the southern side of, and are in part interbedded with the siliceous, sheared, micro-conglomerates of the Westport Grit. Within the phyllites is a lineation plunging at \( 30^\circ \) westwards along \( 80^\circ \), marked by elongation of the mica flakes. This may be a cleavage-bedding intersection lineation.

The Westport Grits are blue-grey in colour, and are usually coarse grained, with occasional pebbles of quartz or feldspar up to 2 cm in diameter, and surrounded by a thin film of green chlorite. This film is clearly the result of a low grade metamorphism of the grit.

In thin section the rock is seen to be composed of individual angular grains of quartz and albite-oligoclase feldspars, set in a fine-grained matrix of sericite and chlorite. The most common of the detrital grains is strained quartz, and both the quartz and the feldspars have irregular margins, which have a cheveux de frise texture. Other detrital grains preserved in the sediment include composite flakes of muscovite and chlorite, and a few zircons. Within one quartz crystal an inclusion of tourmaline has been recognised. The matrix material is principally sericite, with subordinate chlorite.

Sericite and muscovite-chlorite flakes are folded round the axes of intensely developed tight minor folds, which occur in the rock. Closelyw
associated with the folds are later shear movements.

Clearly the Westport Grits are of extremely low metamorphic grade, much lower than the semi-pelites described above. The included detritus, in that it contains muscovite-chlorite flakes, must have been derived from an area of metamorphic rocks. There are many fragments of chert in the rocks but the detritus is virtually identical to that in the Ordovician rocks described in Chapters 2, 3 and 4, and the sediments may have been derived from an essentially similar source of metamorphic rocks. It has been postulated that the metamorphic rocks of both Upper and Lower Dalradian ages acted as a source of debris for the sediments of the Ordovician.

It is possible that the Lower Dalradian metamorphic rocks may have acted as a source for the sediments of the Westport Grit facies, which have therefore been subjected to only the final phases of metamorphism and folding. Rodgers and Bearth (1960) have suggested that the Lebendun gneisses may be a series of younger flysch-like sediments deposited upon the Bundnorschiefer, folded with them between the Antigorio and Monte Leone nappes, and metamorphosed with them to amphibolite facies.

It is possible to envisage debris eroded from mountains of Lower Dalradian rocks, and deposited in part on the surface of the older rocks, during an interval between folding and metamorphism. During the final phases of movement the younger sediments were clearly subjected to shearing accompanied by folding of muscovite flakes. This folding is associated with metamorphism to chlorite grade, which is common to rocks of both Upper and Lower Dalradian age, but which is the only metamorphism recognised in the Upper Dalradian Series.

Therefore it is possible that there may be an unconformity between the higher grade metamorphic rocks of the Lower Dalradian and the lower grade rocks of the Upper Dalradian Series. The unconformity may be associated with the plane of thrusting which is probably just below the black slates in Carrownalurgan. Along a plane of sedimentary discontinuity a decollement could easily develop during folding.
An alternative, and simpler method of explaining the difference in metamorphic grade, may be that there was an original difference of metamorphic grade in rocks formed in separate localities, and these have since been juxtaposed by the thrusting. This obviates the necessity of a sedimentary unconformity based entirely on metamorphic evidence, and justifies the absence of detrital grains of epidote, garnet, biotite, and hornblende, which are known to be present in the Lower Dalradian rocks.
CHAPTER IX
THE CARBONIFEROUS STRATA.

The occurrences of Carboniferous rocks in Eastern Murrisk may be divided into five groups.

1. In the Westport area.
2. In the area outlined by Cooloughra Bridge, the Aille caves and Cordarragh.
3. The long narrow stretch from the Aille caves and Sraheena Lough to Srahlea Bridge.
4. The outliers on the crest of the Partry Mountains.
5. Along the margin of the Central Plains, in the Killawalia - Derrindaffderg area, to the north of Lough Mask.

Kinahan and Symes (1876) described the Carboniferous succession in some detail. They demonstrated a basal siliceous conglomerate, followed by yellow-weathering sandstones, intercalations of shales within thin limestones, and ultimately massive compact grey crinoidal limestones.

**Conglomerate**

Bishop (1950) believed the conglomerates to be of Devonian age, but they are in close association with the overlying rocks known from evidence of fossils to be of Carboniferous age.

The basal conglomerate consists principally of angular pink and white pebbles of vein quartz. It is exposed by the roadside one mile due west of Sraheena Lough, on the bog one mile north of Derrycraff, by the main road, L101, at Kiltarsagham, by the sharp bend in the road east of Derrinkee, and in the small outliers on the watershed of the Partry Mountains.

In the latter occurrence, the nearly horizontal conglomerates and associated sandstones rest directly on the relatively flat surface of the steeply dipping rocks of the Meeelrea Group, to the south and west of Glen Mask. The conglomerate is so distinctive that even where it rests on conglomeratic sandstones it is easily recognised. Even isolated remnants have been distinguished and many small patches of conglomerates are present in the flat, watershed area.

The included pebbles have an orange tinge, and are principally of white vein quartz. They are often ill-rounded and angular, and reach up to 3 inches (8cms) in diameter. Although most of the pebbles are of vein quartz,
some consist of jaspers, welded tuffs and metamorphic quartzite, and all are set in a light-coloured matrix of quartzo-feldspathic material.

The long axes of the pebbles in the wide exposures near the Naweelions (small lakes) lie principally along approximately 60° and 120°, with minor concentrations to each side of these maxima. In this area the conglomerates reach up to 6ft. (2m) in thickness. No overlying sandstones have been identified here, although thin layers of dark grey, flaggy sandstones, red when fractured, are interbedded with the conglomerates south of Glen Mask.

In the exposures at Kiltarsaghaun the conglomerates are massively bedded and strongly jointed. Conglomerates also occur along the Aille River north of Sraheena Lough, but at this locality they do not form the lowest beds of the Carboniferous sediments, for they succeed 30ft (10m) of the non-conglomeratic sandstones. Less than two miles to the west; however, the conglomerates rest directly upon steeply dipping sediments of the Derrylea Group, beside the road south of Teevinish. Conglomerates are present in exposures along the river south of Derrycraff, but it is doubtful whether they represent the lowermost beds of the Carboniferous at this point, where, however, the contact with the underlying Ordovician rocks is obscured by peat.

**Sandstone**

The Carboniferous sandstones are best displayed in a disused quarry beside the Carrowbeg River at Corveagh. At this locality the sandstones are flaggy, and, until the mid-nineteenth century, were worked for use as paving stones. The southward dipping sandstone is almost a pure quartzite, and there are few flecks of black biotite, muscovite, slivers of green slate, and pink feldspar. When weathered the sandstone is pale yellow in colour, but when fresh it has a light grey colour. There are a few thin layers of conglomerate containing pebbles, up to 2 inches (5cms) in diameter, and composed of pink vein quartz, pale green slates, sandstones, and a few darkly coloured mud pellets.

North of Sraheena Lough the sandstones are the lowest Carboniferous rocks exposed. Some 30 ft (10m) of well bedded sandstones, in beds up to 3 ft (1m) thick, and with a few isolated pebbles, are exposed beside the Aille River. These rocks dip gently southwards.
By the school at Sraheen well bedded massive Carboniferous sandstones show pink, green, and black flecks in the generally quartzitic rock of the stream sections below the bridge. The dip is steeper and towards the north here, for the junction between the Carboniferous and Ordovician sediments is faulted. Associated with the fault are shear planes which, even within the sandstones, are coated with plates of pyrite.

The officers of the Geological Survey of Ireland recorded the occurrence of plant fossils in the sandstones in a railway cutting south-east of Westport. No fossils were found in the sandstones during the present work.

**Limestone**

In the valley which runs parallel to the railway south of Westport is a small stream which runs into a cavern at the foot of a 20ft. (6m) high cliff of sandy limestone. The rock is grey in colour, is very hard, and contains isolated crinoidal ossicles. In thin section the detrital fragments are seen to be principally of organic origin. The organic debris is set in a matrix in which irregularly shaped crystals of calcite border the larger fragments. In the spaces between the detritus, and set in the calcite cement are rhombs of dolomite, sometimes twinned, and always euhedral. Clearly partial dolomitisation has occurred. Often the dolomite exists only as margins of crystals, the centres appearing to have been partly replaced by calcite in optical continuity, suggesting that after the development of some dolomite the rock became partly de-dolomitised.

At Westport Quay a disused quarry reveals 15ft (5m) of limestone, which yielded specimens of Spiriferids and Productids, but no corals.

A small hinge fault divides these exposures from those of the limestone in the fields immediately south of Westport. Here the hard grey, crystalline limestone has a large fauna (Survey Memoir (1876) p. 29). Although individual specimens were not identified the presence of Productids, Spiriferids, a Rhynchonellid, crinoid ossicles, and both fasciculate and isolate corals was noted.

The spectacular disappearance of the Aille River into the Aille Caves is one of the principal features of the geology of the limestone country. The river, over 80 ft (26m) wide before the caves, flows into the base of a 30 ft (10m) high cliff of dark grey limestone. The limestone is in beds 2ft - 3ft (70-100 cms) thick, and shows no intervening shales. The cavern
is deep and accessible during the months of May and June, when water
level is low. The water, however, is subject to rapid variation of level
due to virtually immediate run-off of any precipitation, and considerable
cautions is needed in any attempt at exploration. The floor of the cavern
is in part covered with silt, but towards the back of the entrance tunnel,
solid limestone forms the bed of the stream. The course of the flow is
marked by a series of depressions, which mark the sites of collapsed caverns
along the route of the subterranean stream. Clearly the stream flows east-
wards, and reappears three miles due east of the caves, to flow southwards
into Lough Mask.

South of Derrycraff the limestones, partly dolomitised, are exposed
along the stream section. They are dark blue-grey when fresh, and weather
to a honeycomb structure, particularly in the dolomitised beds. The iron
content is often high, and nodules of pyrite are common.

Towards the base, the limestones are arranged in thin beds 2 - 4 inches
(5 - 10 cms) thick, and interbedded with dark shales. Further up the sequence
however, the limestones become thicker, 12 - 15 inches (30 - 40 cms) and
the shales are reduced to intercalations 0.5 - 1.0 inches (1 - 3 cms) in
thickness.

An interesting feature is that early post-depositional fractures in
the rock have been closed and set during later crystallisation of the lime-
stones. Both dolomite and calcite fill veins in the rock.

Although the limestones are exposed at no other localities in the area,
the lush vegetation is a reliable indicator of its presence below the sur-
face. Few disused quarries occur away from Westport; since they are
considered a danger to livestock they are filled in once working has ceased.
A shallow working beside the road at Derrycraff formerly produced lime for
burning in the small kilns which dot the country, especially in the Glen Mask
area.

The Carboniferous sediments rest on a regular surface, of which Dewey
(1960, p.) states: "It is possible to reconstruct the original surface of the
sub-Carboniferous peneplain in the form of a contour map (Fig. 7). The present
limit of the Carboniferous follows approximately the 200 ft contour on this
surface ". There is no other indication concerning the method used for the
production of this surface, and no direct evidence is given on his diagram. It appears that he has used a combination of the present day geomorphological feature of the exhumed peneplain, the accordant summits of the mountains in Murrisk, and also the occurrence of the Carboniferous outliers at some points. He believed that in Eastern Murrisk the sub-Carboniferous surface dipped gently east-south-eastwards. Dewey (1960) showed three principal faults affecting the surface; the Clew Bay, Carrowkennedy, and Erriff faults, on which he demonstrated northward downthrows of 2,900 ft, 500 ft, and 1,000 ft respectively. Associated with the Carrowkennedy and Erriff faults Dewey (1960) believed there was a form of "asymmetry due to sagging on the downthrow side of the faults" (p.27), and he implied that the movements were of early Tertiary age.

Although some attention will be paid to other areas included in Dewey's diagram (his Fig. 7), it is proposed to consider principally the evidence in Eastern Murrisk. This evidence comprises the present location of the exhumed peneplain and of the present distribution of the Carboniferous rocks.

The crest of the Partry Mountains is marked by wide, flat, peat-covered tracts of country. The level of the watershed shows a steady decrease in altitude from south-west to north-east from 1,768 ft near Lough Glenawough to 1,701 ft near the Naweelions, and to 1,200 ft between Tonnasaile and Bohaun.

In the western part of the area, above Lough Glenawough, on the Maumtraena massif, near the Naweelions, and to the south of Glen Mask, isolated outliers of Carboniferous conglomerate occur. These rarely exceed 6 ft (2 m) in thickness, and are often much thinner. The loose blocks of this conglomerate are scattered on the surface over a much wider area than the solid Carboniferous outcrop indicated on the map. Clearly the present plateau in this area is virtually identical to the sub-Carboniferous surface. It is only in this area that the present surface may unequivocally be said to represent the exhumed level.

Further to the north-east, the crest of the Tonnasaile - Bohaun ridge is relatively level, rising gently to 1,294 ft at Bohaun in the north. There are no outliers of conglomerate resting on the Ordovician rocks here. Glacial striations have been seen on the surface of the rocks in this area, and clearly erosion has lowered the surface of the peneplain by an
unknown but probably small amount from its true level. Therefore at the crest of Jochaun mountains the surface existed at a height of at least 1,294 ft. However, two miles due east, at Derrindaffderg, the basal Carboniferous conglomerate rests unconformably on the older sediments at only 200 ft above sea level - a difference of about 1100 ft.

If the conglomerate rests on the formerly nearly level sub-Carboniferous surface at Derrindaffderg, then this surface has been tilted in some manner, and now has a gradient of about 1 in 10 sloping down towards the east. Two alternative methods of producing this gradient are immediately obvious. From his diagram Dewey (1960) appears to have considered that warping of the surface was the only feasible solution. Detailed mapping along the eastern slopes in this area reveals the presence of many small strike faults running north-south, roughly perpendicular to the maximum gradient of the tilted surface. Further south, along the face of the outcrop of the sill on Tonnasaile, and below the sharp turn in the road north-west of Tourmakeady there are distinctive breaks of slope. The latter break is certainly associated with a fault, and the former may be. Some of these faults have thrown the sediments of the Partry Series downwards the east. Not all of the faults have achieved this movement, for the southern boundary of the Partry Series in Glen Saul is a fault which has a downthrow to the north. The principal movement on the Lough Shee fault, high on Tonnasaile, was pre-Carboniferous, for the nearly flat surface of the mountain is at the same height on each side of this fault. There is no direct proof from field evidence that post-Carboniferous faulting is the controlling factor responsible for the change in height of the sub-Carboniferous surface, but it is suggested that such faults were of considerable importance to this change.

Dewey (1960) believed the three principal post-Carboniferous faults warped the surface. He states: 'Associated with the downthrow along the Erriff fault is a syncline, developed asymmetrically due to sagging on the downthrow side of the fault. There is a broad N-E trending complementary anticline on the south side of the fault' (p. 27). There is no evidence for this. The southernmost Carboniferous sediments dip northwards at 27° at Derrinkee and 40° at Sraheen, where, in the latter locality, they are associated with shear planes dipping north-westward at about 65°.
Fig. 75 Intersection of Dewey’s 1960 contours of the sub-Carboniferous surface with the present topography.

Legend:
- Present Carboniferous outcrop
- Outcrop predicted from Dewey’s contours

0 miles
orientation of these shear planes in close association with the fault suggests that the fault plane may have a similar dip. Within 800 ft of the fault in the Cross River at Derrinkee the Carboniferous sediments are seen to dip at no more than 5° southeastwards, 500 ft from the fault the sediments dip northwards at 5°. Thus the syncline associated with the fault is very restricted.

According to Dewey (1960) a steep gradient of the sub-Carboniferous surface should occur in the Derryilre area, north of Sraheea Bridge. However, the few exposures of the Derrylea Group show neither evidence of breaking by faulting nor of bedding plane slip.

It is suggested that the field evidence in this area could best be interpreted by a form of rotation of the block on the northern side of the Erriff fault. The fault plane is probably inclined at about 65° towards the north, and the movement may have been in the form of a hinge, the eastern part of the block moving downwards relative to the west.

There is no evidence of downwarping of the Carboniferous sediments on the southern side of the fault to form a complementary anticline. Since there are no exposures of Carboniferous rocks in this position it is difficult to justify such an assumption.

Similarly there is no evidence for the swing indicated in Dewey's Fig. 7 for the sediments immediately south of the Carrowkennedy fault. The limestone exposures near the Aille Caves are near the line of this fault and show no marked changes of dip. (Nor, indeed, do the exposures in the bed of the Carrowbeg River at Corveagh).

It is an interesting exercise to compare the stratum contour map of the sub-Carboniferous surface, as given by Dewey (1960) (Fig. 7), with the topographically contoured map (Ordnance Survey, sheet 11) also on a scale of 2 miles to the inch. From the intersection of the predicted stratum contours with the actual topographical contours, an outcrop pattern for the Carboniferous rocks which should be found according to Dewey may be produced. (Fig. 75)

In the area of the Naweelions, to the east of Lough Glenawough, the outcrop pattern bears a remarkably close resemblance to the actual pattern, subsequently mapped during the present work, but not previously observed by the Geological Survey of Ireland. The area predicted as being of Carboniferous rocks is a little larger than the observed area, which at
this locality has its northern limit controlled by a post-Carboniferous fault (downthrow to the south of 15 ft. (5 m)).

In the north-eastern part of the Partry Mountains, however, the prediction of a long north-east and south-west trending tongue of Carboniferous sediments is quite erroneous. The sub-Carboniferous surface here rises from 1200 ft on Tonnasaile to 1294 ft at Bohaun, and bears no capping of Carboniferous rocks. The stratum contours given in this area each have a value approximately 100 ft too low. When viewed from the north, the Partry Mountains show a distinct break in their level outline. This break appears to be associated with the Glennagashleeny fault, a north and south trending fracture which appears to have a downthrow of at least 200 ft to the west. Clearly, since the sub-Carboniferous surface is displaced, the fault is a post-Carboniferous feature.

On Corveagh Hill the predicted outcrop is over three miles out of position where it crosses the ridge. Again an error of about 100 ft would largely correct this.

An almost totally revised version of the map showing the stratum contours of the sub-Carboniferous surface has been given by Dewey and McKorrow (1963 Fig. 4), in an account of the geomorphological evolution of Murrisk. This is a considerable improvement on the previous map, in that the new stratum contours intersect the known topographical contours in approximately the correct places, and in that the spuriously predicted outcrop near Bohaun is not repeated. In the area of the known outliers, east of Lough Glenaw Dough the stratum contours now intersect the topographical contours, and an outcrop pattern of slightly less accuracy than before is produced.

The 'asymmetrical syncline with the steep limb lying against the Erriff Fault' is again referred to (p. 263). In the cross-sections of text - Fig. 2 this feature is shown as a gentle, open warp. In the field the northward facing sediments have been seen to extend for less than 200 yards from the fault, and the syncline is clearly a fault drag feature.

The amounts of throw on the Clew Bay, Carrowkennedy, and Erriff Faults, have been revised to maxima of 2,800, 400 ft, and 1,400 ft respectively. The displacement on the Carrowkennedy fault is approximately as they state, but the other two throws cannot be accurately determined in Eastern Murrisk.
Fig. 76 Revised location of the contours of the sub-Carboniferous surface in Eastern Murrisk.
Dewey and McKerrow (1963) suggest that the latest movements on the faults were of Tertiary age, since one fault parallel to the Erriff fault cuts a Tertiary teschenite dyke, south of Killary Harbour.

The steep slope of the sub-Carboniferous surface previously recognised on the eastern side of the Partry Mountains has been recognised further south, near Clonbur, where it has been abruptly downthrown along the Clonbur fault. This fault runs north-north-east to south-south-west, and is approximately parallel to those on the eastern slopes of the Partry Mountains. Again no reason has been given why the increase of gradient should occur along this line.

An additional map showing the stratum contours of the sub-Carboniferous surface in the Eastern Murrisk area only is given in Fig. 76. In this the outliers near the Naweelions are shown, and have been used in construction of the stratum contours for this area. Elsewhere a combination of the height of the summits and flat watershed areas have been used to locate the surface.

It will be noted that the Glennagashleeny fault breaks across this surface, as do the minor Lough Shee faults. Other small faults which have been observed in the stream sections of the eastern slopes of the Partry Mountains have been plotted. It appears that these help the surface to drop from 800 ft to 200 ft in about a mile, just north of Derrinduffderg. The only continuous well-authenticated fault on the south eastern slope is the Treanlaur-Garangerra fault, which is a southward facing normal fault.

Clearly the Erriff fault is the most important of the faults within the area. The subsidiary Carrowkenedy fault runs along a marked topographical valley, and the Aille Caves lie on the continuation of the line within the Carboniferous rocks.

The Erriff fault has a downthrow to the north, while the Treanlaur-Garangerra fault has a downthrow to the south. The Partry Mountain massif may be regarded as a form of horst, broken across by later faults.
CHAPTER X.

SUMMARY OF THE PRE-HISTORY OF MURRISK.

The presence of Dalradian meta-sediments to the north in North Mayo and to the south, in Galway, indicates pre-Cambrian sedimentation. Sneddon and Pitcher have demonstrated that the Dalradian rocks of Galway, Mayo and Donegal present a characteristic Islay succession, which may be traced to Scotland. Read (1961) has summarised the Dalradian sedimentation as of a lower sequence, of shelf facies, and an upper sequence of greywacke facies. He affirmed his belief that, despite the occurrence of the Middle Cambrian trilobite Pagetia in the Leny Limestone of Perthshire, the deposition of the Dalradian sediments occurred in pre-Cambrian times.

In Murrisk the Arenigian Letterbrock Conglomerates yield pebbles of Lower Dalradian orthoquartzites, and so clearly, in western Ireland at least, the Dalradian metamorphism and folding preceded the Arenig. Gilletti et al. (1961) have shown a minimum age of 475 million years for the growth of muscovite and biotite in the Connemara Schists. Dewey (1961) has pointed out that this figure provides an absolute maximum age for the base of the Arenig, which was deposited after the close of the principal metamorphism.

The Arenig sediments of Murrisk represent the northern margin of the South Mayo Trough, which extended to South Connemara. At the base are the Letterbrock Conglomerates, which Dewey (1960) considered to represent boulder flows from the submarine scarp of the Highland Boundary Fault. The present work suggests that the boulders were derived from the north-west, and that their rounded state indicates a long history of erosion before deposition. Clearly they are derived from a dissected Dalradian land surface. Progressive deepening of the trough led to accumulation of greywackes and associated acid volcanic material. This was probably derived from a source within the rising Connemara Cordillera to the south. Thin bands of acid tuff occur sporadically throughout the lower part of the sequence.

The influence of the rising source area to the south is seen in changes in the direction of derivation and in the composition of the greywackes. The dominant axially derived turbidites of the early Arenig sediments were succeeded by the lateral turbidites of the Derrylea Group. The lateral turbidites are associated with spilites and greenstones, which may be analogous to modern palagonite tuffs. These rocks of submarine
volcanic origin have been observed at Bohaun (during the present work), at Tourmakeady (Gardiner and Reynolds, 1909), at Benbraff (McKerrow and Campbell, 1960), and at Charlestown (Cummins, 1954), to the south-east, south, and north-east respectively.

The base of the Glenummera Series is difficult to define in much of the area and the lowest part of the Glenummera Series is probably partly diachronous with the upper part of the Derrylea Group. Fossil evidence from Western Murrisk (Stanton, 1959) has indicated that these rocks are of Llanvirnian age. Intermittent ashes occur within the slates. In their upper parts the slates of the Glenummera Series are lateral equivalents of the lower beds of the Mweelrea Group, as shown by ash beds which cross the lithological boundary. The Mweelrea Group is essentially a shallow water deposit of sandstones and conglomerates. From the pebbles of the conglomerates there is evidence of an exposed land surface composed of metamorphic rocks, of granites, and of granite pegmatites which lay to the south-east of Murrisk. Within the Mweelrea Group are welded tuffs of south-eastern derivation which indicate intermittent volcanic activity in the area. The welding implies accumulation above sea level.

Resting unconformably on the Mweelrea Group is the Maumtrasna Group a further series of conglomerates and sandstones, apparently of Ordovician age, possibly Llandelian. No fossils have been found to enable accurate dating of the Group. The Maumtrasna Group shows evidence of a more easterly derivation and indicates that the metamorphic land mass of the Connemara Cordillera extended at least as far eastwards as the Tuam area. The coarseness of the sediments suggests that the source area had a considerable relief and swiftly flowing, if spasmodic, streams. It has been suggested in Chapter III that the sediments may have been deposited in the rain shadow of the Connemara Mountains, at a time when the area was located south of the equator.

Clearly the Ordovician sediments reflect the infilling of a basin. No rocks which indicate a phase of deepening or the development of the basin have been in Murrisk, for the succession begins with a well-established greywacke facies, and passes upwards into deposits of a shallow water, near shore environment. The changes in the basin were not entirely due to infilling of the trough by accumulated sediment. The rise of the Connemara
Cordillera to the south was of major importance, and it is possible that the movements in this part of Ireland were connected with some of the later 'cold' folding of the Dalradian rocks.

After deposition of the Partry Series a period of middle or late Ordovician folding led to the tilting of the sediments. The tilting was greatest in the north, and the effect decreased towards the south. This is clear from the vertical and overturned position of the Arenig sediments beneath the basal Llandoverian unconformity. The sediments of the Mweelrea syncline have undergone little folding even during later fold movements. In North Wales Shackleton (1952) referred to the mid-Ordovician movements as the Trondheim phase and used the term 'Taconic' to describe movements between the Upper Ordovician and Lower Llandoverian. Since the age of the uppermost parts of the Partry Series is not known it is impossible to say whether the movements in Western Ireland belong to the Trondheim or the Taconic phases. It is possible that both movements had some effect on the Murrisk area, well over 30,000 ft. (probably nearer 35,000 ft) of Lower Palaeozoic sediments would appear to have been eroded. Which way the debris was taken and where it was deposited is unknown for no sediments of L. Llandoverian or even of Caradocian age are known in this part of Ireland. The unconformity at the base of the Upper Llandoverian has been widely recognised in the British Isles (Jones 1921).

The Upper Llandoverian is represented by rocks of shallow water origin, and its upper limit is marked by an unconformity. The small stacks and irregularities in the surface on which the Wenlockian deposits accumulated indicates that lithification had occurred soon after deposition.

The presence of a minor unconformity between the Upper Llandoverian and the Wenlock indicates some minor movement at this time. Above the unconformity, however, the sediments are again essentially of the shelf facies, with conglomerates, shallow water current-bedded sandstones, calcareous sandstones and some clays. A few acid tuffs have been recognised by Dewey (1960). The sediments are known from fossil evidence to be of Wenlockian age. No younger sediments occur in Eastern Murrisk, although Dewey (1960) considered the Louisburgh Group to be of Wenlockian age. Their relationships with the rocks of the Croagh Patrick Syncline is unknown and they may conceivably be of Devonian age. Thus sedimentation, which suffered a minor break during the Wenlockian was interrupted soon afterwards by considerable movements.
The post-Wenlockian folding may, on stratigraphical evidence alone, have occurred at any stage before the deposition of the Lower Carboniferous rocks in Murrisk. In the Curlew Mountains to the east, however, Charlesworth (1960) considered that the Devonian rocks rest unconformably on the Silurian rocks, and stated that a phase of folding took place in the Upper Silurian (Ludlovian) or lower Old Red Sandstone. Clearly the Silurian rocks of the Croagh Patrick Syncline have been folded at this same period.

During this folding fresh muscovite and biotite developed in the rocks of the Croagh Patrick Syncline. Miller (personal communication) has analysed muscovites from the latest fold sequence in the Connemara Schists of the Kylemore area, and has determined an age of $420 \pm 10$ million years. This date may correspond to either of the phases of folding recognised in Eastern Murrisk. This age determination connects very closely with those from the Moinian rocks of Scotland (Gilotti et al, 1961). Holmes (1959) gave a revised geological time-scale in which he suggested the Silurian-Devonian boundary was at $400 \pm 10$ million years ago.

The Upper Silurian or Downtonian movements in the N.W. European Caledonides were referred to by Stille (1924 p.64) as the 'Ardennian' phase of orogenesis. These are the movements responsible not only for the first phase of deformation and metamorphism in the Silurian rocks of Western Ireland, but far greater disturbances in Scotland and Norway. In Murrisk, however, two distinctive periods of deformation, each associated with a low grade metamorphism are known. The second phase of large scale movements may correspond to the Erian movements of Stille, which post-date the Downtonian. These movements are later than the Ardennian disturbance, but yet appear to be earlier than the Corvock Granite (believed to be one of the $365 \pm 10$ million year old granites of Western Ireland).

After the main Ardennic or Erian folding and faulting the area was uplifted and the topography reduced to a peneplain, before submergence during the Lower Carboniferous. The deposits of this period were principally of shallow water, shelf facies, and include massive fossiliferous limestones. Late movement, perhaps Variscan, caused some block faulting, and movement along pre-existing faults. A Tertiary renewal of movement on some of the faults has been postulated (Dewey and McKerrow, 1963).
Intrusions of ophitic dolerites occur in the sediments of the eastern facies of the Partry Series, and these are probably pre-Carboniferous, for they form a sill within 100 ft of the sub-Carboniferous surface. Within this sill are natrolite and chabazite, the earliest recorded zeolites from Western Ireland. In the north of Eastern Murrisk very fresh dykes of olivine dolerite occur in the Black Mountain - Aghamore area, and it is believed that these may be Tertiary in age, for a similar dyke cuts the Carboniferous Limestone to the north-east of Westport.

The sequences of sedimentation and folding in the Murrisk area are interesting for they suggest that the deep water, or geosynclinal environment of deposition which had developed during the Upper Dalradian may have been inherited by the Arenig despite the intervening orogeny. The Dalradian meta-sediments indicate progressive change from shallow water conditions to the geosynclinal environment. The date of a metamorphic event has been placed at 475 million years (Giletti et al 1961, and Dewey 1961) and this appears to be a short time before the start of the Arenig. At the base of the Arenig there is a thin (1350 ft) sequence of relatively shallow lateral turbidites in the Letterbrook Group, but axial turbidites increase in proportion up the sequence and may indicate a deeper environment of deposition. The deep water deposits dominate the succeeding 9,500 ft until the lateral turbidites of southerly origin regained ascendancy, in the Derryles Group. That the Dalradian formed the basement of the Lower Ordovician geosyncline cannot be doubted, but the problem arises as to why the Arenig geosyncline developed where it did. It is most probable that the last phases of the Eocaledonian movements, which metamorphosed and folded the Dalradian sediments were still in progress at the onset of the Arenig. The final movements appear to have produced a depression which continued to sink during the early Arenig. The downward moving Dalradian mass therefore formed the framework of a trough which was deepening. Ultimately the Connemara area began to recover its position and rose again to form a mountain belt to the south and east of Murrisk in the Llandeilian. It appears, therefore, that the Arenigian development of the South Mayo trough may be regarded as an integral part of the Caledonian movements,
and the small geosyncline as only a minor side-product of the larger scale movements of the Dalradian masses.

The larger basin of which the South Mayo trough was the northernmost part originally stretched over the whole of Connemara, for a deep water facies with grevackes and spilites of Arenig age has been recognised in south Connemara (McKie and Burke, 1955). During the Upper Arenig the larger basin became subdivided by the rising Dalradian mass of the Connemara Schists, and the South Mayo trough was separated from the basin to the south. The original asymmetrical eugeosyncline (no southern margin is defined due to absence of exposures of pre-Silurian rocks further south) thus became subdivided, and the inner, near cratonic basin became symmetrical, and was infilled. The original eugeosyncline was in a position at the margin of the cratonic block of Dalradian material, but the South Mayo trough, which was confined by the uplift of the Connemara Schists, assumed a cratonic position in the late Arenig.

Since over 54,000 ft of Ordovician sediments are known to occur today in Murrisk, the depth to which the base of the Arenig was lowered at the latest time before the mid-or late Ordovician (Trondheim stage) movements may have been of the order of 35,000 ft (approximately 10 kms).

The ultrabasic serpentinites which occur along the Highland Boundary Fault occupy an interesting position. Bailey and Holtedahl (1938 p.11.41) state that the serpentinites in the Kirriemuir district of Scotland are of Cambro-Ordovician age. In Murrisk the serpentine may have been injected during the mid-or late Ordovician movements. The area associated with the fault was deeply buried, and the fault probably acted during the orogenetic episode. However, the Highland Boundary Fault and its accompanying serpentinite also lie beside the Silurian rocks on the northern side of the Croagh Patrick Syncline. Post-Ordovician movements may have caused some form of re-injection of the serpentinite, giving rise to intense shearing and rodding on its northern flank.
### Fig. 77. Table of events in Murrisk.

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<tr>
<td></td>
<td><strong>faults</strong></td>
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<tr>
<td>420 m.y.</td>
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<td>Wenlock</td>
<td>Louisburgh Gp.?</td>
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<td><strong>Shallow water sediments</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Basement acts as source of debris</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Land sources to S, S-E, and N.</strong></td>
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<tr>
<td>Caradocian</td>
<td>Maumtrasna Gp.?</td>
</tr>
<tr>
<td></td>
<td><strong>Conglomerates from S.E.</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Current-bedded sandstones</strong></td>
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<tr>
<td></td>
<td><strong>Shallow water sandstones</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Turbidites</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Taconic orogeny</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Reappearance of a S. Mayo trough.</strong></td>
</tr>
<tr>
<td>Llanvirn</td>
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<td><strong>Spilite</strong></td>
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<td><strong>Injection of serpentine?</strong></td>
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<td><strong>Maximum depth of S. Mayo trough</strong></td>
</tr>
<tr>
<td>U. Arenig</td>
<td>Sheeffry Series</td>
</tr>
<tr>
<td></td>
<td><strong>Axial turbidites from E</strong></td>
</tr>
<tr>
<td>M. Arenig</td>
<td><strong>Axial turbidites increase</strong></td>
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<tr>
<td>L. Arenig</td>
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<tr>
<td></td>
<td><strong>Submergence of S. Mayo trough</strong></td>
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<td>U. Dalradian</td>
<td><strong>Metamorphism and folding</strong></td>
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<td>L. Dalradian</td>
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</tr>
<tr>
<td></td>
<td><strong>Sinking basin</strong></td>
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</table>
Read (1961) considered that the lower Arenig magmatic activity in Western Ireland gave rise to pillow lavas and basic pyroclastics. While the existence of pillow lavas has been confirmed, it is important to note that throughout the lower parts of the Arenig succession in South Mayo, beds of acid tuff have been formed. Occasional basic tuffs are known, but the tuffs of the Sheepsex and Owenmore Series are acidic, with the exception of the pillow lavas and tuffs of Bohaun. In the Glenummerra Series the volcanics are both basic and intermediate in nature, but in the Mweelrea Group the welded tuffs are dacitic.

In Western Connacht the formation of granites took place at at least two periods. Pebbles of granite very similar to that of the Oughterard area occur in the Derrylea Group, and are very common in the Partry Series. This granite mass is related to the buried Dalradian mountains of the Tuam area, and is clearly pre-Llandoveryian in age. The later granites are represented by the Corvock and Galway granites, the latter having yielded an age of 365±10 million years (GilletVeyal 1961), indicating a Devonian age.

Comparison with other areas.

The study presented in this thesis represents an advanced stage of the reinvestigation of the Lower Palaeozoic rocks of the Murrisk area, and although further discussion and mapping will doubtless take place, the basis is now fully prepared for comparison with other parts of the world. The similarities of the sediments of Mayo with those of other parts of Ireland have been noted during the individual descriptive passages both in this work and in Dewey (1960). The early Ordovician geosyncline was located in a belt across Ireland from Mayo to Tyrone and into Arran, and beyond into the Highland Border area. Clearly this deep water facies of the Arenig lies in a belt 20-30 miles north of the Southern-Uplands-Cavan belt of Ordovician rocks of greywacke facies, which may be the equivalent of the Lower Palaeozoic rocks of South Connemara. The South Mayo end of the northern deep water belt was cut off during the late Arenig by the freshly risen St Patrick's Land of Connemara and Turk. An attempt to reconstruct the palæogeography of the Wenlockian of Ireland has been made at the end of Chapter V.

Murrisk lies on the western seaboard of Europe and as such would be important in any detailed discussion concerning Continental Drift in the North Atlantic area. Many workers (e.g. Schuchert, 1928, and Du Toit, 1937)
have noted the similarities in stratigraphical successions in eastern Canada, particularly Newfoundland, and the British Isles. A recent summary (Neale et al., 1961) of the tectonic sequences of the Canadian Appalachian region is of considerable importance in this respect. The geology of the Central Newfoundland area may be summarised as consisting of two blocks of metamorphic rocks between which are large outcrops of Ordovician sediments, with subsidiary and marginal outcrops of Silurian rocks. The synthesis of facies changes and the timing of orogenic phases presented by Neale (et al. 1961) is strikingly similar to that of Murrisk: The Middle Ordovician (Tremadoc is Lower Ordovician here) is characterised by greywackes, slates, pillow lavas, greenstones, and cherts, indicating a deep water environment. These are followed by an unconformity which was interpreted as indicating a possible pre-Taconic orogeny. The succeeding Upper Ordovician and Silurian strata, which are varied in lithology, represent a shallow water environment of deposition. The age of the post-Silurian folding, several phases of which are known, varies from place to place and is probably Middle Devonian in the east. A marked unconformity occurs below the Carboniferous, and the whole area has been subjected to post-Carboniferous block faulting. Ultra-basic intrusives are believed to have been emplaced during the Mid-Ordovician deformation. Age determinations have identified many Devonian granites.

In essentials the histories of sedimentation and deformation show distinct similarities when Murrisk and Newfoundland are compared. In both areas the early Ordovician rocks show deep water facies followed by shallow water facies, and after orogenesis, both areas show Silurian shallow water sediments. In each area more than one phase of post-Silurian deformation has occurred, during which the Ordovician and Silurian rocks reacted differently in metamorphism and folding.

As a result of renewed mapping by the Geological Survey of Canada, fresh detailed accounts of the stratigraphy and structure of Eastern Newfoundland are becoming available, and ultimately this will enable the patterns of geosynclinal development, and sedimentation histories to be compared in each area. At present it is clear that the likenesses are great and tend to support the concept of a post-Lower Carboniferous rift and drifting apart of the continents of Europe and America.
Future work.

A further study of the sediments of the Partry Series over the entire outcrop in Murrisk would be an extremely useful contribution to the knowledge of the changes of facies and sedimentary structures on approach to St Patrick's Land.

The red sandstones are eminently suited to a palaeomagnetic investigation, and since they are of Ordovician age they could provide information concerning a period during which little magnetic data from sediments is known.

The fossil evidence for the ages of the rocks of Murrisk is in need of re-examination, with particular reference to the Partry Series. Such a study might clarify the age relationship between the Mweelrea and Maumtrasna Groups (eastern and western facies of the Partry Series). It may be possible to relate the two Groups in the Owenbrin Valley, or the area to the west of it.

The age of the welded tuffs below the base of the eastern facies of the Partry Series is unknown, and determination of their age, and that of the Mweelrea Tuffs would be useful. The time at which the metamorphism of the Silurian rocks of the Croagh Patrick Syncline took place is unknown and it might be possible to investigate this using muscovites developed during the metamorphism.

A more detailed study of the variation in the heavy mineral content of the Arenig turbidites is being made, and it is hoped that this will reveal greater detail concerning the unroofing of the Connemara Cordillera during the Upper Arenig.
ACKNOWLEDGEMENTS

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My thanks are also due to my many colleagues at Imperial College for their forbearance, toleration, and encouragement at all times.

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Works referred to in the Text


129. Prentice, J.E., 1956. The interpretation of flow-markings and load-casts, Geol. Mag., 93, 393-400.


APPENDIX  I
Modal analyses from the Arenig sediments:

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<th>Slide No.</th>
<th>Quartz</th>
<th>K feldspar</th>
<th>Plagioclase</th>
<th>Chlorite &amp; Micas</th>
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<th>Silica Matrix</th>
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L = Derrylea Group; L = Luggaculliwee Group; LC = Letterbrock Conglomerate Group; C = Gwenmore Group; S = Spinl Group; T = Palaeozoic tuff
Hodal analyses from the Partry Series

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Backispiece: Croagh Patrick, Owenwee and Bohem Lough.