SEDIMENTOLOGY OF TERTIARY EVAPORITES, UĞURLUDAĞ AREA, ÇANKIRI-ÇORUM BASIN, TURKEY.

By

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TO MY WIFE, SEMIHA

and

TO MY SON, EMRE

ABSTRACT

The Upper Tertiary sediments in the Ugurludag Area of the Cankiri-Corum Basin, comprise two redbed-evaporite megacycles with an intervening angular unconformity. The redbeds, the Incik and Kizilirmak Formations, are both fluviatile conglomerates,sandstones,siltstones and mudstones. The Bayindir Formation,the evaporite member of the lower megacycle, is characterized by nodular secondary gypsum rocks which alternate with fine-grained fluviatile clastics in the lower part,and carbonate mudstones in the upper part. The original anhydrite nodules grew displacively during early diagenesis.The whole formation was deposited in a continental environment.

The Bozkir Formation,the evaporite member of the upper megacycle, comprises cyclic alternations of gypsum-bearing mudstones and laminar gypsum rocks which are the deposits of an intermontane playa lake.The gypsum of both the laminar gypsum rocks and the mudstones shows great diversity. In most cycles,it is wholly primary, while in others it is either wholly or in part secondary after anhydrite.The alteration of primary gypsum to anhydrite took place in the environment of deposition.The primary gypsum shows a variety of crystal habits and modes of growth.Some of the gypsum crystals grew intersititially in the sediment which now contains them,while others grew free at a sediment-water interface.Where the gypsum is primary,the carbonate of the associated mudstones is dolomite,but where the gypsum is wholly secondary after anhydrite,the carbonate mineral is magnesite. Where the rocks carry both primary and secondary gypsum,the

carbonate is a mixture of dolomite and magnesite.The change from gypsum to anhydrite and from dolomite to magnesite is believed to have resulted from periodic drying out of the playa.

The secondary gypsum of both the Bayindir and the Bozkir Formations comprise porphyroblastic and alabastrine crystal fabrics which replaced the earlier anhydrite.The hydration of the anhydrite to secondary gypsum is believed to have taken place late in the history of the rocks in response to exhumation.In the Bozkir Formation,the hydration is probably related to the present land surface,but that which affected the Bayindir Formation may have taken place during the interval represented by the unconformity between the two megacycles.

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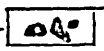
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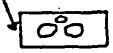
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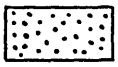
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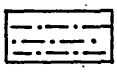
LITHOLOGY

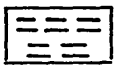

Conglomerate


Intraformational phenoclasts

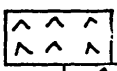

Extraformational phenoclasts

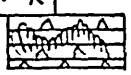

Sandstone

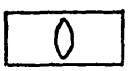

Siltstone


Mudstone

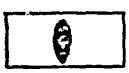

Volcanic ash replaced by clinoptilolite


Gypsum


Laminar gypsum


Discoidal crystals of primary gypsum

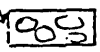

In part primary, in part secondary gypsum crystals


Gypsum pseudomorphs after anhydrite after primary gypsum

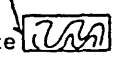

Secondary gypsum

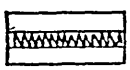

Chicken-wire structure

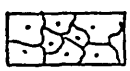

Prismatic gypsum

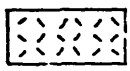

Nodular structure

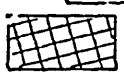

Discus-like masses of gypsum

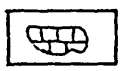

Enterolithic structure


Satin-spar veins


Porphyroblastic fabric of secondary gypsum

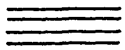

Alabastrine fabric of secondary gypsum


Anhydrite


Calcareous nodules

SEDIMENTARY STRUCTURES

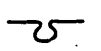

Cross-bedding


Horizontal lamination


Graded bedding

Desiccation cracks

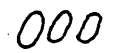

Ripple marks


Load casts


Primary current lineation


Scoured surface

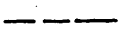

Palisade structure


Pebble imbrication


Burrowing structure

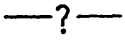

Grove casts

BEDDING PLANE CONTACT


Gradational

Sharp, flat


Erosional


Undifferentiated

ABBREVIATIONS

C	Calcite
D	Dolomite
M	Magnesite
CL	Celestite
P	Primary gypsum
S	Secondary Gypsum
PS	In part primary, in part secondary gypsum

CHAPTER I

GENERAL INTRODUCTION

I. 1. GEOGRAPHY OF THE UGURLUDAG AREA

1.1. Location

The part of Turkey which is the subject of this thesis is situated in the Province of Corum, around the town of Ugurludag (Figure I.1). It covers an area of 402 square kilometres between longitudes 34°23' and 34°26' N, and latitudes 40°15' and 40°31' E. It is covered by the following map sheets: CANKIRI $H32b_1$, $H32b_2$, CORUM $G32c_3$ and $G32c_4$; scale 1/25,000.

1.2. Topography and Drainage

The Ugurludag area is one of moderately low relief relative to the rest of Turkey, with few parts being more than 1000 metres above sea-level. The area divides naturally into two main topographic divisions: a northern half and a southern half, each of which has a general NE-SW trend. The northern half of the area is a low plateau, 500-600 metres above sea-level, characterized by rolling hills and broad open valleys. It is principally underlain by horizontal to gently dipping beds of Miocene gypsum and poorly consolidated clastic rocks. The topography of the southern part of the area is generally steeper than that of the northern part. Gently rounded ridges are separated by sharp V-shaped debris-filled valleys. The ridges generally run approximately NE-SW, parallel to the trend of known major thrust faults (App. III.3). This part of the area is underlain by Oligo-Miocene redbeds, Eocene volcanics and marine sediments, and an ophiolitic complex.

The entire area is drained by the west to east flowing Kizilirmak River and a few other perennial streams, which join it in the north. The perennial streams, of which the two largest are the Karani Dere and Urla Cayi, have their maximum flow in winter and spring.

Recent landslides are widespread (Fig I.2.). They range from rockfalls at one extreme to mudflows at the other, but mudflows are the commonest type. In the northern part of the area, there is an abundance of topographic features which appear to be old landslips, now considerably modified by erosion. Indeed it seems likely that much of the detail of the landscape has been shaped by landslips.

1.3. Climate and Vegetation

The Cankiri-Corum Basin has a continental type of climate, similar to that of the rest of central Anatolia. Summers are hot and dry, but the winters are bitterly cold. The mean annual temperature is about 12°C, but in summer it may rise as high as 35°C during the daytime. The annual precipitation is small, with most of the rain during the spring. Snow can be expected in the area from late October, but the winter snows have usually melted away by mid-March. The climatic data for 1967 at two stations adjacent to the area are given in Figure I.3.

For the geologist, the Ugurludag area affords a workable field season of up to six months; from early April to mid-october.

Because of the climate and large areal extent of gypsiferous rocks, the natural vegetation is very poor. However various types of pine and oak occur on the ridges in the southern part of the area, while poplars and plane trees are found along the Kizilirmak valley and other stream courses. Wheat and barley are grown wherever the land is suitable. Rice fields are located along the southern side of the Kizilirmak valley while vineyards and vegetable gardens are present alongside many streams.

1.4. Transport and Settlement

Communications within the area are generally very poor. There is only one all-weather road, this connects the town of Ugurludag with Corum and Iskilip. It enters the area from the north-east, and runs

parallel to the Kizilirmak valley as far as the village of Eski Celtek; from there it provides a route south to the town of Ugurludag. Apart from this, the rest of the roads in the study area are usually passable only in the dry season. The town of Iskilip, where field camps were established, lies about 20 km to the north of the area. The town of Ugurludag is the regional centre for marketing, transport and administration. The interior of Anatolia is sparsely populated with fewer than 15 persons per square kilometre on average. In the area studied the population density reaches its maximum, and is concentrated mainly in the north, along the valley of the Kizilirmak River, and in the town of Ugurludag, (population 3000), which is situated on the east side of Urla Cayi. A few small villages, with populations of between 200 and 400 are scattered here and there along stream courses in the southern part of the area, but apart from these the greater part of the region is almost uninhabited. It seems that agricultural potential plays the important role in determining distribution of inhabitants.

I. 2. PURPOSE OF THE STUDY

The main objective of the research was to study the sedimentology of the late Tertiary evaporites of the Ugurludag area in the Cankiri-Corum Basin. Evaporites cannot be studied usefully without attention to associated lithogies. For this reason, the sedimentology of the redbed sequences which occur in association with the evaporites have also been studied.

The Ugurludag area had not been mapped in detail prior to the commencement of this research project. The only geological maps of the region were those made by Erol (1953) and Yucel (1953) on a scale of 1:100,000. Thus an additional objective of the research was the mapping of the area on a scale of 1:25,000.

I.3 METHODS OF THE STUDY

3. 1. Fieldwork

A total of nine months was spent on fieldwork during the summers of 1974 and 1975. An area of almost 400 square kilometres was mapped geologically on the basis of litho-stratigraphic units. Stratigraphic and reference sections in each of the evaporite and redbed units were identified and measured. An Abney Level and a Jacob's Staff were used to measure the sections, and the characteristics were recorded on logs.

Colours were determined in the field by direct comparison with the "Rock Color Chart" (Goddorf and others 1948). Representative chips were hammered from the rocks and their colours were recorded for both the weathered and freshly broken surfaces. Because many of the rocks are deeply weathered and oxidized, the colours recorded on the logs may not be a true indication of the colour of the fresh rock.

Grain size was determined in the field by direct comparison with a grain-size chart based on Wentworths grade scale. The terminology used to describe stratification and cross stratification followed that of McKee and Weir (1953).

All of the measured sections were sampled, and a total of 1,200 specimens, predominantly gypsum rocks, were collected and taken to the laboratory for detailed mineralogical, petrographical and geochemical studies.

3.2. Laboratory Work

Laboratory work was carried out during the winters of 1974-75 and 1975-6 at Imperial College, London. Particular attention was paid to the gypsum rocks. Altogether 370 thin sections were studied in detail under the petrographic microscope, and polished slabs of these rocks were also examined with a stereoscopic microscope.

The mudstones of the gypsum-bearing formations are too fine-grained for normal microscopic study, and for this reason more than 100 mudstone samples were analysed by X-ray diffraction. Scanning electron microscopy was also used, particularly for the study of the zeolite mineral clinoptilolite, beds of which have been found in the course of the field surveys.

I.4. REVIEW OF PREVIOUS WORK

The first recorded geological observations in the Cankiri-Corum Basin were made in the early 1900's by German explorers. From then on little work was done until the establishment of the Mineral Research and Exploration Institute (M.T.A.) of Turkey in 1935.

Lahn (1939) was the first to make a comprehensive study on the rocks of the basin, and in his report he described the stratigraphy of the Corum region and discussed the oil potential. A second report was produced by Lahn in 1943, and this dealt with the possible economic importance of the Lower Tertiary coals of the Iskilip area. At about this time M.T.A. started to publish the first geological map of Turkey at a scale of 1:800,000. The map, which comprises eight sheets was in fact based on the earlier geological observations. The Ankara sheet included the Cankiri-Corum Basin.

In 1943, a programme of geological mapping of the country to a scale of 1:100,000 was initiated by M.T.A. and this provided valuable information on the geology and economic potential, with respect to oil, coal and gypsum in the basin. The relevant reports are:- Baykal, 1943; Blumenthal, 1948; Erol, 1953; Yucel, 1953; Ketin, 1955; Akarsu, 1959 and Sajova, 1961. Amongst these the report by Erol, 1953 on "The geology of the Kizilirmak Basin in the area between Cankiri-Tuney and Sungurlu", which was accompanied by a map on a scale of 1:100,000, is of particular

interest because it includes the area that forms the subject of this thesis.

The 1:100,000 scale maps were compiled for publication on a scale of 1:500,000. The Sinop sheet which includes the entire area of the Cankiri-Corum Basin was published in 1962 by Ketin. The map together with the explanatory text still forms the essential reference to the geology of the Cankiri-Corum Basin. In the text, the broad outlines of the geological framework of the region were established and sedimentary, metamorphic and volcanic units were named and defined in terms of time stratigraphic units.

In the ten years which followed the completion of Ketin's report, i.e. after 1962, very little work was carried out in the basin, apart from a further investigation of coals in the Iskilip and Corum regions, and some brief comments by Beer (1964) on the possible presence of potash salts in the area between Cankiri and Sungurlu. As a result of Beer's recommendations, M.T.A. drilled three unsuccessful wells in the summer of 1965 in the vicinity of the salt mine of Cankiri, in the west-central part of the basin. The "completion report" of these wells was written by Saydamer (1966).

However from 1972 onwards there was a resurgence of interest in the basin. Norman (1972a) presented his post doctoral thesis on the stratigraphy of the Upper Cretaceous - Lower Tertiary sedimentary rocks in the Yahsihan area, and a brief summary of his thesis was published by the Geological Society of Turkey (Norman 1972b). Two other papers by Norman appeared in the following year. The first described the primary sedimentary structures of the Lower Tertiary rocks and discussed the formation of olistostromes and submarine slumps, (Norman 1973a). The second discussed the post Eocene tectonic development of the Yahsihan region (Norman 1973b).

In the summer of 1973, the Petroleum Geology Department of M.T.A.

began a detailed study of the whole basin with particular emphasis on the stratigraphy of the Lower Tertiary marine sediments and their equivalents. Three reports concerning specific parts of the basin were prepared in 1973 and 1974, these were: Aziz (1973), Tanriverdi (1973) and Unalan (1974). The final report was prepared in 1975 by Birgili et.al. It was entitled "Geology and petroleum possibilities of the Cankiri-Corum Basin". It was a compilation of all stratigraphical, palaeontological and sedimentological data available at that time. The report contains an extremely detailed and accurate geological map (1:50,000 scale) together with facies maps, logs of the measured sections and correlated sections.

In 1974, Senalp presented a doctoral thesis at the University of London, on the sedimentology of the Tertiary succession in the Sungurlu region. Although Senalp's thesis was concerned mainly with turbidites of Eocene age, the study also contributed to a better understanding of the stratigraphic succession.

In the same year a paper by Usenmez dealt with the Geology of the Candir area in the west-central part of the basin; and another by Tekkaya (1974) described a new species of Anthropoid (primates) of Neogene age found in the Candir area.

In 1975, Norman published two more papers: one dealing with some tectonic features of the Cankiri-Corum Basin seen on ERTS-A satellite imagery; and the other concerned with an analysis of palaeo-current directions in the Lower Tertiary sediments. Finally, in the same year Tekkaya et.al. wrote a discussion on the age of the vertebrate fossils found in the Neogene continental redbeds.

I.5. STRATIGRAPHY OF THE CANKIRI-CORUM BASIN (A REVIEW)

The Cankiri- Corum Basin is situated in the north-central part of Turkey. It is elongate E-W and occupies an area of about 15,000 square kilometres. It lies in the Anatolids tectonic zone (Figure I.4), and is

bordered by crystalline massifs. These are the Kastamonu-Ilgaz massif to the north and north-west, the Tokat massif in the east and the Elmadag and Kirsehir massifs in the south.

The stratigraphic sequence of the basin comprises marine and continental sediments which range in age from Maestrichtian to Pliocene. The sediments of the Maestrichtian Paleocene and Eocene are of marine facies. The Oligo-miocene, Upper Miocene and Pliocene are represented by three fluviatile and two evaporite-bearing formations. Various place names have been used by different authors to designate the same stratigraphic units, and consequently most units have been given more than one name (Figure I.5.). For this reason time units will be used in this review.

5.1. Mesozoic

The Mesozoic rocks comprise a series of ophiolitic melange complexes followed by Maestrichtian sediments.

1.1. The Mesozoic Ophiolitic Series

Extensive outcrops of Mesozoic ophiolites and ophiolitic melanges occur in various parts of the basin. They trend E-W approximately parallel to the Pontids. Lithologically they are composed of serpentinized ultramafic rocks, spilites, agglomerates, tuffs, various types of limestones, radiolarites with pockets of flysch and polymictic breccias.

The age and mode of origin of the complex are matters of contention. Bailey and McCallien (1953) considered it to be a system of large nappes which came from the Pontids and developed in association with the Anatolian Thrust. They called it the 'Ankara Melange', and believed that it ranged in age from Triassic to Jurassic, but that it was emplaced sometime during the Tertiary.

Ketin (1962) considered the complex to be autochthonous and mapped the unit as 'The Mesozoic Ophiolitic Series' which he believed to range from

Jurassic to Upper Cretaceous.

An allochthonous origin was suggested by Norman (1972b) who examined the complex in the Yahsihan area, on the southern margin of the basin. He agreed with the ideas of Bailey and McCallien (Op.cit) to a certain extent, but he interpreted the complex as a large olistostrome transported by gravity sliding, turbidity currents and slumping. A similar interpretation was also proposed by Senalp (1974) for exposures seen in the Sungurlu area.

1.2. The Upper Cretaceous

The Upper Cretaceous rocks appear to be restricted to the Maestrichtian. The succession begins with conglomerates, sandstones and siltstones. This basal member is succeeded by dark green breccias and sandstones. The top member of the succession is a limestone unit. The sandstones of the unit were interpreted as proximal turbidites by Norman (1972a,b). The following Maestrichtian fossils were found by Unalan (1974):-

Orbitoides media	D'ARCH
Cuvillierina cf.	SOZERI SIREL
Bolivinordes draco	MARSSON
Bolivino incrisata	REUSS
Oolina delicata	SLITER
Heterohelix elegons	RZEHAK

The presence of the Lapeirousia jounmeti (DES.MOUL) BAYLE which characterizes the Maestrichtian was also reported from the Yahsihan area by Norman (1972b).

In places the Maestrichtian is overlain unconformably by sediments of Palaeocene age (Unalan 1974, and Birgili et.al. 1975). However in the southern parts of the basin it passes up gradationally into the sediments of Palaeocene age (Norman 1972a,b).

5.2. TERTIARY

2.1. The Paleocene

The Paleocene comprises conglomerates, sandstones, siltstones and conglomeratic limestones. Lenses of reef limestone are also present in the upper parts (Unalan 1974).

The following fossils which characterize the Paleocene have been found in this sequence by Unalan 1974, and Birgili et.al.(1975). They are:-

Laffitterina bibensis

Miscellanea misello D'ARC

In the southern part of the basin the unit passes up gradationally into the overlying Eocene, but elsewhere there is a marked angular unconformity. In the Yahsihan area, the facies of the Paleocene were interpreted as submarine channel deposits, turbidites and pelagic deposits, Norman (1972a,b).

2.2. The Eocene

The deposits of Eocene age comprise a flysch sequence, with glauconite-bearing sandstones, shales and conglomerates in the lower part. These are conformably overlain by limestones and calcarous mudstones (Senalp 1974; Unalan 1974 and Birgili et.al. 1975). In the northern parts of the basin the sequence contains interbedded andesitic lavas, tuffs and agglomerates in its upper part (Bayat Formation of Birgili et.al. 1975).

The flysch sequence is the most widespread Tertiary unit in the Cankiri-Corum Basin. It rests unconformably on the Pal eocene and pre-Tertiary basement rocks (Birgili et.al. 1975) and is conformably overlain by the limestone facies with a transitional contact. The sediments of the flysch sequence were interpreted by Senalp (1974) as distal, intermediate and proximal turbidites which were probably formed by southward progradation of a submarine fan.

The flysch sediments contain the following fossils which indicate a Ypresian- Lutetian age (Ketin 1962, and Birgili et.al. 1975). They are:-

Nummulites globulus	LEYM
Assilina exponses	SOWERBY
Assilina granulosa	D'ARCHIAC
Assilina mamillota	D'ARCHIAC
Assilina spira	DE ROISSY
Assilina praespira	DE ROISSY
Nummulites atacicus	LEXMERIE
Nummulites laevrgatus	BRUG
Nummulites uroniensis	DE LA HARPE
Globigerina cf. veguensis	WEINZIER
Textularia cf. minuta	TEROUEM

The succeeding limestones and calcareous mudstones carry minor amounts of conglomerate and sandstones in their basal parts. The succession has been interpreted as representing the deposits of a shallow sea cut by submarine valleys (Senalp 1974) and of a stable shelf which became unstable from time to time (Birgili et.al. 1975).

Senalp (1974) and Birgili et.al.(1975) stated that the upper boundary of this limestone facies appears to be gradational with the overlying Oligo-miocene redbeds, but Sajova (1961 and Ketin (1962) believed that there is an unconformity between the two.

2.3. Oligo-miocene

The Oligo-miocene succession starts with fluviatile redbeds which vary from conglomerates and coarse sandstones to siltstones and mudstones. These are named the Incik Formation in this study following the terminology of Birgili et.al. (1975). No 'age diagnostic' fauna has been found, but on the basis of lithological comparison with Oligo-miocene sequences in other parts of Anatolia, the redbeds have been referred to the Oligo-miocene

(Ketin, 1962; Birgili et.al, 1975). However, Senalp (1974) collected fresh water fossils and he suggested that the age of the sequence ranges from Lutentian to Miocene. He called it the Buyukpolotli Formation, and the fossils were:-

Unio sp	
Melanopsis cf. sandbergeri	TOUR
Planorbis sp.	
Cyprideis cf. Lifforalis	BRADY
Ilyacypris gibba	RAMDOHR

The succeeding evaporite facies which conformably overlies and interfingers with the redbeds, is composed of gypsum and mudstones with minor amounts ofsiltstones and sandstones in the lower part. The age of this facies which is termed the Bayindir Formation in this thesis, is also considered as Oligo-miocene on the basis of its stratigraphic position.

2.4. The Miocene

A brief episode of late Oligocene uplift, folding and thrusting, followed by widespread erosion and peneplanation of the pre-Miocene rocks intervened before sedimentation was resumed in the Middle Miocene. The succeeding deposits comprise two facies. The first, a continental redbed facies, is called the Kizilirmak Formation in this study. It is dominated by conglomerates, sandstones, siltstones and mudstones with some lenses of freshwater limestone, gypsum, salt and lignite. It gradually passes up into a predominantly evaporitic facies, the Bozkir Formation, which is composed of gypsum, mudstones and siltstones.

2.5. The Pliocene

The topmost unit of the stratigraphic succession in the Cankiri-Corum Basin comprises alluvial fan deposits of Pontian age. These rest with a marked angular unconformity on all preceeding formations. The

fans are built mainly of poorly sorted conglomerates, sandstones and conglomeratic mudstones (Senalp 1974). The following fossils were found by Ketin (1962).

Helix cf. rugosa	MART
Helix cf. comatula	SANDB
Limnea sp	

Senalp (1974) also found fossil teeth and a jaw of Hipparion sp in the Sungurlu area.

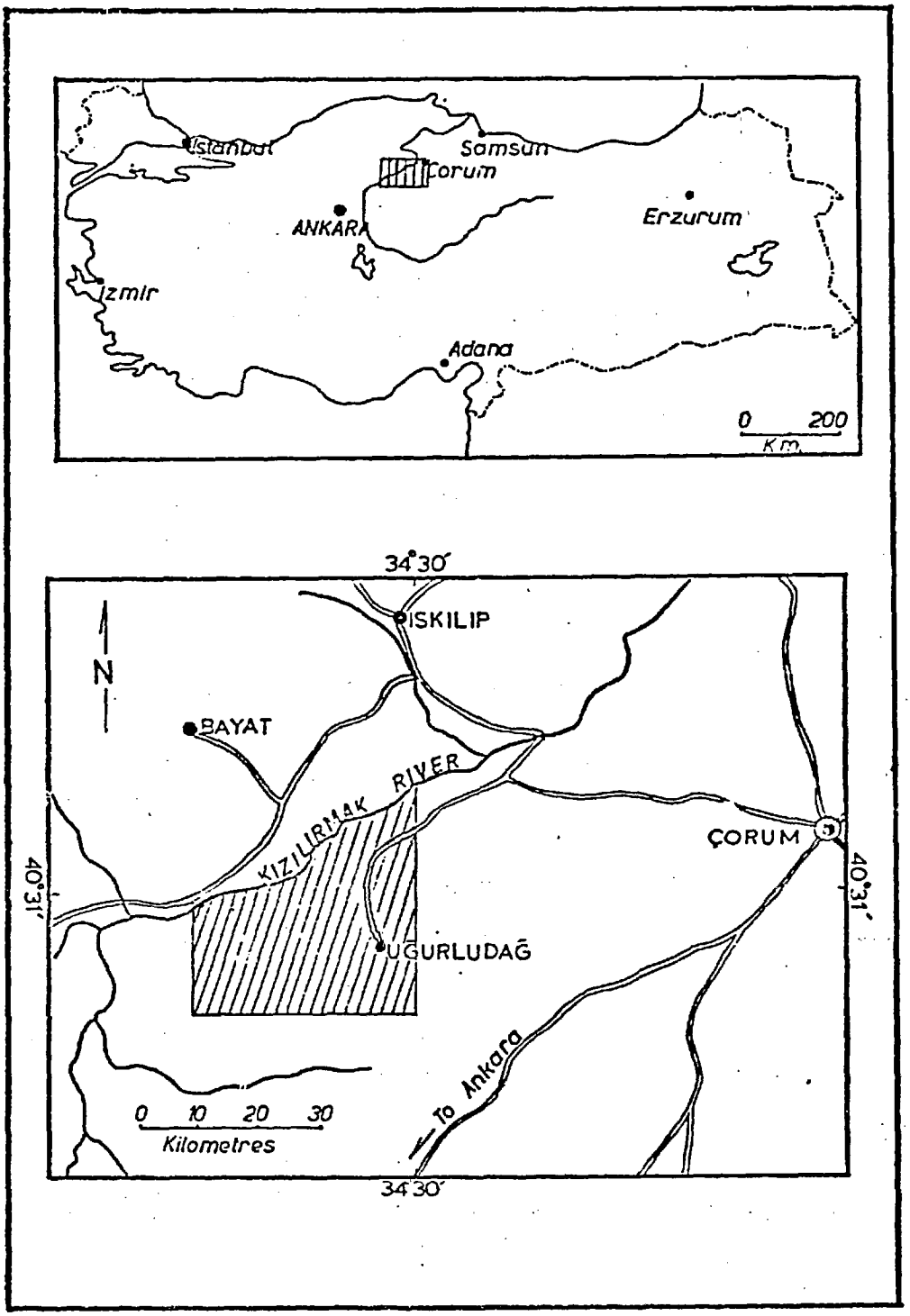


FIG. I.1 Location map of the study area.



FIG. I.2 A general view showing one of the landslides on the west slope of Buyuktepe near the village of Eski Celtek.

FIGURE I.3. TABLE OF CLIMATIC STATISTICS OF CANKIRI-CORUM BASIN*

	Cankiri	Ankara
TEMPERATURE (°C)		
Mean	11.5	11.7
Maximum	23.5 (July)	23.3 (August)
Minimum	-2.0 (January)	-1.0 (January)
RAINFALL		
Maximum	May	May
Minimum	August	August
Annual Precipitation (mm)	387	360
SNOWFALL (cm)		
Maximum	58	33

* Translated from a resume by Unalan (1974) of the 1967 statistics of D.M.I. (Meteorological Institute of Turkey).

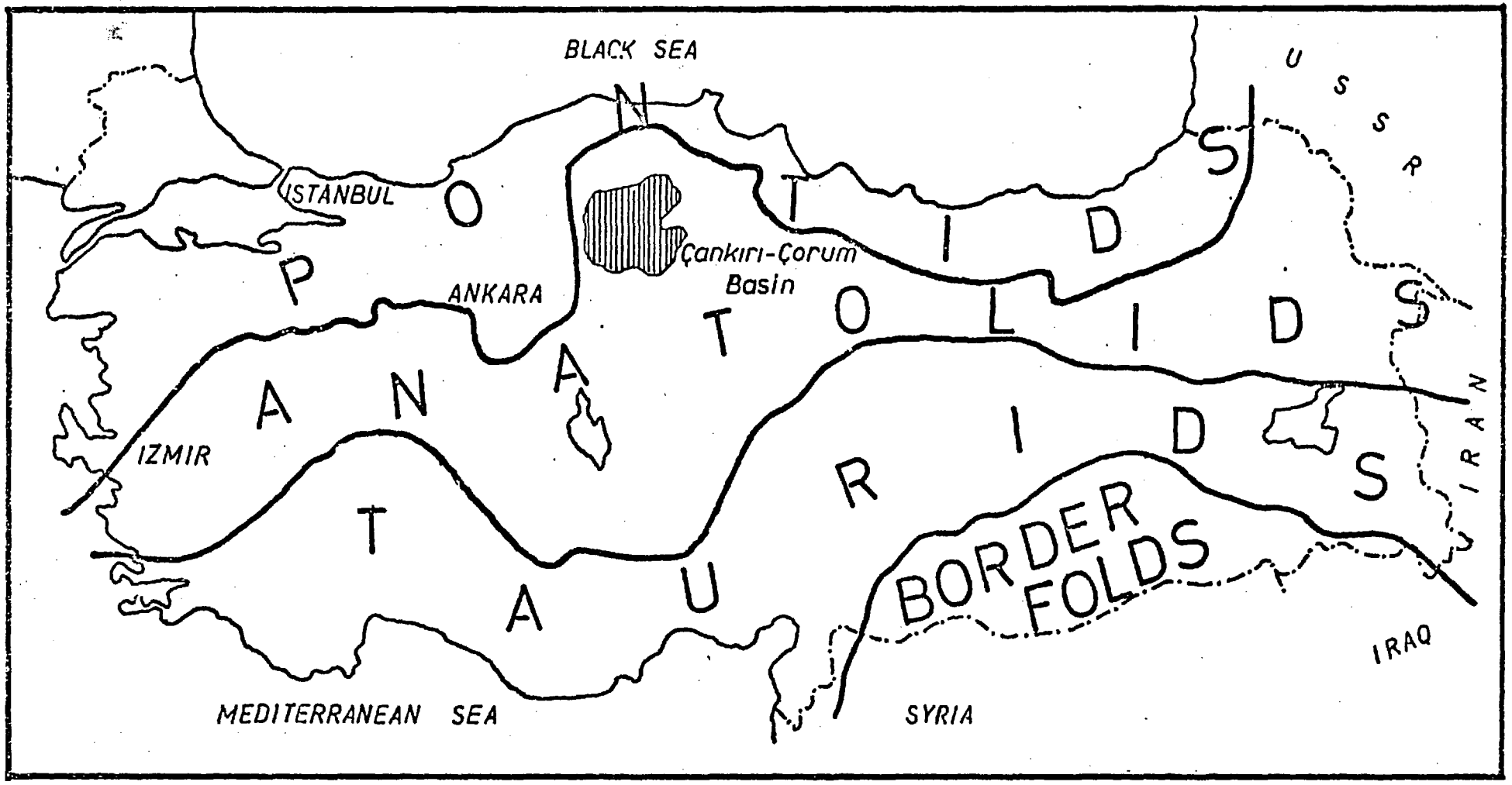


FIG.I.4 The location of the Cankiri-Corum Basin with respect to the Tectonic Units of Anatolia (After Ketin, 1966)

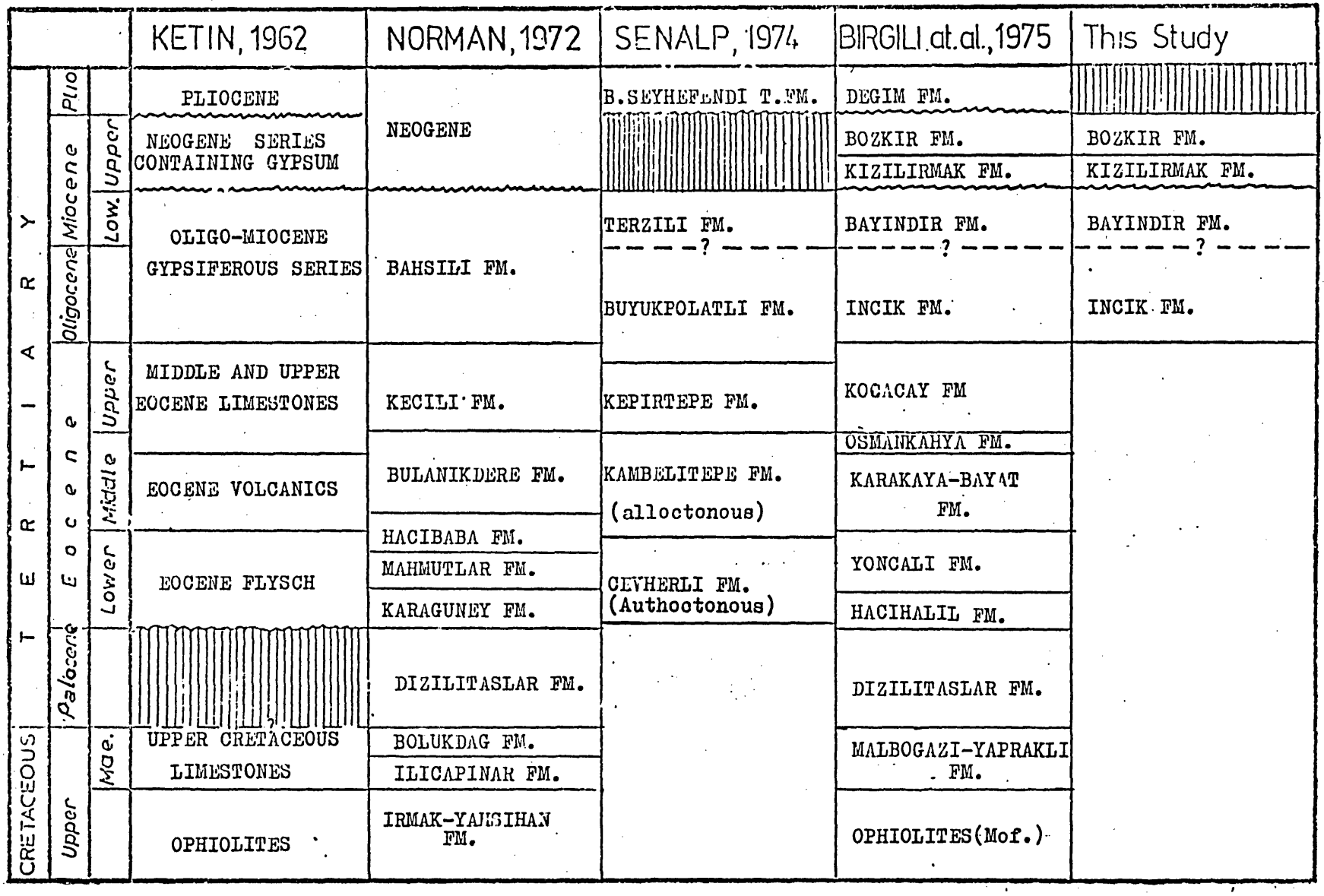


FIG.I.5 Comparative stratigraphic nomenclature of the Cankiri-Corum Basin.

CHAPTER II

THE INCIK FORMATION

II. 1. INTRODUCTION

The Incik Formation is the lowermost litho-stratigraphic unit of the sedimentary succession studied in the Ugurludag area. Lithologically, it comprises rhythmic repetitions of conglomerates, sandstones, siltstones and mudstones in the form of fining-upward cycles. Three thin beds of volcanic ash, which have been altered to the zeolite mineral, clinoptilolite, have been found in the upper part. Beds of nodular secondary gypsum after anhydrite, and veins of satin-spar gypsum are also present as subordinate lithologies in the upper part of the formation.

Where the formation is exposed in the study area, its contact with the underlying volcanics of Eocene age appears to be a thrust, (Fig. II.1) In most places, the top of the formation passes gradationally up into the succeeding Bayindir Formation, but in the north-eastern part of the area, around the villages of Gender (Grid: Cankiri $H32b_2$; 83-84; 26-27) and Torunlar (Grid: Cankiri $H32b_2$; 81-82, 25-26) it appears to be overlain with a marked angular unconformity by the redbeds of the Kizilirmak Formation.

II. 2. DISTRIBUTION AND THICKNESS

The formation crops out over large areas covered by the map sheets CANKIRI $H32b_1$ and CANKIRI $H32b_2$. It is extensively exposed in the southern part of the area, around the villages of Karaevliya (Grid: Cankiri $H32b_1$; 73-74; 13-14), Buyuk Erikli Grid: Cankiri $H32b_1$; 75-76; 16-17), Kucuk Erikli and Dutpinari, (Grid: Cankiri; $H32b_2$; 78-79; 18-19). In the northern part of the area good exposures are found around the villages of Torunlar and Gokceagac (Grid: Cankiri $H32b_2$; 82-83; 23-24) (Fig II. 2).

The thickness of the formation varies considerably from place to place. It achieves a thickness of 2000-2500 metres in the south western part of the area ($H32b_1$ map sheet), but becomes thinner towards the north east, and finally wedges out about 2 km to the north east of the village of Gender, just outside the area which has been mapped. It seems that the variations in thickness are due partly to large scale thrusting (App III.3) and possibly also to the angular unconformity where the formation is overlain by the redbeds of the Kizilirmak Formation. Elsewhere in the basin, the estimated maximum thickness of the formation is 3100 metres (Birgili et.al., 1975).

Four reference sections all of which represent the upper part of the formation were measured in the course of the present study. These are:-

(i) The Karaevliya Section (FIG. II.3): This section, which is 102 metres thick, was measured on the eastern flank of Bekci Tepe, which is situated to the west of the village of Karaevliya.

(ii) The Dutpinari Section (FIG. II.4): This section is 68 metres thick and was measured on the south side of Bekci Tepe, around the village of Dutpinari. The section commences with the lowermost bed of volcanic ash, now clinoptilolite, which is 65 cm thick.

(iii) The Boroluk Dere Section (FIG. II.5): This section is situated about 300 metres to the south west of the village of Dutpinari and is parallel to the Boroluc Dere. It is 93.50 metres thick.

(iv) The Gokceagac Section (FIG. II.6): This section was measured along the Koy Deresi stream near the village of Gokceagac. It represents the topmost 360 metres of the formation.

II. 3. LITHOLOGY

The formation is composed mainly of conglomerates, sandstones, siltstones and mudstones. The most conspicuous feature of the formation is the

cyclic nature of the sediments. It is made up essentially of repetitions of fining-upward cycles (Fig II. 7). Each cycle starts with a conglomerate unit. This grades up into the coarse-grained sandstones which become progressively finer-grained upward, and these are, in turn, overlain by siltstones. Each cycle is closed by a mudstone unit. A scoured surface generally intervenes between cycles (Fig II.8).

The thicknesses and compositions of the cycles vary stratigraphically and laterally from place to place. Conglomerates are the dominant component of the cycles in the lower part of the formation, but they become less abundant upward and are absent in the uppermost parts of the formation. The upward decrease in abundance of conglomerates is accompanied by an increase in the proportions of mudstones and siltstones. In the upper parts where conglomerates are absent, very coarse-grained sandstones rest on the scoured surfaces.

The thickness of individual cycles ranges from 0.60m to 4.00 metres in the lower part of the succession.

3.1. Conglomerates

The conglomerates are mostly dusky red (5R3/4) to pale reddish brown (10R5/4), but there are some which are olive gray (5Y4/1) to greenish gray (56Y6/1) in colour. Both extra and intraformational types are present. However the majority of the phenoclasts are of extraformational type. The cobbles and pebbles range from 3 up to 20cms in diameter. The largest being found in the lower part of the formation. The phenoclasts of extra-formational origin mainly comprise various types of limestones, volcanic and ophiolitic rock fragments. Metomorphic rock fragments are also present.

Pebbles of pale reddish brown (10R5/4) to dark reddish brown (10R3/4) and greenish gray (566/1) to dark greenish gray (564/1) mudstone and siltstone which resemble the mudstones and siltstones present elsewhere in the formation are considered to be intraformational in origin.

They tend to occur in the basal part of the conglomerate beds.

As mentioned previously the conglomerates usually grade up into coarse grained sandstones, but in some cycles the contact between the two appears to be sharp.

In cross-sections, the conglomerate beds are lens-shaped. In the lower part of the formation they spread for distances of a few tens of metres, but in the upper part they rarely exceed ten metres.

3.2. Sandstones

Sandstones are the most abundant rock type in the formation. They vary in colour from grayish purple (5RP 4/2) to dusky red (5R 3/4) and from greenish gray (5 6Y6/1) to dark greenish gray (5 G4/1).

The sand grains are generally angular to subangular and show moderate to poor sorting. They mainly comprise quartz, feldspars (mostly plagioclase), horn_blends, pyroxenes, detrital calcite, radiolarian chert, volcanic, ophiolitic and metamorphic rock fragments. Minor proportions of reworked skeletal fragments, transported nummulites, biotite, epidote and glaucophane are also present. Opaque minerals such as hematite and chromite are common constituents. Most of the grains are coated with limonite. The coarse-grained sandstones which form channels in the upper part of the formation contain some mudstone grains. These resemble the mudstones present in the formation and were evidently intraformational in origin. The sandstones are poorly cemented by calcite but occurrences of silica cement as overgrowths are not rare.

3.3. Siltstones and Mudstones

Dark reddish brown (10R/34) to pale reddish brown (10R5/4) and dark greenish gray (5G 4/1) to greenish gray (5G 6/1) mudstones and siltstones make up more than 40 percent of the formation. The siltstones occur

either as a transitional rock type between the sandstones and mudstones or as small lenses in the mudstones. They show moderate to poor sorting and individual grains are angular to subangular. They comprise grains of quartz, feldspar, radiolarian chert, hornblend, detrital calcite and pyroxenes.

In the upper part of the formation calcium carbonate concretions i.e.'cornstones'), lenses of nodular secondary gypsum and satin spar veins occur in association with the mudstones.

3.4. Clinoptilolite

In the uppermost 400 metres of the formation, three conspicuous, white (N9) to yellowish gray (5Y 8/1) horizons stand out in marked contrast to the essentially red background of the formation. These are well seen in the vicinity of the village of Gokceagac, (Fig. II. 9), whence they can be followed towards the southwest for distances of up to 15 kms as far as the village of Karaevliya. The lowest bed is 90 cms thick, but the middle and upper beds are thinner being 35 and 12 cms thick respectively. They occur in association with mudstones and their white colour is locally marred by a red iron oxide stain. When the lowest bed is traced laterally, its top is locally cut by channels of sandstones which belong to the succeeding fining-upward cycle. Locally this bed carries blebs of native copper.

Microscopic examination of thin sections of these rocks shows that in ordinary light they have the texture of volcanic ash, but X-ray diffraction analysis has revealed that they are almost entirely of the zeolite mineral clinoptilolite.

Clinoptilolite was identified as a new mineral in 1923 by Schaller; and it was considered to be similar to mordenite. In 1934 Hey and Bannister showed that it could be classified as a silica-rich variety

of heulandite. It was defined by Mumpton (1960) as the high silica member of the heulandite structural group of zeolites. Mumpton proposed a range of 4.25 to 5.00 for the Si/Al ratio of clinoptilolite and 2.75 to 3.25 for the heulandite. Mason & Sand (1960) used the content of calcium and alkili metals to distinguish clinoptilolite from heulandite. Calcium predominates in heulandite while sodium and potassium characterize clinoptilolite. The formula is Na Al $Si_{4.2-5}$ $O_{10.4-12}$ 3.5-4 H_2O. Its specific gravity ranges from 2.13 to 2.17 (Hay, 1966).For a more comprehensive review of the features and occurrences of clinoptilolite the reader is referred to Deffeyes (1959) and Hay (1966).

The d spacings and calculated intensities of clinoptilolite found in the study area are shown in Fig.II.1o, for comparison with those of clinoptilolites described from Hector, California by Mumpton (1960) and Patagonia, Argentina by Mason and Sand (1960).

Quartz, biotite and a few altered grains of feldspar are present with the clinoptilolite but these do not exceed 3 percent of the whole rock. Quartz occurs as subangular to angular monocrystalline grains with a diameter of between 0.3 and 0.6 mms. Biotite forms long, narrow flakes which are about 1mm long and 0.3 - 0.4 mms wide.

Samples were examined by scanning electron microscopy, and it was found that the former volcanic shards are pseudomorphed by aggregates of crystals of clinoptilolite (Fig II. 11). The inner parts of the former shards exhibit drusy textures and are characterized by euhedral tabular cystals of clinoptilolite up to 10-20 m across (Fig. II.12) These crystals are very similar to those described from Agura, California, U.S.A. by Wise et.al., 1969, (c.f. Figs.12:,a and b The outer parts of the shards have been replaced by the sheaf-like cystals of clinoptilolite which form rosettes (Fig. II.13). Some of the latter crystals appear to be fibrous (Fig. II.14). Similar arrangements of clinoptilolite

crystals were described from the Oligocene sediments of Trans-Pecos, Texas (Walton 1975).

The lowest clinoptilolite bed contains patches of native copper. Microscopic study using reflected light has revealed the presence of traces of native silver, cuprite and malachite in association with the native copper.

The lines of petrographical and minerological evidence presented above clearly indicate that the beds under discussion were originally deposited as volcanic ash and that each of the shards was subsequently pseudomorphed by an aggregate of clinoptilolite crystals. The question which arises is that of the mechanism of replacement.

Four possible diagenetic processes have been suggested for the formation of zeolites by alteration of volcanic ash. These are:-

(1) Hydrothermal alteration (Hoover 1968)

(2) Reaction of volcanic ash and water in a saturated system below the water table (Hoover 1968)

(3) Leaching and deposition in an unsaturated system above the water table (Hoover 1968)

(4) Burial metamorphism (Coombs 1961)

The first mechanism, hydrothermal alteration, is unlikely for the occurences in the Incik Formation, because no evidence of hydrothermal activity of appropriate age has been observed elsewhere in the basin.

3.5. Gypsum

(i) Layers of nodular secondary gypsum

Nodular gypsum makes its first appearance about 50 metres above the uppermost clinoptilolite bed and becomes increasingly abundant upwards. It is best exposed in the Koy Deresi where the Gozkceagac section was measured. It is also found on the left side of the road which connects the villages of Dutpinari and Belkavak (Grid CANKIRI $H32b_2$; 81-82, 18-19). The layers

of nodular gypsum occur in the mudstones and range in thickness from 3 to 20 cms up to 35cms. They tend to be lenticular, and they pinch out in distances of up to 100 metres depending upon their thicknesses. The constituent nodules vary in size from 0.3 cm to 10 cm in diameter. The shapes of the nodules are also variable. Subspherical to spherical shapes are the commonest, but elipsoidal and irregularly shaped nodules are not infrequent. The layers usually exhibit 'chicken-wire' structure, i.e. individual nodules have been packed so closely that only thin films of host sediment separate them from one another (Fig. II.15). Enterolithic structures are also developed here and there.

The non-evaporitic sediments between the nodules are pale reddish brown (10R 5/4) in colour and appear to be normal background clastic sediment. Horizontal to subhorizontal veins of satin-spar gypsum are also present between some of the nodules and many of the veins also cut across nodules.

Petrographically, the nodules are entirely composed of crystals of secondary gypsum, and both porphyroblastic and alabastrine fabrics are present (Fig II.16). Porphyroblastic fabrics are the predominant type, and most of the porphyroblasts enclose corroded relicts of anhydrite. The presence of these unreplaced relics of anhydrite leaves little doubt that the gypsum is secondary, and that the nodules were formerly composed of anhydrite.

(ii) Veins of satin-spar gypsum

As has been mentioned above, horizontal to near-horizontal veins of gypsum occur in association with the gypsum nodules. Most of the veins are less than 2mm in width, but a few reach 3 mms. They are mainly satin-spar gypsum: i.e. they are composed of gypsum fibres that extend from wall to wall. Some of the veins cut across the nodules and appear to be continuous for some distances, but many pinch out within a distance

of a few cms. However they are not confined to the layers of nodular secondary gypsum; they are also present in the underlying mudstones. The width of the veins in the mudstones varies from place to place, even along an individual vein, but in general they are thicker than those found in the nodular gypsum layers. An excellent example of this type of horizontal vein can be seen in the vicinity of the village of Gokceagac. There, a 30 cm thick layer of nodular secondary gypsum occurs in pale reddish brown (10R 5/4) laminated mudstone unit (Fig II.15). A horizontal vein of satin-spar gypsum, 3 cms wide, occurs 30 cms below the nodular gypsum layer. The vein tapers and pinches out laterally and disappears in a distance of 5 metres. The contacts of the vein with the laminated light brown mudstones of the wall rock are sharp, but the vein carries small rafts of mudstone which were obviously derived from the wall rock. It displays a lamination-like zonation which runs parallel to the walls and crosses the fibres. The microscopic features of this and other horizontal to subhorizontal veins of satin-spar gypsum are very similar to those of the Bayindir and Bozkir Formation, which will be described in chapter VI.

In addition to horizontal to subhorizontal veins, vertical to subvertical veins of gypsum have also been found. An interesting example of this type of vein was found at a roadside exposure near the village of Dutpinari (on the Dutpinari - Belkavak road). At this locality, the fining-upward cycles are composed of sandstones, siltstones and mudstones. A few of the mudstone units of the cycles contain thin layers of nodular secondary gypsum. In one of these cycles, the mudstones and siltstones are cut by a vein of gypsum which is inclined at 60°. It starts at the top of the sandstones and cuts across the siltstones and mudstones up to the layer of nodular gypsum (Fig II.17). The vein has an average width of 4 cms, but it thickens and thins locally. It is fibrous, but it

differs from the horizontal to subhorizontal veins in the orientation of fibres, which tend to run vertically: i.e. the fibres are not normal to the walls of the vein.

Another peculiar feature of this vein is the presence of a nodule of secondary gypsum (Fig II.17). The nodule is flattened parallel to the vein walls and it is composed mainly of porphyroblastic secondary gypsum with minor amounts of alabastine secondary gypsum.

II. 4. SEDIMENTARY STRUCTURES

The most common sedimentary structures seen in the clastic redbeds are: cross-bedding, graded-bedding, laminated bedding, scoured surface, sole markings, desiccation cracks and primary current lineation. Other sedimentary structures include mottled structures, rain prints and root structures.

4.1. Cross-bedding

Cross-bedding is a characteristic sedimentary structure of the coarse to medium-grained sandstones, but it is also occasionally observed in the conglomerates (Fig II.18). Both planar cross-bedding and trough cross-bedding occur, but trough cross-bedding is the most common type. The coarse grained sandstones show large scale cross-bedding while some of the medium to fine-grained ones display small-scale cross-bedding.

No detailed measurements of the attitudes of the cross-bedding were made in the present study, but it has been observed that most occurrences dip in a general southerly direction.

4.2. Graded bedding

Graded bedding is the most prevalent sedimentary structure of the Incik Formation. Two varieties of graded bedding are present. One type is the continuous upward grading from conglomerate to mudstones within an individual cycle. Where the cycles are well developed i.e. all members

of the cycle are preserved, this grading is best seen. Conglomerates or very coarse-grained sandstones in the upper part of the formation grade into the coarse-grained sandstones which become finer-grained progressively upward and finally grade into the siltstones and mudstones.

In some thick cycles, however, the medium to fine-grained sandstones are cut by conglomerates or sandstones to form a new cycle. In this case the type of the graded bedding is described as repetitive

4.3. Laminated bedding

Many of the siltstone and mudstone units display conspicuous lamination. The clinoptile beds and some very fine to fine-grained sandstones are also laminated. Although horizontal lamination is the modal type in the siltstones, mudstones and clinoptilolite beds, some of the fine to very fine-grained sandstones show cross-lamination.

4.4. Scoured surface

Allen (1962) and Friend (1965) applied the term "Scoured surface" to describe sharp, discordant, laterally extensive contact between the coarse-grained basal unit (conglomerates or very coarse-grained sandstones) of a cycle and the mudstones at the top of an underlying cycle in the Old Red Sandstone of Wales. Such sharp and discordant contacts between the conglomerates or coarse-grained sandstones and mudstones of the preceeding cycle are common throughout the Incik Formation. One of these is illustrated in figure II.18

4.5. Other sedimentary structures

Grove casts, flute casts and load casts are occasionally present on the underside of the individual cycles. Primary current lineations occur in the laminated fine-grained sandstones, and desiccation cracks are seen in most of the mudstone together with mottled structures, rain prints and root structures. The latter are also seen in the lowest clinoptilolite bed.

II. 5. THE AGE OF THE FORMATION

No fossils of unequivocal diagnostic age have been reported from the Incik Formation. It seems that it is devoid of fauna, other than a few freshwater gastropods, astracods and vertebrate bone fragments.

Since the early study of Erol (1953) the age of the formation has been assigned as Oligo-miocene by the majority of workers. The assumption is based on the presence of an unconformity between the Incik Redbeds and the underlying Eocene sediments and another unconformity between the Upper-Miocene Redbeds of the Kizilirmak Formation and the Bayindir Formation which conformably overlies and interfingers with the Incik Redbeds. However Senalp (1974) found Cuprideides cf. Littoralish (BRADY) in the upper part of the formation in the Sungurlu area. Cuprideides has been in existence since the Miocene. He argued that the basal contact of the formation is transitional to the underlying Lutetian limestones and it is transitionally overlain by the Bayindir Formation which is in turn overlain by Pontian sediments. Senalp (op. cit.), therefore, concluded that the formation as a whole ranges from Upper Eocene to Pontian. No fossils have been observed in the Ugurludag area during the present study except for a few transported nummulites of Eocene age.

II. 6. THE ENVIRONMENT OF DEPOSITION

The most distinctive feature of the Incik Formation is that it is made up by the repetitions of fining-upward cycles. 'Fining-upward' cycles of this type characterise fluviatile sedimentation, especially deposits of meandering streams (Allen, 1964, 1965, 1970; Beerbower, 1964; Friend, 1965; Allen and Friend, 1968).

The conglomerates and/or very coarse-grained sandstones which form the basal part of the cycles are comparable with stream channel deposits described by Allen (1965). The vertical sequences of sedimentary structures and grain

size distribution of the sandstone beds compare well with sedimentary structures and grain size observed in modern point bars of meandering streams (Fraizer and Osanik, 1961; Bernard and Major, 1963; Harms et.al., 1963; Allen 1964, 1965; Visher, 1965; Friend, 1965 and Allen and Friend, 1968). The presence of large-scale cross-bedding in the coarse-grained sandstones and the small-scale cross-bedding in the overlying fine-grained sandstones suggest that the sandstones were probably deposited by the lateral accretion on the point bars in the upper part of the lower flow regime and the lower part of the lower flow regime (Allen, 1965). The siltstones and mudstones show many of the characteristics of modern flood plain deposits. Figure II.19 presents a summary of the lithology, sedimentary structures and inferred depositional sub-environments of an idealized fining-upward cycle. In the Sungurlu area, which is situated 25 kms to the south of the study area, the lateral equivalents of the formation have also been interpreted as representing a fluviatile environment dominated by meandering streams by Senalp (1974). However the presence of nodular gypsum after anhydrite and cornstones are suggestive of aridity at the site of deposition, at least for the upper part of the formation. The likelihood is that the rain which fed the streams fell over a mountainous hinterland which probably lay somewhere to the north.

The presence of the volcanic ash beds all of which have subsequently been replaced by clinoptilolite, indicates that volcanicity was active somewhere in the vicinity during the deposition of the upper part of the formation. The evidence suggests that the material was probably 'air-dropped' into the flood plain environment.



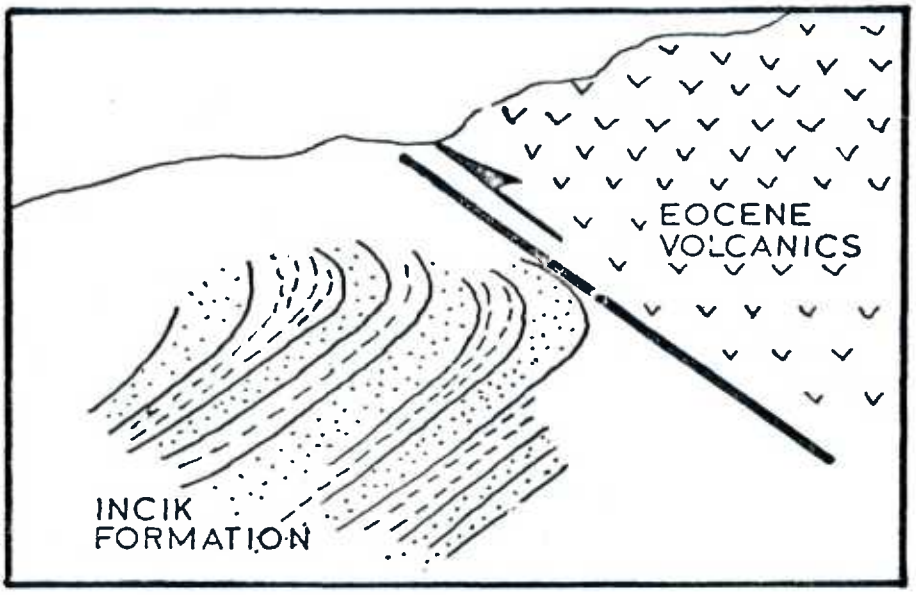


FIG. II.1 The thrust contact between the Incik Formation and the Eocene Volcanics, North side of Kotudag, near the village of Torunlar.

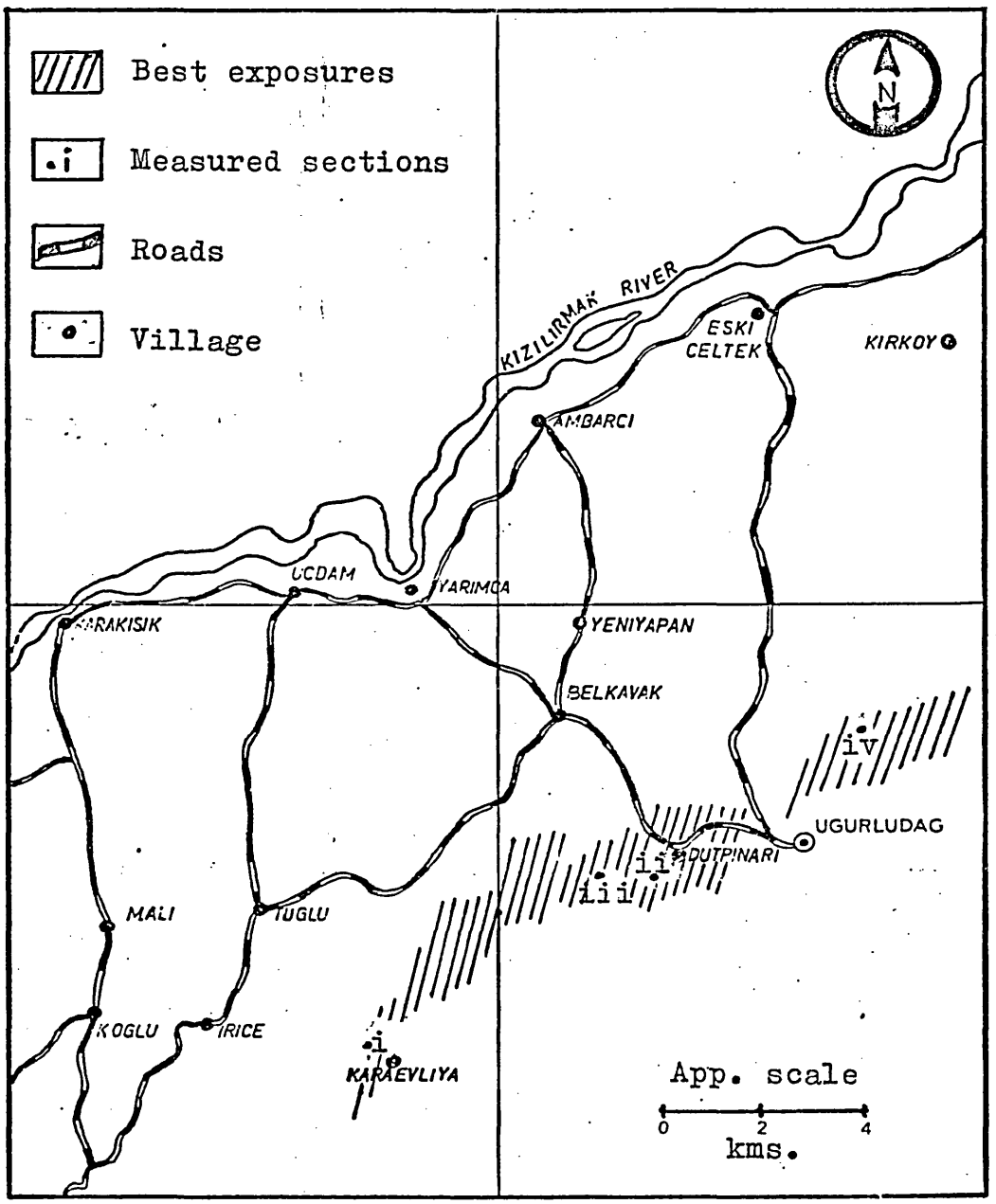


FIG. II.2 A schematic map of the study area showing best-exposed outcrops and the locations of measured sections of the Incik Formation.

i. The Karaevliya Section
ii. The Dutpinari Section
iii. The Borolukdere Section
iv. The Gokceagac Section

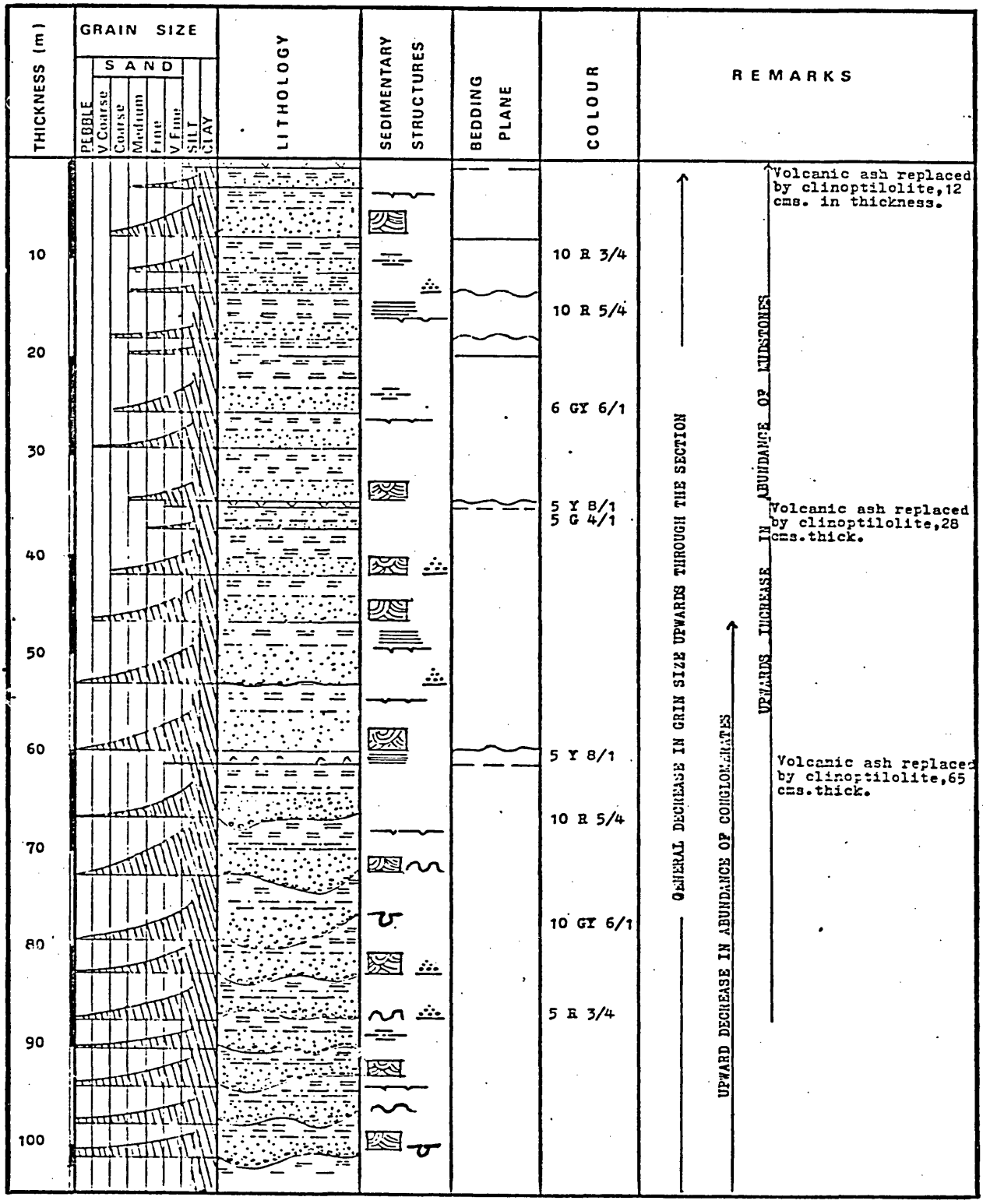


FIG. II.3 The Karaevliya Section.

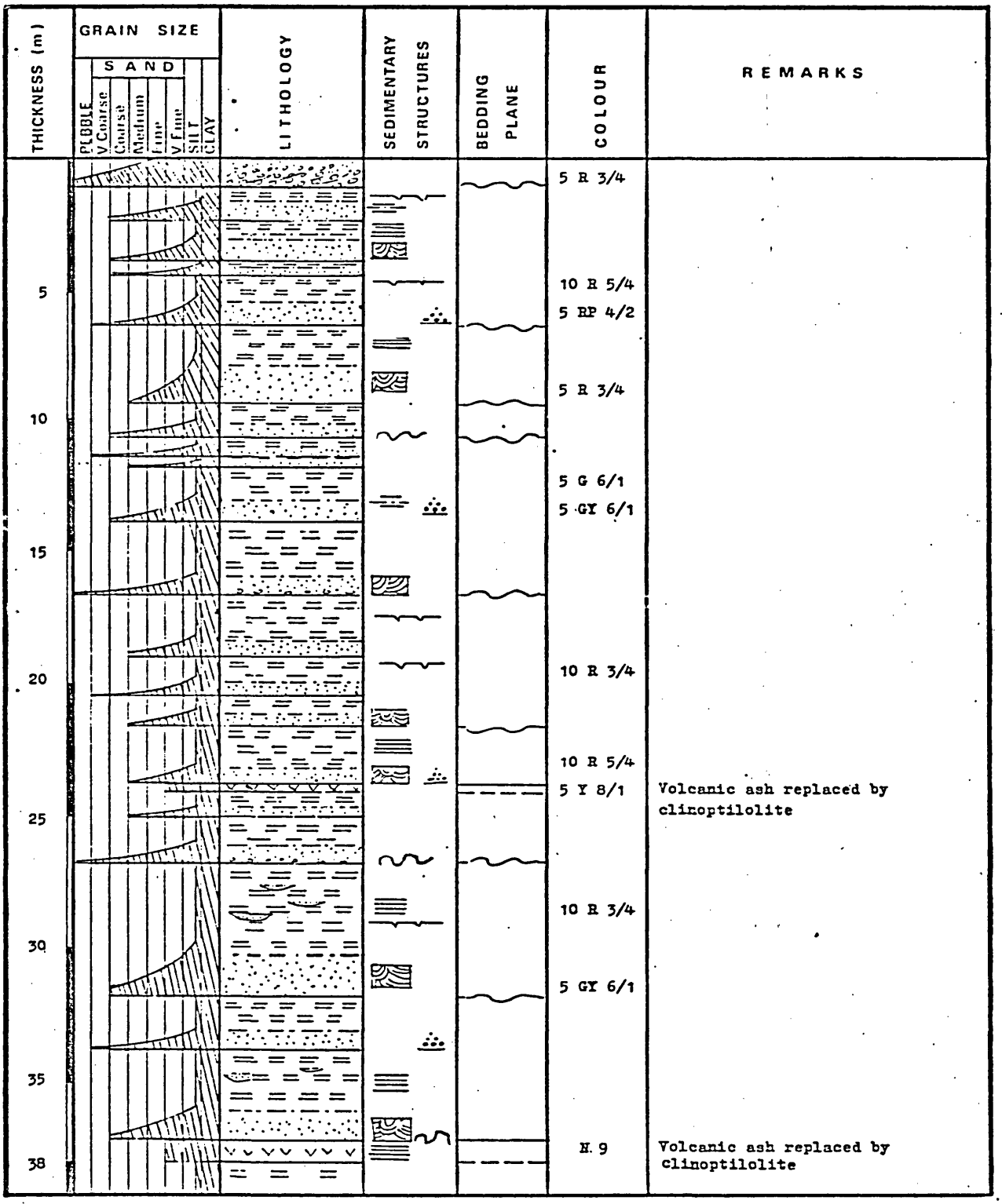


FIG. II.4 The Dutpinari Section.

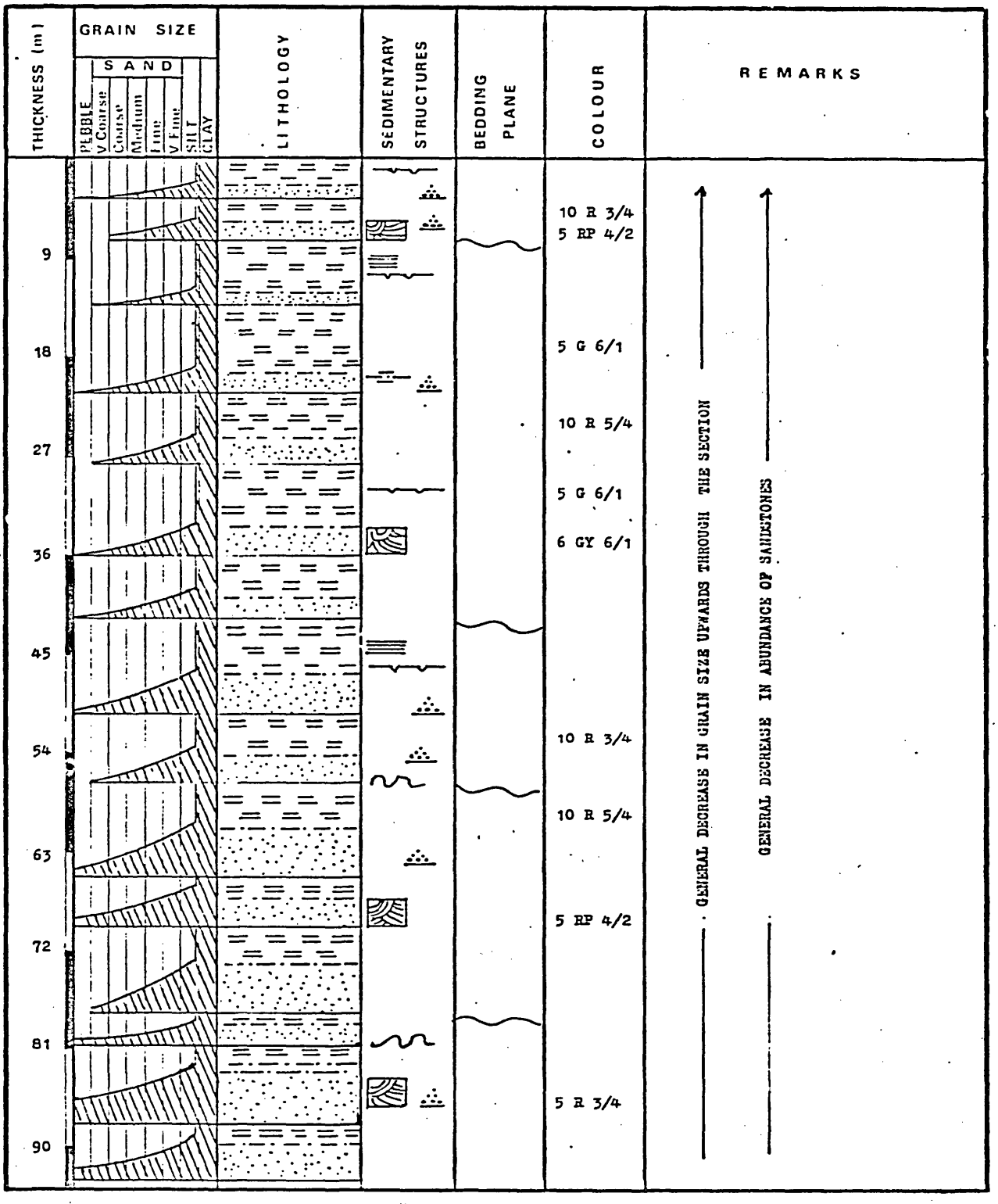
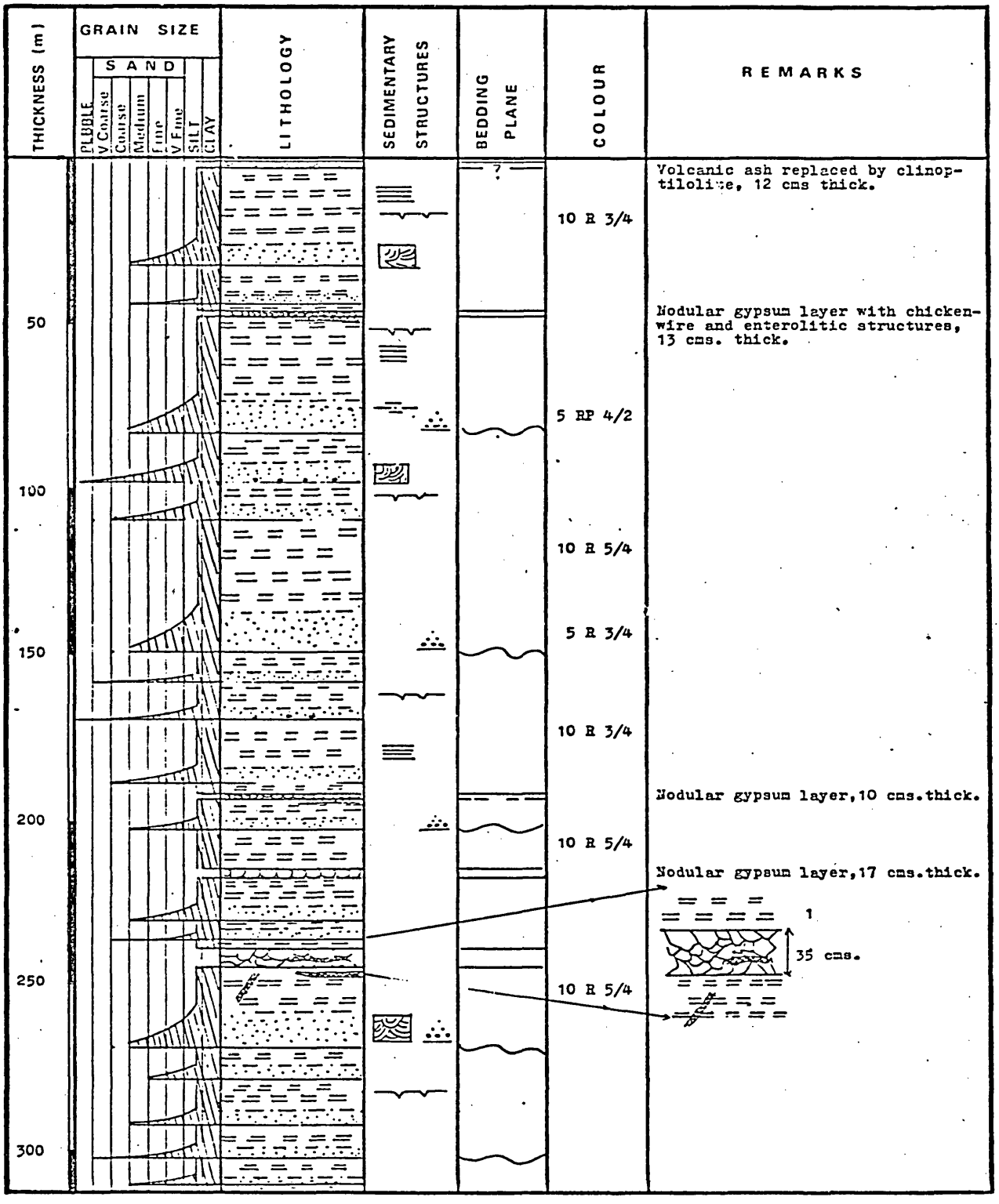


FIG. II.5 The Boroluk Dere Section.


THICKNESS (m)
GRAIN SIZE
SAND
PEBBLE
V.Coarse
Coarse
Medium
Fine
V.Fine
SILT
CLAY
LITHOLOGY
SEDIMENTARY STRUCTURES
BEDDING PLANE
COLOUR
REMARKS
50
100
150
200
250
300
10 R 3/4
5 RP 4/2
10 R 5/4
5 R 3/4
10 R 3/4
10 R 5/4
10 R 5/4
Volcanic ash replaced by clinoptilolite, 12 cms thick.
Nodular gypsum layer with chicken-wire and enterolitic structures, 13 cms. thick.
Nodular gypsum layer,10 cms.thick.
Nodular gypsum layer,17 cms.thick.
1
35 cms.

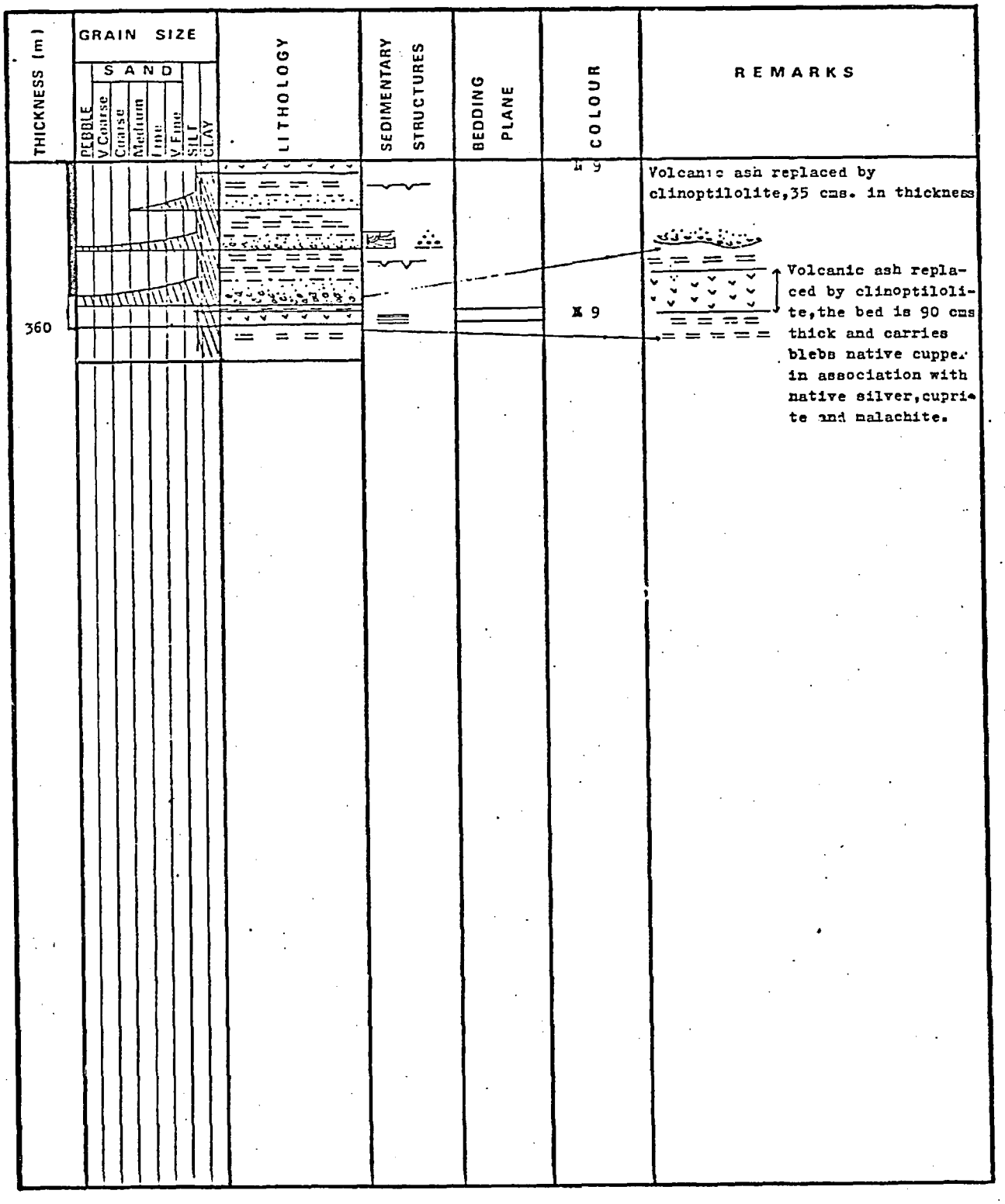


FIG.II.6 The Gokceagac Section.



FIG. II.7 General field appearance of redbeds of the Incik Formation, showing two fining-upward cycles.

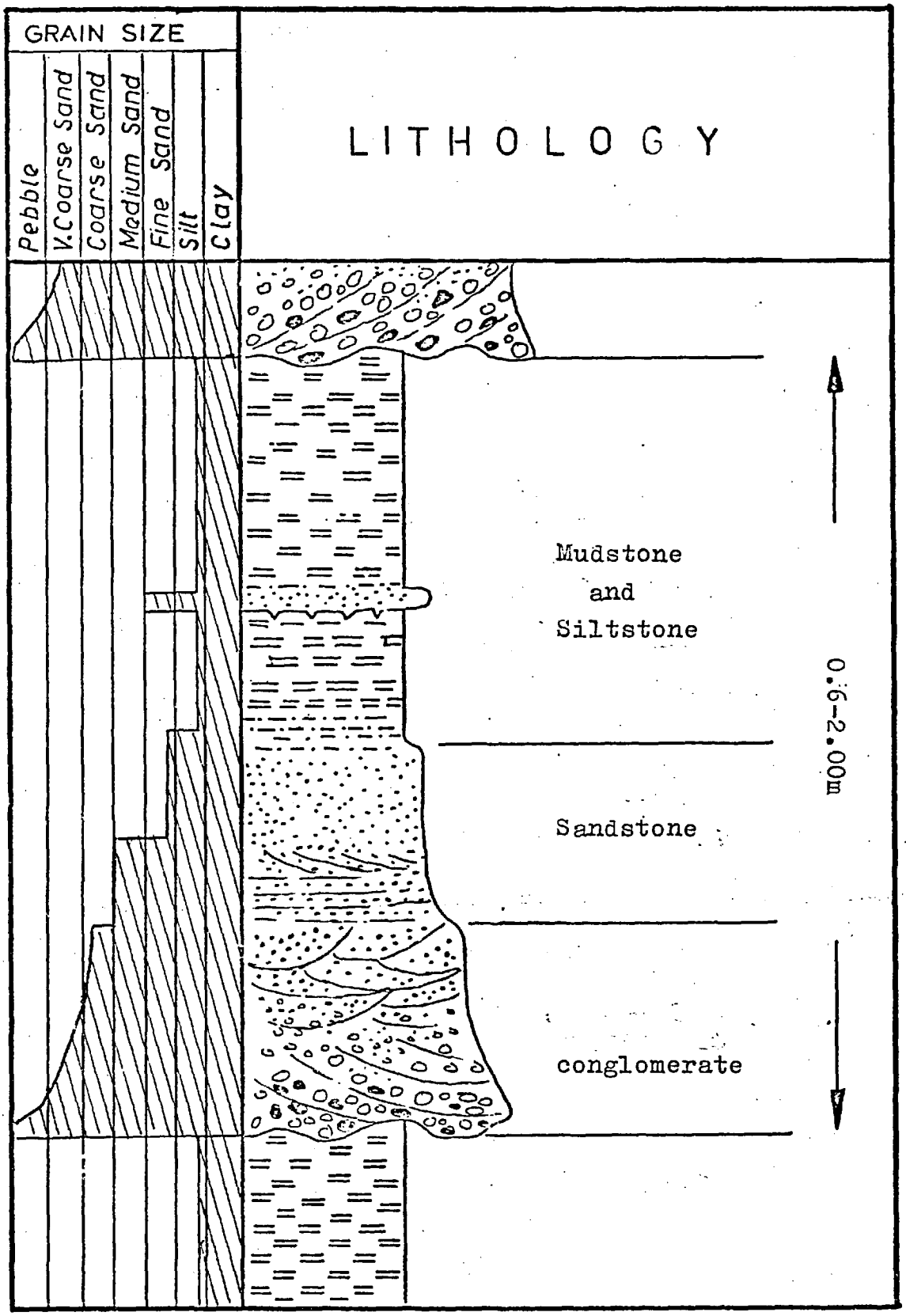


FIG. II.8 Schematic diagram showing details of a typical fining-upward cycle in the Incik Formation.



FIG. II.9 Photograph showing two of the beds of clinoptilolite(white),upper part of the Incik Formation,near the village of Gokceagac.

FIG. II.10 d - spacings and calculated intensities of clinoptilolite and heulandite.

1. Present study, Cankiri-Corum Basin.
2. Hector, California, U.S.A. (Mumpton, 1960)
3. Patagonia, Argentina (Mason and Sand, 1960)
4. Prospect Park, New Jersey, U.S.A. (Mumpton, 1960)

vs Very strong
s Strong
m Medium
w Weak
vw Very weak

1 Clinoptilolite		2 Clinoptilolite		3 Clinoptilolite		4 Heulendite	
d(A)	I	d(A)	I	d(A)	I	d(A)	I
9.02	10	9.00	10	8.96	vs	8.90	10
7.94	4	7.94	4	7.94	m	7.94	2
6.78	2	6.77	3	6.80	w	6.80	1
6.63	2	6.64	2			6.63	1
5.91	1	5.91	1	5.98	vw	5.92	1
5.25	3	5.24	3			5.24	1
5.11	3	5.11	1	5.13	m	5.09	1
4.65	2	4.69	2	4.65	w	4.69	1
4.36	1	4.34	2	4.35	w	4.36	1
3.96	10	3.96	10	3.97	vs	3.97	2
3.91	6	3.90	8			3.89	2
3.82	1	3.83	1			3.83	3
3.75	1	3.73	1	3.72	w	3.71	1
3.55	2	3.55	2	3.55	w	3.56	1
		3.46	2			3.47	1
3.42	4	3.42	6	3.43	m	3.40	2
3.12	2	3.12	2	3.18	w	3.12	2
3.07	2	3.07	2	3.10	vw	3.07	1
		3.04	2				
2.97	6	2.97	5	2.98	s	2.97	4
		2.87	1				
2.79	2	2.82	3	2.81	m		
2.79		2.80	1			2.80	1
2.73	1	2.73	1	2.74	w	2.72	1
2.67	1	2.68	1	2.68	vw	2.67	1
2.53	1						
						2.48	1
2.45	1	2.44	1	2.44	w	2.43	1
						2.35	1



FIG. II.11 Scanning electron photomicrograph showing shards of former volcanic glass pseudomorphed by aggregates of clinoptilolite crystals.



FIG. II.12,a Scanning electron photomicrograph showing the tabular habit and crystal faces of clinoptilolite from the Incik Formation.

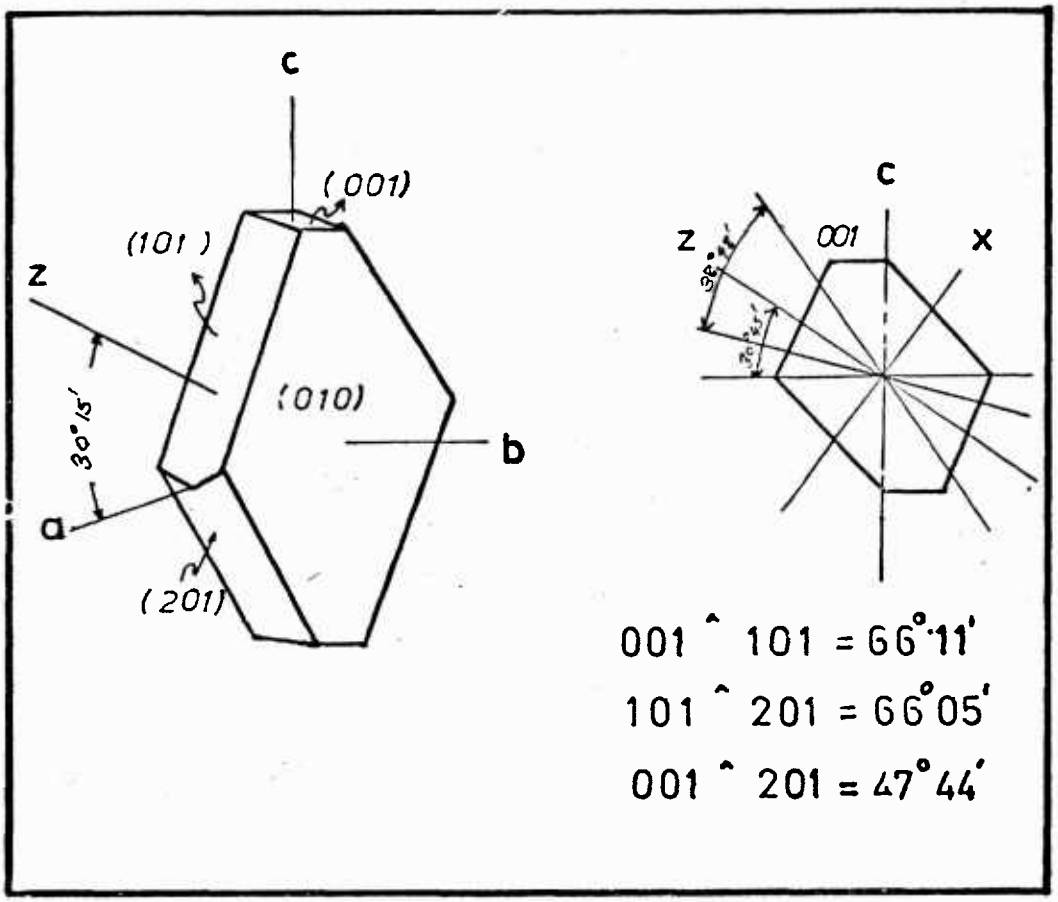


FIG. II.12,b Habit and crystallographic orientation of clinoptilolite from Agura, California (After Wise et. al., 1969).



FIG. II.13 Scanning electron photomicrograph showing rosettes of clinoptilolite:Incik Formation.

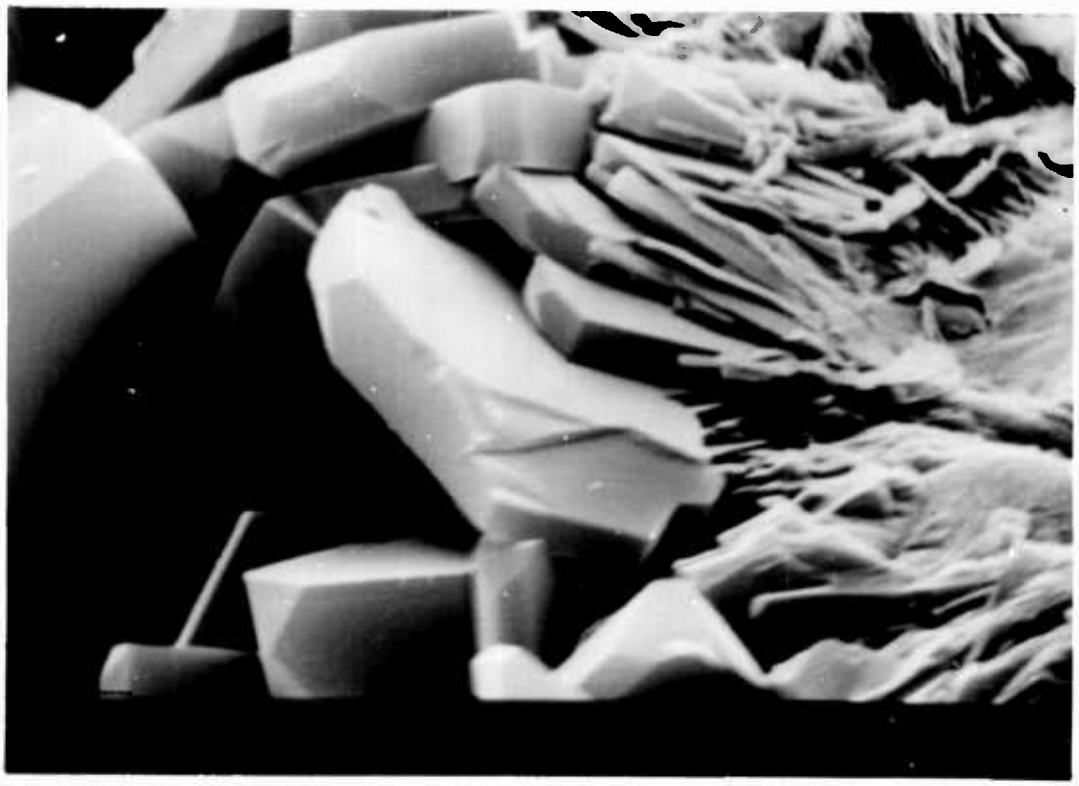


FIG. II.14 Scanning electron photomicrograph showing the lateral transition from fibrous crystals of clinoptilolite at the margin of a former shard to euhedral tabular crystals in the inner part.

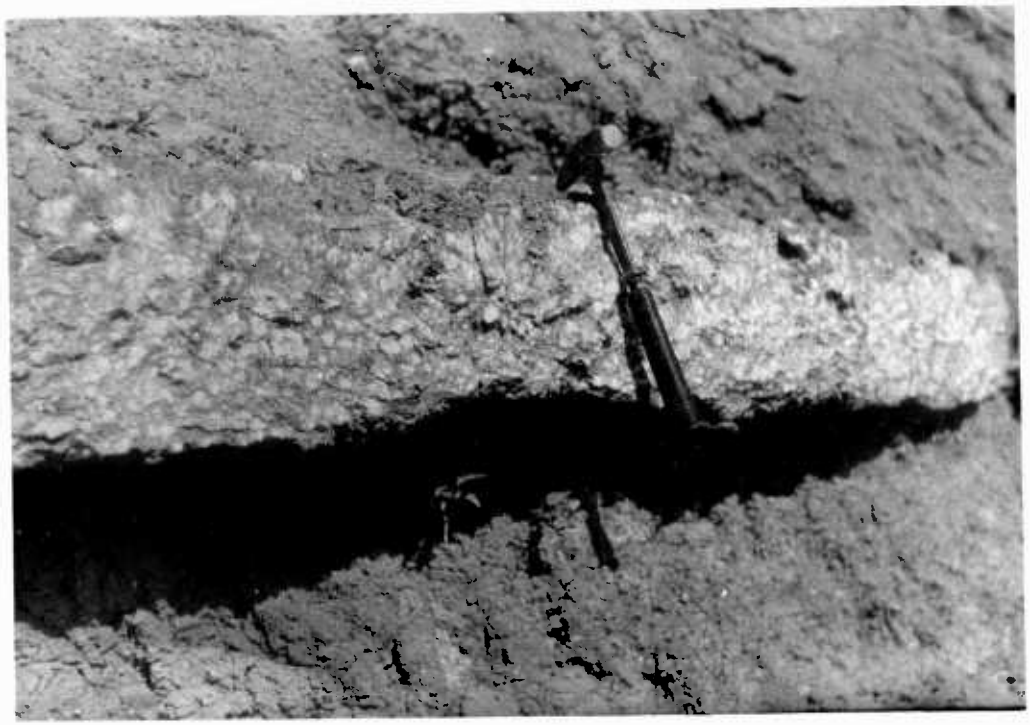
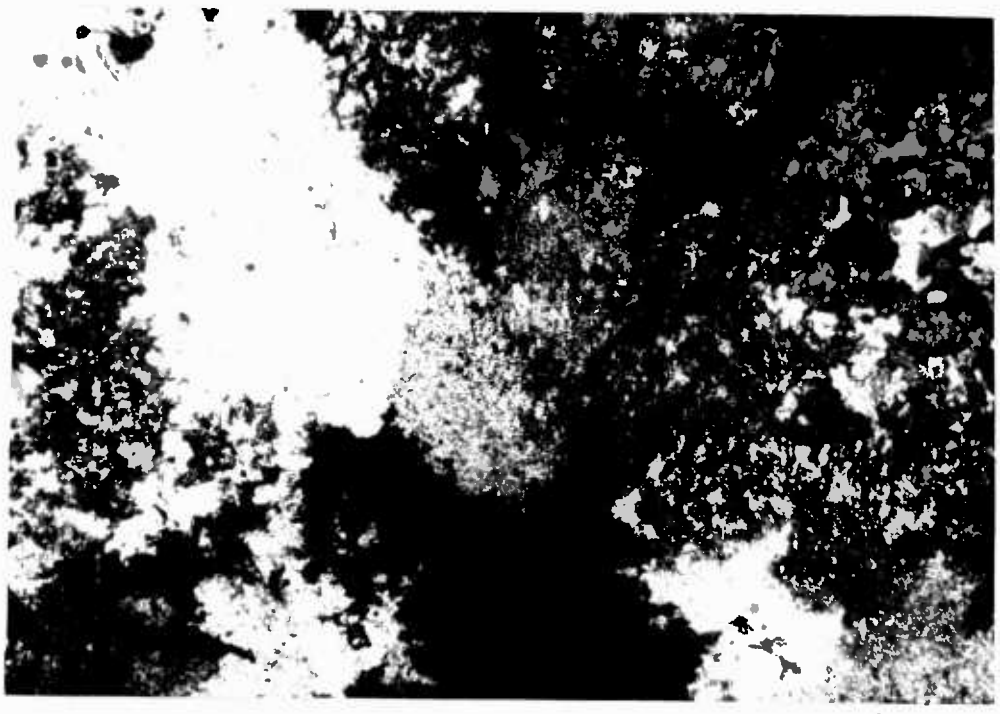


FIG. II.15 A layer of nodular gypsum in the upper part of the Incik Formation.Note the "Chicken-wire" structure.



(x30)

FIG. II.16 Photomicrograph showing porphyroblastic and alabastrine fabrics in secondary gypsum: Incik Formation. (Crossed-polars)

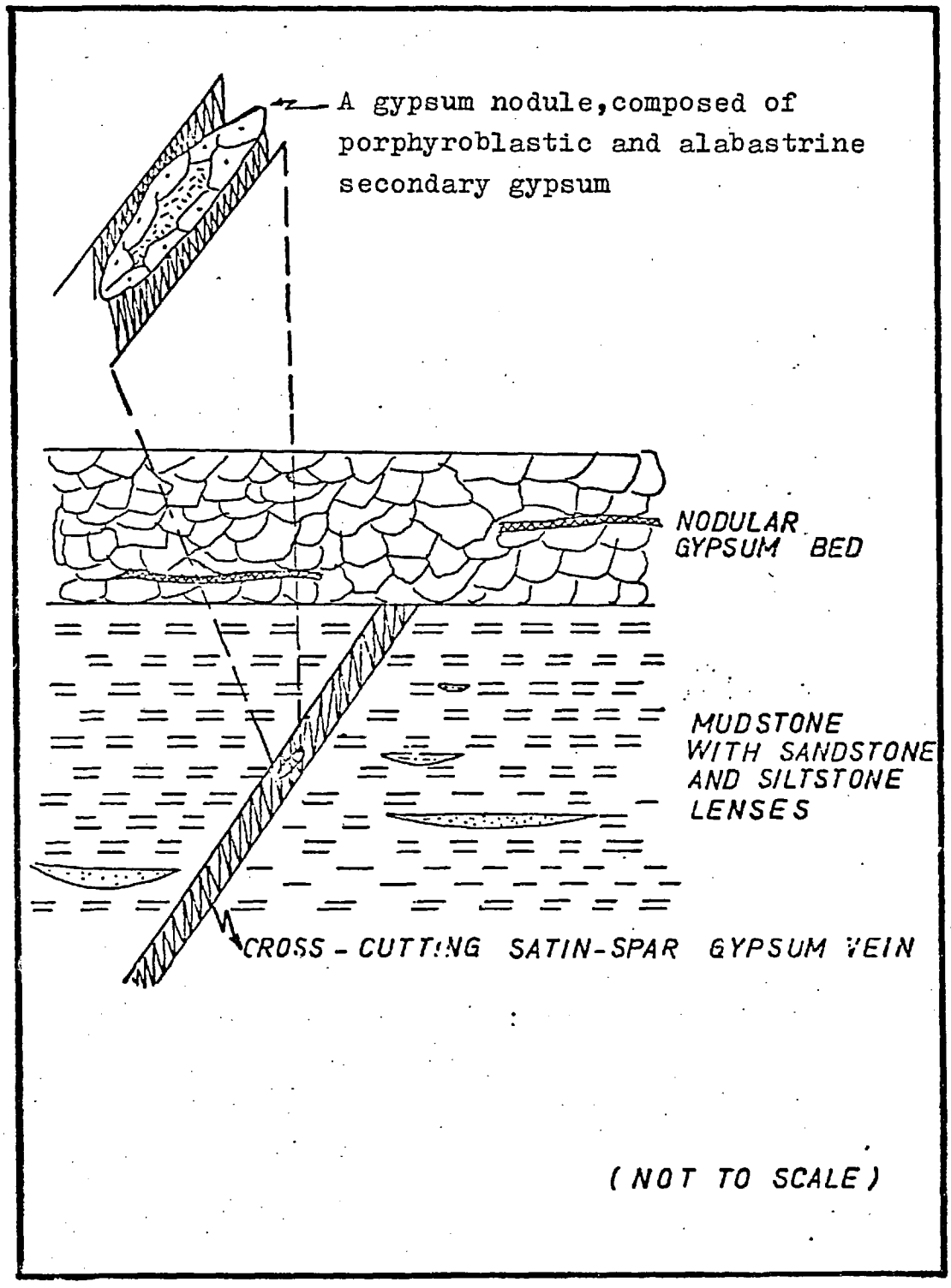


FIG. II.17 A field sketch showing the relationship between a nodular gypsum bed and a subvertical satin-spar vein in the upper part of the Incik Formation, near the village of Dutpinari.



FIG. II.18 Scoured surface between the conglomerate and mudstone:Incik Formation,near the village of Dutpinari.Note the cross-bedding of the conglomerates.

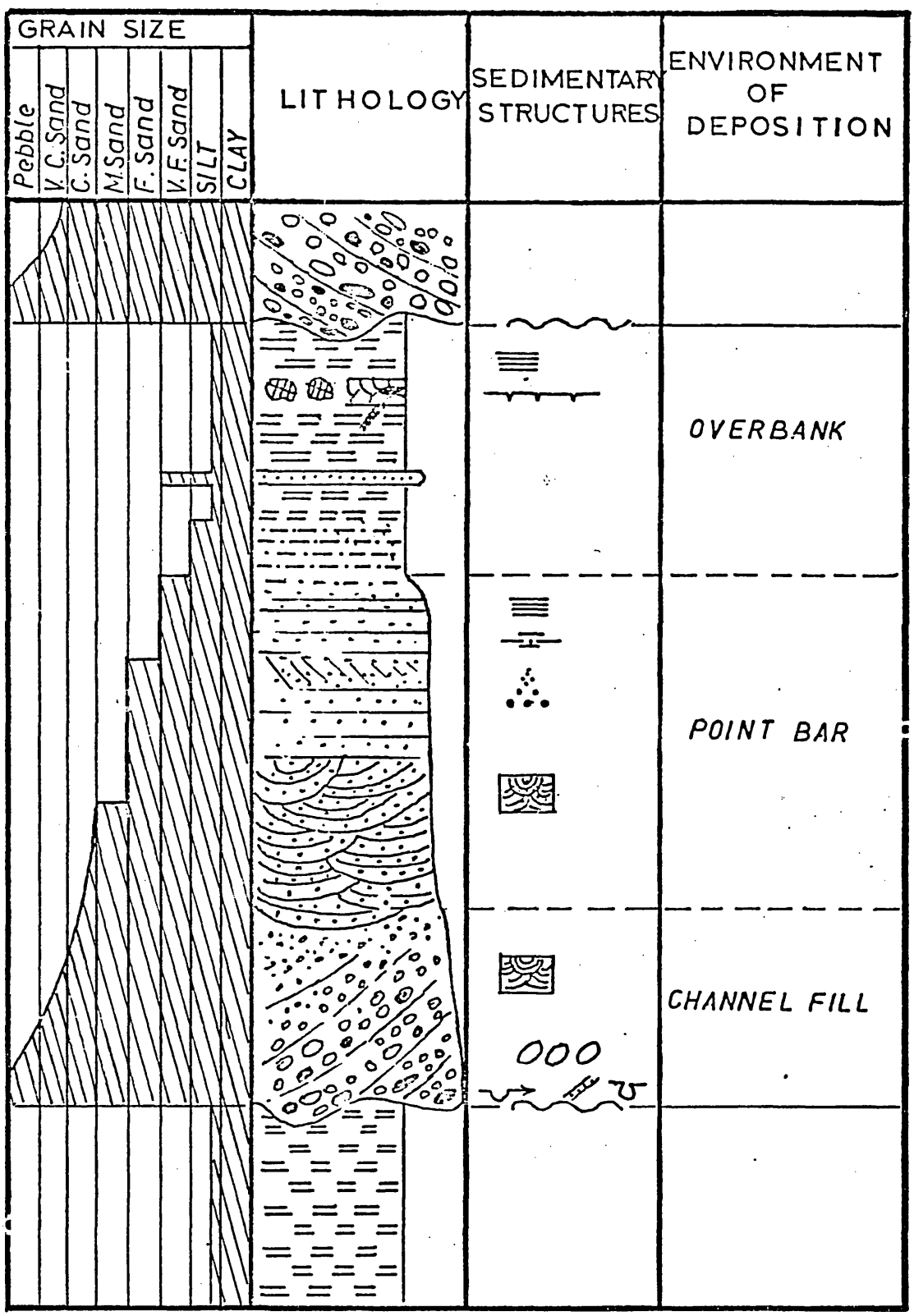


FIG.II.19 A summary of the sedimentary features and inferred depositional sub-environments of the Incik Formation.

CHAPTER III

THE BAYINDIR FORMATION

III. 1 INTRODUCTION

The redbeds of the Incik Formation are succeeded by a sequence of interbedded gypsum and fine-grained clastics, termed the Bayindir Formation by the Cankiri-Corum mapping group of M.T.A. (Birgili et.al. 1975). These rocks had previously been treated as part of the Oligo-miocene Gypsiferous Series (e.g. Erol, 1953; Yucel, 1953 and Ketin, 1962). The lateral equivalent of the formation in the Sungurlu area was named the Terzili Formation by Senalp (1974) who, incidently was the first to recognize the nodular character of the gypsum rocks.

The Bayindir Formation overlies the Incik Formation conformably, but it is overlain by the Upper Miocene redbeds of the Kizilirmak Formation with a marked angular unconformity. In many places the base of the formation is seen to be transitional; the transition from redbeds being marked by the appearance of thin beds of gypsum in the fining-upward cycles in the topmost part of the Incik Formation. Thus it is difficult to define the base of the Bayindir Formation precisely, but for practical purposes in the field it has been taken at the base of the first significant and laterally persistent gypsum bed.

III. 2. DISTRIBUTION AND THICKNESS

Although the formation crops out over large parts of the areas covered by map sheets: CANKIRI $H32B_1$, CANKIRI $H32b_2$ and CORUM G32 C_4; it is on the whole poorly exposed. The best exposures are found in two places. One extends from the village of Irice (Grid: CANKIRI H32 b_1; 74-75, 09-10), along the Ceel Tepe to Bestepe, and is about 3 kms long. The other extends from the east of the village of Karakisik (Grid: H32 b_1; 83-84; 06-07) to the village of Ucdam (Grid: G32 c_4; 85-86, 12-13), along the northern border of the study area (Fig. III.1.) These exposures are mainly in the lower part of the formation, and no well-exposed sequences

suitable for section measurement have been found in the upper part of the formation.

Four reference sections have been measured in the lower part of the formation. They are:-

(i) The Bestepe Section (Fig. III.2)

The Bestepe Section is located on the eastern slope of Bestepe Hill, 2 kms. to the south of the village of Kalenderoglu (Grid: CANKIRI H32 b_1; 74-75, 07-08). The section has a thickness of 220 metres and represents the transition zone between the Bayindir and Incik Formations.

(ii) The Kiziltepe Section (Fig. III.3)

The Kiziltepe section is situated 1 km to the east of the village of Karakisik (Grid: CANKIRI H32 b_1; 83-84, 06-07), on the northern slope of the Kiziltepe. It also represents the transition zone between the Bayindir and underlying Incik Formation and is 180 metres thick.

(iii) The Ceel Tepe Section (Fig. III.4)

This section is located on the eastern slope of Ceel Tepe; 500 metres west of the village of Irice (Grid: CANKIRI H32 b_1; 74-75, 09-10). The section is 22 metres thick and appears to start about 50 metres above the top of the transition zone.

(iv) The Duzce Dere Section (Fig III.5)

The Duzce Dere Section, which is 15 metres thick, was measured on the west side of the Duzce Dere around the Fasoluk Pinari (Grid: CANKIRI H32 b_1; 72-73, 07-08). It appears to start about 10 metres above the top of the transition zone.

Due to lack of exposures the thickness of the formation cannot be determined precisely in the area which has been studied, but it cannot be less than 350 metres. The maximum known thickness of the formation elsewhere in the basin is 600 metres (Birgili et.al., 1975).

III. 3. LITHOLOGY

The Bayindir Formation consists mainly of gypsum and mudstones. The gypsum occurs as nodules scattered in the mudstones and also as beds composed entirely of coalesced nodules. A distinctive feature of the lower part of the formation is the presence of veins of satin-spar gypsum. They are mostly horizontal to subhorizontal with respect to bedding, but some vertical to subvertical veins are also present.

As already mentioned, the formation does not show a complete section anywhere in the study area. However, it is possible to build up a generalized stratigraphic sequence by piecing together such information as can be obtained from small exposures (Fig. III. 6). The formation is broadly divisable into a lower unit and an upper unit on the basis of lithology.

3.1. The Lower Unit

The lower unit comprises cyclic alternations of beds of clastics, several tens of metres thick, and beds of gypsum, up to 13 metres thick, (Fig. III.7). The clastic member of each cycle is cyclic within itself and is built up of a series of clastic subcycles. Further, the whole unit can be considered as a cyclic progression: because if the gypsum members are ignored, the clastics pass from being mainly sandstones at the base, to mudstones at the top. This pattern of cycles within cycles is presented schematically in figure III.8 .

The thickness of the unit appears to vary from place to place. A thickness of 220 metres was measured at Bestepe, where nine clastic-gypsum cycles were counted ranging in thickness from 15 metres up to 53 metres. 22 kms to the north, at Kiziltepe, the thickness is 180 metres and only five cycles were found (Figs. III.2 and 3).

The clastic members of the cycles are composed of sandstones, siltstones and mudstones. The sandstones and siltstones vary in colour

from greenish gray (6 6Y 6/1) to olive gray (5Y 4/1) and from dusky red (5R 3/4) to dark reddish brown (10R 3/4), but the mudstones are mostly reddish brown (10R 3/4). The sandstones appear to be shoestring channel fill deposits. The sandstones and siltstones gradually decrease in abundance upwards through each cycle, and there is an accompanying increase in the proportion of mudstones (Fig. III. 8.) Further within the assemblage of sandstones, there is a progressive decrease in grain size upwards through each cycle.

A striking feature of some of the clastic members of the cycles is that they are cyclic within themselves (Fig. III. 8). These latter cycles are termed 'sub-cycles' for the purposes of description. There is no positive relationship between the thickness of a clastic member and the number of the sub-cycles. The sub-cycles comprise fining-upward successions of sandstones, siltstones and mudstone ranging from 30 cms to 10 metres in thickness. Scoured surfaces are not a characteristic feature, but they do occur locally.

The gypsum members of the cycles vary in thickness from 60 cms up to 13 metres. They follow the mudstones of the topmost sub-cycle of each cycle (Figs. III. 2 and 3) and the contact between them is gradational. The gypsum beds are nodular and the sediment between the nodules appears to be normal background material i.e. it resembles the underlying mudstones. The upper surfaces of the gypsum beds are usually sharply defined, and in a few places they can be seen to be channelled by the sandstones of the basal part of the succeeding cycle. No positive relationship appears to exist between the thicknesses of the gypsum members and the thickness of the cycles to which they belong (Fig. III. 2 and 3). Individual gypsum beds apparently pinch out laterally, because they cannot be traced from one outcrop to another (c.f. Fig. III. 2 and 3).

Gypsum veins, mainly satin-spar are abundant in the upper parts of the mudstones. The veins vary from 2 mm to 3 cm in width and are mostly horizontal to subhorizontal. They are not continuous in lateral extent, but usually pinch out within short distances depending upon their thickness. There are also some vertical to subvertical veins. These range in width from 2 mm to 2 cm. Some run from top to bottom of a mudstone unit, but most of them die out within a few tens of centimetres.

The gypsum beds themselves are also cut by horizontal to subhorizontal satin-spar veins (Fig. III. 9). These rarely exceed 1 cm in width and occur both in the partitions of sediment between adjacent nodules and in the nodules themselves. Some veins cut across both sediment partitions and nodules. They are not uniform in width but thicken and thin laterally.

3.2. The Upper Unit

This unit is characterized by gypsum interbedded with mudstones. The gypsum beds tend to be gradational into the underlying mudstones while the upper contacts are usually abrupt. The gypsum beds are similar to these in the underlying unit, i.e. they are nodular. The thickness of the individual beds ranges from a few centimetres up to 7 metres. The ratio of thickness of gypsum to mudstone varies greatly, but it is generally larger in the upper parts of the unit.

The mudstones vary in colour from very pale orange (10 YR.8/2) to light brown (5 YR 5/6) and from grayish yellow green (56Y 7/2) to dark greenish gray (5 6Y 4/1). Some of the mudstones are not continuous, but pinch out laterally within the gypsum beds. They vary in extent from a few metres to several tens or, in some cases hundreds of metres, and range in thickness from 10 cms up to 4 metres. Locally some of the mudstones carry isolated nodules of gypsum but these are volumetrically insignificant. Small lenses of siltstone occur in some of the mudstones

in the lower part of the unit.

Figures III. 10 , 11 and 12 are part sections which illustrate the overall nature of the unit. Veins of satin-spar gypsum are commonly found in the lower part of the unit, but they decrease progressively upward in abundance and disappear in the upper part of the unit. Horizontal to subhorizontal veins are the most common type but vertical to subvertical veins do occur. Locally the horizontal veins tend to be concentrated in the topmost parts of the mudstones, i.e. in the transitional zone between the mudstones and the nodular gypsum (Figs. III. 11 and 12). However it is not unusual to find veins in the upper parts of the bodies of the nodular gypsum.

3.3. Petrography and mineralogy of the clastics

(i) Petrography

Because of the scope of the study, no attempt has been made to study the sandstones and siltstones of the Bayindir Formation in detail, However, a few thin sections were examined under the microscope. They share many features in common with those of the underlying Incik Formation and the only essential difference is that the Bayindir sandstones appear to be better sorted.

(ii) Mineralogy

Nine samples of mudstone were taken from different stratigraphic levels for x-ray diffraction analysis. The location of the samples and approximate relative abundance of the constituent minerals are given in App. (II). Apart from gypsum, the major components are calcite and quartz. Clay minerals and feldspars are also present in almost every sample in minor but variable amounts. Two of the samples were analysed specifically for clay mineralogy. Smectite, chlorite, illite, kaolinite and montmorillonite were found to be present. X-ray diffraction analyses

of the sediments between gypsum nodules in the gypsum beds, showed that they are similar in mineralogy to the underlying mudstones. Dr. H. Shaw gave advice in the identification of the clay minerals.

III. 4. SEDIMENTARY STRUCTURES

4.1. Structures in Gypsum Rocks

(i) Description

The gypsum rocks of the Bayindir Formation exhibit a wide variety of sedimentary structures which are developed either individually or in combinations. Many classifications have been proposed for the structures of anhydrite rocks and these are applicable to gypsum rocks derived from them. Some of these classifications are presented in Fig. III. 13 .

In a general way these appear to be gradational forms between three end members. The end members are: nodular structure, chicken-wire structure and enterolithic structure. For purposes of description therefore, the structures observed in the gypsum rocks of the Bayindir Formation are dealt with under these three headings:-

A. Nodular Structure

Three varieties of nodular structure have been recognised in the gypsum rocks: 'isolated nodular structure' (Fig.III. 14) 'coalesced nodular structure' (Fig. III.17) and 'bedded nodular structure' (Fig. III. 19). The latter two structures are in fact varieties of the first type. Isolated nodules are commonly found in the lower parts of the gypsum beds and they usually grade upwards into other types. However, it is not uncommon to see gypsum beds made up wholly of isolated nodules (Fig. III. 15). Individual nodules vary a great deal in size; ranging from 1-2 mm to 10-15 cm up to 30 cm in diameter. The shapes are mostly spherical to subspherical, but there are some which are oblate parallel to the bedding (Fig. III.11).

Polished sections of some of the nodules show concentric zoning. A typical example of this is shown in Figure III.16. The outlines of the zones follow those of the nodules. This is not the first record of the concentric zoning in nodular gypsum rocks: similar concentric zoning has been described from the Ayora Gypsum Formation of Valencia, Spain by Orti (1976).

Close examination of large nodules, some as large as 30 cms in diameter, has revealed that many of them are not single nodules, but that they are in fact made up by many small sub-nodules. These latter range in size from a few millimetres up to a few centimetres. Several varieties of coalesced nodular structure occur in the formation, two of them are illustrated in figures III.17 and 18.

At some localities the nodules are coalesced laterally in a manner which simulates bedding (Fig. III.19). The individual nodules of these 'beds' have the same essential features as those described previously.

B. Chicken-wire Structure

"Chicken-wire structure" is a widely accepted descriptive term for the anhydrite or gypsum rocks in which individual nodules are so closely packed together that only thin films of host sediments separate them one from another. This is the most common type of structure seen in the gypsum rocks of the Bayindir Formation (Figs. III. 20 and 21). There is a considerable variation in size among the constituent nodules, and this is noticable even in small hand specimens. The great majority of the nodules are irregular in shape, but spherical to sub-spherical and ovate-shaped forms can also be seen. Some of the gypsum rocks, particularly those in the upper part of the formation are almost wholly of the chicken-wire type.

Locally, the host sediment between the nodules is discontinuous and adjacent nodules are in direct contact with one another. At first sight,

these rocks appear to be massive, but close examination reveals that they do in fact have chicken-wire structure. Holliday (1971) applied the term "wispy structure" to similar occurrences of Eocene age in Jamaica. This structure also appears to be the same as that termed "penemosaic texture" by Rooney and French (1968).

C. Enterolithic Structure

In some places the gypsum rocks show fold-like contortions (Fig. III. 23), known in evaporites as 'enterolithic structure'. Similar structures have been named enterolithic veins by West (1965); contorted structure by Riley and Byrne (1961); Maiklem et.al (1969) and Holliday (1971); and Ptygmatic structures by Fuller and Porter (1969). Close examination of these structures reveals that most, if not all,of them are in fact compounded of nodular aggregates (Fig. III. 22). Many of the occurrences of enterolithic structures can be followed laterally or vertically into other varieties of gypsum structures within a distance of a few tens of centimetres. Fig. III. 22 for example shows the passage from gypsum with enterolithic structure into gypsum with chicken-wire structure.

ii. Interpretation

In the past, the formation of nodules of anhydrite was ascribed to many different processes including: wave action (Imlay 1940), water depth and degree of agitation (Richter- Bernburg, 1955), flowage of semi-fluid sediment (Riley and Byrne, 1961) and displacive growth by precipitation of calcium sulphate from interstitial water (Withington, 1961). However it is now known that anhydrite is forming at the present day in the sediments of coastal sabkhas around the peninsula of Arabia. There the nodules grow displacively from interstitial brines within subarially exposed unconsolidated sediment above groundwater table in a manner analogous to that suggested by Withington (eg. Shearman, 1963; 1966; 1970; Kinsman, 1964a,b; 1966; 1969; Butler, 1965; 1969; 1970; Butler et.al. 1965;

Kendall and Skipwith, 1969 and Bush, 1973a,b). However, it does not necessarily follow that all anhydrite nodules form in emergent settings. Many authors have argued that nodules could form equally easily under standing bodies of brine (e.g. Dean et.al., 1975; Wardlow and Christie, 1976). According to Dean et.al., (1975) "A ground-water source of the calcium sulphate and subaerial crystallization of the calcium sulphate are not necessary conditions for formation. All that is required is a source of calcium sulphate for recrystallization" (p.371).

The remarkable similarity of the gypsum structures described herein to those of the recent anhydrite in the coastal sabkhas of Arabia suggested that they were formed in a similar manner during early diagenesis.

There has been some debate on whether the nodules of anhydrite in recent sabkha sediments are primary or secondary after earlier formed gypsum crystals. According to Shearman (1966) and Kinsman (1966), the nodules are mainly primary, but Butler (1970) argued against a primary origin and concluded that "..... if some primary anhydrite does occur, it is volumetrically insignificant to anhydrite formed from other processes particularly from the alteration of gypsum" (p.150). In recent years, many papers have appeared in the geologic literature supporting the theory that anhydrite nodules were initiated as gypsum which subsequently dehydrated to anhydrite (e.g. Kerr and Thompson, 1963; West, 1964; 1965; Holliday, 1968; 1971; 1973). It was suggested that each nodule was derived from a single gypsum crystal (Kerr and Thompson, 1963; West, 1965; Murray 1964; Butler, 1970 and Holliday, 1971) and the size of the nodules was related to the size of the original crystals (Butler, 1970; Holliday, 1971). It was also suggested that coalesced nodules were probably derived from intergrown masses or rosettes of gypsum (Holliday, 1971).

The nodular anhydrite rocks (now secondary gypsum) of the Bayindir Formation do not anywhere, to the writers knowledge, show any trace or

even hint of former presence of primary gypsum. In this respect, they stand in marked contrast to the nodules in the Bozkir Formation, which will be described later, where there is indisputable evidence of gypsum precursors. Thus, although the present available evidence is unequivocal, the writer inclines to the likelihood that the anhydrite of the Bayindir Formation was dominantly, if not wholly primary.

4.2. Sedimentary Structures of the Clastic Sediments

The sedimentary structures which are commonly seen in the clastic sediments of the Bayindir Formation are lamination, graded bedding, cross-bedding and desiccation cracks. Lamination is the characteristic feature of the mudstones where horizontal lamination is the most common type, although wavy lamination is not rare. Horizontal lamination is also seen in some siltstones and fine-grained sandstones. The coarse-grained sandstones exhibit cross-bedding and a few of the siltstone beds display cross lamination. Wherever sandstones, siltstones and mudstones are found together they form fining-upward cycles, i.e. sandstones grade up into siltstones which are in turn overlain by mudstones. As already mentioned, scoured surfaces do occur locally, although they are not characteristic structures in the fining-upward cycles of the Bayindir Formation. Desiccation cracks are one of the most striking features of the mudstones, Less common sedimentary structures include: ripple marks and primary current lineations in the fine-grained sandstones.

III. 5. THE AGE OF THE FORMATION

The age of the Bayindir Formation has been a subject of controversy for many years and its precise age is still unknown as no fauna has yet been found. The formation together with the Incik Redbeds was considered to be Oligo-miocene by the majority of previous workers, (e.g. Erol, 1953; Yucel, 1953; Beer, 1964; Ketin, 1955, 1962; Aziz, 1973; Birgili et.al., 1971). This interpretation was based on the stratigraphic relationships of the formation with the underlying and overlying lithofacies.

A similar assumption was also made by Senalp (1974) who examined the lateral equivalents of the formation in the Sungurlu area. There the basal contact of the formation is gradational into the underlying redbeds, but it is overlain by Pontian alluvial fan deposits with an angular unconformity. From these relations, Senalp (1974) suggested an age in the range from Upper Lutetian to Pontian. However, the presence of an angular unconformity between the Bayindir Formation and succeeding Upper Miocene Redbeds of the Kizilirmak Formation indicates that it is not younger than Upper Miocene in the area studied.

III. 6. THE ENVIRONMENT OF DEPOSITION

Most previous studies on the Bayindir Formation were concerned with stratigraphy (e.g. Erol, 1953; Yucel, 1953; Ketin, 1962; Beer, 1964; Birgili et.al., 1975) and except for Senalp (1974), only general attempts were made to interpret the depositional environment of the formation. These interpretations focused primarily on two factors: (a) the complete absence of fossils, (b) the conformable - transitional nature of the formation with the underlying redbeds of the Incik Formation which are believed to be continental in origin. From these lines of evidence, some workers considered that the sediments of the Bayindir Formation were deposited in an intermontane lake environment subjected to an arid to semi-arid climate. Others envisaged deposition in a lagoonal environment (Sajova, 1961; Beer, 1964). None of these workers considered the possible environmental significance of the nodular structure except for Senalp (Op.cit.) who was the first to recognize the nodular nature of the gypsum rocks and he suggested that they formed in a continental sabkha environment. Senalp cited the channelling of sandstones, the presence of fining-upward graded bedding, climbing ripples in siltstones and fine grained sandstones, horizontal lamination and desiccation cracks in mudstones and the complete absence of fossils as

evidence. He thought that deposition took place "a vast arid, or semi-arid, fairly flat and low laying area with possibly temporary, shallow interior lakes (playas) which were fed by intermittent rivers." (p.327). He considered that the gypsum rocks formed originally as anhydrite by displacive growth within subareally exposed soft detrital sediments above the groundwater table. The source of sulphate was thought to be from groundwaters which had passed through older evaporites. The hypothetical model suggested by Senalp for the environment of deposition of the formation is shown in Figure III.24.

The lines of evidence which appear to be critical for discussion on environment of deposition and early diagenesis of the Bayindir Formation are as follows:-

1. The formation shows perfectly conformable transitional relationships with the underlying fluviatile redbeds of the Incik Formation.

2. The bulk of the gypsum rocks is characterized by nodular, chicken-wire and enterolithic structures.

3. Petrographic examination has revealed that the gypsum rocks are essentially secondary and that both porphyroblastic and alabastrine varieties are present. The porphyroblastic secondary gypsum rocks contain many corroded relics of anhydrite and these leave no doubt that the gypsum rocks were formerly anhydrite which later hydrated to gypsum. No evidence has been found which would indicate that gypsum was the original form of the calcium sulphate and that this subsequently dehydrated to form nodular anhydrite either during the early diagenesis (e.g. West, 1964, 1965; Butler, 1970; Holliday, 1971), or during burial (Murray, 1964). Therefore the anhydrite is considered to have been primary.

4. If the Bayindir Formation had been deposited in a coastal sabkha environment, then there should be other evidence which would be indicative of a shoreline environment. However the sandstones, siltstones and

mudstones which are interbedded with the nodular gypsum rocks were clearly deposited in a continental, largely fluviatile environment.

5. Although studies on recent and ancient evaporite deposits have shown that the nodular form of anhydrite occurs abundantly in coastal sabkha environments, it has also been found in continental sabkha environments inland along the Trucial coast by both Kinsman (1969) and Bush (personal communication).

6. Only a few workers (e.g. Dean et.al., 1975; Wardlaw and Christie, 1975) have argued that nodular anhydrite could be formed in deep water environments.

7. Desiccation cracks are an essential characteristic of the mudstones which are interbedded with the gypsum rocks. The cracking of muddy sediment by desiccation most commonly occurs during subaerial exposure.

The lines of evidence presented above seem to support Senalp's interpretation. However, the interpretation poses the problem of the source of the sulphate. Four possible ources come to mind: (i) that it was derived from pre-existing evaporite deposits, (ii) that it was derived from pyrite deposits, (iii) that it was of volcanic origin, and (iv) that it was derived from the sea by long distance percolation. These will now be discussed and some comparisons will be made.

(i). If one considers gypsum or anhydrite rocks formed in a continental environment, the first possibility for the source of the sulphate is that pre-existing sulphate-bearing formations. For instance, in the Tertiary continental sabkha evaporites of the Ebro Basin, Spain, it has been convincingly demonstrated that the sulphate was supplied by groundwater percolating through Triassic evaporites (Birnboum, 1976).

As far as the present writer is aware, there are no older evaporite deposits in or around the Cankiri-Corum Basin, except for a few minor occurrences of gypsum as lenses which underlie the Incik Redbeds in the

village of Koracay[1], (Senalp, per comm, 1975). These deposits are clearly too small and restricted to be called on as a likely source.

(ii). Schleh (1967) stated that, in the presence of water and oxygen, pyrite oxidizes to form sulphuric acid and iron sulphates. If the sulphuric acid is introduced to calcium carbonate-bearing rocks, gypsum forms as the result of the reaction. The formation of gypsum by the oxidation of iron sulphides is a common phenomenon in many pyrite deposits and pyrite-bearing sedimentary rocks.

Pyrite is known to occur extensively in and around the basin. Thus, although pyrite may have been a part source, it is unlikely that it was the whole source of the sulphur necessary to form the extensive deposits of calcium sulphate minerals present in the basin.

(iii). The presence of ash beds in the upper parts of the Incik Formation indicates that volcanicity was taking place in the vicinity. Volcanicity is another possible source of sulphate.

(iv). With respect to a marine origin for the sulphate, some workers have argued that the base of the Incik Redbeds is transitional from the underlying shallow marine carbonates of the Lutetian age, (Aziz, 1973; Senalp, 1974; Unalan, 1974, and Birgili et.al., 1975). Others, however, have stated that there is an unconformity (Lahn, 1939; Erol, 1953; Sajova, 1961 and Ketin, 1962). As already pointed out the contact cannot be seen in the study area because of thrusting. Therefore the following discussion is based on the pre-existing literature.

If the contact is a transitional one, then the interpretation of Senalp (1974) and Birgili et.al., (1975) that the Incik Redbeds were deposited in an intermontane basin, is not necessarily valid. Fluviatile sediments which show a gradation from underlying shallow marine carbonates are more easily explained as representing deposition on a coastal plain (Fig. III.25.). If this was the case, then the calcium sulphate of

[1]The village of Kocacay is situated 15km to the south of the area which has been studied.

the Bayindir Formation may have been supplied by long distance percolating marine derived groundwaters (Fig. III. 25). If the contact is an unconformity, then deposition of the Incik Redbeds post dated the regression of the Eocene Sea from the basin. In which case, it is possible that an intermontane basin developed and that fluviatile sediments, the Incik Redbeds, were deposited in the marginal parts while evaporites were forming in a playa lake which occupied the central part of the basin.

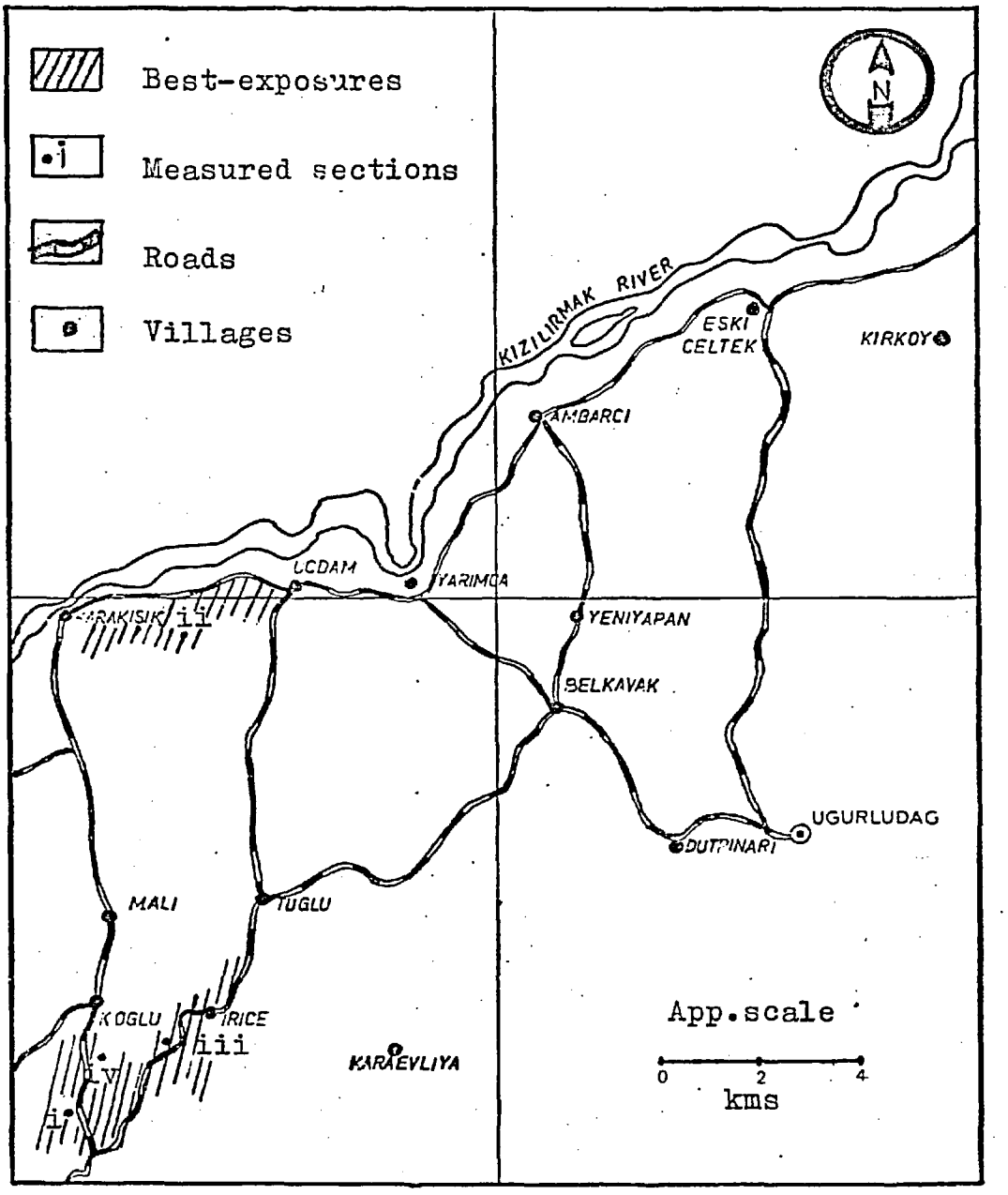


FIG.III.1 Schematic map of the study area showing best-exposed outcrops and locations of measured sections of the Bayindir Formation.

i. The Bestepe Section
ii. The Kiziltepe Section
iii. The Ceeltepe Section
iv. The Duzce Dere Section

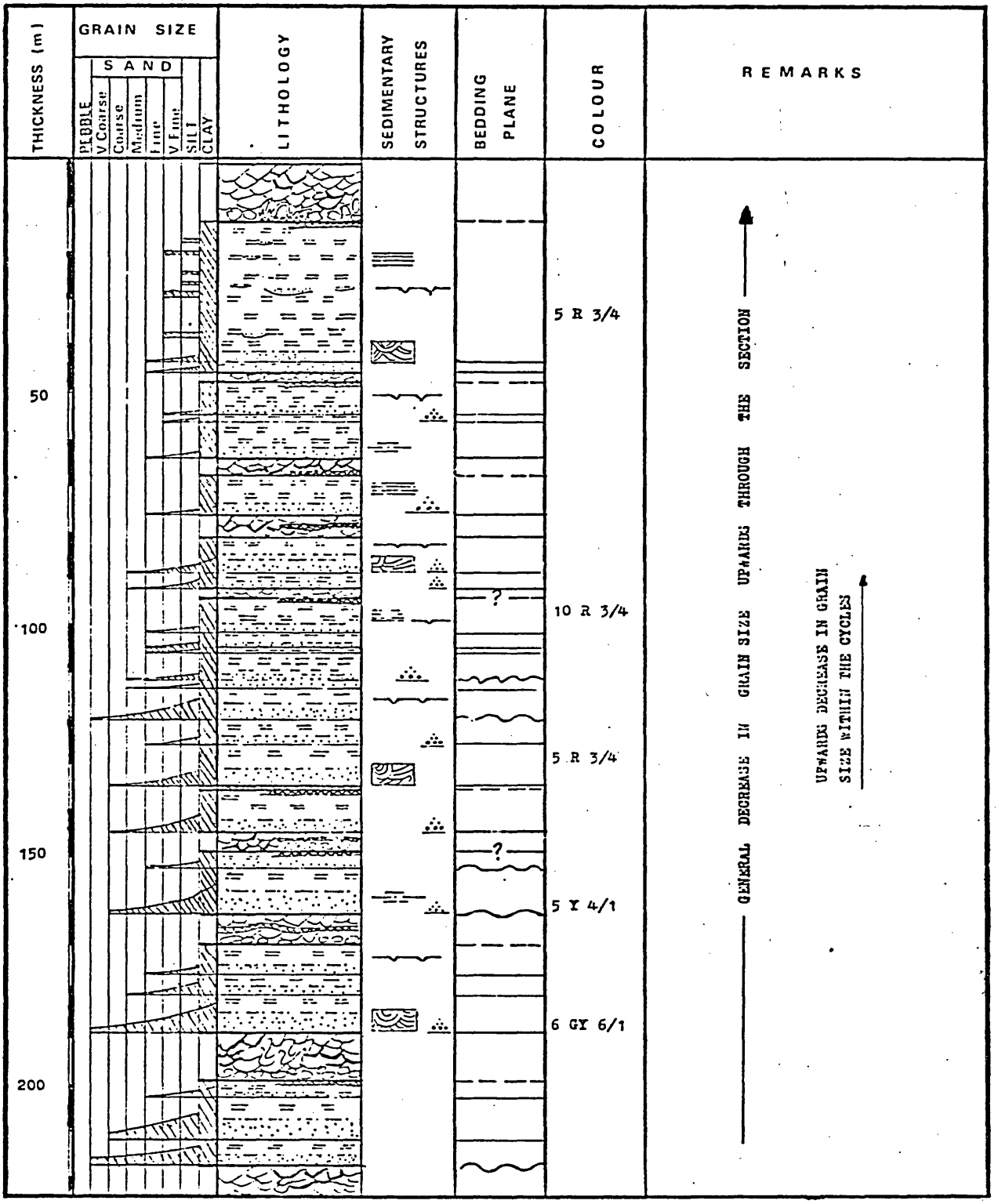


FIG. III.2 The Bestepe Section.

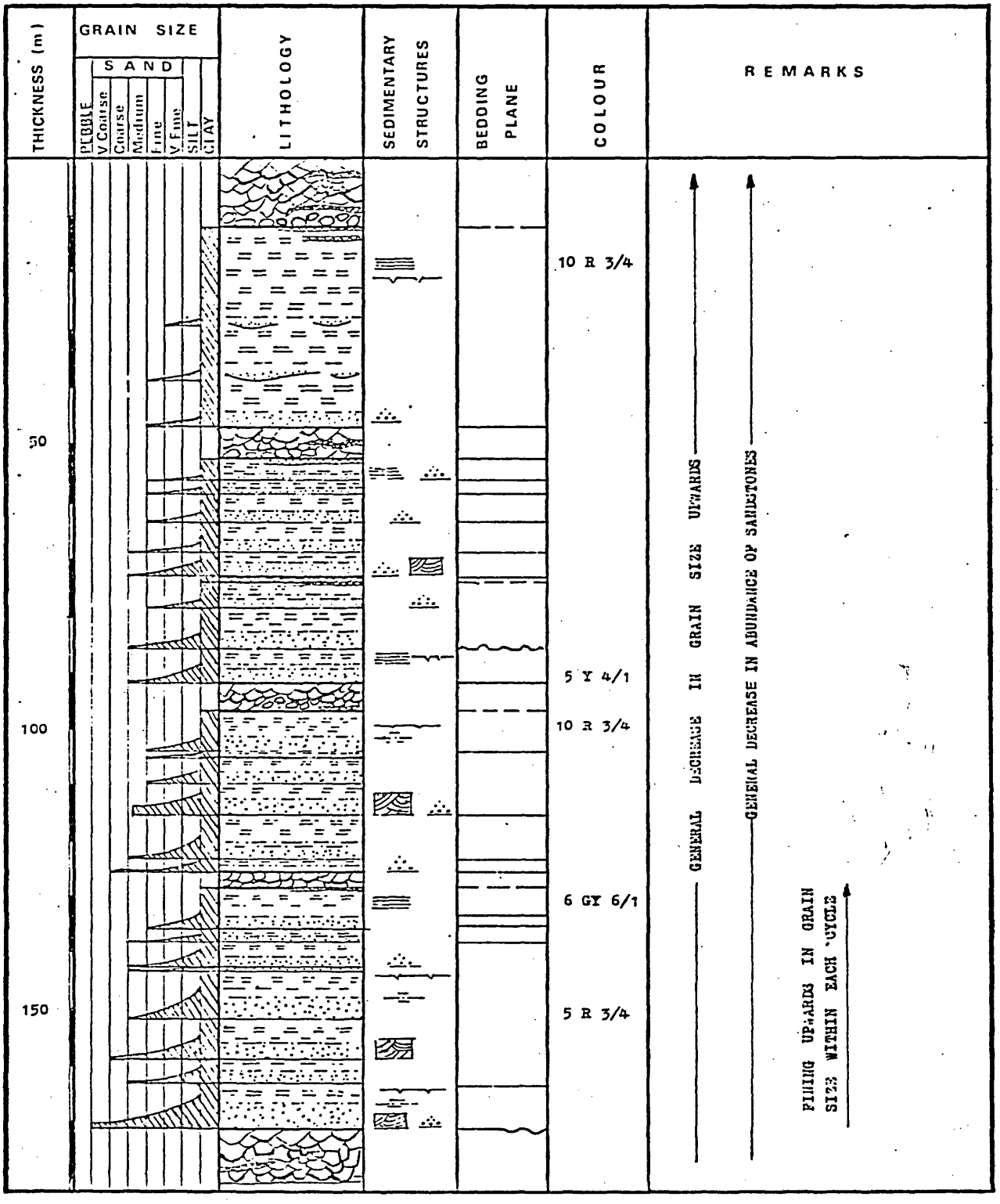


FIG. III.3 The Kiziltepe Section.

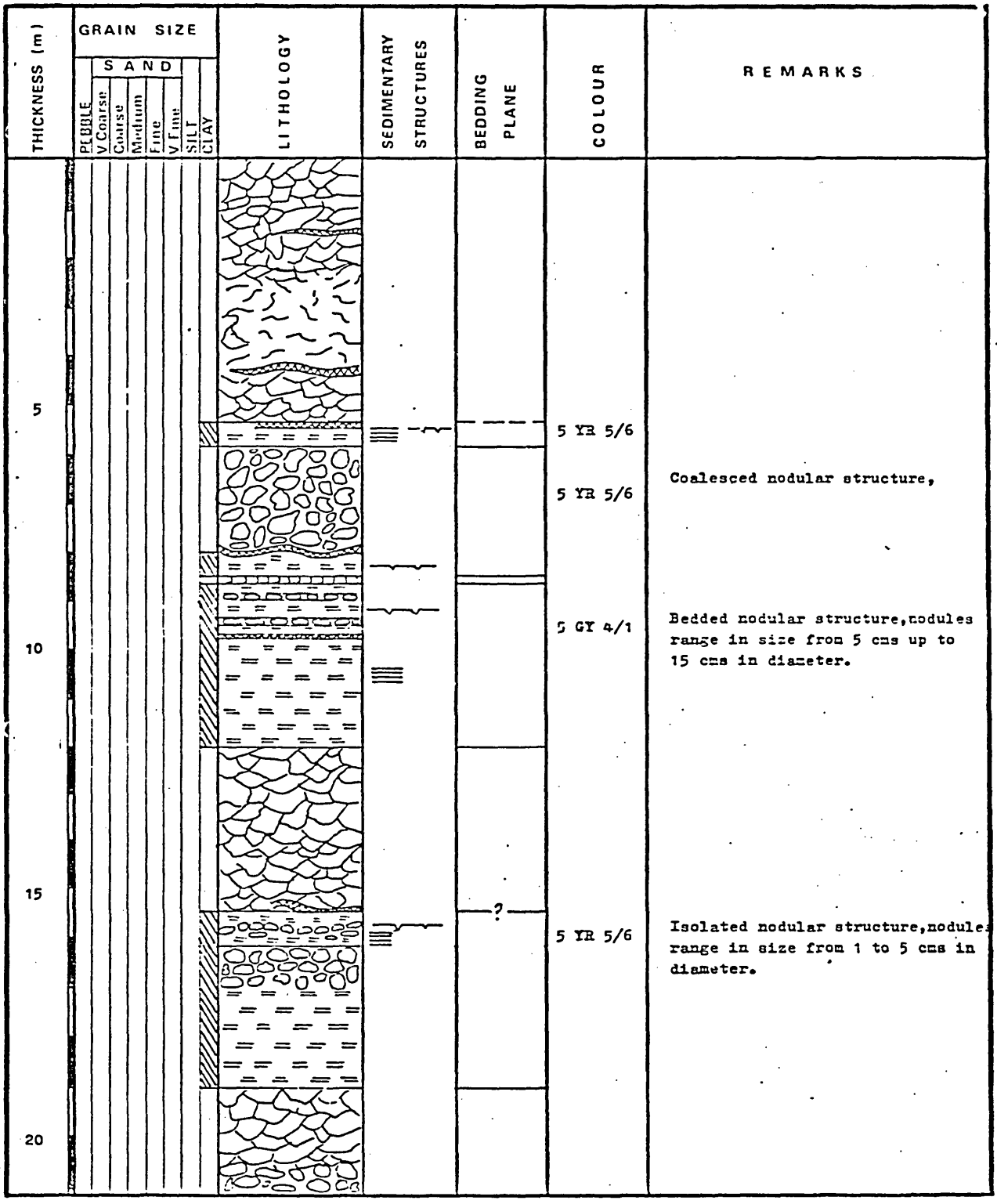


FIG. III.4 The Ceel Tepe Sections.

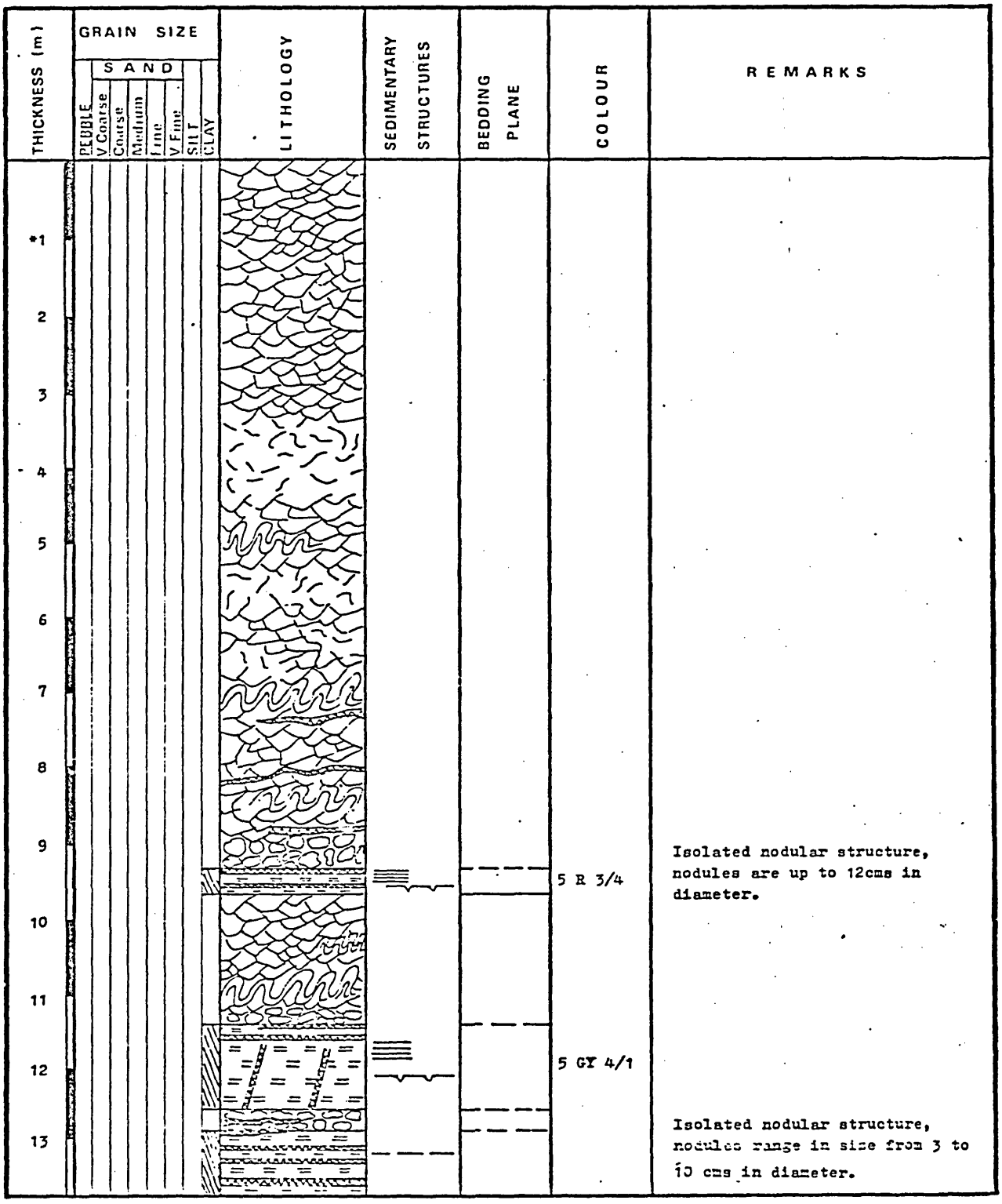


FIG. III.5 The Duzce Dere Section.

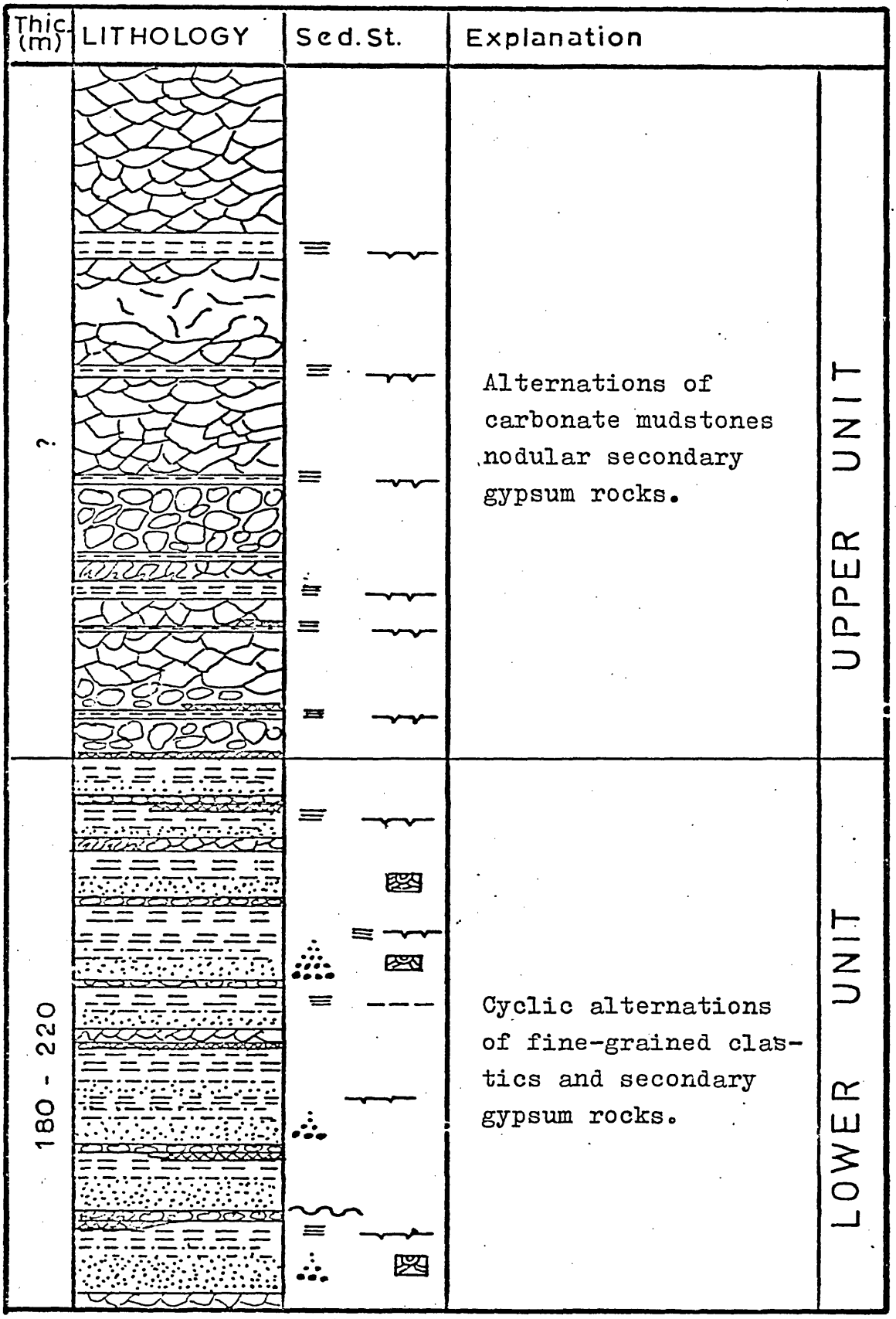


FIG. III.6 Generalized stratigraphic section of the Bayindir Formation.



FIG. III.7 A general field view of the Lower Unit of the Bayindir Formation.Bestepe,near the village of Irice.

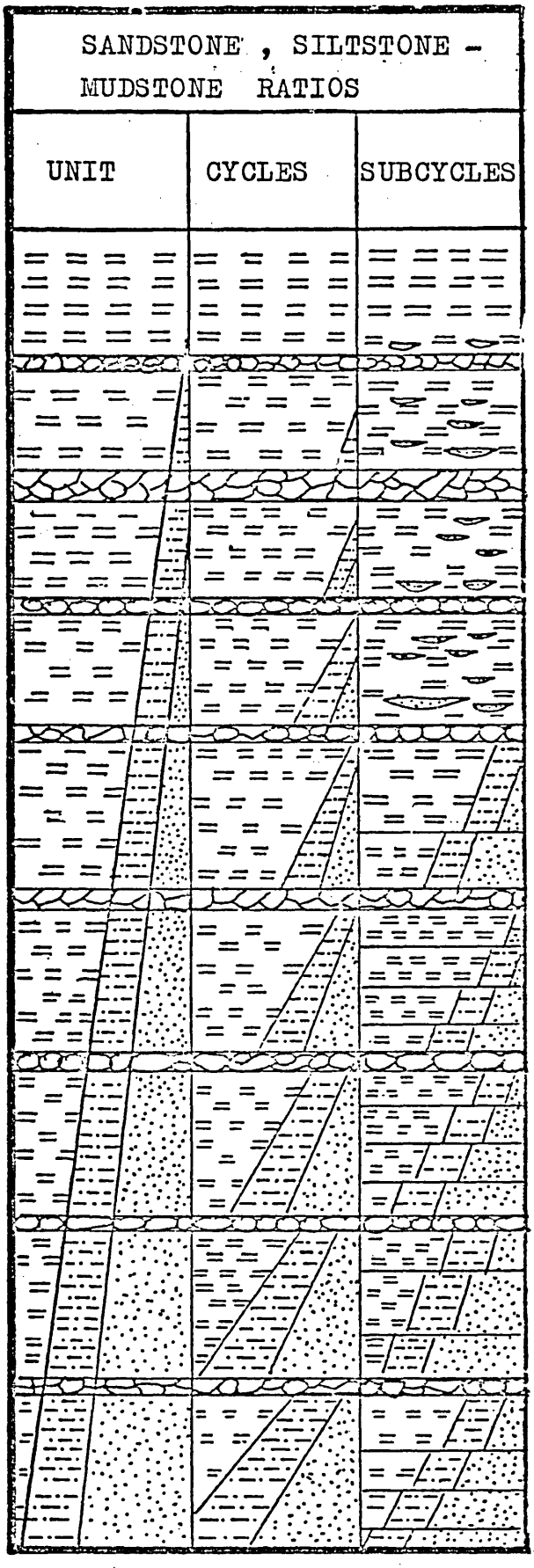


FIG. III.8 Schematic sketch showing the upward decrease of the sandstones and siltstones in abundance in the sub-cycles, cycles and the unit as a whole: The lower unit of the Bayindir Formation.

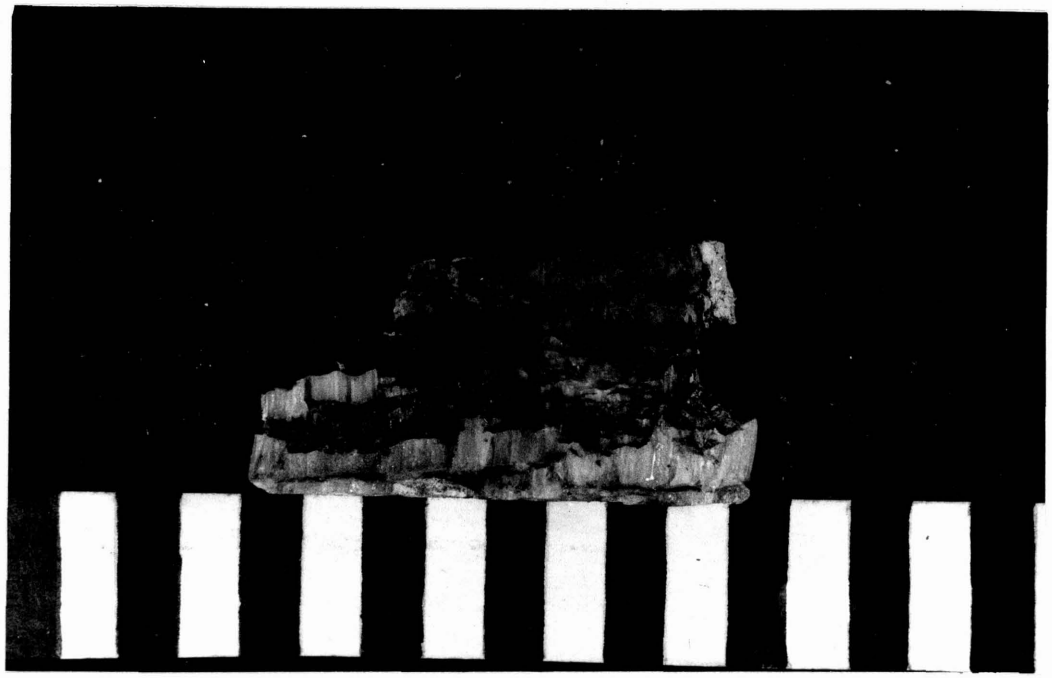


FIG. III.9 Veins of satin-spar gypsum in nodular secondary gypsum.Note the pinch out of one of the veins.(Scale in cms.)

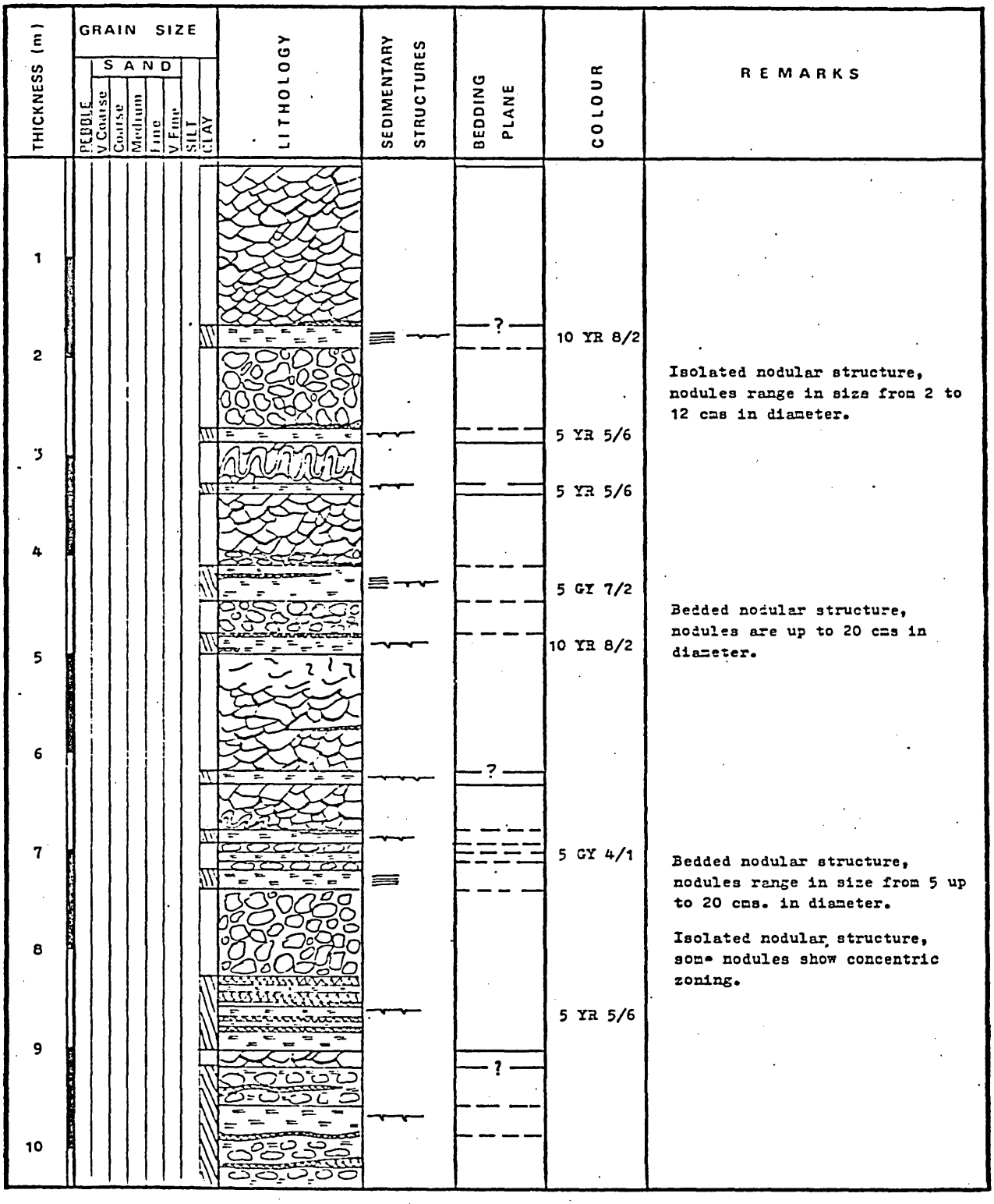


FIG. III.10 Mudstone-nodular secondary gypsum cycles of the upper unit of the Bayindir Formation. Section measured from Ceeltepe.

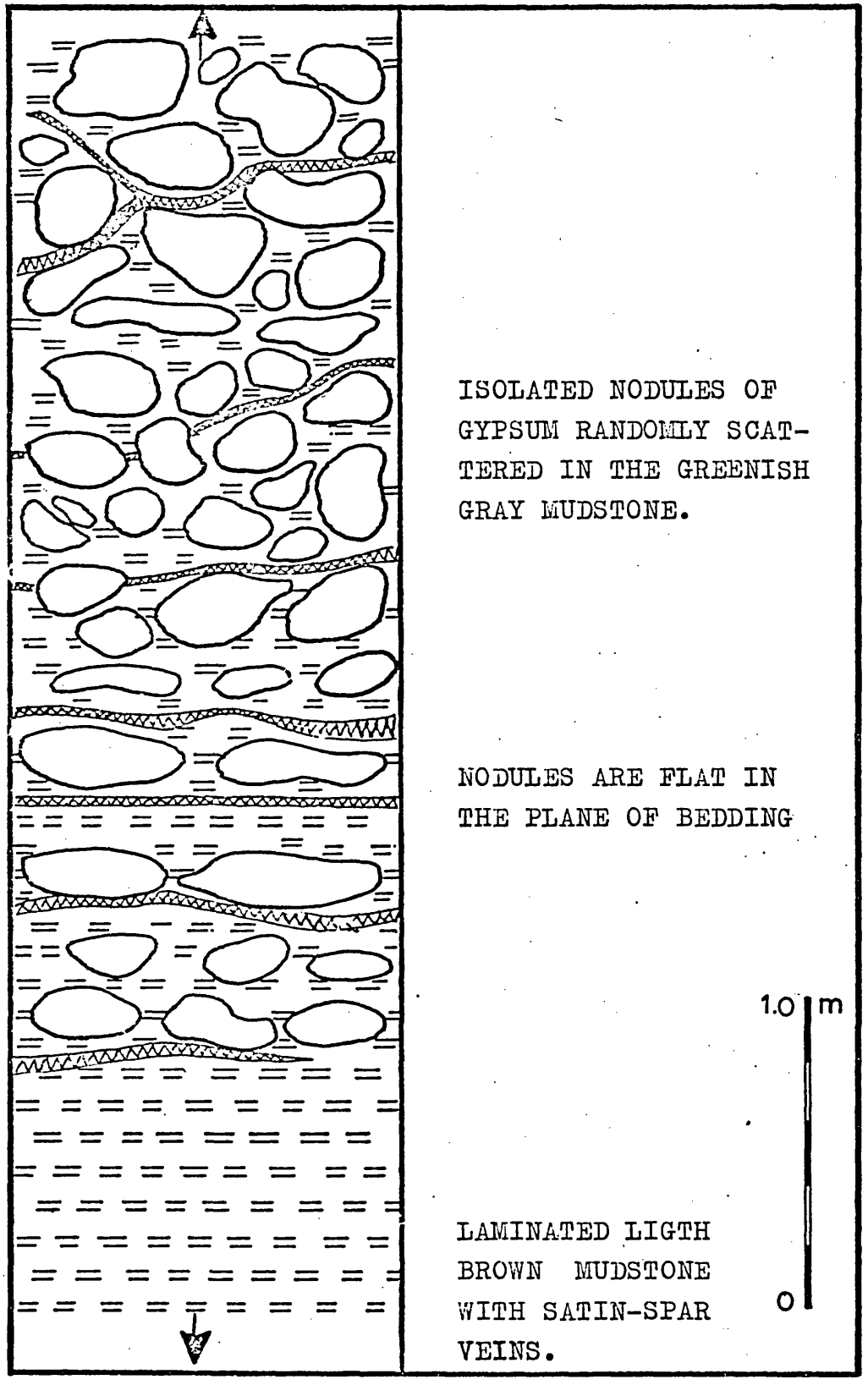


FIG. III.11 A representative field sketch showing isolated noduls of gypsum in a mudstone groundmass.The Upper Unit of the Bayindir Formation.

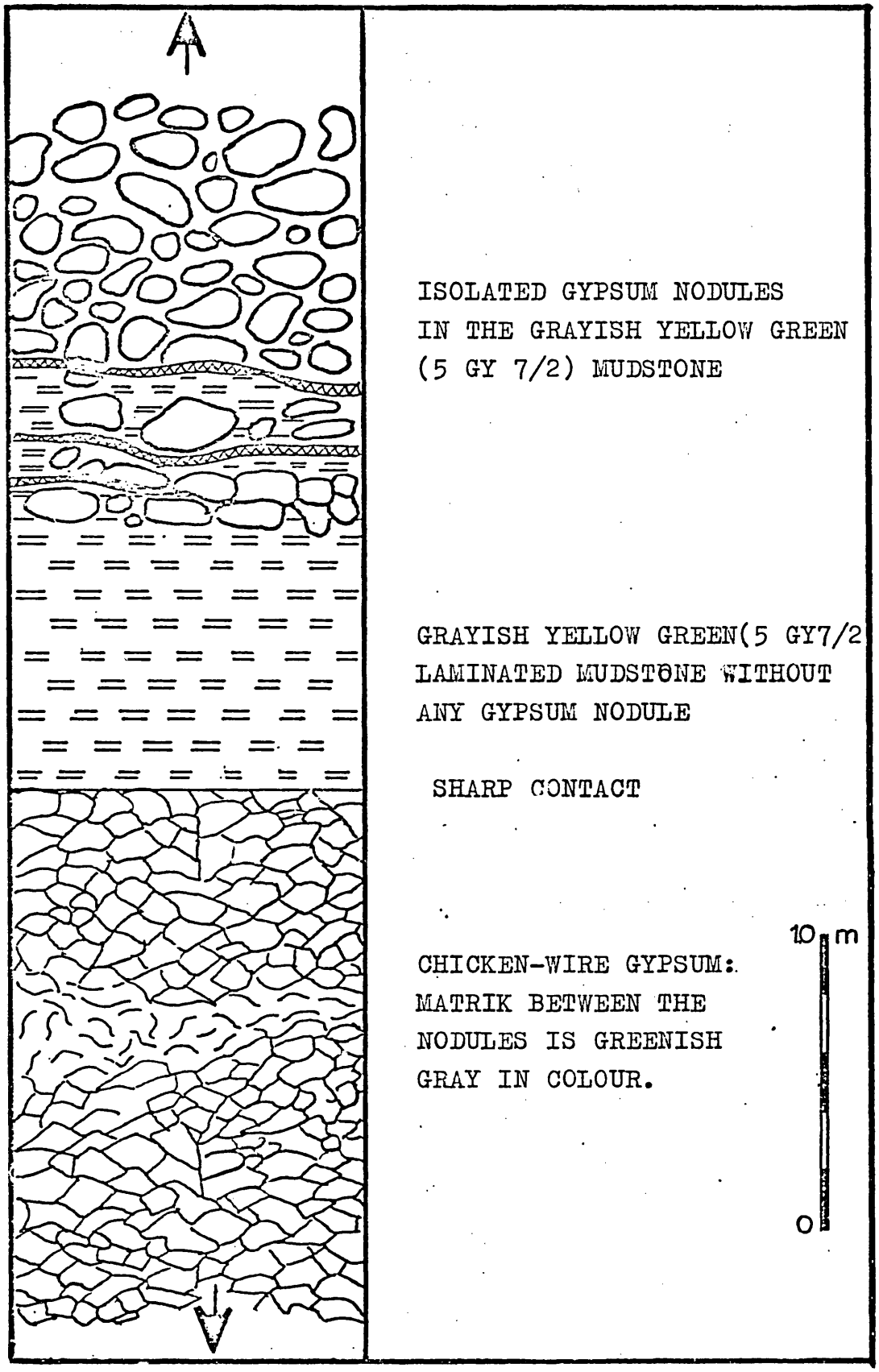


FIG. III.12 Representative field sketch showing general characteristics of the Upper Unit of the Bayindir Formation.

<table>
<tr><th>RILEY & BYRNE, 1961</th><th>WEST, 1965</th><th>MAIKLEM at. al, 1969</th><th>HOLLIDAY, 1970</th><th>THIS STUDY</th></tr>
<tr><td rowspan="2">Authiclastic</td><td rowspan="4">Macrocell
Structure</td><td>Nodular</td><td>Nodular</td><td rowspan="2">Nodular
Structure</td></tr>
<tr><td>Nodular
Mosaic</td><td>Nodular
Mosaic</td></tr>
<tr><td>Mosaic</td><td rowspan="2">Mosaic</td><td>Mosaic</td><td rowspan="2">Chicken-wire
Structure</td></tr>
<tr><td>Flocculent</td><td>Wispy</td></tr>
<tr><td>Contorted</td><td>Enterolithic
Veins</td><td>Contorted
Mosaic</td><td>Contorted
Mosaic</td><td>Enterolithic
Structure</td></tr>
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FIG. III.13 Comperative table of some classifications proposed for the structures seen in anhydrite and secondary gypsum rocks elsewhere and the descriptive terms used in this study.

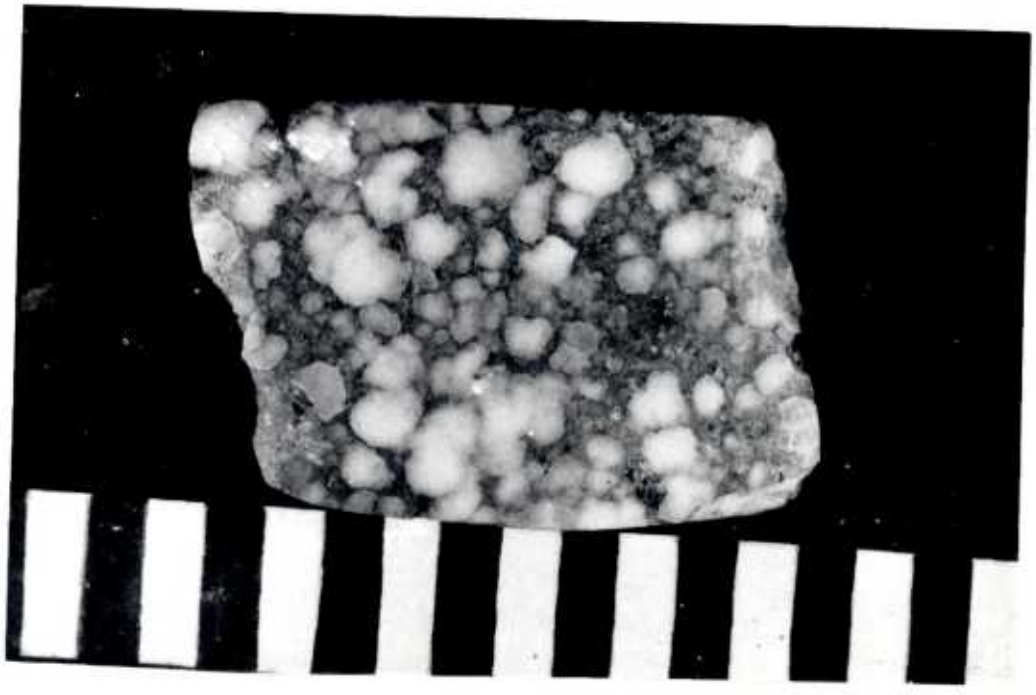


FIG. III.14 Photograph of a polished slab showing isolated nodules of secondary gypsum.Note the variation in the size of the nodules.(Scale in cms.)



FIG. III.15 Isolated nodular structure:Bayindir Formation

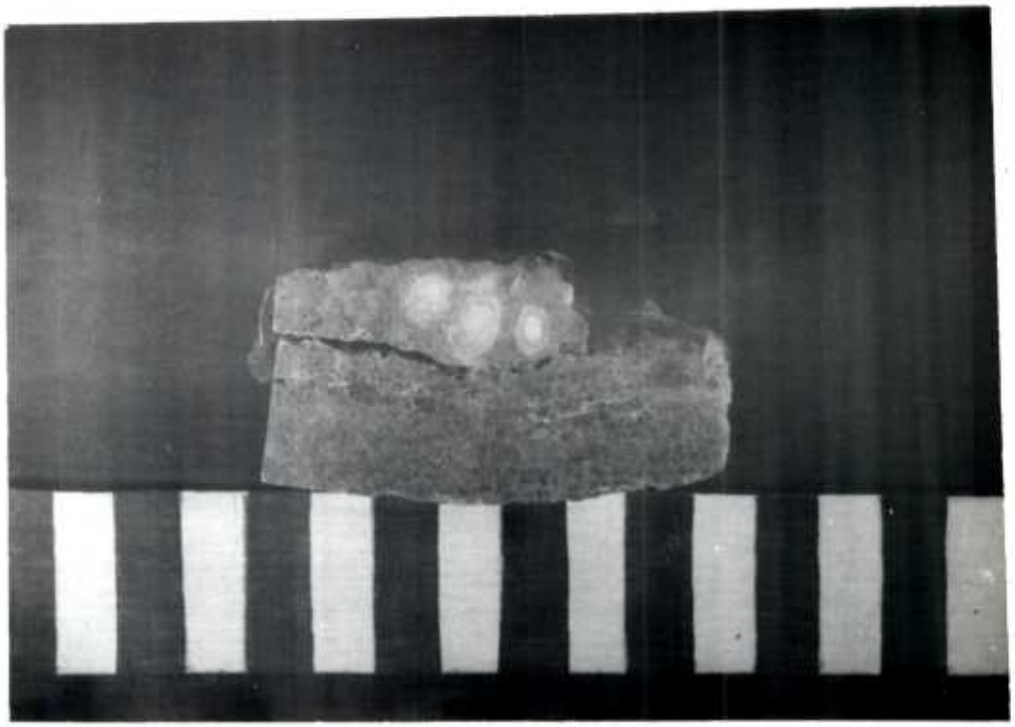


FIG. III.16 Polished section of a secondary gypsum rock showing concentric zoning of nodules.





FIGS. III.17 and 18 Coalesced nodular structures:Bayindir Formation.

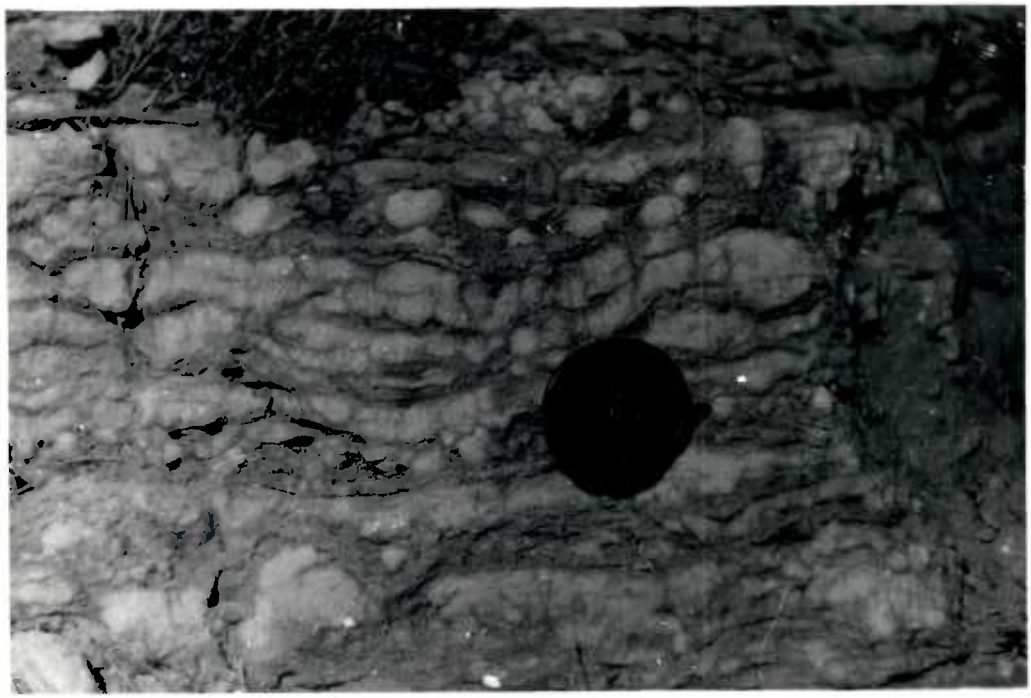


FIG. III.19 Bedded nodular structure:Bayindir Formation.





FIGS. III.20 and 21 Chicken-wire structures: Bayindir Formation.



FIG. III.22 Photograph showing transition from enterolitic structure to chicken-wire and bedded nodular structures.



FIG. III.23 Enterolitic structure:Bayindir Formation.

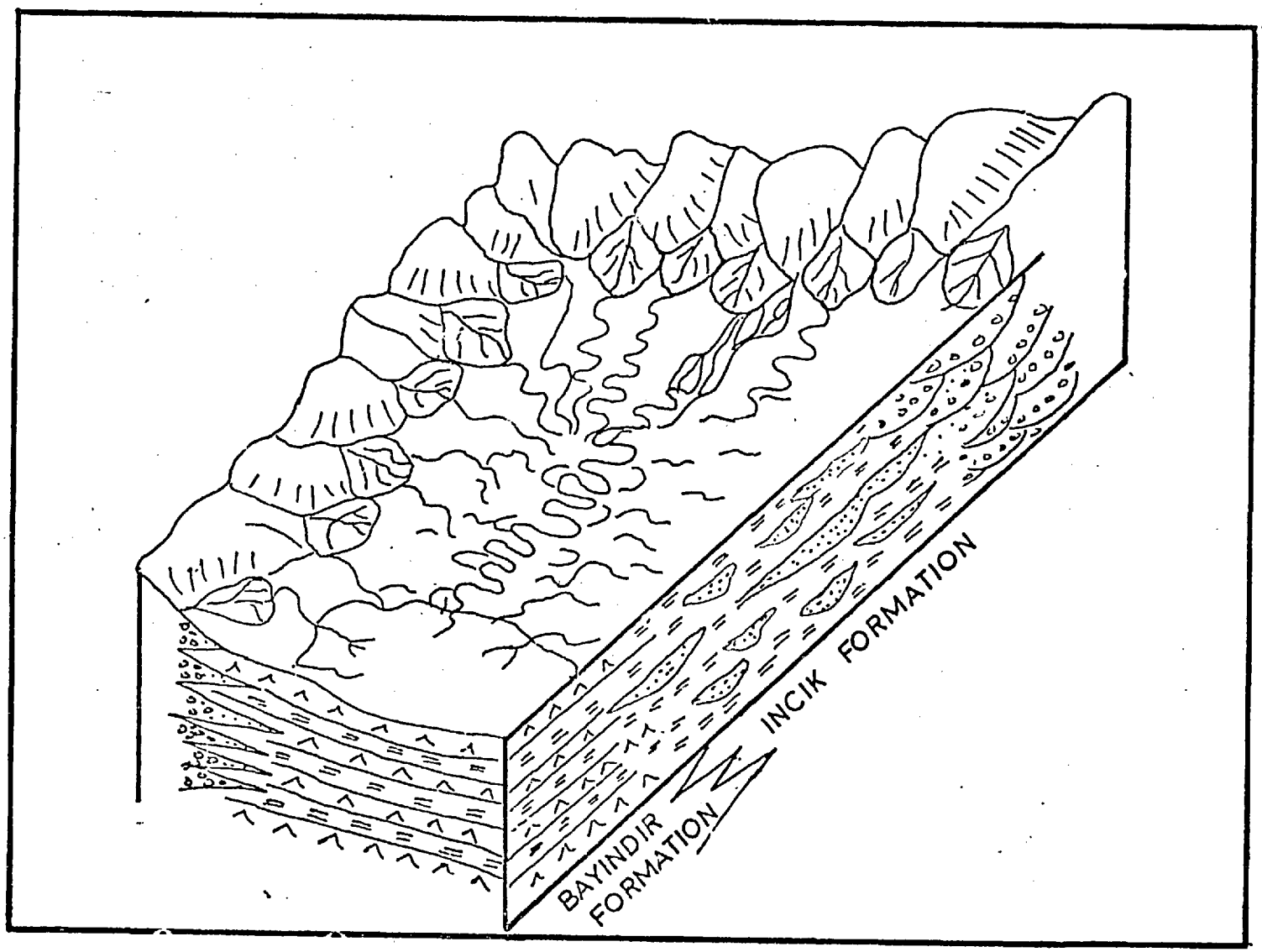
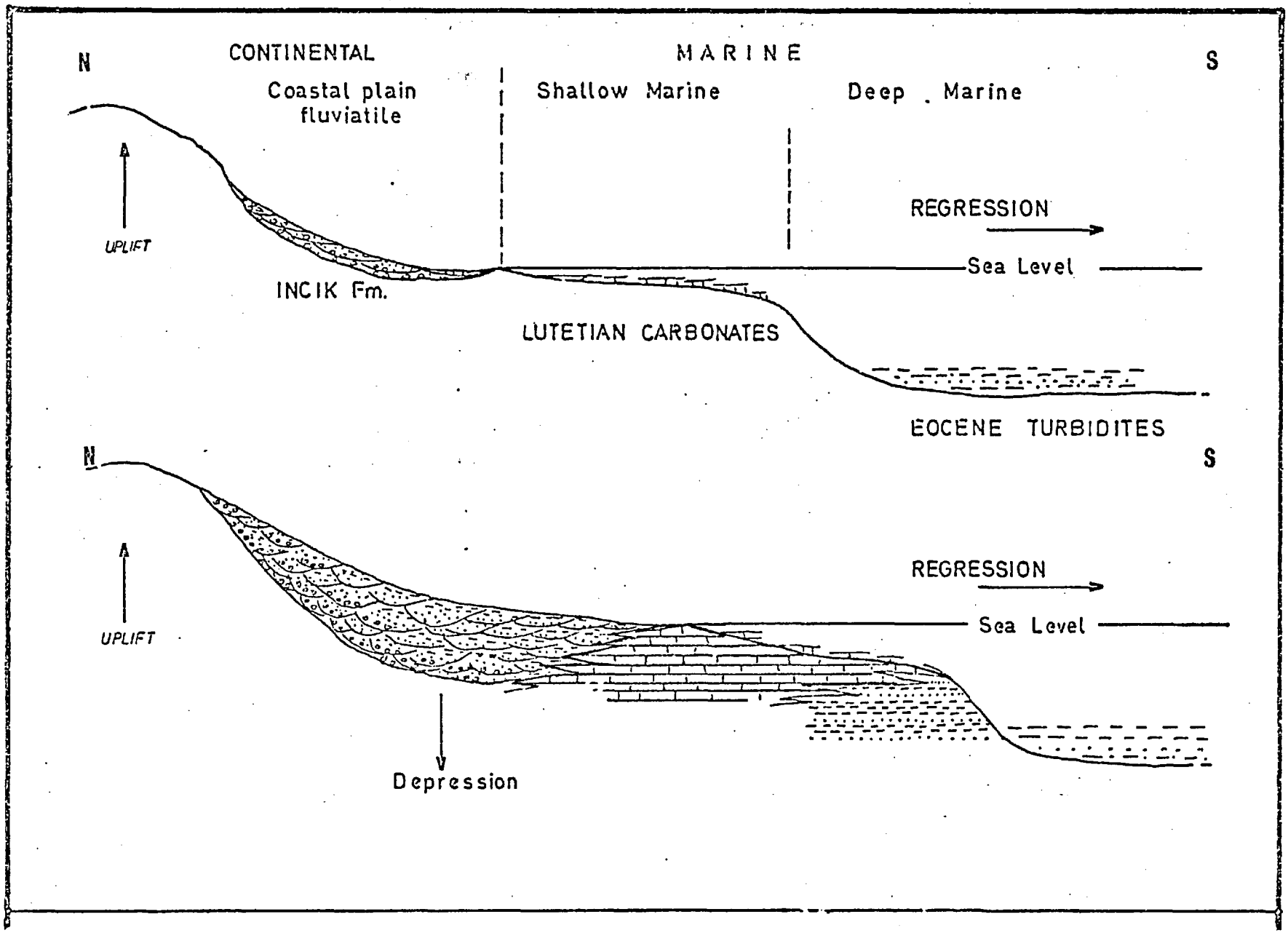
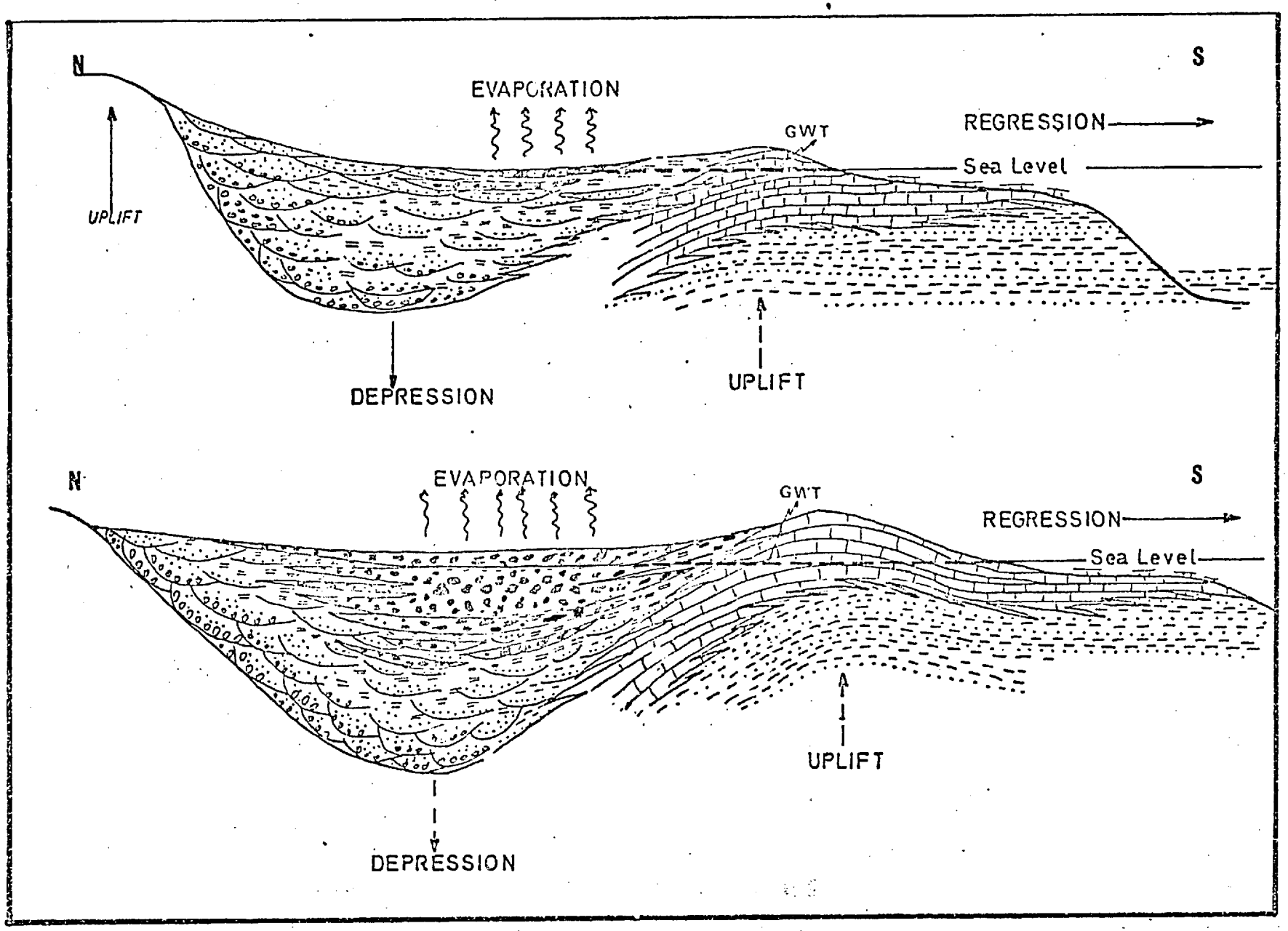


FIG. III.24 Hypotetical model for the depositional environments of the lateral equivalents of the Bayindir and Incik Formations(Adopted from Senalp,1974)

FIG. III.25 A hypotethical model for the depositional environments of the Bayindir Formation and the underlying redbeds of the Incik Formation.(Hypothesis is based on the interpretation of Senalp,(1974) and Birgili et. al. (1975) that the contact between the Incik Redbeds and the underlying shallow-marine carbonates is gradational.


N
CONTINENTAL
MARINE
S
Coastal plain
fluviatile
Shallow Marine
Deep Marine
UPLIFT
REGRESSION
Sea Level
INCIK Fm.
LUTETIAN CARBONATES
EOCENE TURBIDITES
N
S
UPLIFT
REGRESSION
Sea Level
Depression


N
S
EVAPORATION
GWT
REGRESSION
Sea Level
UPLIFT
DEPRESSION
UPLIFT
N
S
EVAPORATION
GWT
REGRESSION
Sea Level
UPLIFT
DEPRESSION

CHAPTER IV

THE KIZILIRMAK FORMATION

IV. 1. INTRODUCTION

The Kizilirmak Formation succeeds the Bayindir Formation with a marked angular unconformity and marks the beginning of the second redbed-evaporite megacycle. The formation derives its name from the town of Kizilirmak which is situated 25 kms to the west of the map area. The lateral equivalents of the formation in the western parts of the basin, around the town of Candir were termed the Candir Formation by Tekkaya et.al., 1975.

The formation overlies the Bayindir Formation with a marked angular unconformity around the villages of Belkavak (Grid: CANKIRI $H32b_2$; 81-82, 23-24) and Yeniyapan (Grid: CANKIRI $H32b_2$;82-83, 23-24).

In the north eastern part of the area, around the villages of Gokceagac (Grid: CANKIRI, $H32b_2$; 82-83, 23-24) and Gender (Grid: CANKIRI $H32b_2$; 83-84, 26-27) it rests unconformably on the Incik Formation due to the pinch out of the Bayindir Formation. The formation passes transitionally upwards into the overlying Bozkir Formation from which it can be distinguished for the mapping purposes by its red colour (Fig. IV. 1).

Lithologically, the formation comprises mainly conglomerates, sandstones, siltstones and mudstones in the form of fining-upward cyclotherms. In places, however it carries rhythmical alternations of gypsum cemented sandstones and dolomitic laminated mudstones. Subordinate lithologies include primary and secondary gypsum and calcarous nodules (cornstones).

IV. 2. DISTRIBUTION AND THICKNESS

The formation is poorly exposed in the study area, and no exposures suitable for a type section have been found. It was however studied in several discontinuous outcrops available in the stream and road cuttings, where three reference sections have been measured (Fig. IV. 2).

(i) The Kepeztepe Section (Fig. IV. 3): The locality from which the Kepeztepe Section was measured is situated 4 kms south of the village of Eski Celtek (Grid: CORUM G32c_3; 90-91, 22-23) on the left side of the Ugurludag - Eski Celtek Road. The section is 42 metres thick and represents the topmost part of the formation.

(ii) The Esekcitepe Section (Fig. IV. 4.): This section was measured on the northern slope of Esekci Tepe, 3 kms to the east of the village of Ambarci (Grid: CORUM G32c_3; 87-88, 17-18). The thickness of the section is 23 metres.

(iii) The Kuskayasi Section (Fig. IV. 5): This section is exposed approximately 1.5 kms to the east of the village of Eski Celtek. It is 30.50 metres thick, and again represents the topmost part of the formation.

The estimated total thickness of the formation is not in excess of 600 metres any where in the basin.

IV. 3. LITHOLOGY

The Kizilirmak Formation is composed mainly of conglomerates, sandstones, siltstones and mudstones. The latter carry cornstones and crystals of primary gypsum with discoidal habit in the upper part of the succession. Thin horizons of chicken-wire gypsum and some extremely large compound nodules of secondary gypsum after anhydrite are also developed in the topmost 20 metres of the formation.

3.1. Conglomerates

The conglomerates which are greenish gray (5 GY 6/1) to olive gray (5 Y 4/1) in colour are the most common lithologies in the lower part of the formation. They decreased progressively upward and become minor lithologies in the upper part. They carry phenoclasts of both extra and intraformational origin. In the lower part of the formation the size of the pebbles varies from 3 to 15 cms but they never exceed 5 cms in

diameter in the upper part.

The extraformational phenoclasts comprise many kinds rock fragments, but volcanic fragments (mainly andesitic) are predominant. Next in abundance are ophiolitic materials: serpentinites, peridotites, basalts and radiolorites with various types of limestones. Quartz and metamorphic rock fragments are also important.

The intraformational phenoclasts are characteristically pebbles of reddish brown (10 YR 3/4) and light brown (5 YR 4/1) mudstones. They tend to occur in the basal parts of the conglomerate beds.

The grain size of the conglomerates decreases upwards and they pass gradationally up into the very coarse grained sandstones.

The conglomerate beds are generally lenticular in geometry and appear to be channel fill deposits. In the lower part of the formation they pinch out laterally over a distance of a few tens of metres, but in the upper part they do not exceed a few metres in lateral extent.

3.2. Sandstones

Sandstones are the most common lithologies present in the formation, although they become subordinate to the mudstones and siltstones in the uppermost part. Two types of sandstones have been recognized. The first type are the sandstones of the fining-upward cycles. Where they are present in association with conglomerates, these sandstones occur as a gradational rock type between the conglomerates and siltstones, i.e. complete fining-upward cycles. In the upper part of the formation, however they occur as channel fill deposits and wedge out in a distance of a few tens of centimetres or a few metres (Fig. IV.6). In thelatter case they tend to be gravelly in their basal parts and carry phenoclasts of both intra and extraformational origin. Wherever found they vary in colour from red (5R 3/4) to reddish brown (10 R 3/4) and gray (5Y 4/1) to greenish brown (5 YR 4/1). They show poor to moderate sorting and roundness. The

individual grains which form the framework of these sandstones comprise mono-to . polycrystalline quartz, plagioclase, detrital calcite and chert grains, amphiboles pyroxenes and volcanic and ophiolitic rock fragments. Minor constituents include a few skeletal fragments, epidote, glaucophane and some opaque minerals. The rocks are poorly cemented by calcite. Iron oxide is present in almost every thin section examined as grain coating.

The second type of sandstones differ from the first by being rich in carbonate grains and being locally cemented by poikilitic secondary gypsum after anhydrite (Fig. IV.7). They occur in the topmost parts of the formation, at Kepeztepe and Kuskayasi, where they alternate with gypsum bearing dolomitic mudstones (Figs. IV. 3 and 5). They are generally uniform in grain size and do not grade into the other lithologies. The thicknesses of individual sandstone beds of this type range from 30 cms to 2.00 metres. The majority are yellowish gray (5Y 7/2 in colour. They are composed of skeletal fragments, pellets, detrital calcite, quartz and feldspars (mainly plagioclase). Minor constituents include glaucophane, volcanic and ophiolitic rock fragments, radiolarian chert and reworked nummulites.

At Kuskayasi, one of these sandstone beds 50 cms in thickness, carries tiny nodules of secondary gypsum after anhydrite. The nodules are 0.5 to 2 mms in diameter and tend to be flattened with respect to the bedding plane (Fig. IV. 8).

Geometrically these sandstone beds appear to be sheet-like bodies.

3.3. Siltstones

The siltstones of the Kizilirmak Formation are the very fine-grained equivalents of the first type of sandstones. They commonly represent a transitional rock type. On the one hand they grade upward into mudstones, often as graded beds in which the proportion of muddy sediment increases as the grain size of the silt-sized grains drops, passing from sandstones

to mudstones with a few scattered silt size grains. On the other hand they pass gradually down into the underlying sandstones. They contain more red stained matrix than the sandstones and are distinctly darker in hue.

3.4. Mudstones

The Kizilirmak Formation contains two types of mudstones. The first, which varies in colour from reddish brown (10 YR 3/4) to light brown (5 YR 4/1), occurs in association with the siltstones, sandstones and conglomerates of the fining-upward cycles. They generally contain a significant proportion of silt which is either concentrated in lenses or scattered randomly. The silt grains are predominantly quartz with accessory feldspars and chert. They generally display horizontal lamination, and individual laminae are seperated from one another by iron oxide rich films. These mudstones are the most abundant rock type in the upper parts of the formation and are of less importance in the lower parts. In some places they contain calcerous nodules and crystals of primary gypsum with discoidal habit.

The second type of mudstones occurs only in the topmost part of the formation at Kuskayasi and Kepeztepe. They form discrete beds which range in thickness from 40 cms up to 8 metres and alternate with the gypsum cemented carbonate grain rich sandstones, i.e. second type of sandstones. They vary in colour from pale brown (5 YR 5/2) to moderate brown (3 YR 3/4) and from light olive gray (5Y 6/1) to dark greenish gray (5 GY 4/1). They are evenly laminated and are composed of thick (2-3 mms) light coloured, (either pale brown or olive gray) layers which alternate with thinner dark laminae (either moderate brown or dark greenish gray). These mudstones characteristically carry crystals of primary gypsum with discoidal habit. At Kiskayasi a few thin layers of chicken-wire secondary gypsum and some extremely large discus-like bodies of gypsum have been found in these

mudstones.

The general mineralogical composition of eight mudstone samples was determined by x-ray diffraction analysis (see Appendix for location of the samples and relative abundance of the constituent minerals). Three of the samples are representative of mudstones of the first type; the remainder is of the second type. Two samples of the first type of mudstones were found to be composed of calcite and quartz with accessory feldspars and clay minerals. The third contained dolomite, calcite, quartz and gypsum with accessory feldspars and clay minerals. All of the samples of the second type of mudstones, with one exception, have the same composition: dolomite, feldspars and clay minerals. However, the relative proportions of the minerals vary from sample to sample. The one sample which is significantly different contains magnesite as the most abundant mineral. The magnesite is accompanied by gypsum, quartz, feldspars and clay minerals.

3.5. Gypsum

(i) Primary gypsum

Crystals of primary gypsum have been found in many mudstone units of the fining-upward cycles, in the uppermost 50 metres of the formation, (Fig. IV.9). They are discoidal in shape and flat nearly perpendicular to C-axis. They occur either singly or as interpenetrating clusters. Individual crystals range in size from a few millimetres up to 5 cms or more in diameter. A characteristic feature is that they tend to be arrayed with their planes of flatness nearly vertical with respect to bedding (Fig. IV. 9). The crystals contain inclusions of the host sediment, mainly concentrated along the 010 cleavage planes.

In some places, as has already been pointed out, the topmost part of the formation is characterized by alternations of mudstones of the second type and gypsum-cemented carbonate-grain rich sandstones.

Microscopic examination has revealed that these mudstones contain very small crystals of primary gypsum with discoidal habit. The crystals are concentrated in particular laminae and are absent from others. The crystals are identical in habit to those previously described in other parts of the formation. The only difference is their size: they never exceed 2-3 mms in diameter.

Another habit of gypsum is found in one of the mudstones at Esekcitepe (Fig. IV.4). The crystal habit is illustrated in figure (IV. 10). The gypsum normally occurs as interpenetrant 'cruciform' twins. They occur together with others which have the discoidal habit described above, (Fig. IV.11). This juxtaposition of two crystal habits is taken to imply that they formed at different times. The discoidal crystals were demonstrably formed penecontemporaneously with deposition of the host sediment. The others appear to be of late, possibly very late origin.

(ii) Secondary gypsum

A. Discus-like masses of gypsum

Some extremely large masses of secondary gypsum after anhydrite have been found to occur in association with the second type of mudstones in the topmost part of the formation at Kuskayasi. Four such masses are exposed in situ at outcrop. They all occur at the same stratigraphic level and are connected laterally by a thin bed (5 cms in thickness) of chicken-wire gypsum. A schematic section showing the approximate position of the discus-like masses is presented in Figure IV. 12.

They lie in the plane of bedding and are discus-shaped, being circular in plan and lenticular in cross-section, (Fig. IV.13 a, b). They range from 70 cms up to 1.10 metres in circular diameter and from 20 to 30 cms in thickness.

These masses are aggregates of large nodules. When viewed in plan they have a radial appearance: the nodules at the polar parts are

circular to subcircular in shape but they become elongate towards the edges (Fig. IV.14-15). In cross section, it is seen that the central parts have chicken-wire structure, and that the nodules in the outer parts are elongate (Fig. IV.16).

One mass of gypsum was found which although akin to the other, is irregular in shape and lacked radial arrangements of its constituent nodules (Fig. IV. 17). It is 1.25 metres in diameter.

The bedrock laminae curve over and under the masses conformably with their shapes and thin as they do so. This arrangement suggests that the masses of gypsum grew displacively.

Petrographically, the constituent nodules are composed mainly of alabastrine secondary gypsum with minor amounts of porphyroblastic gypsum. The porphyroblasts form narrow selvedges around the outer parts of each constituent nodule (Fig. IV. 18). The latter contain corroded relics of anhydrite. The presence of these relics leaves no doubt that the nodules were anhydrite once and were subsequently hydrated to secondary gypsum.

Spherulites of lutecite (length-slow chalcedony), either isolated or in groups, have been found in thin sections of the constituent nodules of the discus-like masses (Fig. IV.19). The sizes of these spherulites vary considerably, but they usually range from 100 μ to 500 μ and do not appear to exceed one mm in diameter. Their boundaries with the surrounding alabastrine secondary gypsum seem to be sharp, and growth lines are visible. Some of the lutecite spherulites carry numerous inclusions of anhydrite. This indicates that the lutecite replaced anhydrite and also provides corroborative evidence that the alabastrine gypsum is secondary after anhydrite.

Spherulitic aggregates of lutecite similar to those described above were first described from the Tertiary evaporites of the Paris Basin as

early as 1895 by Mighel-Levy and Munier Chalmas (in Cayuev 1916). They have subsequently been described from numerous evaporitic formations (e.g. Wilson, 1966; Folk and Pittman 1971; Pittman and Folk, 1971: Siedlecko, 1972; Schreiber, 1974; and Clarke, 1976). All of these occurrences, except for the lutecites described by Schreiber (Op.cit) which were detrital, have been interpreted as indicative of evaporite environment.

B. Beds of chicken-wire gypsum

It has already been mentioned that a thin bed of chicken-wire secondary gypsum occurs between the discus-like masses. In addition to this, a few thin beds of chicken-wire gypsum are also present at a slightly lower level. These latter do not exceed 2 cms in thickness. Apart from the smaller size of the individual nodules, they are closely similar to those which have been described from the lower part of the preceeding Bayindir Formation.

C. Gypsum veins

Both horizontal to subhorizontal and vertical to subvertical veins of gypsum are developed in the topmost parts of the formation. The horizontal veins are of satin-spar and occur in association with the discus-like masses of secondary gypsum and the beds of the chicken-wire gypsum. Where they occur in association with the discus-like masses, the veins curve over and under each mass, and at the same time stay more or less concordant with the bedding. There is a positive relationship between the thickness of the gypsum beds and the number and thickness of the satin-spar veins.

Vertical to sub-vertical veins of satin-spar are relatively common. They occur not only at Kuskayasi, where the masses and the chicken-wire beds of secondary gypsum are found, but also elsewhere in the topmost parts of the formation. They vary in width from the order of 1 mm up to 2 cms or more.

3.6. Cornstones

Calcareous concretions are one of the characteristic features of the Kizilirmak Formation. They occur in association with the mudstones of the fining-upward cycles in the upper part of the formation, i.e. in the first type of mudstones. In many cycles they are accompanied by crystals of primary gypsum with discoidal habit (Fig. IV. 9). The shapes of the concretions usually tend to be spherical to subspherical but irregular shaped ones are not rare (Fig. IV. 20). They range in size from 1 cm up to 10 cms in diameter. Although the common colour is yellowish gray (5Y 8/1), some are moderate orange pink in colour due to iron oxide staining.

Petrologically, they are composed almost entirly of microcrystalline calcite with fragments of quartz (mono-to poly - crystalline), grains of feldspar, lithic fragments and occasional glaucophane are also found. Some have a brecciated or mottled appearance due to the presence of veins and patches of coarsely crystalline calcite.

IV. 4. SEDIMENTARY STRUCTURES

The distribution of the sedimentary structures present in the Kizilirmak Formation, appears to be governed by cyclic patterns of sedimentation. Two types of cyclic patterns are seen in the formation: (i) fining-upward cycles of conglomerates, sandstones, siltstones and mudstones, and, (ii) mudstone-gypsum cemented sandstone cycles. The latter are restricted to the uppermost part of the formation.

A complete fining-upward cycle starts with a scoured surface which sometimes exhibits groove casts, flute casts and load casts. This is succeeded by the conglomerates which are generally massive, but display cross-bedding in some cycles. The conglomerates grade up into coarse-grained, cross-bedded sandstones which are in turn overlain by fine-grained,

horizontal bedded and micro-cross-laminated sandstones. These pass up into siltstones and finally mudstones. The siltstones display horizontal lamination and micro-cross-lamination in some cycles. The mudstones are evenly laminated and characteristically show desiccation cracks. The tops of the mudstones are defined by scoured surfaces on which the succeeding cycles rest.

In the upper part of the formation, conglomerates are absent in many cycles. In these coarse-grained sandstones, which tend to be pebbly in their basal parts, rest on the scoured surfaces. As in the Incik Formation, a number of the cycles are not complete. Some are interrupted by development of conglomerates or very coarse-grained sandstones within the very fine-grained sandstones. These interruptions may or may not be associated with a scoured surface. They probably represent the start of a new cycle before the old one was completed.

In the mudstones of the mudstone-gypsum cemented sandstone cycles, horizontal lamination and desiccation cracks are the characteristic sedimentary structures. The sandstones display cross-bedding and ripple marks.

IV. 5. THE AGE OF THE FORMATION

No fossils have been found in the study area except for a few ostracods and plant fragments. The fauna elsewhere in the basin includes ostracods, vertebrate remains, spores and pollen. These were well documented by Aziz (1973), Birgili et.al., (1975) and Tekkaya et.al., (1975).

Aziz (op.cit.), on the basis of spores and pollen found in lignite lenses in the upper part of the formation, 1 km north of the study area, assigned an Upper Miocene age to the formation. Birgili et.al., (Op.cit.) also suggested an Upper Miocene age on the basis of ostracods and spores and pollen found in the lignite layers around Cankiri, north-central part of the basin. However Tekkaya et.al. 1975, found vertebrate fossils

including Sivapithecus pilgim (Sivapithecus Alpani) which was believed to be Tortonian, near the town of Candir, in the south-central part of the basin. They concluded therefore that the formation ranges from the Middle Miocene to Pliocene.

I.V. 6. THE ENVIRONMENT OF DEPOSITION

All previous workers including Erol (1953); Ketin (1962); Tekkaya (1974); Birgili et.al. (1975) and Tekkaya et.al. (1975) recognised the continental origin of the Kizilirmak Redbeds and they suggested that deposition took place in an intermontane lake environment subjected to an arid to semi-arid climate. Unalan (1974), however suggested a fluviatile origin for the lower parts of the succession in the south-central part of the basin.

In the area which has been studied, 9/10 of the Kizilirmak Formation is made up of fining-upward cycles of conglomerates, sandstones, siltstones and mudstones. Gypsum only appears in the uppermost parts of the formation. Fining-upward sequences similar to those of the Kizilirmak Formation have been interpreted to be deposits of meandering river systems dominated by lower flow regime hydraulics (e.g. Allen 1965; Visher 1965). It seems reasonable, therefore, to interprete the fining-upward cycles as representing fluviatile deposition from meandering streams. The conglomerates (very coarse-grained sandstones in the upper part of the formation) appear to be channel-fill deposits. The succeeding cross-stratified sandstones probably represent point bar deposits, while the laminated siltstones and mudstones are thought to be overbank deposits.

The incoming of evaporites in the upper 30 metres of the formation herald a radical change in environmental conditions.



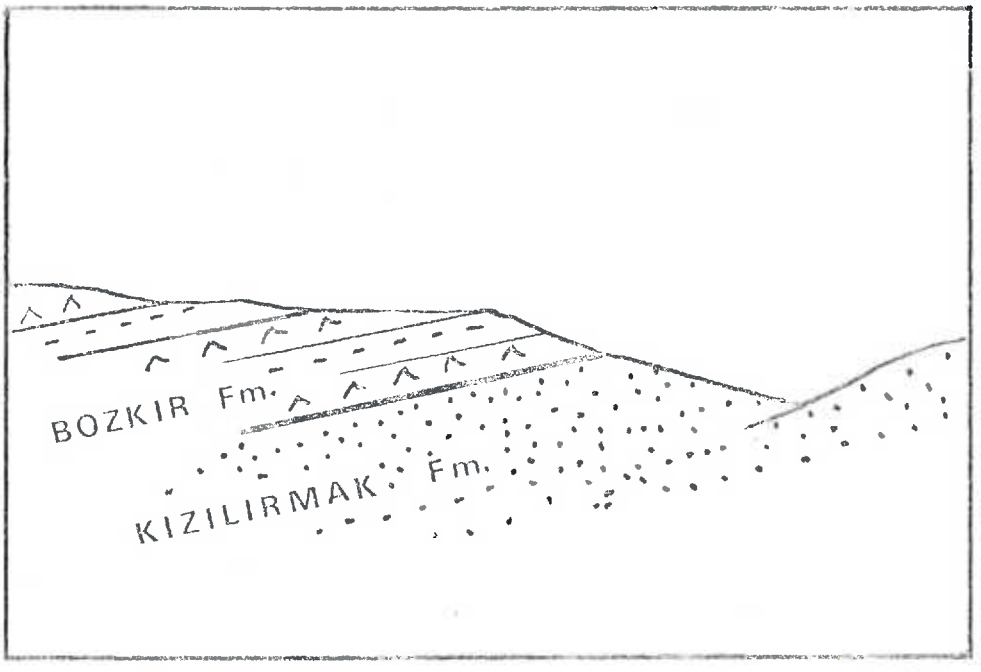


FIG. IV.1 A general field view showing the contact between the Kizilirmak and overlying Bozkir Formations.

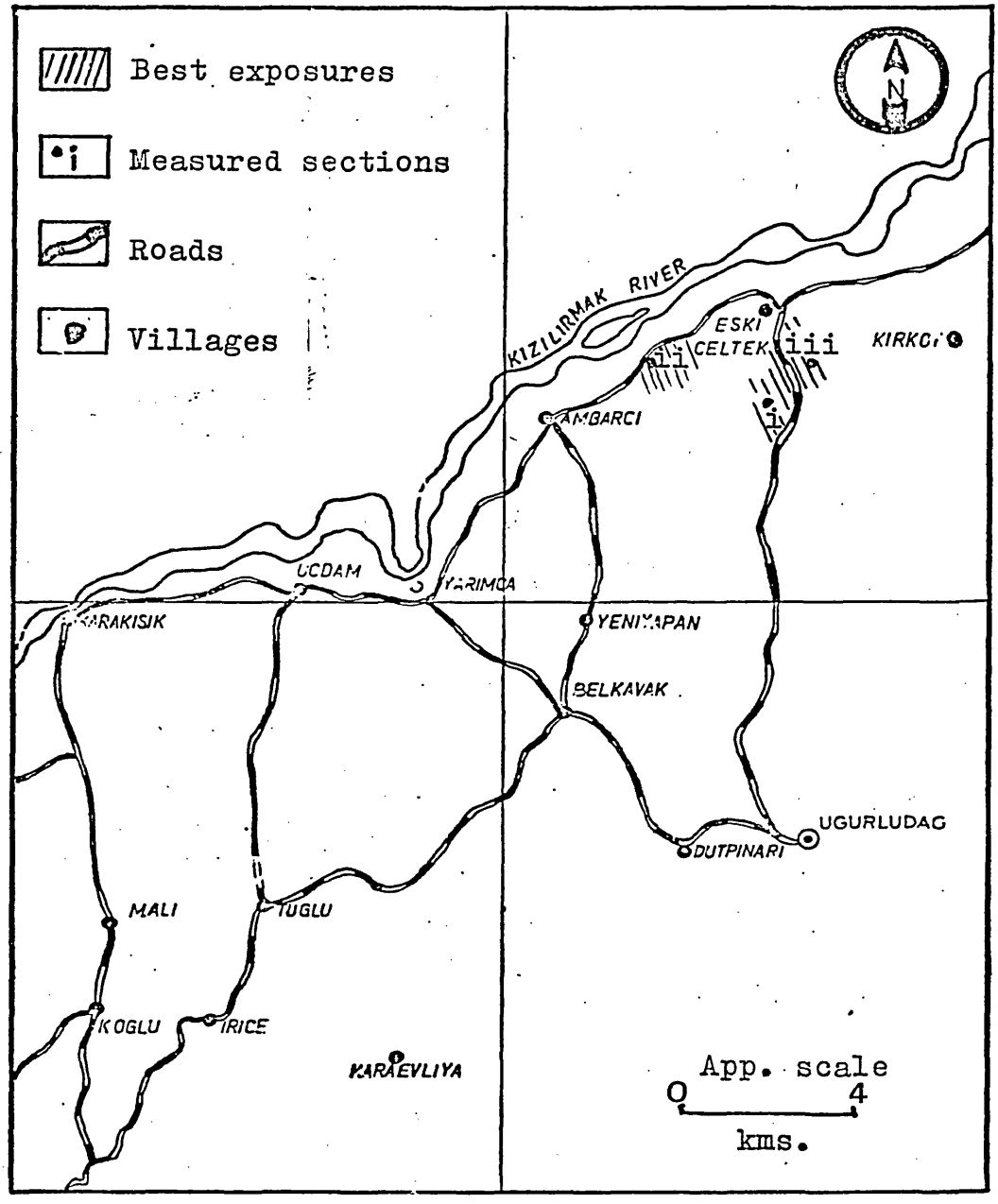


FIG. IV.2 A schematic map of the study area showing best-exposed outcrops and the locations of measured sections of the Kizilirmak Formation.

i. The Kepeztepe Section
ii. The Esekcitepe Section
iii. The Kuskayasi Section

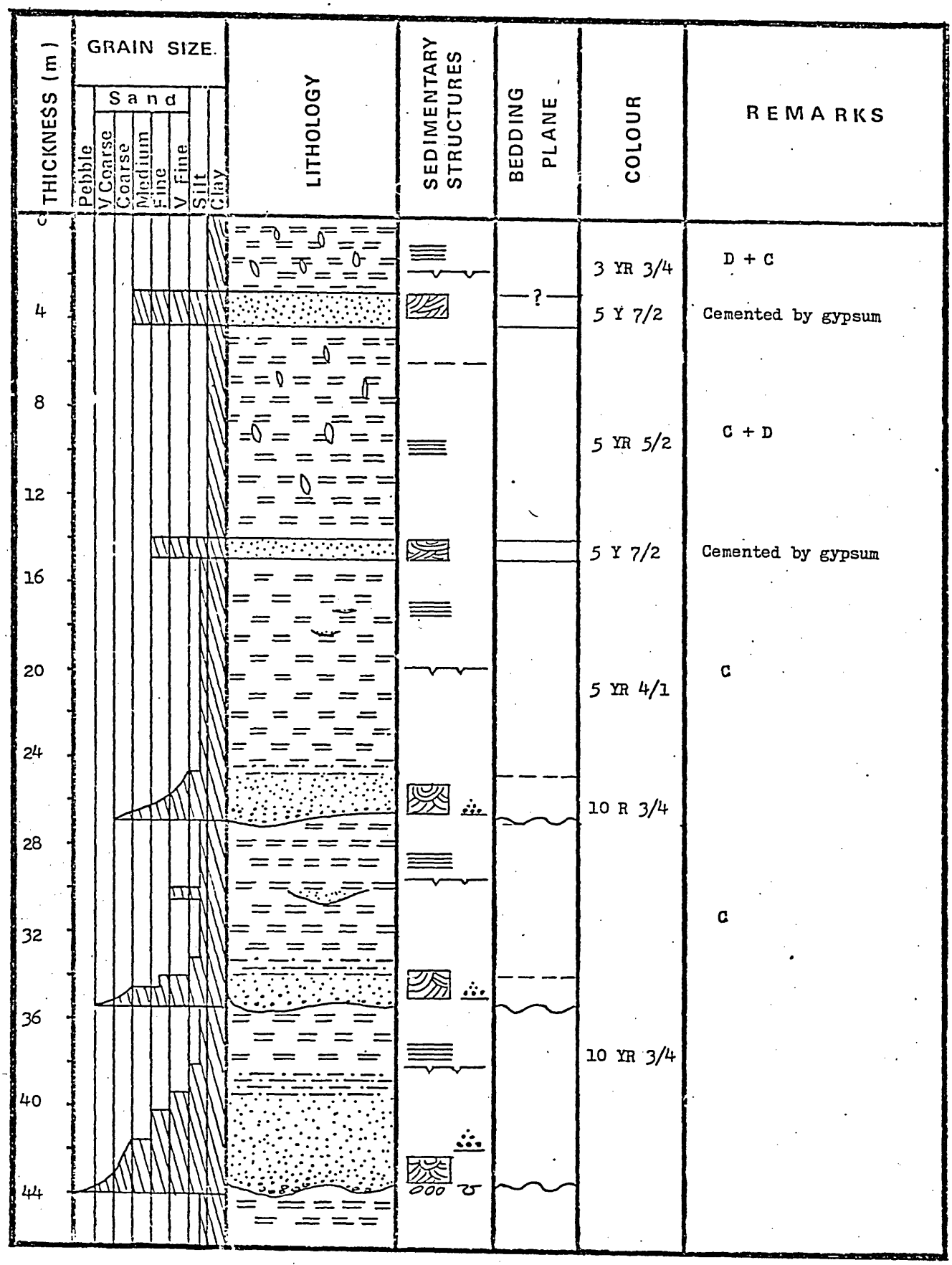


FIG. IV.3 The Kepeztepe Section.

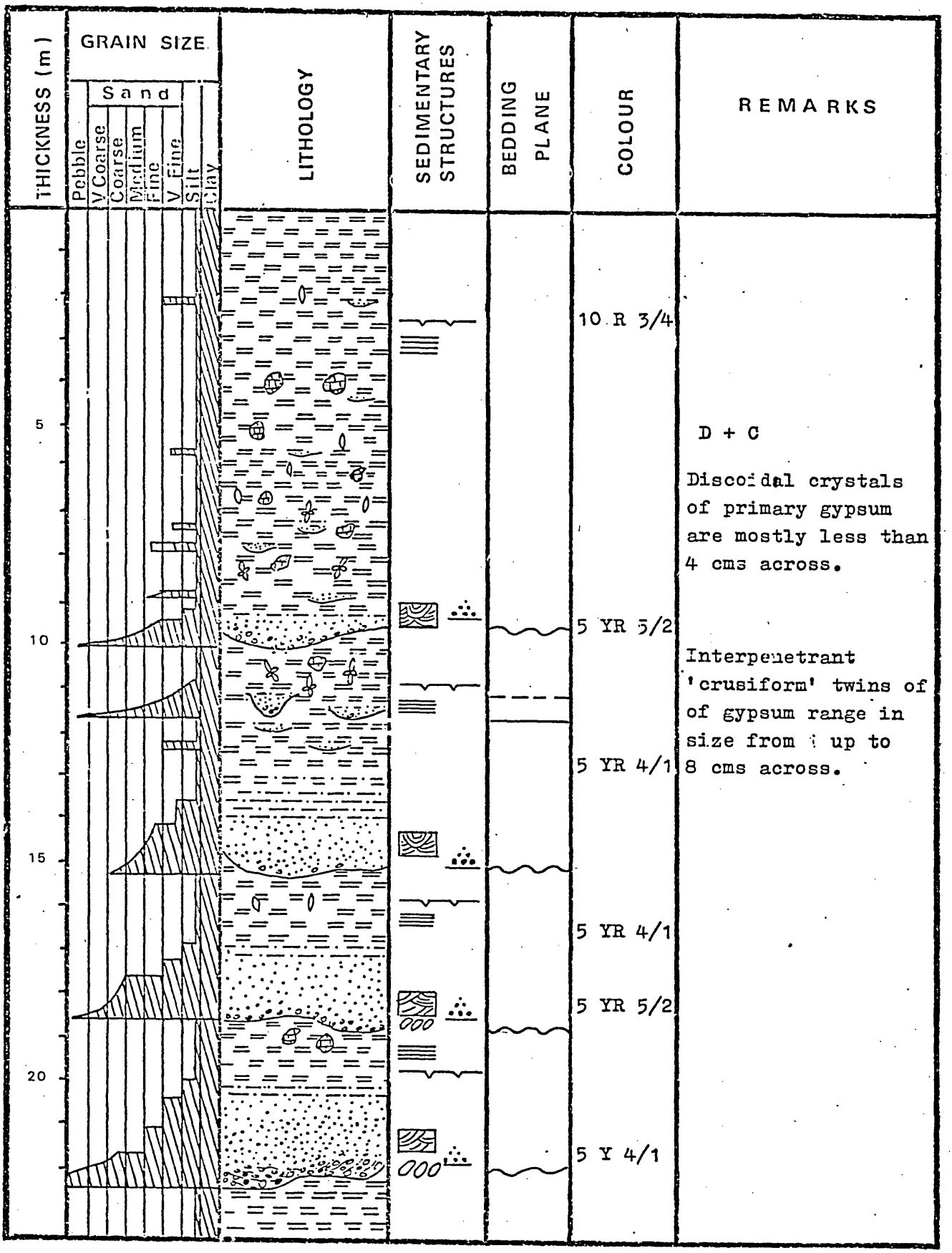


FIG. IV.4 The Esekcitepe Section.

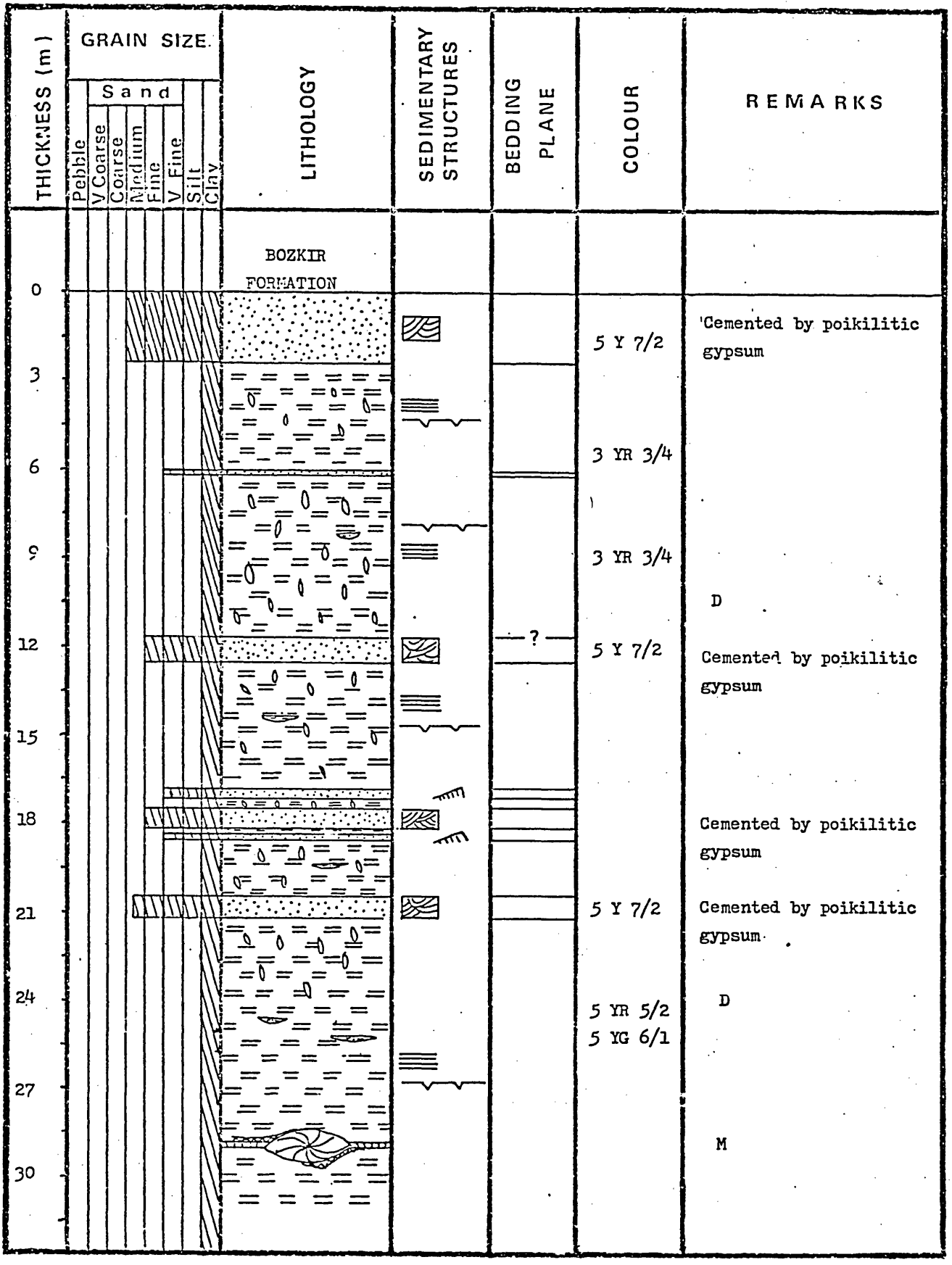


FIG. IV.5 The Kuskayasi Section.



FIG. IV.6 A field photograph showing one of the channel-fill sandstone beds in the upper part of the Kizilirmak Formation.Note the presence of a few very small channel-fill sandstone lenses(Dark brown) in the upper half of the photograph.

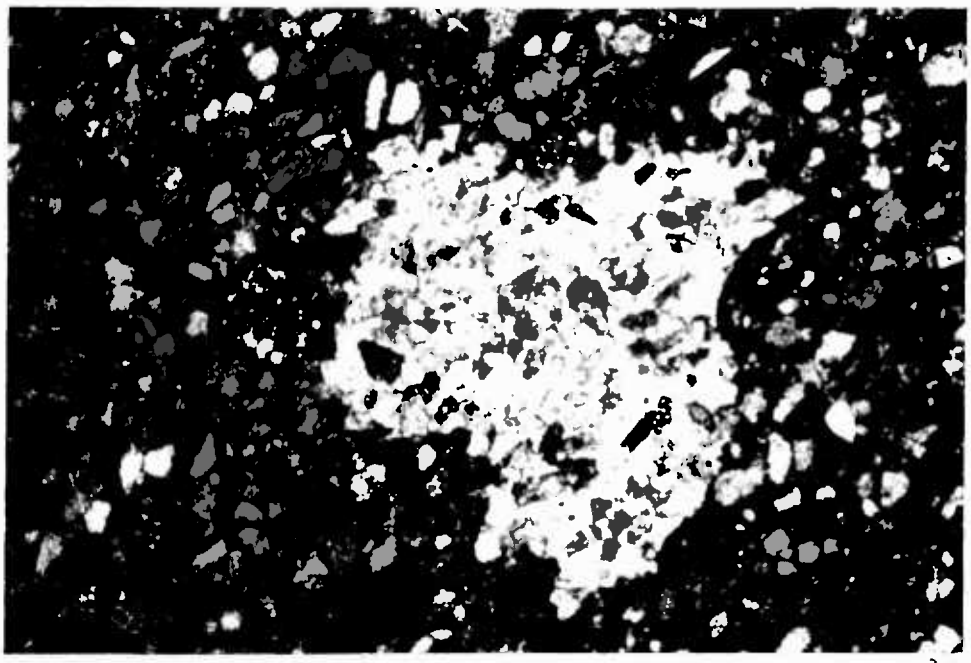
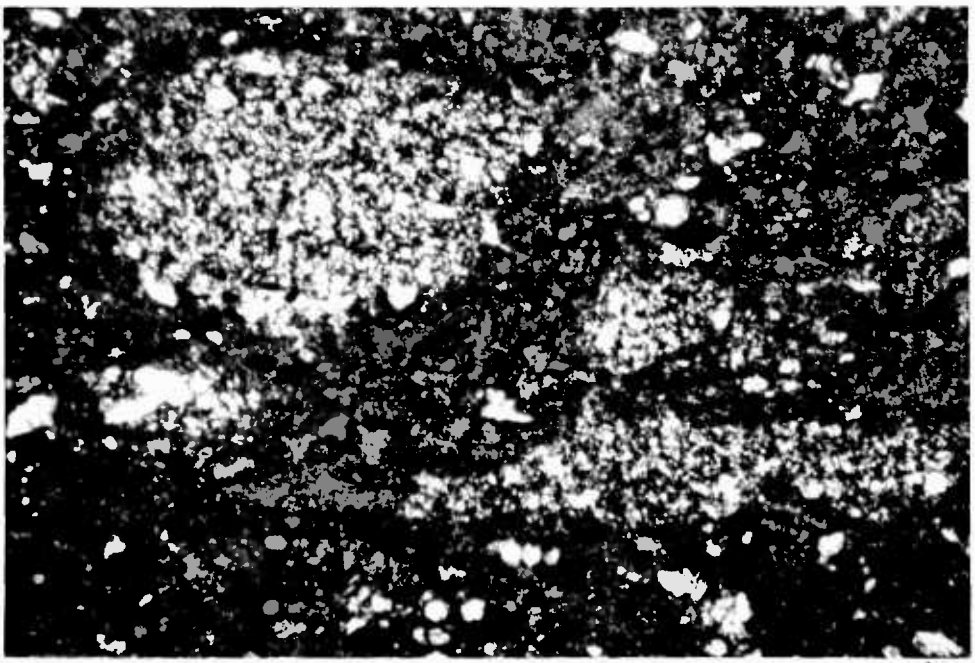


FIG. IV.7 Low magnification photomicrograph showing poikilitic gypsum cement in the second type of sandstones, Kizilirmak Formation.



(x30)

FIG. IV.8 A low magnification photomicrograph showing tiny nodules of secondary gypsum after anhydrite in the second type of sandstones.The nodules comprise both porphyroblastic and secondary gypsum.Thin section cut normal to the bedding.Kizilirmak Formation.

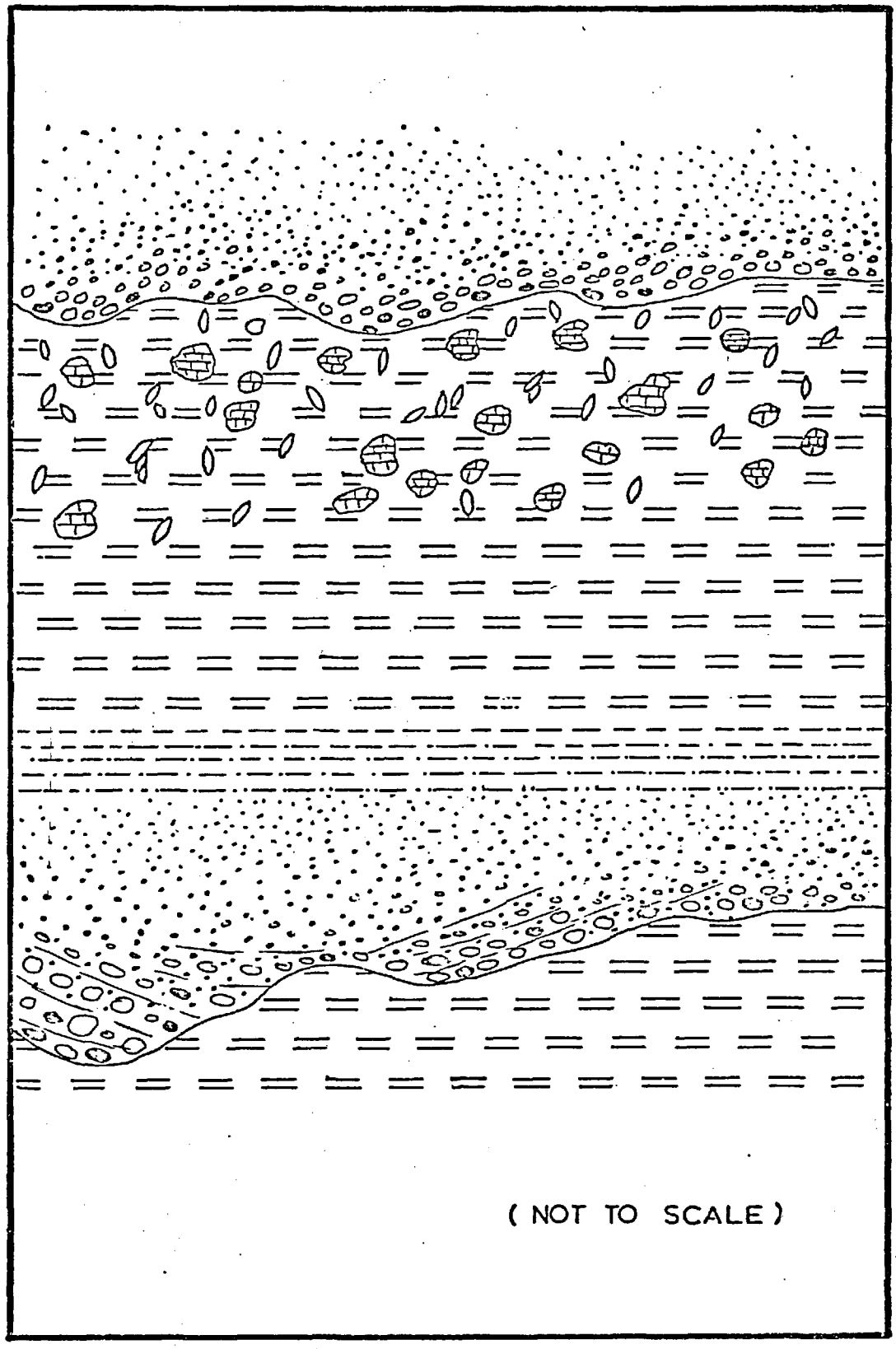


FIG. IV.9 A representative field sketch showing discoidal crystals of primary gypsum and calcareous nodules in one of the fining-upward cycles of the upper part of the Kizilirmak Formation.Besiktepe,2 kms west of the village of Eski Celtek.



FIG. IV.10 Interpenetrant 'crusiform' twins of primary gypsum.Scale in cms.

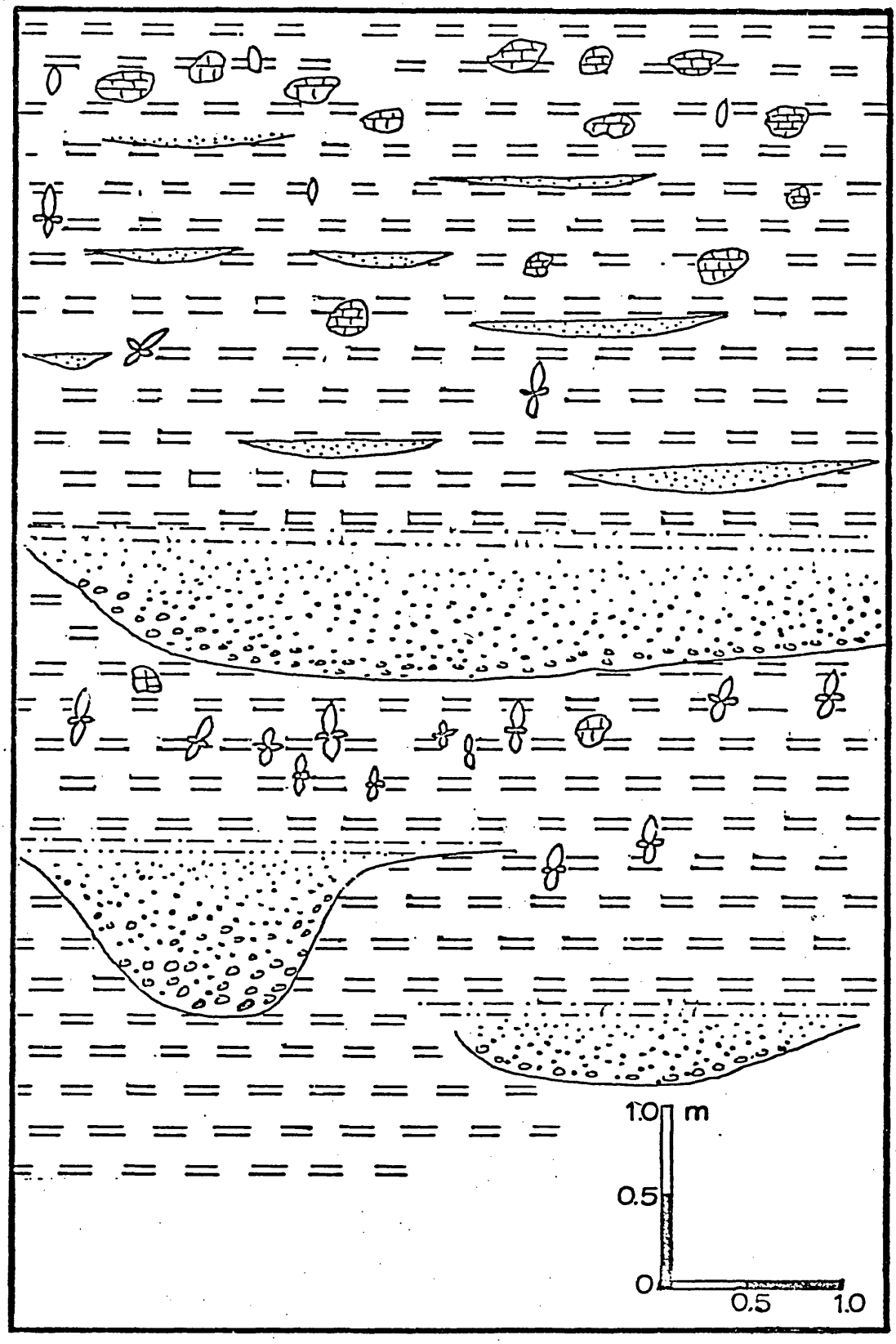


FIG. IV.11 A representative field sketch showing the interpenetrant 'crusiform' twins of primary gypsum, Esekcitepe section, upper part of the Kizilirmak Formation.

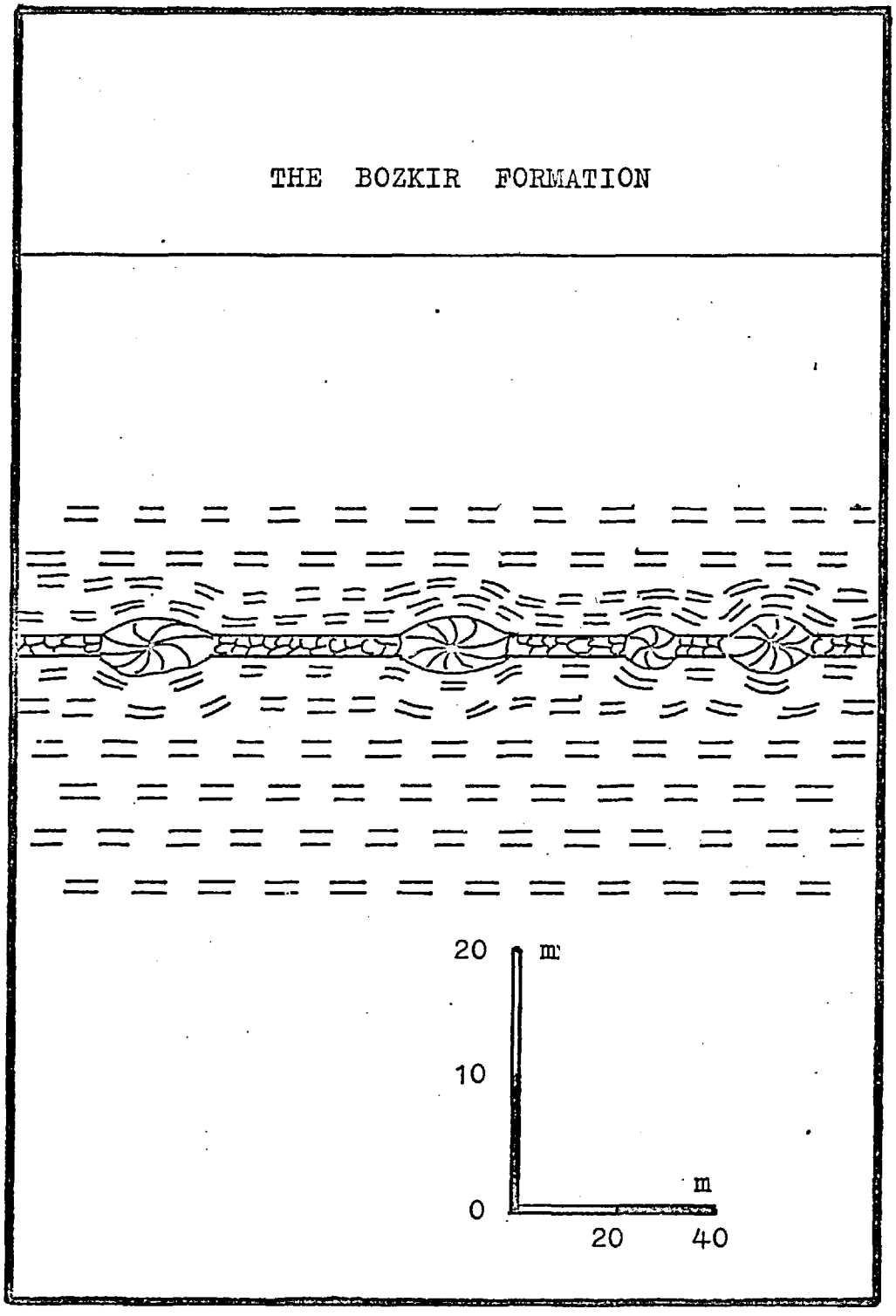


FIG. IV.12 A representative field sketch showing the stratigraphic position of the discus-like masses of gypsum at Kuskayasi:Kizilirmak Formation.



FIG. IV.13,a Field photograph showing one of the discus-like masses of secondary gypsum.



FIG. IV.13,b Close up of Fig.13,a.Note the shape of the gypsum mass.



FIG. IV.14 As for Fig.13,a another view..



FIG. IV.15 The radial structure of the discus-like masses of secondary gypsum,-fallen block.



FIG. IV.16 Cross-section of the outter part of one of the discus-like gypsum masses.Constituent nodules are flat in a plane of bedding: fallen block.



FIG. IV.17 Irregular mass of secondary gypsum:Kizil-irmak Formation.

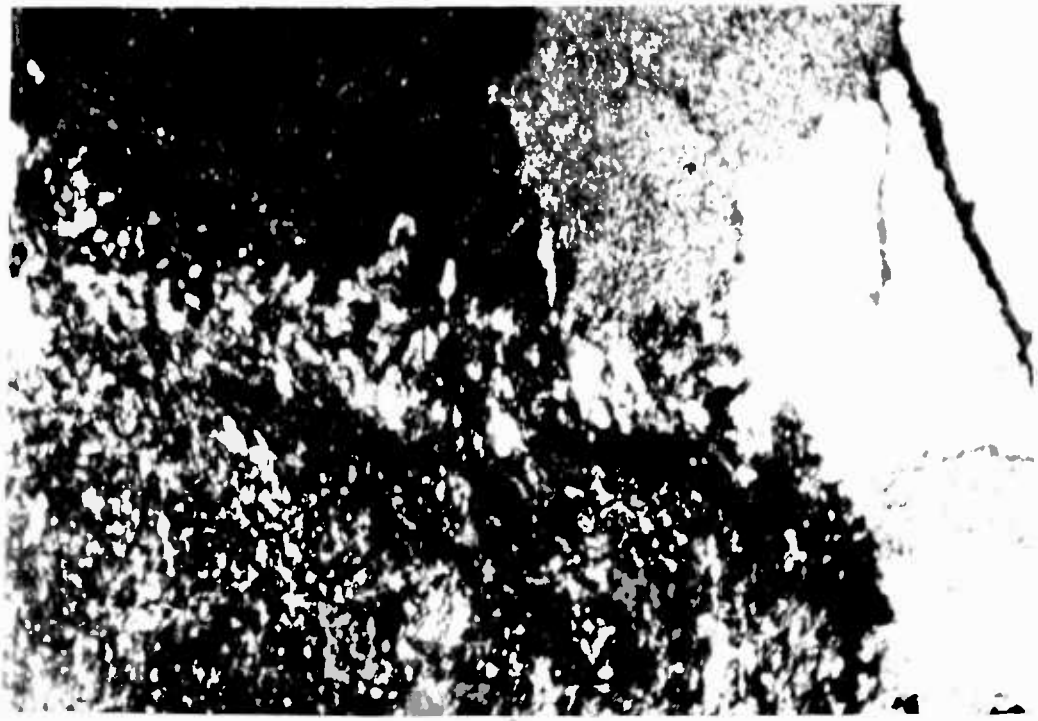
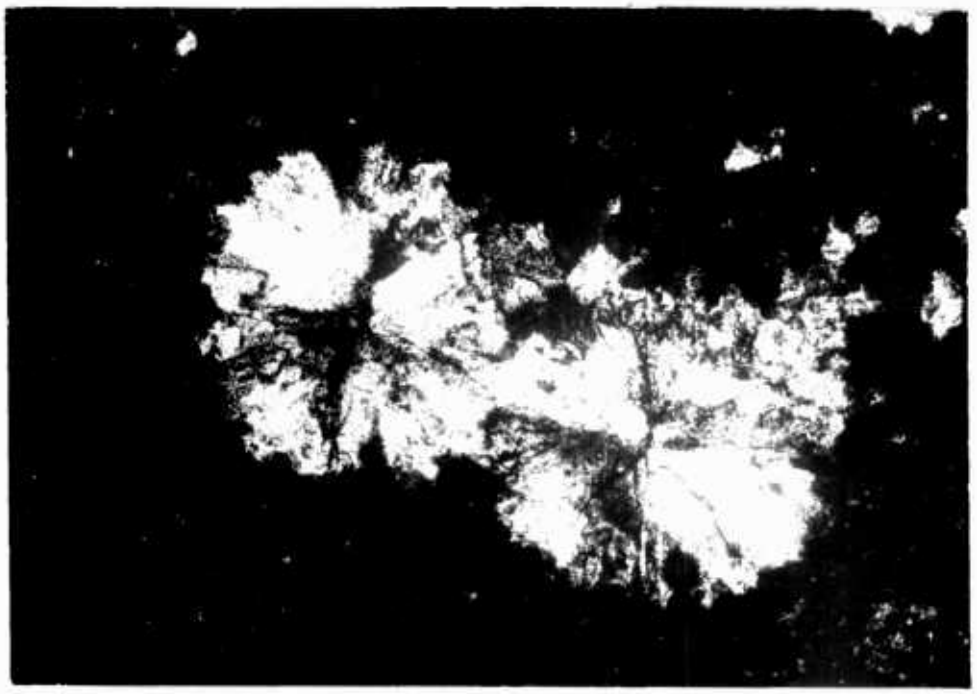


FIG. IV.18 Photomicrograph of a constituent nodule of the discus-like masses of secondary gypsum.



(×50)

FIG. IV.19 Spherolites of lutecite(Lengh slow chalcedony) in a groundmass alabastrine secondary gypsum fabrics in the discus-like masses of gypsum.



FIG. IV.20 Field photograph showing calcareous nodules in light brown mudstone:upper part of the Kizilirmak Formation.

CHAPTER V

THE BOZKIR FORMATION

V. 1. INTRODUCTION

The Bozkir Formation is the topmost lithostratigraphic unit of the sedimentary succession in the area, which has been studied. In part it overlies the redbeds of the Kizilirmak Formation, and in part interfingers with them.

Lithologically, it is a sequence of cyclic alternations of gypsum rocks and mudstones; the latter also carry gypsum. The gypsum rocks show great diversity. The majority are laminar, but some tend to be massive. Many beds comprise unaltered primary gypsum, but others are either wholly or in part secondary after anhydrite. The primary gypsum shows a variety of crystal habits and modes of growth which differ from cycle to cycle. In some instances, the gypsum crystals evidently grew free at a sediment-water interface, but in other cases, the gypsum grew intersitially in the sediment which now contains them. The secondary gypsum rocks show evidence which suggests that the original mineral was gypsum, but that it was altered to anhydrite during early diagenesis, and this anhydrite was later hydrated to secondary gypsum in the course of exhumation.

In some places, the lithology is rather different. It is cyclic, but the cycles are characterized by alternations of gypsum-cemented sandstones and mudstones which carry discoidal crystals of primary gypsum. In the lowermost 40-60 metres of the formation, horizontal to sub-horizontal veins of satin-spar are developed in both the laminar secondary gypsum rocks and associated mudstones, and a few vertical to sub-vertical veins are also present.

No fauna diagnostic of age has been found in the area. However, if the age determinations of the underlying Kizilirmak Formation by previous workers are correct, then on the basis of stratigraphic relationships, it is reasonable to assign an Upper Miocene age to the Bozkir Formation.

V. 2. GEOGRAPHICAL DISTRIBUTION, THE TYPE LOCALITY AND THICKNESS

Although most of the north-eastern part of the study area is underlain by the sediments of the Bozkir Formation, good exposures are limited to a few stream and road cuttings. It is best exposed on the south side of the Kizilirmak Valley, along the road between the villages of Kimceltigi (Grid: CORUM, G32C3; 89-90, 26-27) and Ambarci (Grid: CORUM, G32C3; 87-88, 17-18). Exposures are also good in the Acidere, Acioz Dere and Guydumdere stream valleys and along the road which connects the village of Kirkoy (Grid: CORUM, G32C3; 94-95, 26-27) to the main road,[1] (Fig. V.1). Elsewhere because of large scale landslips, outcrops are so greatly distorted that no detailed sections can be measured.

The type locality for the formation is situated on the western flank of Buyuk Tepe, 500 m. to the east of the village of Eski Celtek (Grid: CORUM, G32C3; 90-91, 22-23).

In addition to the type section, seventeen reference sections were measured centimetre by centimetre, in order to record the variations in lithology, sedimentary structures and geometry of the cycles. The locations thicknesses and stratigraphic positions of these sections are shown in Fig. V.2, and the logs are presented in the following pages.

The thickness of the formation is 367 metres at the type locality. Although, no complete section could be measured other than at the type locality, it seems that the formation thins gradually westward as far as the village of Ambarci, where it apparently interfingers with the redbeds of the Kizilirmak Formation. It also appears to thin to the east and to the south.

V. 3. MUDSTONE - LAMINAR GYPSUM CYCLES

Throughout the study area, the Bozkir Formation is made up of rhythmic repetitions of mudstones and gypsum (Fig. V. 20) except for the sections

[1] Iskilip-Ugurludag Road.

at Ambartepe (Fig. V.5,6) and Tuzlantepe (Fig. V. 18), where it also comprises alternations of various types of gypsum-cemented sandstones and mudstones. Each cycle consists of a basal mudstone unit with an overlying laminar gypsum unit. The mudstone units also carry gypsum. The contact between the two is generally transitional but in some cycles it appears to be erosional. The contact between the laminar gypsum unit and the overlying mudstone unit of the succeeding cycle is always sharp.

The thicknesses of the cycles vary considerably from place to place: ranging from 2 cms up to 3.50 metres. At the type section (App. I), more than 200 cycles have been recorded. The relative thicknesses of the mudstone and laminar gypsum units are not constant in all cycles, but in general the ratio of mudstone to laminar gypsum is about 1:2.

Due to lack of the continuous exposures, it is difficult to assess the lateral extent of individual cycles, but it is apparent from exposures in the Kizilirmak Valley and the Guydumdere Valley that some of the laminar gypsum units are lens-shaped while others appear to be laterally continuous.

The mudstones range in colour from yellowish gray (5Y 7/2) to light olive gray (5Y 6/1) and light brownish gray (5YR 6/1) to brownish gray (5YR 4/1). The laminar gypsum units are characteristically yellowish gray (5Y 8/1) to light gray (N 8).

Horizontal lamination and desiccation cracks (Fig. V. 21) are the characteristic sedimentary structures of the mudstones. The laminae are present in pairs, one of which is light coloured and between 1 to 3 millimetres thick, while the other is dark and much thinner, generally less than 0.5 millimetres. X-ray and thin section studies have shown that the dark coloured laminae are films of iron oxide, which are discontinuous and tend to die out within a few centimetres. Some of the mudstone units contain small siltstone lenses. Burrow-like structures have also been observed in two of the mudstone units.

Lamination is the dominant sedimentary structure of the gypsum units and the thicknesses of the laminae vary between 2 mms and 1 cm. The laminar appearance is the result of different concentrations of non-evaporitic materials. The colour becomes darker with increase in proportion of non-evaporitic material. Generally speaking, the light coloured laminae are thicker than the dark coloured ones. Some cross-lamination is present, but it is only seen in those cycles, in which the contact between the two units of the cycle is erosional.

Ripple marks are common in the gypsum rocks (Fig. V.22). Most, if not all, of the ripples appear to be symmetrical and both sharp and round crested forms have been observed. Their amplitudes range from 1 cm up to 5 cms, and their wave lengths generally extend between 4 to 8 centimetres.

For the purposes of description, it is convenient to subdivide the cycles into three groups on the basis of whether the gypsum is primary or secondary after anhydrite. These are:-

(1) Cycles in which the gypsum of the laminar gypsum rocks and the mudstones is all unaltered primary gypsum. These are termed "Mudstone-laminar gypsum cycles with primary gypsum".

(2) Cycles in which the gypsum of the laminar gypsum rocks and mudstones is in part primary and in part secondary after anhydrite. These are designated "Mudstone-laminar gypsum cycles, with primary and secondary gypsum".

(3) Cycles in which the gypsum of the laminar gypsum and the mudstone units is all secondary after anhydrite. These are called "Mudstone-laminar gypsum cycles, with secondary gypsum".

3. 1. Mudstone-laminar gypsum cycles, with primary gypsum

These cycles are characterized by a basal dolomitic mudstone unit followed by an overlying laminar primary gypsum unit. The dolomitic mudstones characteristically carry crystals of primary gypsum which are

discoidal in habit (Fig. V. 23). Approximately two-thirds of the cycles are of this type: see logs of type and reference sections.

Because of their extremely fine-grain size, the mudstones were studied by x-ray diffraction and scanning electron microscopy. 23 mudstone samples from different cycles were taken for x-ray diffraction analysis. Dolomite is the most abundant mineral in all samples, and quartz is also present in minor but variable amounts. Clay minerals and feldspars were also detected, and very small amounts of celestite were found in some samples. The approximate relative abundance of the constituent minerals together with the locations of the samples are presented in Appendix II.

Four mudstone samples were analysed specifically for clay minerclogy, and were found to contain smectites, including montmorillonite; chlorites, illites and a mineral of the kaolinite group.

Examination of some of the mudstone samples under the scanning electron microscope has shown that the dolomite is present as well developed rhombohedral crystals which range from 0.5 to 4 microns in diameter, (Fig. V.24 a,b).

The dolomitic mudstones characteristically enclose crystals of primary gypsum of discoidal habit. (Fig. V. 25). These crystals occur either singly or as interpenetrating clusters, and their sizes vary considerably from cycle to cycle; ranging from a millimetre up to 27 centimetres, (Fig. V. 26 and 27). There is no positive relationship between the thicknesses of the mudstone units and the size of the gypsum crystals which they contain. In some cycles, the crystals are all approximately of the same order of size, but in others, the crystals increase in size upwards through the lower half of the mudstone units, above which they progressively decrease in size towards the top (Fig. V. 28).

In the field, the gypsum crystals are usually arranged with their plane of flatness vertical or near vertical with respect to bedding.

The crystals are flat in a plane approximately normal to the c-crystal axis. They are diamond-shaped or near circular in plan, and roughly lenticular in cross sections. The surfaces of some of the crystals are curved and there are no rational crystal faces. These crystals give perfect lanceolate cross-sections (Fig. V. 29, a). Other crystals have well developed hemipyramid faces closed by two curved surfaces (Fig. V. 26). The cross sections of the latter type are lozenge-shaped on 010 cleavage surfaces (Fig. V. 29., b).

The crystals contain carbonate and brine inclusions. The carbonate inclusions occur along the 010 cleavage planes in all instances. Examination of 010 cleavage flakes under the microscope has revealed that the crystals contain abundant brine inclusions. These are of two types: primary brine inclusions and secondary brine inclusions (Dr. A. Rankin). The primary inclusions which are rectangular in outline with rounded corners, are oriented parallel to c-crystal axis (Fig. V. 30). The secondary brine inclusions are circular to near circular in outline and are randomly arranged.

The crystals were examined under ultraviolet light and it was found that they did not respond uniformly. The curved surfaces showed a strong yellowish fluorescence, but the other parts of the crystals fluoresced only very weakly.

Crystals of primary gypsum with discoidal habit have been found in the recent sediments of the Laguna Madre, Texas (Masson, 1955; Keir & Thomson, 1963), the coastal sabkhas of Abu Dhabi, Trucial Coast (now U.A.E) eg., Shearman, 1963, 1966; Kinsman, 1964; Butler, 1966; Bush, 1973 a,b). Clayton Playa, Nevada (Moiola and Glover, 1965) and many other places.

In those places, the gypsum has grown displacively in the sediments during early diagenesis. In all essential respects the crystals of primary gypsum with discoidal habit, which have been found in the mudstone-laminar

gypsum cycles of the Bozkir Formation resemble those which occur in the Recent sediments of the tidal flats of Laguna Madre, Texas (Masson, 1955) and elsewhere. Therefore, it is suggested that they were formed interstitially and emplaced by mechanical displacement while the sediments were still in the environment of deposition.

The laminar primary gypsum units comprise alternations of gypsarenites and layers of "vertically" oriented gypsum crystals which have palisade-like appearance (Figs. V. 31, 32 and 33). The gypsarenites are dominantly delicately laminar, but more massive beds up to to 5 cms thick are present in some cycles. The palisade-like horizons range in thickness from a few millimetres up to 5 cms. The constituent crystals are arrayed with their long axis normal or near-normal to bedding. Individual crystals tend to increase in width upwards and superficially appear to be cone-shaped. Such an arrangement is suggestive of competitive growth of crystals which nucleated at a brine-sediment interface. Similar palisade structure is present in the Tertiary evaporites of the Paris Basin.

Two varieties of palisade structures have been recognised: planar palisade structures (Fig. V. 31), and undulose palisade structure (figs. V. 32 and 33). They usually show lateral transitions from one type to another, i.e. planar palisade structures become undulose locally and vice-versa. Both asymmetrical and symmetrical undulose palisade structures can be seen. The latter usually follow ripple surfaces (Fig. V. 33).

An interesting example can be seen in a cutting along the Iskilip-Corum road, near the village of Tozluburun, just outside the area which has been mapped. The crystals are relatively large, being between 4 and 17 centimetres in length, and they are arrayed with their lengths normal or approximately normal to bedding (Fig. V. 34). They cleave readily on 010 which is usually at right angles to the bedding. The great majority, if not all, of the crystals enclose some carbonate impurities which are

arranged in zones. A conspicuous and spectacular feature of these carbonate zones is their chevron-like arrangement (Fig. V. **34**) which is taken as marking the position of former crystal faces at various stages during growth of the crystals. The thicknesses of the carbonate zones generally range from 0,5 to 1 millimetre, but in some crystals they reach up to 3 millimetres. More than 30 carbonate zones were counted in one crystal which was 15 centimetres long. It is important to note that some of the zones can be traced from one crystal to another, thus indicating that the crystals grew at the same time (Fig. V. **35**).

The crystals appear to be very similar to those described from Marion Lake, Australia (Dickinson and King, 1949; Goto, 1968; and Hardie and Eugster, 1971) and Pleistocene evaporites of Montallegro, Sicily (Schreiber and Kinsman, 1975, p.475).

According to Goto (op. cit) and Schreiber and Kinsman (op. cit) the c-crystal axes are parallel to the lengths of the crystals. However, the orientation of etch-pits induced by acid treatment of 010 cleavage surfaces indicates that the c-crystal axes are oblique to the length of the crystals: i.e. they lie at low angles with respect ot bedding. Goto and Schreiber and Kinsman interpreted the chevron arrangement of the zones as being the traces of the form (111). They were wrong in making the assumption, the zones are, in fact the traces of the form (120), (Fig. V.**36**).

In thin section, under the microscope, the laminae of the lamina primary gypsum are defined sometimes by grain size differences, and sometimes by laminae of carbonate minerals, usually dolomite.

Figure V. **37** is a low magnification photomicrograph of a thin section of laminar gypsum cut perpendicular to the bedding. The upper part of the photomicrograph shows a carbonate-rich lamina, while the lower part shows a gypsum lamina which is almost free of carbonate. The boundary between the two is not sharp; wisp-like extensions of carbonate penetrate the

under-lying gypsum lamina. The latter comprises a coarsely crystalline mosaic of primary gypsum crystals in which individual crystals range from 0.1 up to 2 millimetres in diameter. Some of the crystals are separated one from another by thin films of carbonate, but most are in direct contact and the contacts between them are near-linear compromise boundaries; although some show interpenetrations reminiscent of pressure solution. The gypsum crystals of the carbonate laminae are euhedral and tend to be oriented with their long axes parallel to sub-parallel to bedding. They vary in size from 50 microns up to 0.8 millimetres in length.

The gypsum crystals of the carbonate-free laminae are mostly randomly arranged, but in some specimens their long axes do lie parallel to near parallel to bedding (Fig. V. 38). In the carbonate rich laminae the gypsum crstals are often lenceolate in shape.and tend to be oriented with their long axes perpendicular to near perpendicular to bedding. In some laminea the crystals are lenceolate in shape, but their long axes do lie parallel to near parallel to bedding (Fig. V. 39).

3.2. Mudstone-laminar gypsum cycles, with primary and secondary gypsum

Some of the Mudstone-laminar gypsum cycles are of interest in that both the laminar gypsum rocks and the discoidal 'crystals' of gypsum in the mudstones both contain secondary gypsum after anhydrite as well as primary gypsum. In the laminar gypsum rocks the distribution of the secondary gypsum is patchy (Fig. V. 40., 42), but in the discoidal crystals it usually occupies the central parts of the crystals (Fig. V.41). The ratio of secondary gypsum to unaltered primary gypsum varies from cycle to cycle and almost all intermediates between the two end members can be found.

In thin section, under the microscope, the secondary gypsum is seen to enclose corroded relicts of anhydrite. It is evident from this that parts of the original primary gypsum crystals had been altered to anhydrite, and that this anhydrite was subsequently hydrated to secondary gypsum.

As far as the writer is aware, this is probably the first recorded occurrence of primary gypsum and secondary gypsum within single crystals.

X-ray diffraction analysis has shown that the mudstones comprise dolomite, magnesite, quartz together with minor amounts of feldspars and clay minerals. The ratio of dolomite to magnesite varies considerably from cycle to cycle. Comparison of the x-ray data obtained from 13 samples with the field observations suggests a positive correlation between the ratio of dolomite to magnesite on the one hand, and the ratio of unaltered primary gypsum to secondary gypsum after anhydrite on the other (Fig. V. 43)

3.3. Mudstone-laminar gypsum cycles, with secondary gypsum

In a number of cycles the gypsum is entirely secondary after anhydrite. This applies both to the laminar gypsum units and to the mudstone units. Examples of the laminar secondary gypsum rocks are illustrated in figures V. 44 and 45. Because of the white colour of the secondary gypsum, the individual laminae are more conspicuous than the laminae in the cycles which consist only of primary gypsum. Many of the laminae are undulose. The secondary gypsum in the mudstones tends to be nodular, but discoidal shapes are dominant (Fig. V. 46). Some occur individually, while others form interpenetrant clusters, (Fig. V. 47). The sizes, shapes and arrangements of the masses of secondary gypsum suggest that they were originally crystals of primary gypsum.

Magnesite is the only carbonate mineral present in these cycles, and dolomite appears to be completely absent.

3.4. The formation of dolomite

It has long been suggested that there is a relationship between the process of early or penecontemporaneous dolomitization and the formation of gypsum in carbonate sediments. The relationship appears to have been postulated as early as 1884 by von Marlot (Cayuex, 1935), and strength was given to the argument by the discovery of the association of the dolomite

with gypsum and aragonite in the Recent sediments along the coast of the Qatar, (Wells, 1962).

It is now known that dolomite has formed in association with gypsum in the Recent carbonate sediments (mainly aragonite) of the intertidal and supratidal zones along the Trucial Coast of the Persian Gulf (Curtis et.al., 1963; Shearman, 1963, 1966; Kinsman, 1964, 1969; Illing et.al., 1965; Butler, 1966, 1970; and Bush, 1973 a,b, and other references cited in Purser, 1973), and in Bonaire Island, Dutch West Indies (Deffeyes et.al., 1965; Lucia, 1968). It has also formed in the continental environment of Tuz Golu (Salt Lake), Turkey (Irion and Muller, 1968; Muller and Irion, 1969). In all of these areas the dolomite crystals are usually less than 5 microns across and rarely exceed 20 microns. Most of these occurrences are proto-dolomites. Studies on groundwater chemistry and mineralogy of the associated sediments have shown that, the magnesium to calcium ratio of the brines increases as a result of the precipitation of gypsum and calcium carbonate minerals (principally aragonite); when the ratio reaches sufficiently high levels, the magnesium reacts with the aragonite of the sediment to form dolomite,

In the Mudstone-laminar gypsum cycles of the Bozkir Formation, the dolomite characteristically occurs in association with crystals of early diagenetic primary gypsum which have the discoidal habit. Apart from the non-carbonate constituents, the mudstones are composed entirely of dolomite, i.e. no calcium carbonate minerals are present. The complete absence of calcium carbonate minerals leaves the possibility open that the dolomite may in fact be primary.

It is important to note that in the underlying Kizilirmak Formation, the mudstones which carry crystals of primary gypsum with discoidal habit contain dolomite in addition to calcite and there is a positive relationship between the calcite-dolomite ratio and the number and size of the gypsum

crystals. The dolomite is thought to have been formed by replacement of calcium carbonate concommitant with the formation of the crystals of early diagenetic primary gypsum.

In conclusion, although the early diagenetic replacement origin seems more probable, the lines of available evidence are not sufficient to indicate whether the dolomite of the Bozkir Formation was formed by replacement of former calcium carbonate minerals during the early diagenesis, or whether it was formed by primary precipitation.

3.5. The formation of celestite

In the Recent Coastal sabkhas of the Abu Dhabi, Trucial Coast of the Persian Gulf, celestite has been found to occur as an early diagenetic mineral in association with early diagenetic gypsum and dolomite (Evans and Shearman, 1964; Kinsman, 1964, 1969; and Bush, 1973 a,b). It was suggested by Evans and Shearman (op. cit.) that although some celestite may have been precipitated directly from seawater, much of it is probably the product of the reaction between the strontium released during dolomitization of aragonite and calcite, and sulphate from brines.

In the mudstone-laminar gypsum cycles of the Bozkir Formation, celestite occurs as a minor constituent in the dolomitic mudstones which carry discoidal crystals of primary gypsum. If the dolomite is early diagenetic, then the strontium of the celestite might have been supplied in consequence of dolomitization of former aragonite. If the dolomite was primary then formation of the celestite can only be explained by direct precipitation.

3.6. Alteration of gypsum to anhydrite

The lines of evidence presented in the previous sections of this chapter clearly indicate that in all of the mudstone-laminar gypsum cycles of the Bozkir Formation, the original mineral was gypsum. In most of the cycles, it is preserved unaltered, but in some it was partially or wholly

replaced by anhydrite. In some cycles, the alteration went to completion, in others however, it was only partial. This section is concerned with the change from primary gypsum to anhydrite. The subsequent hydration of anhydrite to secondary gypsum will be discussed in the following chapter.

As it has already been pointed out in Chapter III alteration of gypsum to anhydrite can take place, either during early diagenesis, i.e. while sediments were still in their environments of deposition, or during burial. At depths of between 900 and 1200 metres, gypsum apparently becomes unstable due to increase in rock temperature, and below that depth it alters to anhydrite. In the rocks under discussion the problem is that of when the change from primary gypsum to anhydrite took place.

Throughout the formation, cycles with primary gypsum alternate randomly with those which carry both primary and secondary gypsum or secondary gypsum only. In a few cycles, there are lateral transitions from primary gypsum into a mixture of primary and secondary gypsum, or from a combination of primary and secondary gypsum into secondary gypsum only.

The fact that crystals of unaltered primary gypsum are preserved at outcrop suggests that the rocks had never been sufficiently deeply buried to take them out of the stability field of gypsum with respect to temperature.

These lines of evidence suggest that the primary gypsum was altered to anhydrite during early diagenesis: i.e. while the sediments were still in their environment of deposition and before deposition of the next cycle.

Alteration of gypsum to anhydrite is taking place at the present day in the coastal sabkhas of Abu Dhabi (Butler, 1969, 1970; Kinsman, 1969; Park, 1969; and Bush, 1973, a) and in the Clayton Playa, Nevada (Moiola and Glover, 1965). All gradations from unaltered crystals of primary gypsum to anhydrite pseudomorphs have been found in the coastal sabkhas of Abu Dhabi by Bush (op. cit).

On the basis of experimental studies[1], Hardie (1967) concluded that the change from gypsum to anhydrite is promoted by a decrease in the activity of the interstitial brines. Studies of the groundwater chemistry of the coastal sabkhas of Abu Dhabi have shown that the conditions under which primary gypsum changes to anhydrite at the present day are in accord with the experimental results of Hardie (op. cit) (Kinsman, 1966; Bush, 1970, a). Bush (op. cit) reported that 'the activity of the water has been reduced by the addition of sodium chloride in the Abu Dhabi Sabkha' (p.273).

Three possible mechanisms for the alteration of gypsum to anhydrite in contact with brines were proposed by Butler (1970). (1) Direct dehydration to anhydrite (loss of structural water). (2) Stepwise dehydration through intermediate bassanite series and (3) A solution precipitation process. Butler (op. cit) found rinds of bassanite in the solution cavities of the gypsum crystals which occur in association with anhydrite in the Abu Dhabi Sabkhas and he suggested that in some instances dehydration of gypsum to anhydrite is a step-wise process. Bassanite has similarly been found associated with gypsum and anhydrite from Clayton Playa (moiola and Glover, 1961) and Baja California (Butler, 1970). Experimental studies by Hardie (1967) and Zen (1965) have also shown that sodium chloride solutions promote step-wise dehydration mechanism.

On the basis of strontium contents of gypsum and anhydrite formed by dehydration Butler (op. cit) concluded that '..... the process of gypsum dehydration to anhydrite is essentially a solution-precipitation process' (p. 149).

In the mudstone laminar gypsum cycles of the Bozkir Formation, no evidence has been found which would indicate that the dehydration of primary gypsum to anhydrite was a step-wise process. It is thought that the dehydration was probably a dissolution-precipitation process, i.e. dissolution

[1]Other experimental works on the transition temperature will be summarized in chapter VI, where the late hydration of anhydrite to secondary gypsum is considered.

of gypsum molecule by molecule with concommitant precipitation of calcium and sulphate ions to form anhydrite. It is suggested that in some cycles, the environment dried out following deposition and the formation of early diagenetic primary gypsum, but that the residual brines remained as groundwater in both the mudstones and the laminar gypsum. The activity of these residual brines became progressively reduced and this promoted the alteration of primary gypsum to anhydrite. In some cycles, the change went to completion, in others it was only partial.

3.7. The formation of magnesite

The following observations must be borne in mind, before any attempt is made to explain the formation of magnesite in the mudstone-laminar gypsum cycles of the Bozkir Formation. These are:-

1. Where the discoidal crystals of primary gypsum are preserved unaltered, the associated mudstones are characterized by dolomite only.
2. Where the primary gypsum was wholly altered to anhydrite, the associated mudstones contain magnesite only.
3. Where the primary gypsum was only in part altered to anhydrite, the associated mudstones contain both dolomite and magnesite.
4. In the latter, there appears to be a direct relationship between the extent of alteration of the primary gypsum and the ratio of magnesite to dolomite.

These lines of evidence suggest that the magnesite was formed by the replacement or alteration of dolomite.

Experimental studies have shown that the reaction between the magnesium rich brines and dolomite to produce magnesite is enhanced by increase in ionic concentration i.e. lowering of the activity of brine (Sayles and Fyfe, 1973). As it has already been pointed out, the change from gypsum to anhydrite takes place under similar conditions (Hardie,1967).

Thus the liklihood is that the change from gypsum to anhydrite was accompanied by 'replacement' of dolomite by magnesite.

In the coastal sabkha of Abu Dhabi, it has been observed that magnesite characteristically occur in association with anhydrite which is believed to have formed by alteration of gypsum, whereas unaltered gypsum crystals are usually associated with dolomite (P. Bush, per. com.).

V. 4 EARLY DIAGENETIC GYPSUM AFTER ANHYDRITE

In the Kayayol Section (Fig. V. 10), the mudstone units of two mudstone-laminar gypsum cycles carry gypsum crystals which are different in habit from those normally encountered. These crystals are prismatic or tabular parallel to 010, and many are swallow-tails. Etch-pit studies of the twinned crystals have shown that they are twinned on the 100 law. Individual crystals range in size from less than a millimetre up to 15 millimetres in length. Some of these crystals contain corroded relicts of anhydrite.

The crystals are not uniformly distributed in the mudstones, but occur as groups of a few, a few tens or a few hundreds of crystals (fig. V. 48).

X-ray diffraction analysis have shown that the associated mudstones are composed mainly of dolomite, celestite (figs. V.49,a and b:) and quartz. Detectable amounts of feldspars and clay minerals are also present.

Shearman (1966), in describing the early diagenetic evaporites of the coastal sabkhas of Abu Dhabi, noted that on landward side, anhydrite nodules locally pass into gypsum. This gypsum is characteristically prismatic or tabular on 010 and is commonly twinned on the swallow-tail law. They contain corroded relicts of anhydrite which suggest that the gypsum crystals were formed by hydration of anhydrite probably due to influves of less saline waters. It is suggested that those of the Bozkir Formation formed in a

similar way.

The associated mudstones are dolomitic. This is of interest because in the other cycles magnesite is associated with former anhydrite. Thus the possibility arises that the early diagenetic hydration of anhydrite to gypsum may also have led to replacement of magnesite by dolomite.

In the coastal sabkhas of Abu Dhabi, significant amounts of celestite have been found to occur in association with the crystals of early diagenetic gypsum after anhydrite (Butler, 1970). Strontium of this celestite was thought to have been released from the anhydrite in the course of hydration to early diagenetic gypsum (Butler, 1970). Similarly, the celestite present in the mudstones of the Bozkir Formation, which carry early diagenetic gypsum after anhydrite might have been formed in the same way.

V. 5. PELLETOID GRAINSTONES CEMENTED BY POIKILITIC GYPSUM

In some mudstone-laminar gypsum cycles, the mudstone units contain thin (5 to 20 centimetres), very pale orange (10 YR 8/2) coloured carbonate sands which are lustre-mottled by gypsum.

In thin section, they are found to be pelletoid grainstones cemented by crystals of poikilitic gypsum, up to several centimetres across (Fig. V. 50). The pelletoids (Milliman, 1974) generally float in the gypsum cement, but some are in contact with one another. All the pelletoids have a fringe of first phase calcite cement (Fig. V. 51). In some samples only ghosts of the pelletoids remain and the gypsum cement appears to have replaced them.

In some thin sections, the gypsum was seen to carry corroded relicts of anhydrite. The presence of the anhydrite relicts suggests that the gypsum cement is secondary after anhydrite. In any one gypsum crystal all the anhydrite relicts go into extinction simultaneously. This suggests that the former anhydrite was very coarsely crystalline and that the

replacement took place on a piecemeal basis. It has already been noted that some of the pelletoids are partially replaced by the poikilitic gypsum cement: this suggests that the poikilitic secondary gypsum cement was originally replacement anhydrite.

V. 6. SATIN-SPAR VEINS

In the lowermost 40-60 metres of the formation the mudstone-laminar gypsum rocks contain horizontal to sub-horizontal veins of satin-spar gypsum. The veins which occur in the mudstones, range in thickness from 0.5 up to 7 cms. They are not continuous in lateral extent, but usually pinch out within short distances depending upon their thicknesses. Some of the thicker veins appear to be multiple, and an excellent example can be seen at Kuskoyasi, where one of the veins which is 7 cms in thickness is composed of 8 sub-veins (Figs. V. 52 and 53).

In the laminar secondary gypsum rocks, the veins are generally thinner than those in the mudstones. They range in thickness from a millimetre up to 1 cm. A positive relationship appears to exist between the thickness of the laminar secondary gypsum units and the number and thicknesses of the veins present.

A few sub-vertical veins of satin-spar are also present in some of the mudstone units at Buyuktepe and Acicay. These are closely similar to those of the Bayindir Formation, i.e. the fibres are vertical and oblique to the walls of the veins.

V. 7. PALAEOGEOGRAPHY

The first question which arises is that of the source of the sulphate ions necessary to form the deposits of calcium sulphate in the Bozkir Formation. The mineral composition of the evaporites of the formation, i.e. gypsum, celestite, dolomite and magnesite, is consistent with an

origin from marine derived brines, but examples of wholly continental playa evaporites which have the same mineral assemblage are well known. Stratigraphical, palaeontological and sedimentological evidence suggests that the deposition of the formation took place in a continental environment. Two possibilities come to mind: (1) that the formation was deposited in an intermontane playa lake complex and that the sulphate ions were derived from within the catchment area or (2) that it accumulated on landward side of a wide coastal plain and that the sulphate ions were marine derived.

Despite the considerable research which has been carried out on Recent sediments, relatively very little attention has been directed to present day playa lake environments. Published works are mostly geomorphological in approach and only a few are concerned with the sediments and modes of early diagenesis (e.g. Jones, 1965; Irion and Muller, 1968; Kinsman, 1969; and Muller and Irion, 1969). However it is possible to see from these studies that playas are characterized by three main sub-environments of deposition. These are:- (i) a peripheral fluviatile environment, built up by outwash from the surrounding mountains; (ii) a mudflat environment; and (iii) a central lacustrine environment.

Descriptions of ancient playa deposits are also rare in the geologic literature. The Green River Formation is probably the best known example. Although, this formation was considered by early workers to have been formed in a deep-water lake. Recent studies have challenged this interpretation and have demonstrated that it was deposited in a playa-lake complex (Wolfbouer, 1971, 1973; Eugster and Surdam, 1973; Eugster and Hardie, 1975; and Surdam and Wolfbouer, 1975). The lacustrine facies is represented by oil shales and deposits of trona, the mudflat facies is

mainly carbonate mud and the fluviatile or marginal facies is characterized by sandstones and siltstones (Surdam and Wolfbouer, 1975).

In the Bozkir Formation the mudstones and laminar gypsum rocks show evidence which suggests that they were deposited subaquously under standing bodies of water of shallow depth; but that the environment dried out periodically and became exposed subar e.ally. These rocks are interpreted as the mudflat and lacustrine facies.

The formation appears to interfinger with the redbeds of the Kizilirmak Formation in the west, and a similar relationship appears to exist around the town if Iskilip about 20 kms to the north of the study area. The Kizilirmak Redbeds are interpreted as the fluviatile facies.

The Bozkir & Kizilirmak Formations as presently found represnt only one half of the intermontane basin complex, because the other half, i.e. the south and east sides, having been removed by uplift and erosion. Because of this limitation, there is the alternative interpretation, that deposition took place on the landward side of a wide coastal plain complex.

If the former is the case, the source of sulphate could have been the evaporites of the pre-existing Bayindir Formation. If the latter is the case, then the sulphate was marine derived.

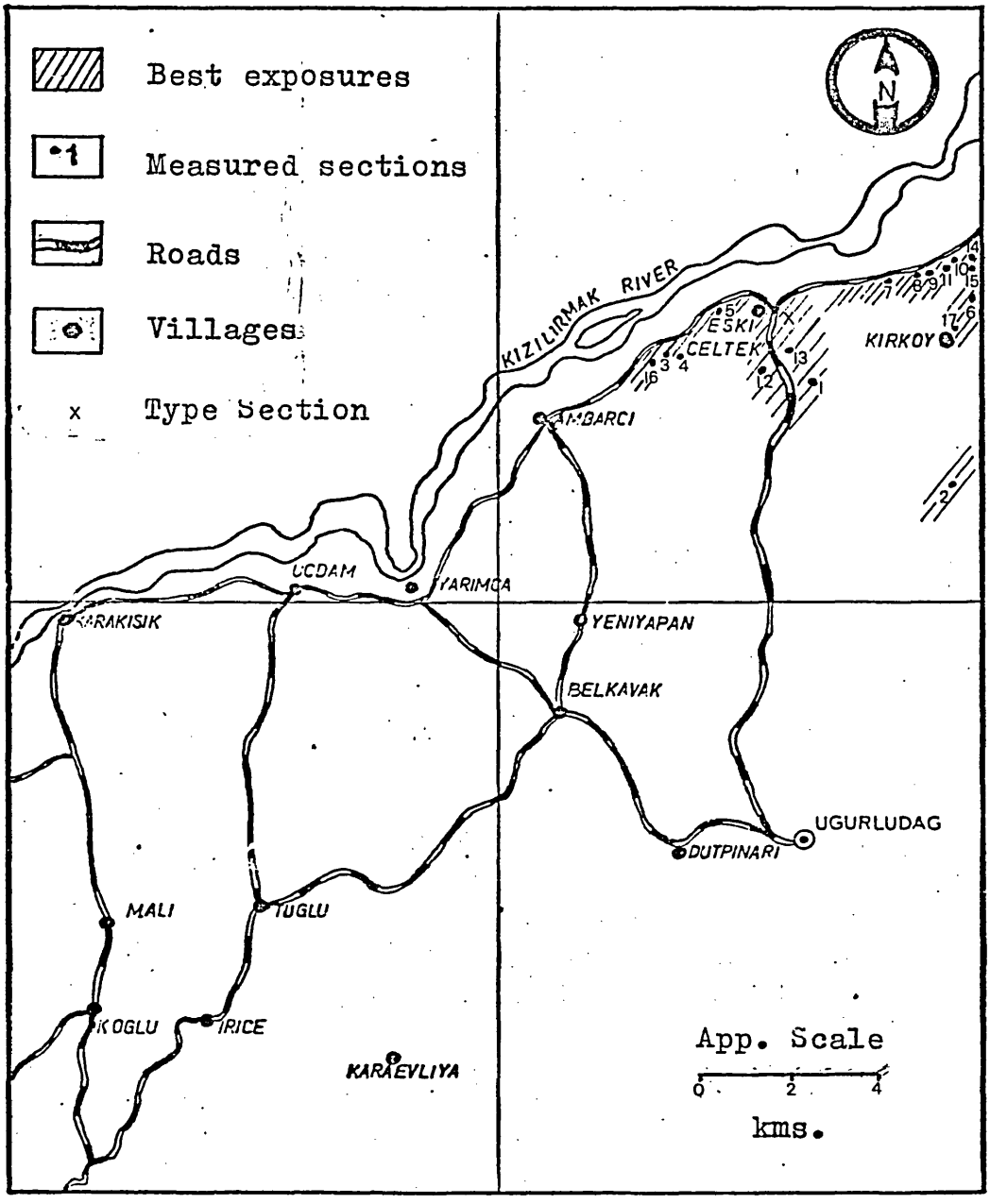


FIG. V.1 Schematic map of the study area showing best-exposed outcrops and the locations of measured sections of the Bozkir Formation.

SECTION No.	SECTION NAME	LOCATION	THICKNESS(Metres)	STRATIGRAPHIC POSITION
1	ACIDERE	Acidere valley,3 kms to the south of the village of Eski Celtek (88-89),(24-25)	5.00	UPPER PART
2	ACIOZ	Acioz Dere Valley,(86-87),(15-16)	17.50	LOWER PART
3	AMBARTEPE 1	Ambartepe,4 kms to the west of the village of Eski Celtek,(89-90); (20-21)	24.00	UPPER PART
4	AMBARTEPE 2	" " "	14.00	UPPER PART
5	BESIKTEPE	Besiktepe,1 km to the west of the village of Eski Celtek,roadside exposure,(90-91);(19-20)	6.00	LOWER PART
6	GUYDUMDERE	Guydumdere valley,2 kms NE of the village of Kirkoy,(91-92);(26-27)	59.50	LOWER PART
7	KAYAYOL SIRTI	Northern flank of Kayayol Sirti, Kirkoy road,(92-93);(24-25)	15.00	LOWER PART
8	KIZLARCUKURU 1	Kizlarcukuru Mevkii,1 km E of the Kayayol Sirti Section(92-93)(25-26)	11.00	LOWER PART
9	KIZLARCUKURU 2	" " "	6.00	LOWER PART
10	KUMCELTEK 1	Iskilip-Ugurludag Road,1.5 kms to the south of the village of Kum-celtigi,(92-93);(26-27)	6.00	UPPER PART
11	KUMCELTEK 2	" " "	61.00	LOWER PART
12	SARPBASI SIRTI	Sarpbasi Sirti,2 kms to the south of the village of Eskiceltek (87-88);(22-23)	30.50	LOWER PART
13	SEKILER SIRTI	Western flank of Sekiler Sirti, 1 km S of the type Section (89-90);(23-24)	8.80	LOWER PART
14	TOZLUBURUN	Guydumdere valley,2 kms NE of the Guydumdere Section,(92-93);(26-27)	10.00	UPPER PART
15	YAZITARLA	" " "	10.50	UPPER PART
16	TUZLANINTEPE	Northern slope of Tuzlanintepe, 1.5 kms west of the Ambartepe 1 Section,(89-90);(19-20)	10.30	UPPER PART
17	KIRKOY	The village of Kirkoy	28.50	LOWER PART

FIG. V.2 Thicknesses,locations and stratigraphic positions of the reference sections measured from the Bozkir Formation.

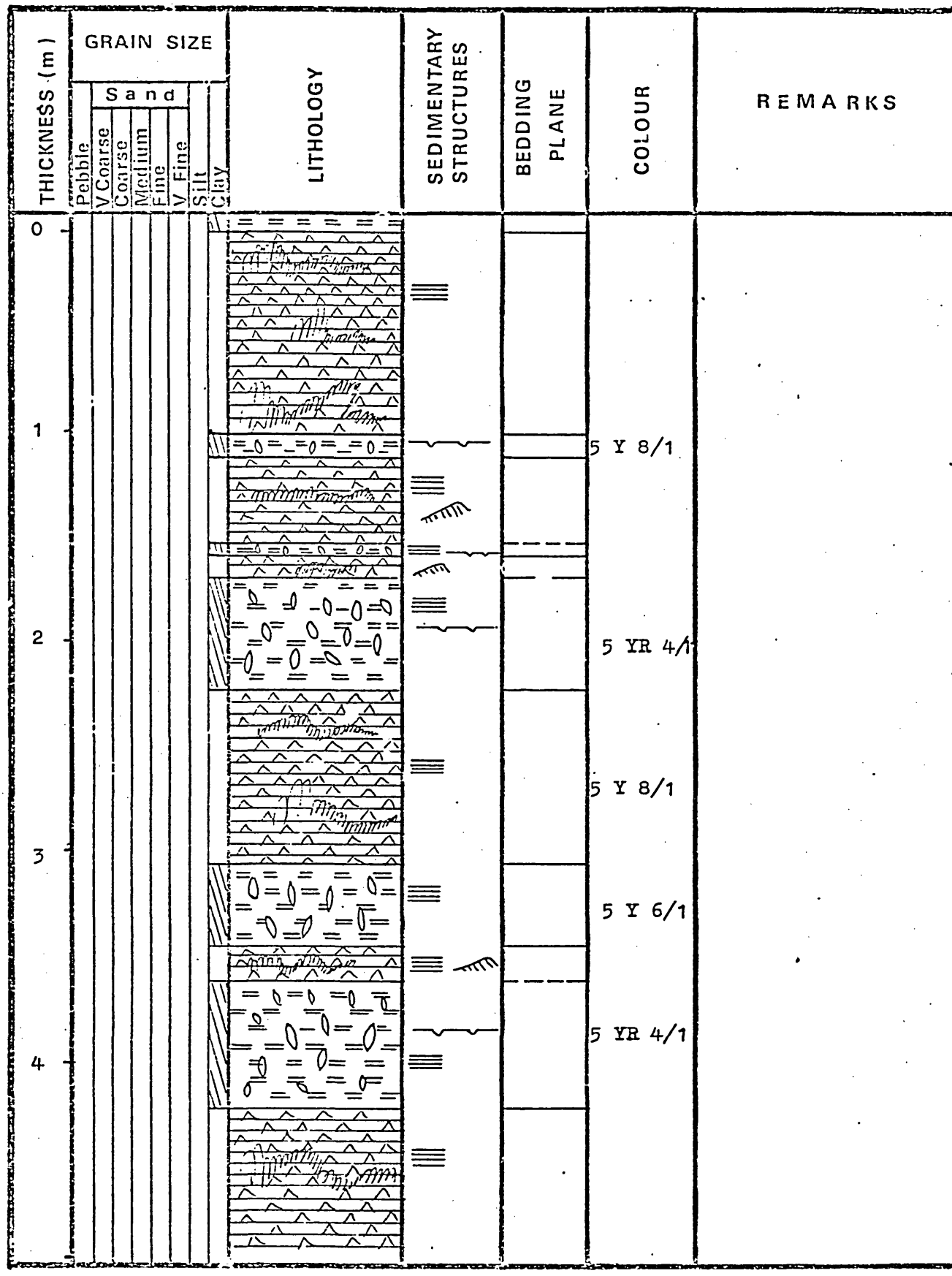


FIG. V.3 The Acidere Section.

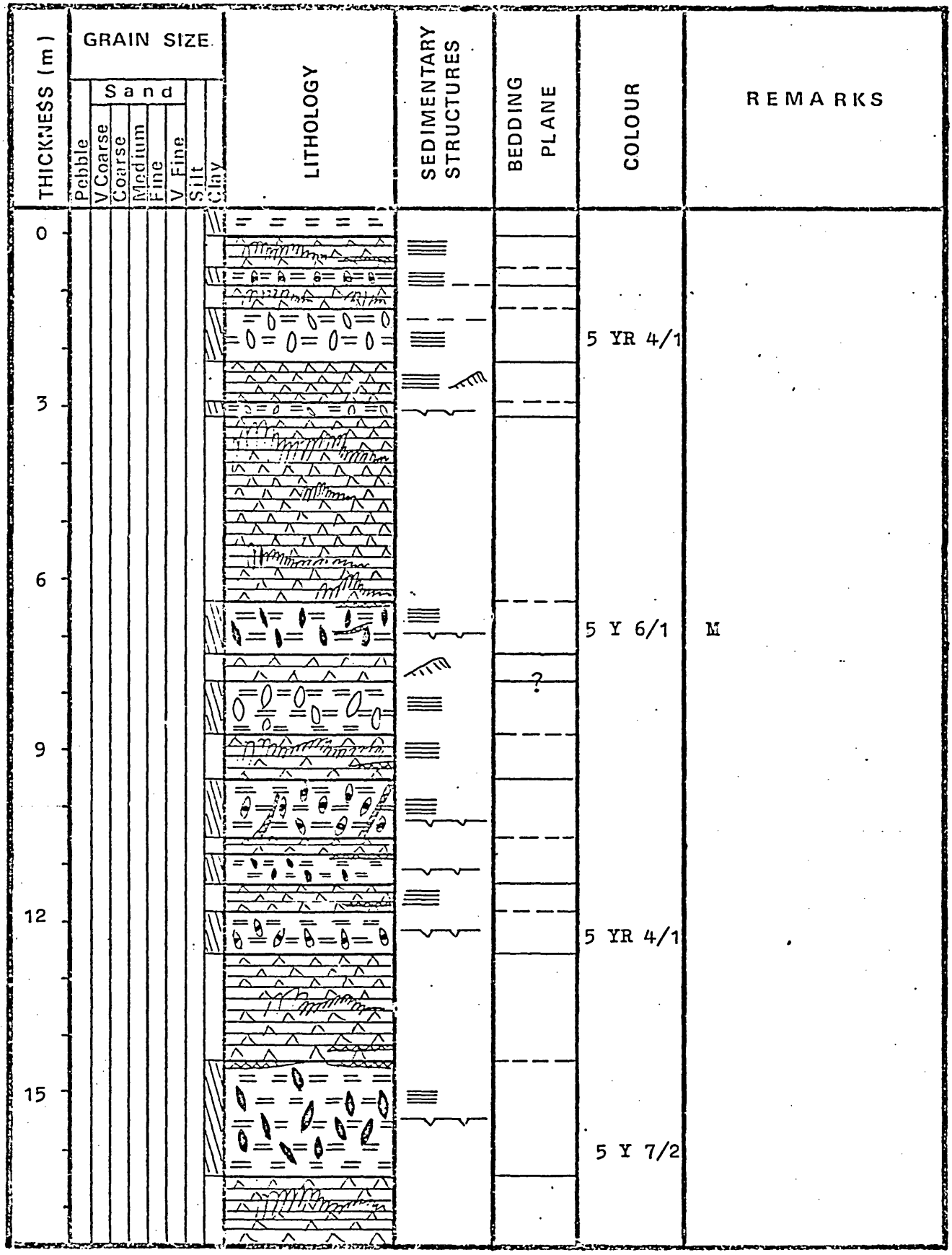


FIG. V.4 The Acioz Section.

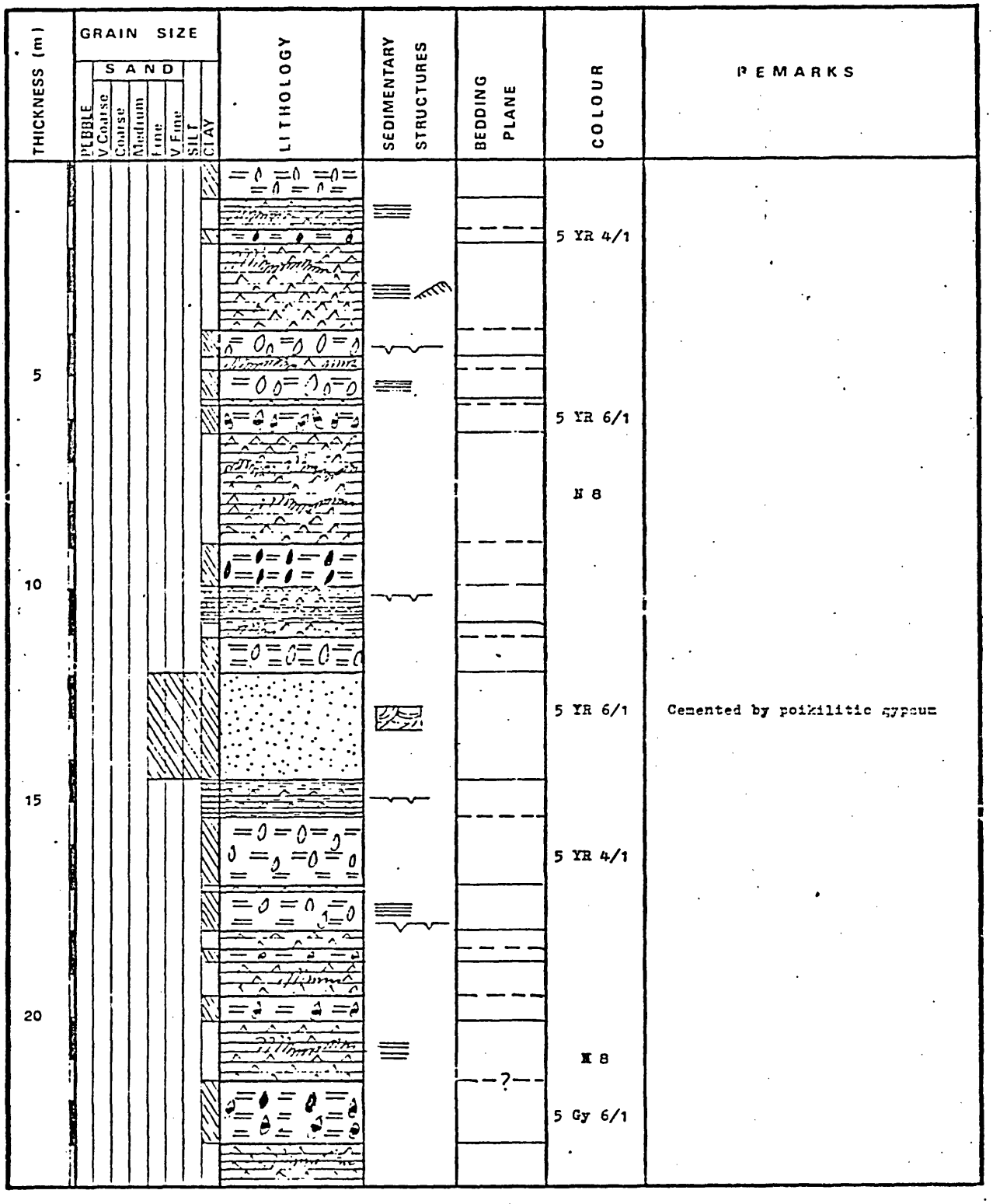


FIG. V.5 The Ambartepe I Section.

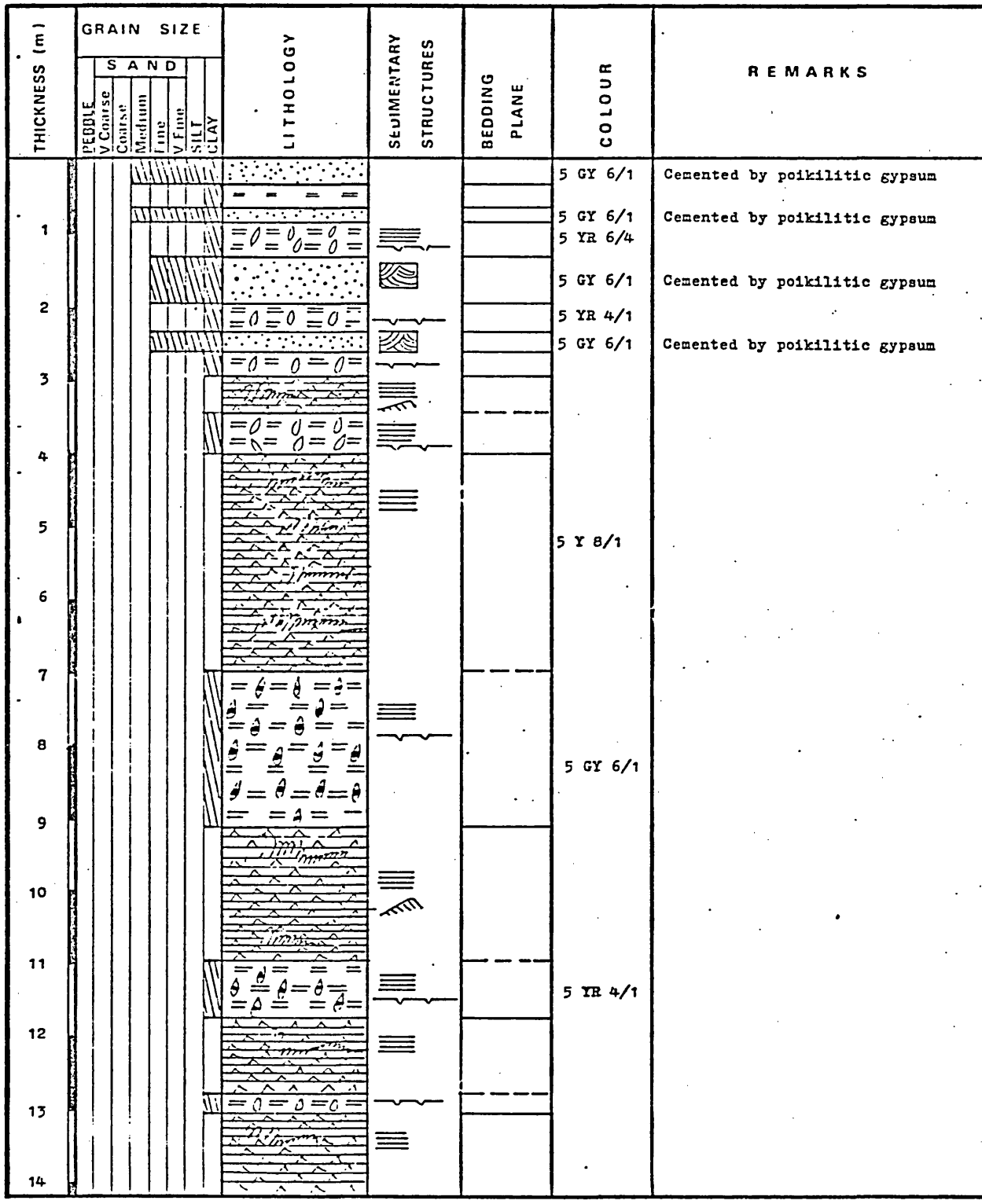


FIG. V.6 The Ambartepe II Section.

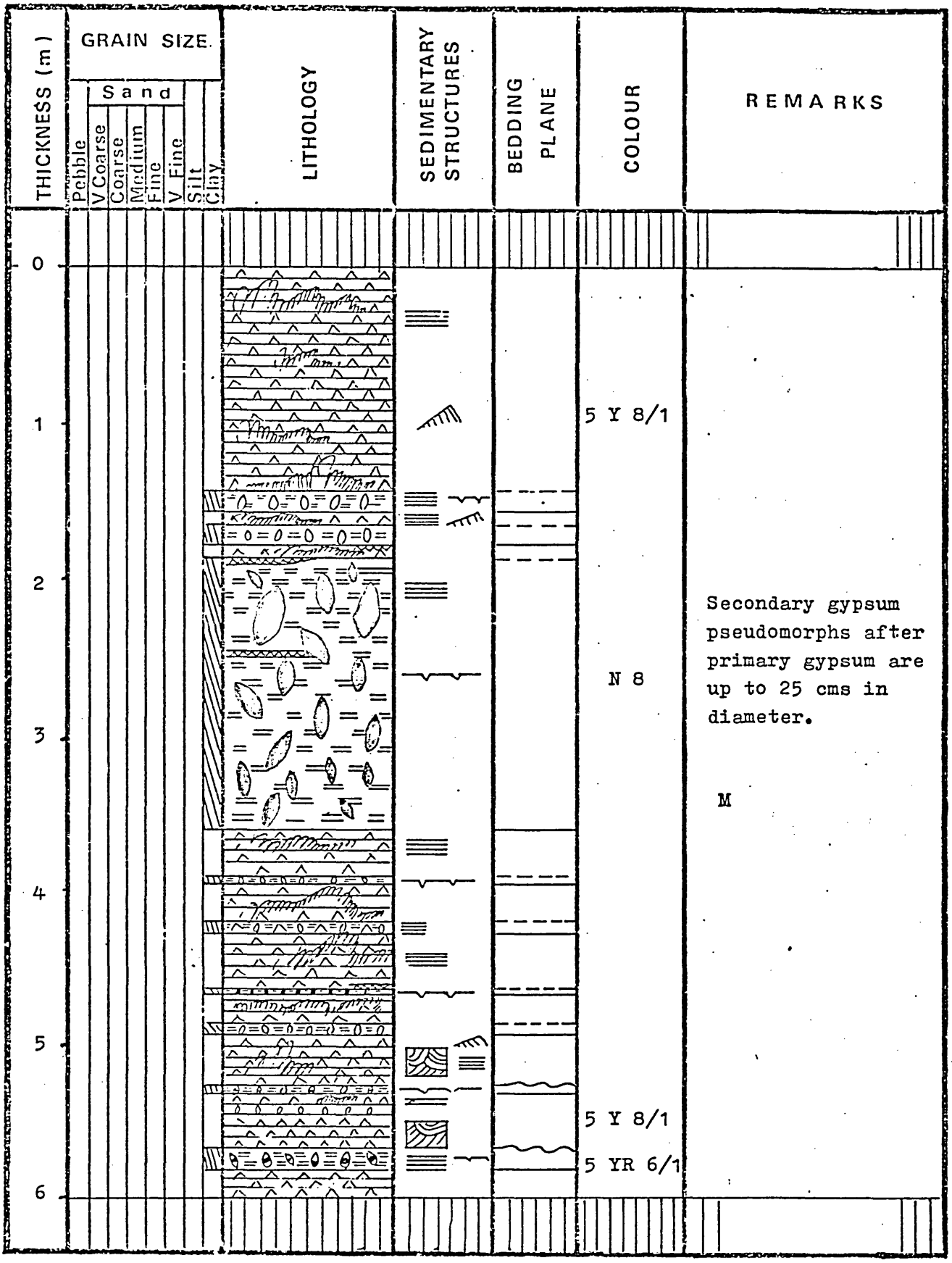
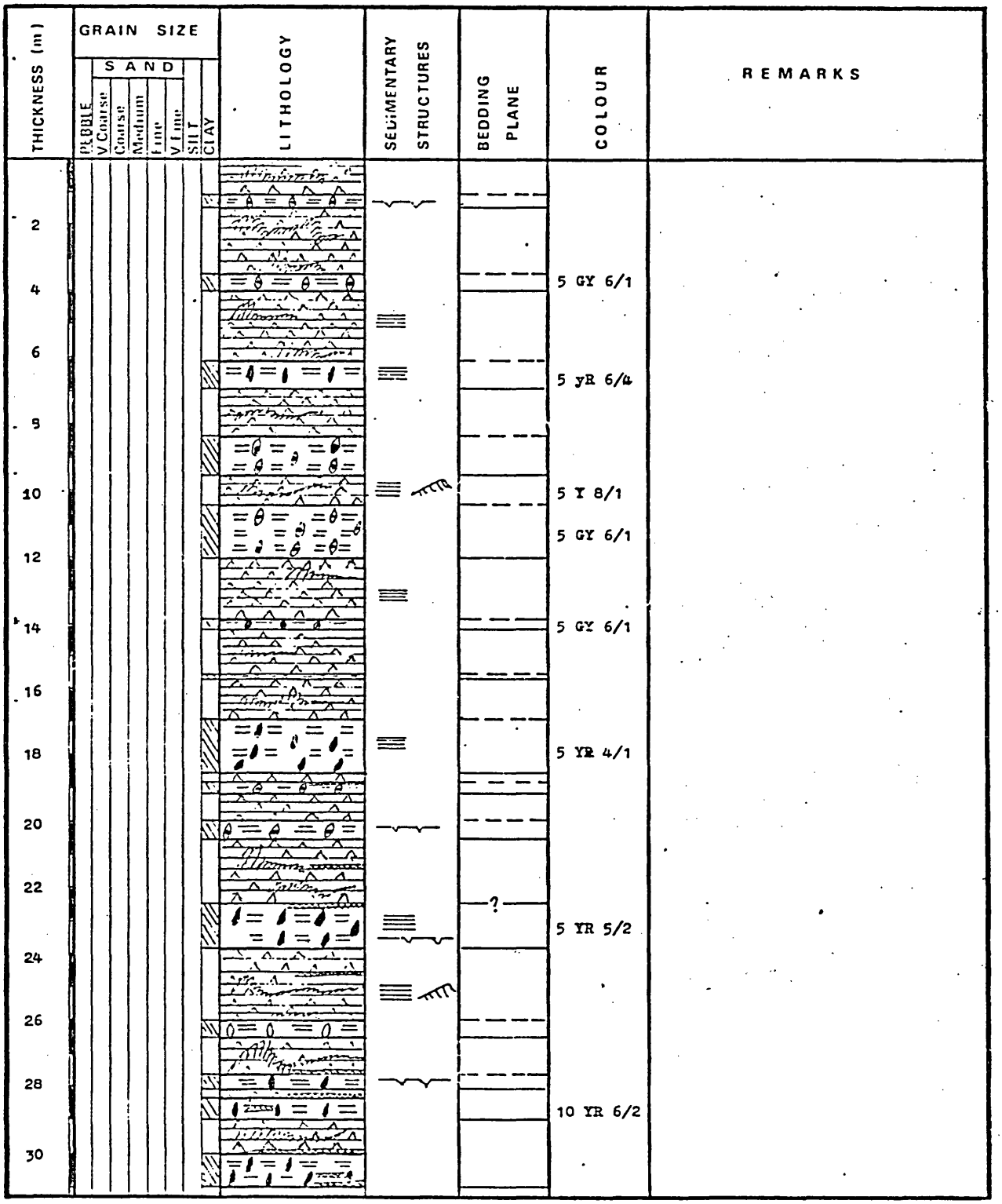


FIG. V.7 The Besiktepe Section.


THICKNESS (m)
GRAIN SIZE
SAND
PEBBLE
V Coarse
Coarse
Medium
Fine
V Fine
SILT
CLAY
LITHOLOGY
SEDIMENTARY STRUCTURES
BEDDING PLANE
COLOUR
REMARKS
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
5 GY 6/1
5 yR 6/4
5 Y 8/1
5 GY 6/1
5 GY 6/1
5 YR 4/1
?
5 YR 5/2
10 YR 6/2

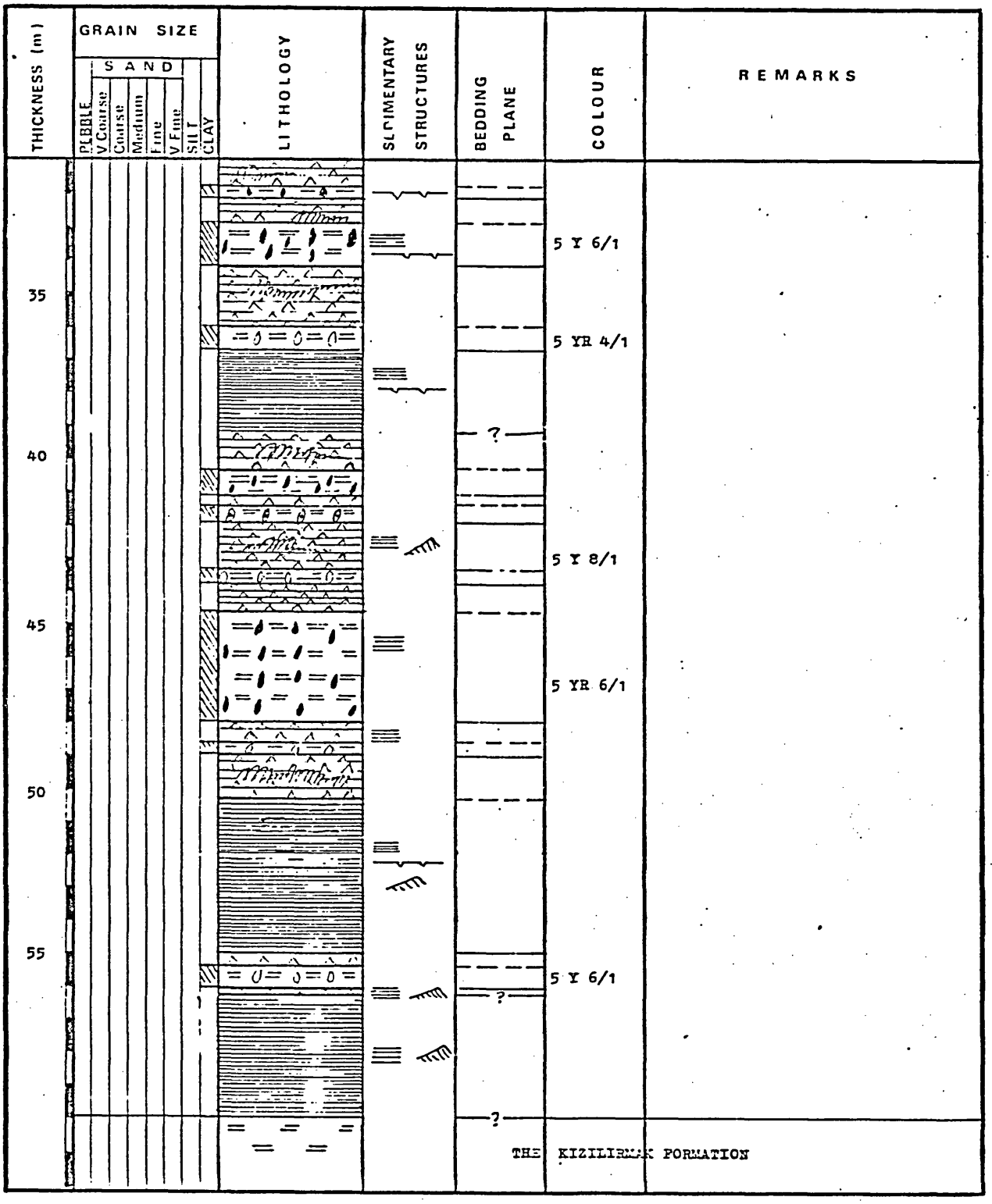


FIG. V.8 The Guydumdere Section.

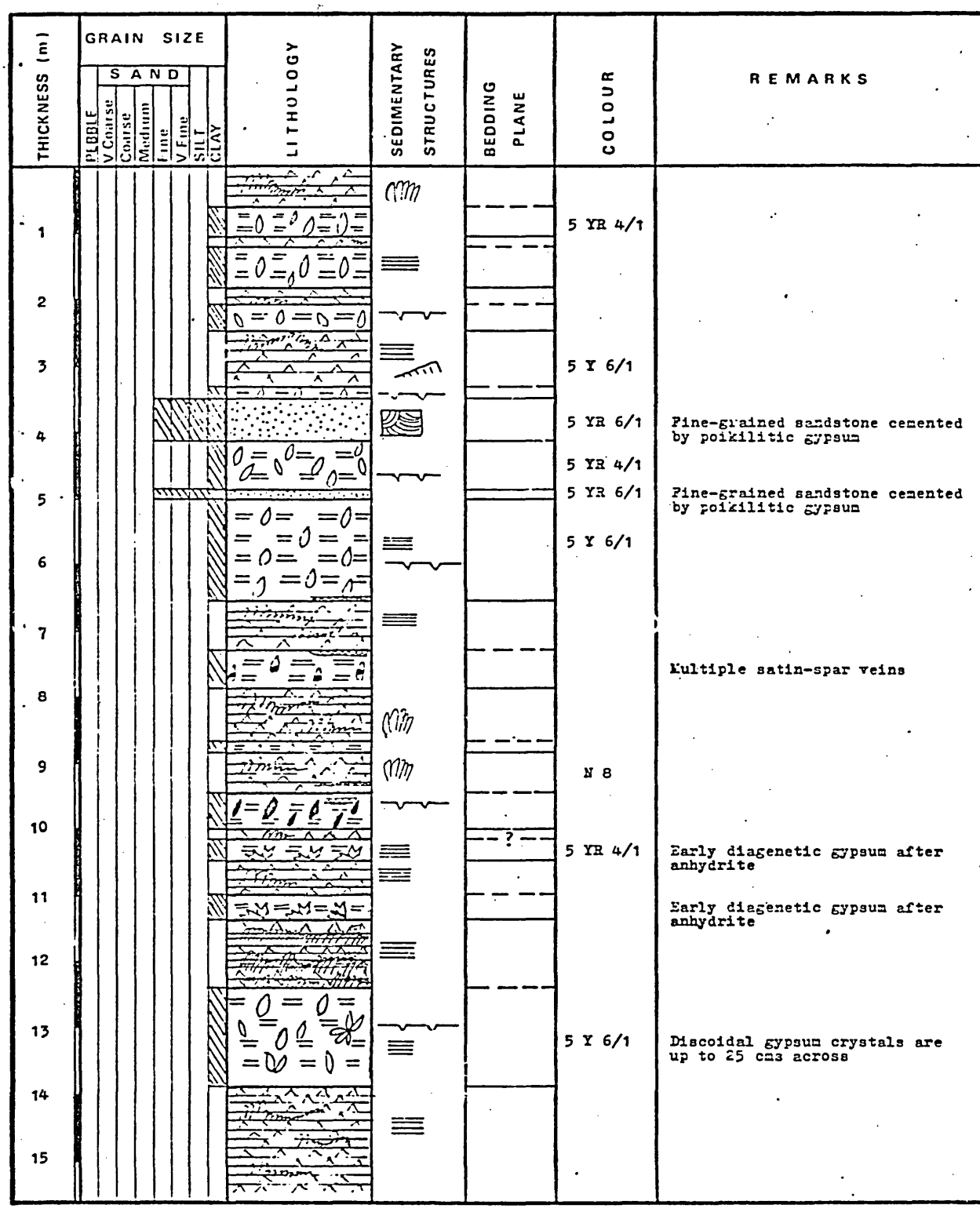


FIG. V.9 The Kayayol Sirti Section.

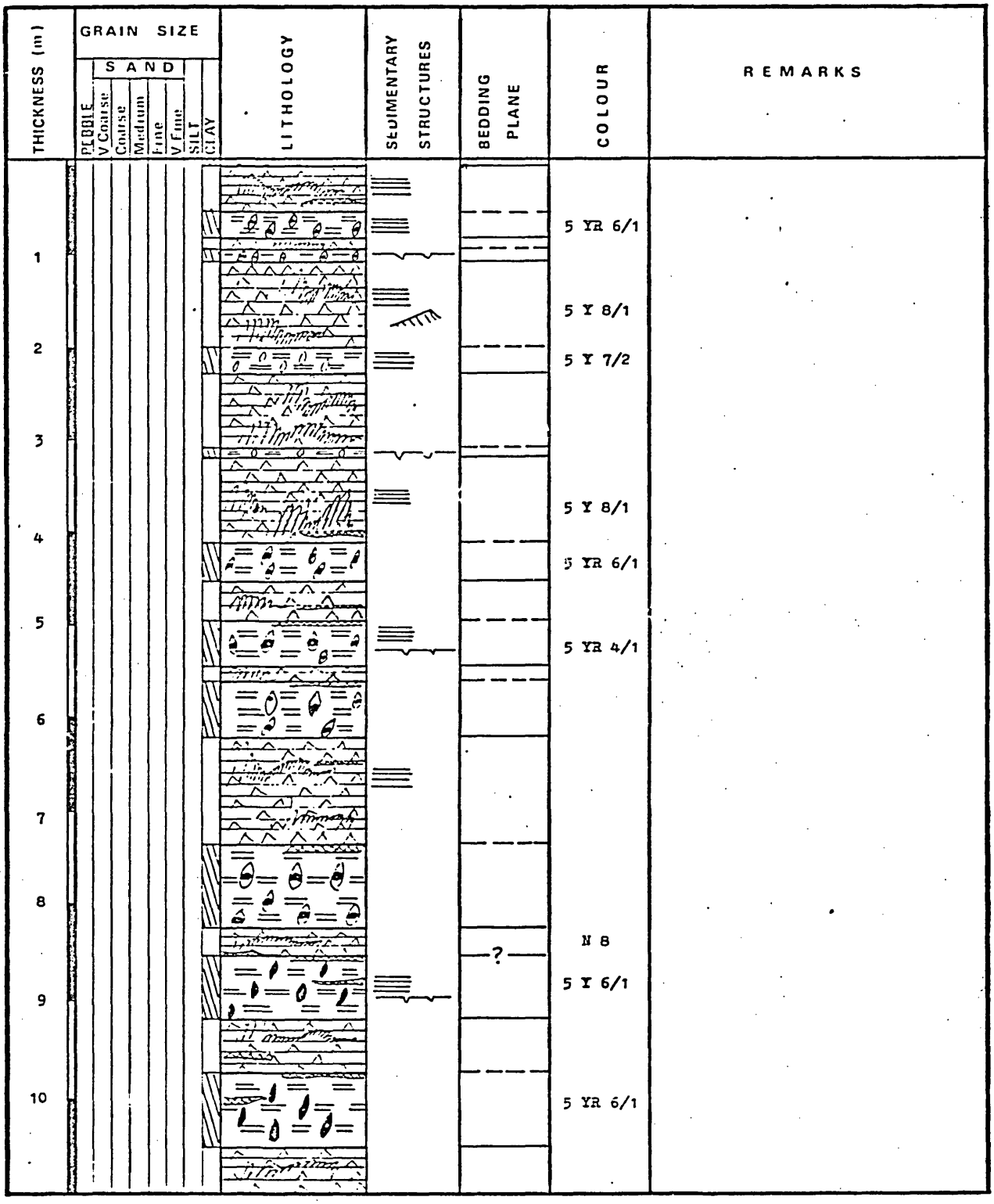


FIG. V.10 The Kizlarcukuru I Section.

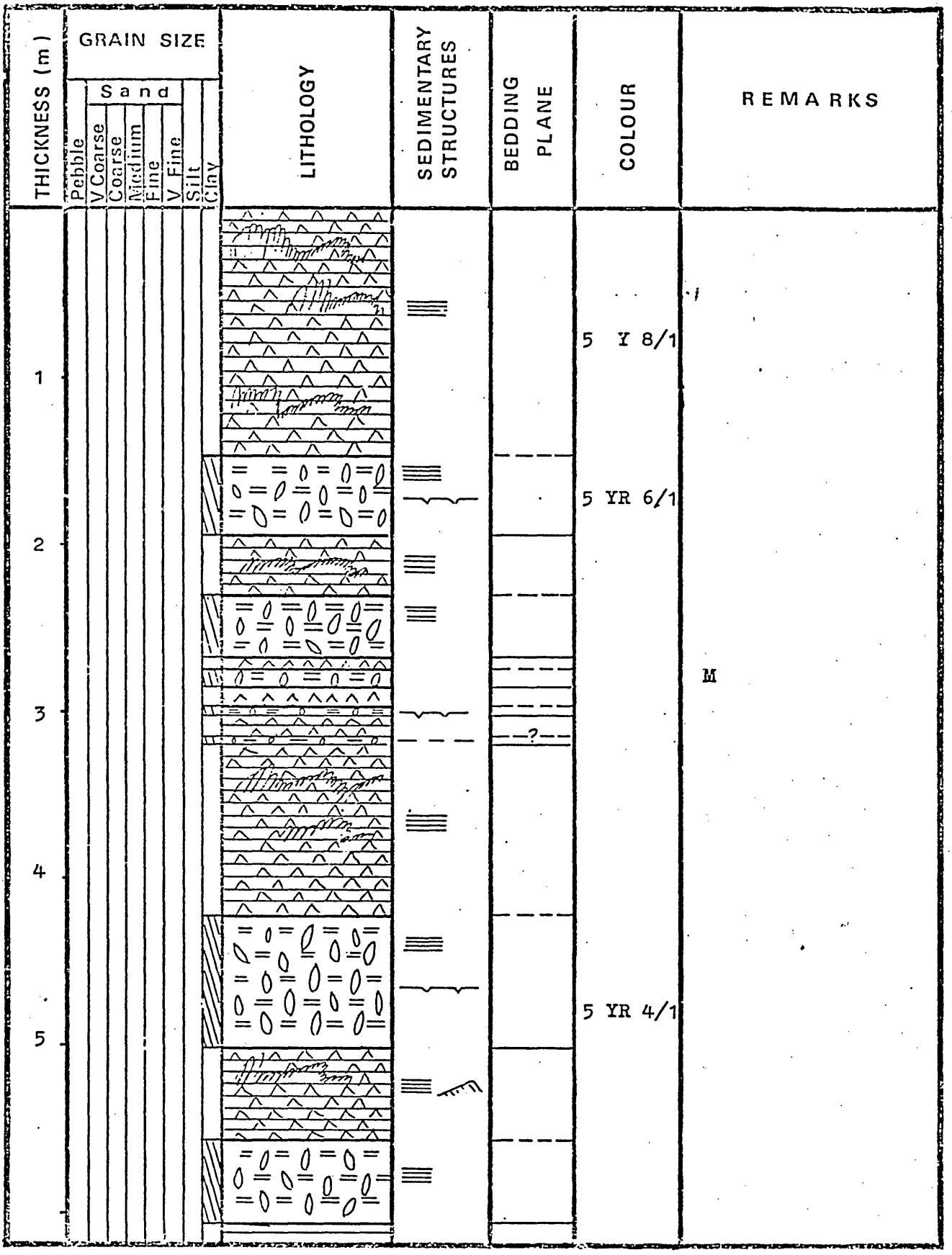
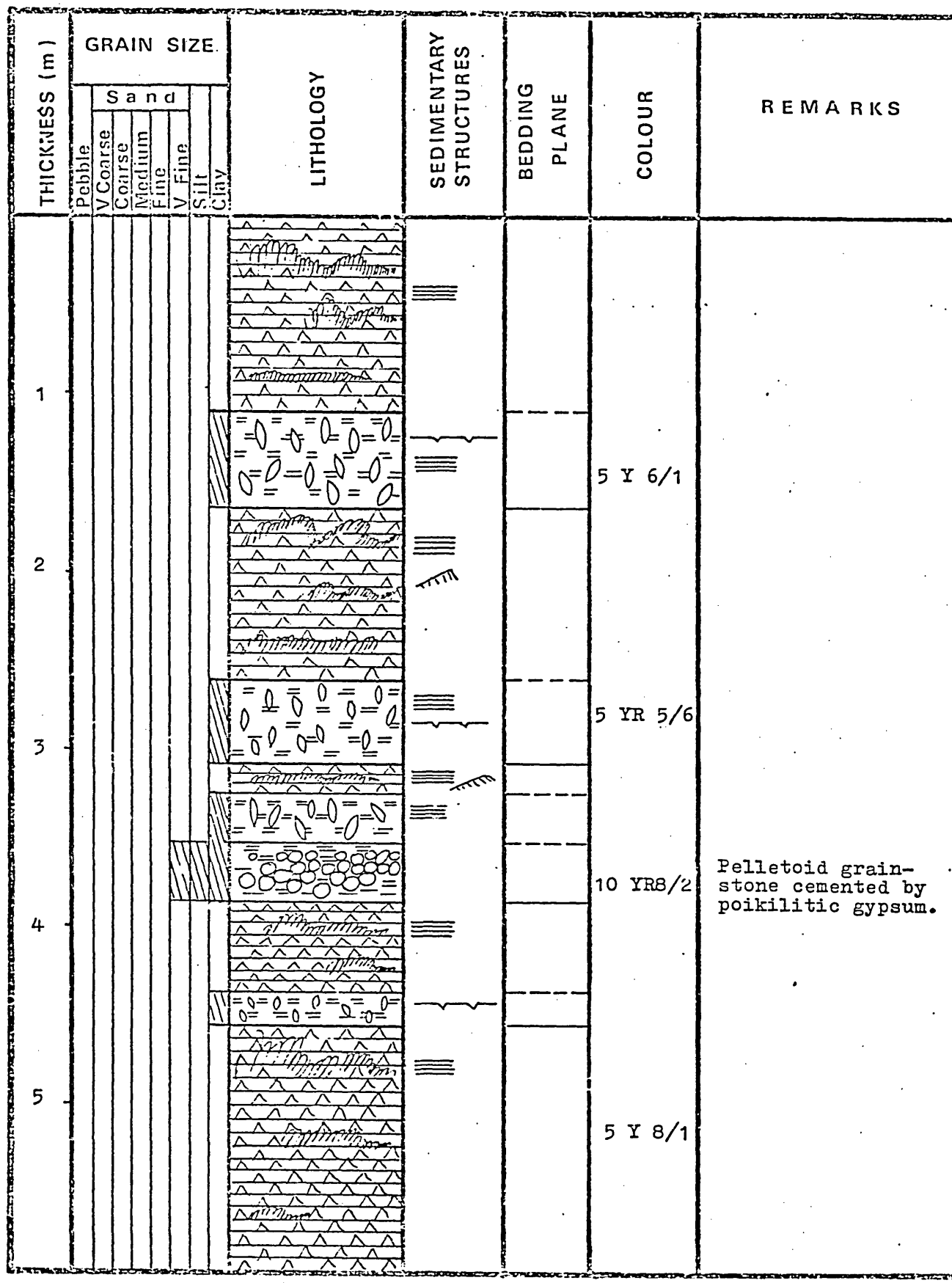
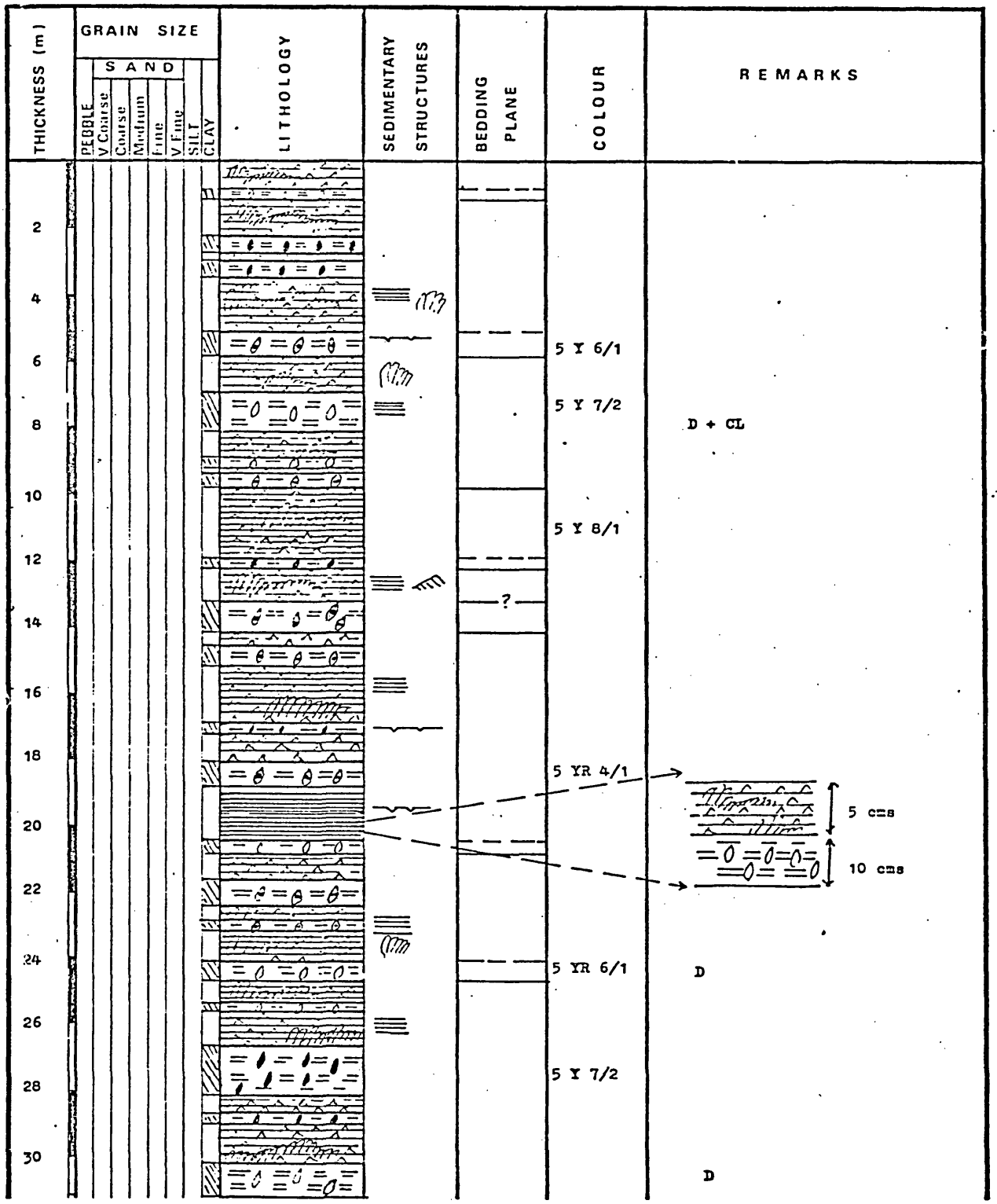


FIG. V.11 The Kizlarcukuru II Section.



FIG, V.12 The Kumceltek I Section.


THICKNESS (m)
GRAIN SIZE
SAND
PEBBLE
V.Coarse
Coarse
Medium
Fine
V.Fine
SILT
CLAY
LITHOLOGY
SEDIMENTARY STRUCTURES
BEDDING PLANE
COLOUR
REMARKS
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
5 Y 6/1
5 Y 7/2
D + CL
5 Y 8/1
?
5 YR 4/1
5 cms
10 cms
5 YR 6/1
D
5 Y 7/2
D

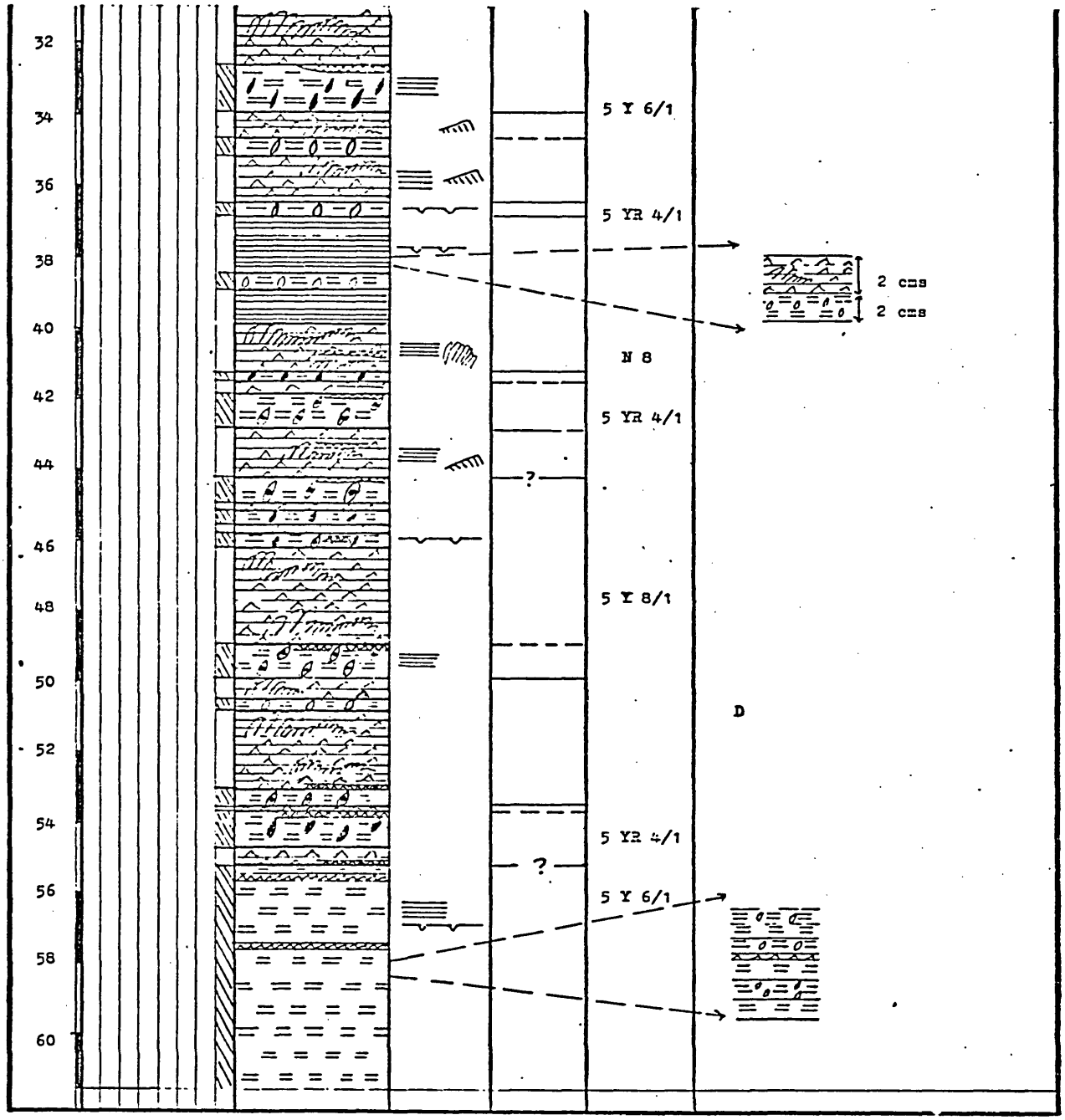


FIG. V.13 The Kumceltek II Section.

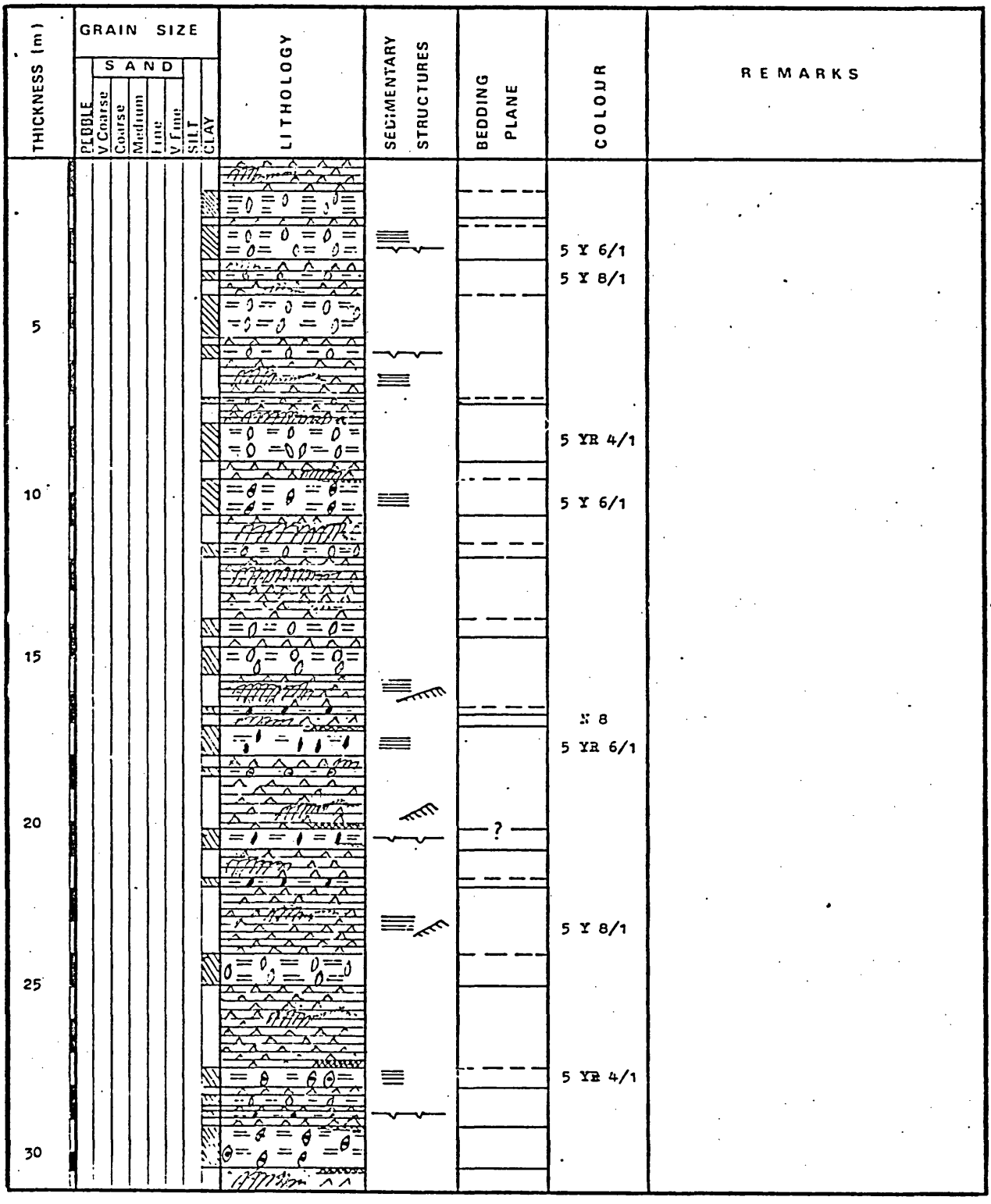


FIG. V.14 The Sarpbasi Sirti Section.

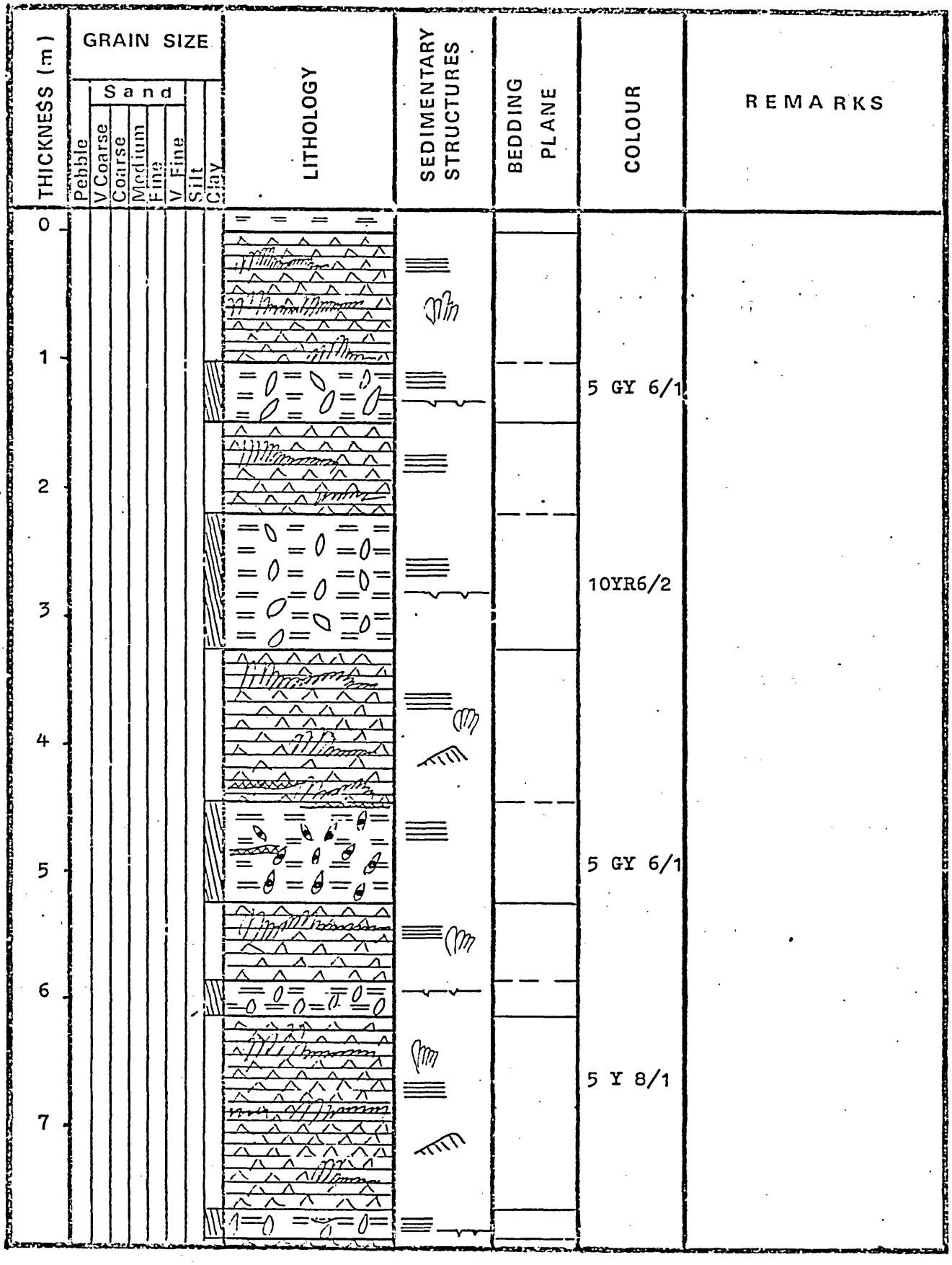


FIG. V.15 The Sekiler Sirti Section.

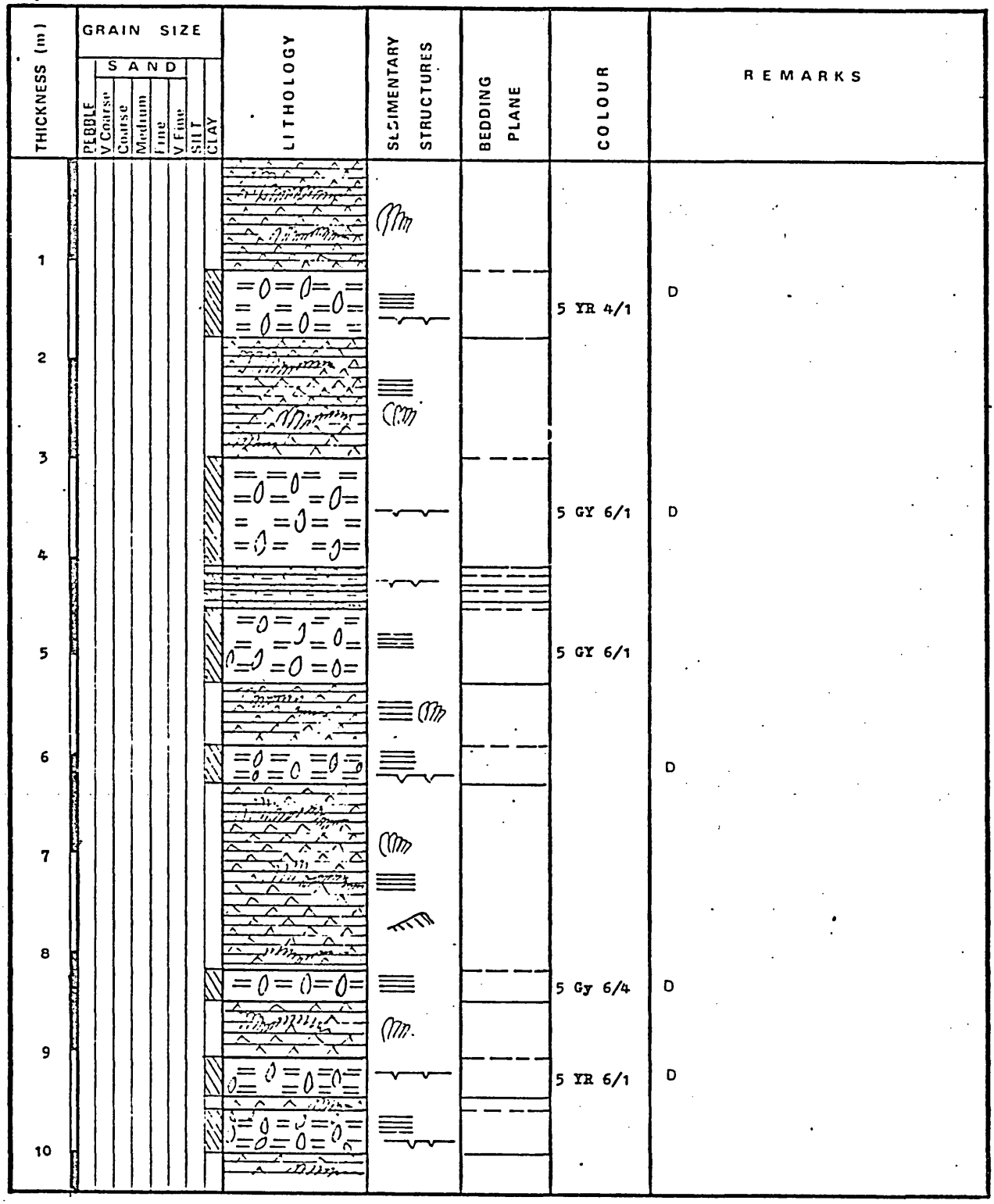


FIG. V.16 The Tozluburun Section.

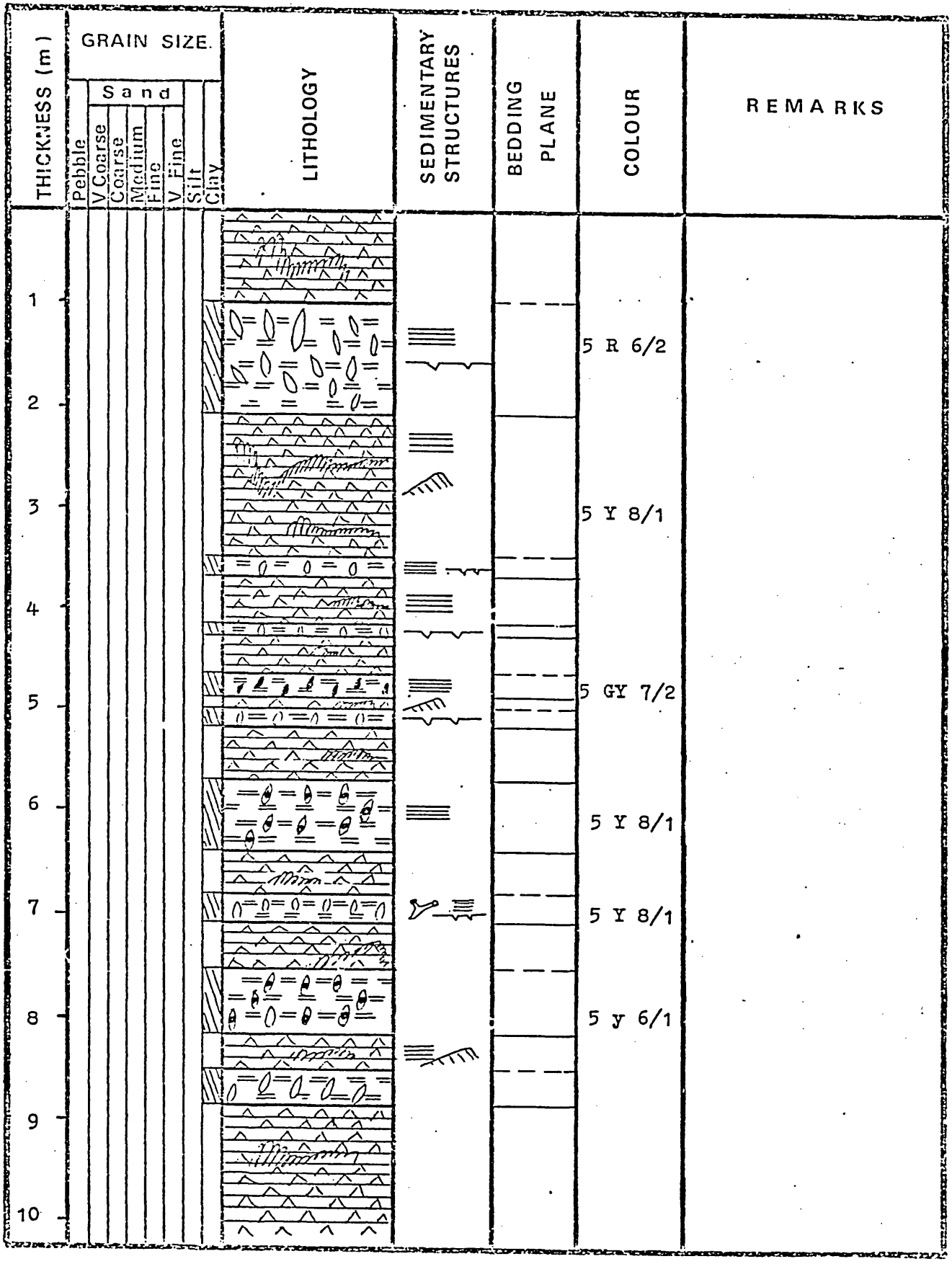


FIG. V.17 The Yazitarla Section.

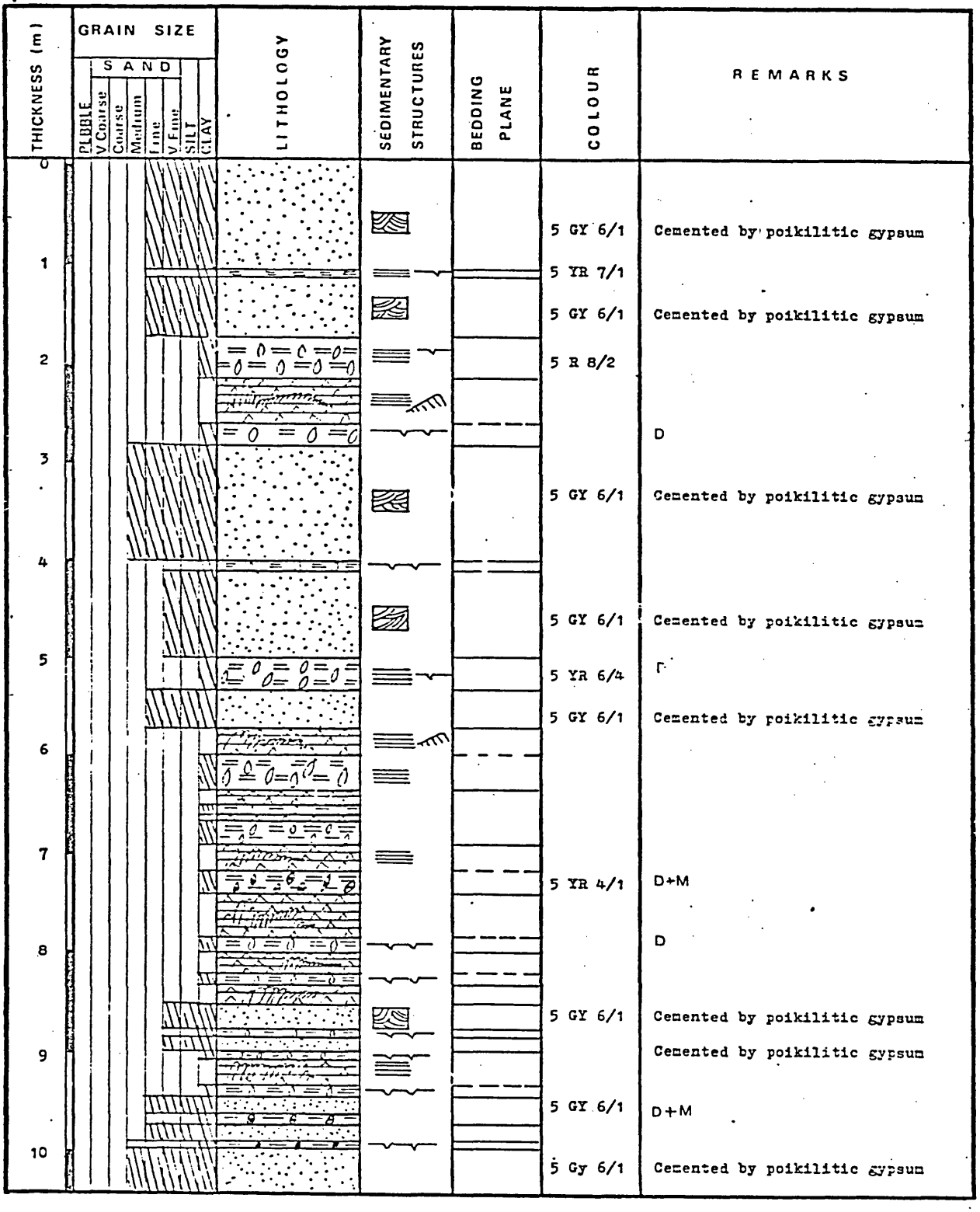


FIG. V.18 The Tuzlanintepe Section.

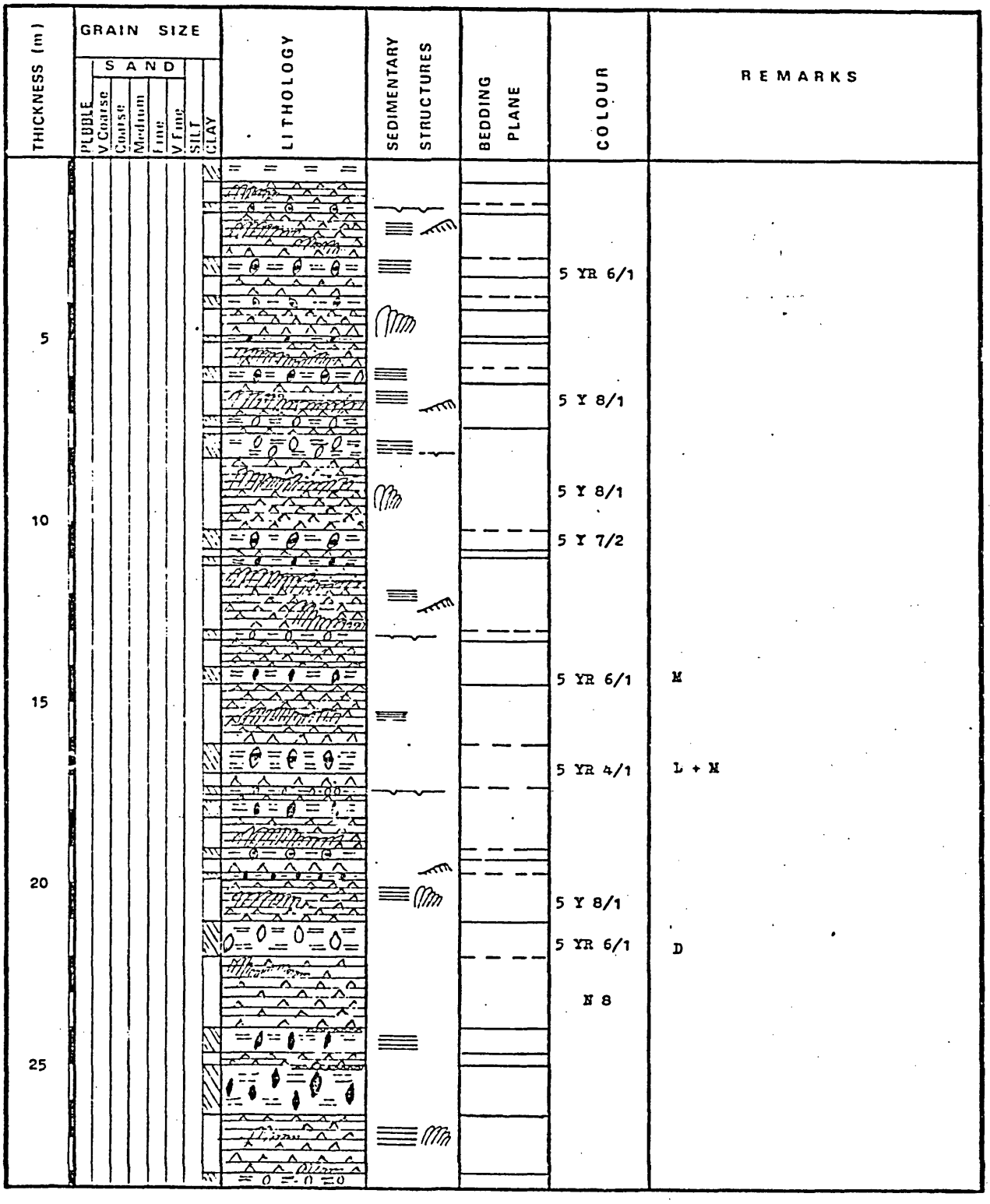


FIG. V.19 The Kirkoy Section.



FIG. V.20 Mudstone-Laminar gypsum cycles of the Bozkir Formation. The prominent beds are the laminar gypsum units.



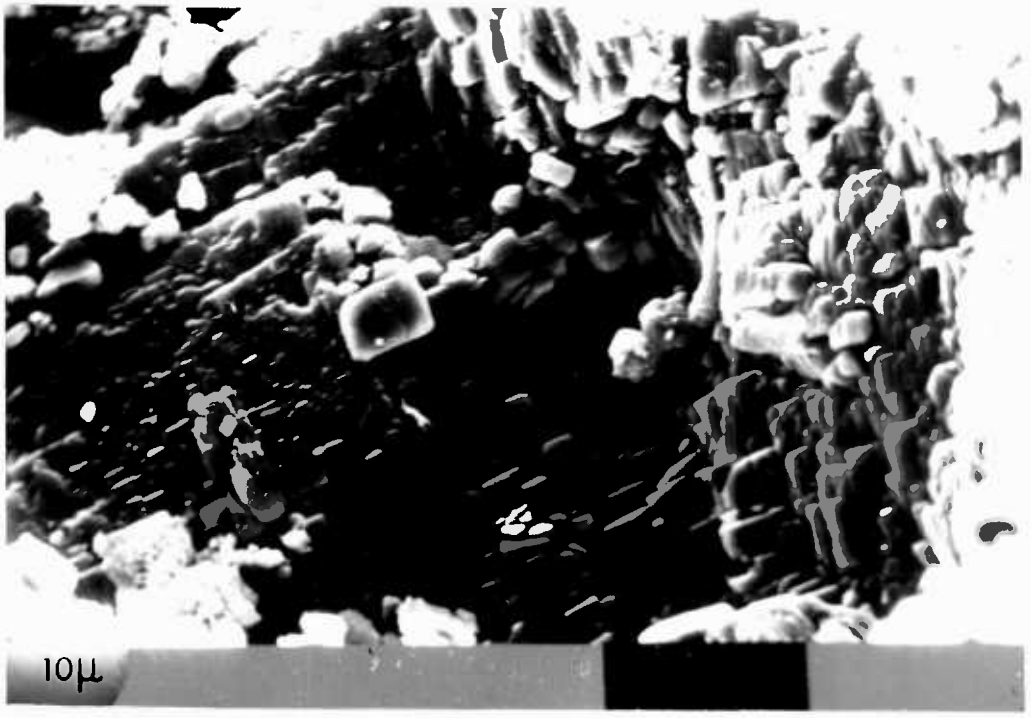
FIG. V.21 Desiccation cracks in the mudstone of the Mudstone-Laminar gypsum cycles:Bozkir Formation. Scale in cms.



FIG. V.22 Ripple-marks in the laminar gypsum unit of one the the Mudstone-Laminar gypsum cycles:Bozkir Formation.



FIG. V.23 A typical mudstone-laminar gypsum cycle with prmary gypsum.Note the crystals of primary gypsum with discoidal habit in the mudstone unit.



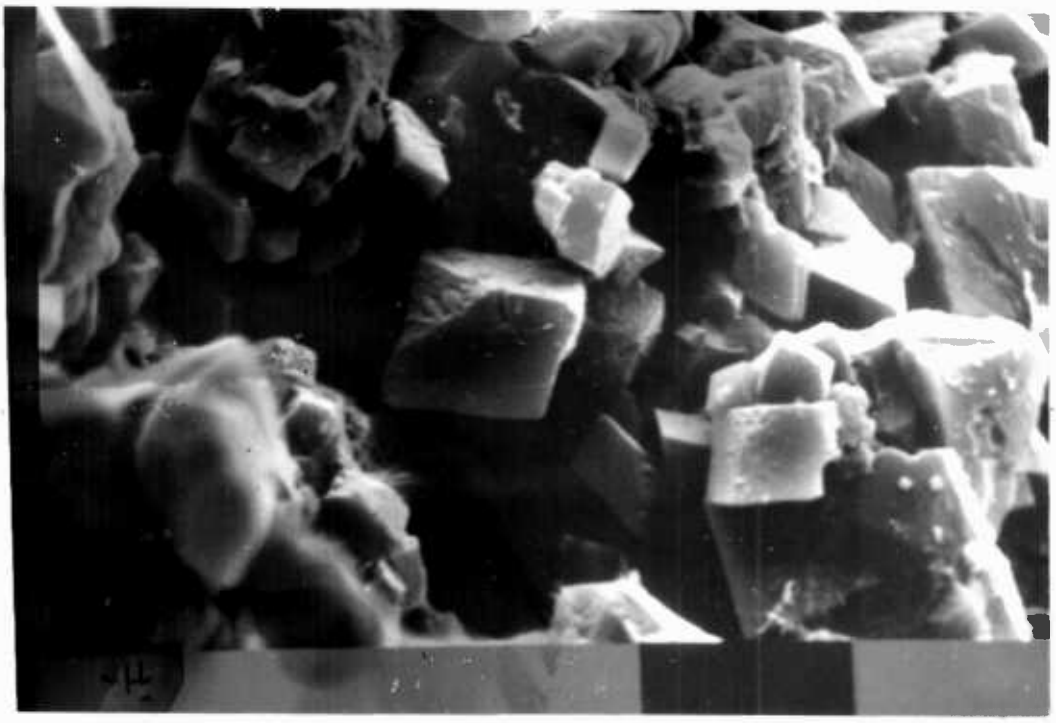


FIG. V.24,a,b Scanning electron photomicrographs of the dolomitic mudstones:Mudstone-laminar gypsum cycles with primary gypsum, Bozkir Formation.



FIG. V.25 Discoidal crystals of primary gypsum in ligth brown mudstone.



FIG. V.26 Discoidal crystals of primary gypsum.Note the hemipramid faces and curved surfaces.Scale in cms.



FIG. V.27 010 cleavage flakes of large crystals of primary gypsum with discoidal habit.Scale in cms.

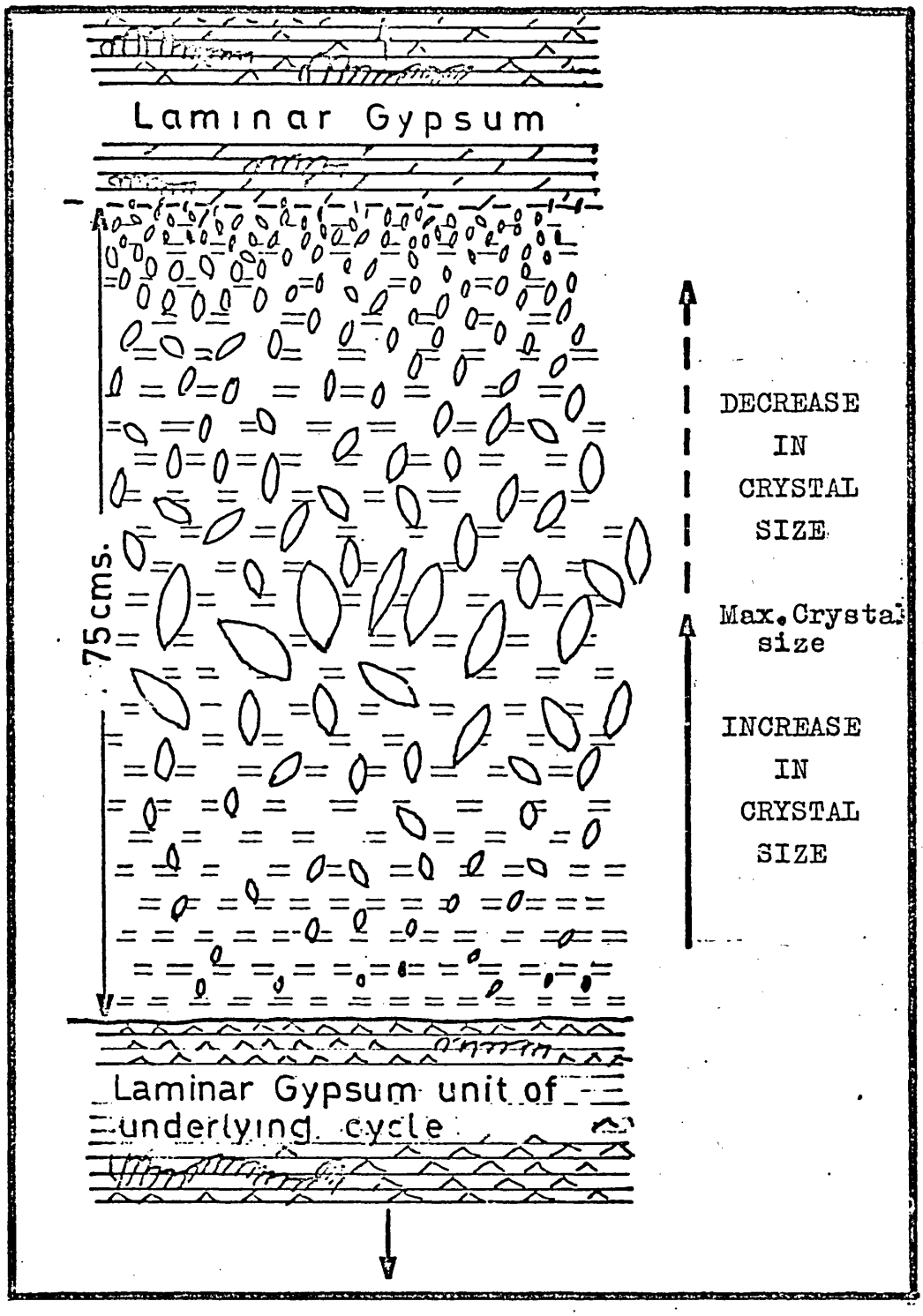


FIG. V.28 Field sketch showing the variations in the crystal size of the discoidal crystals of primary gypsum within a mudstone-laminar gypsum cycle.

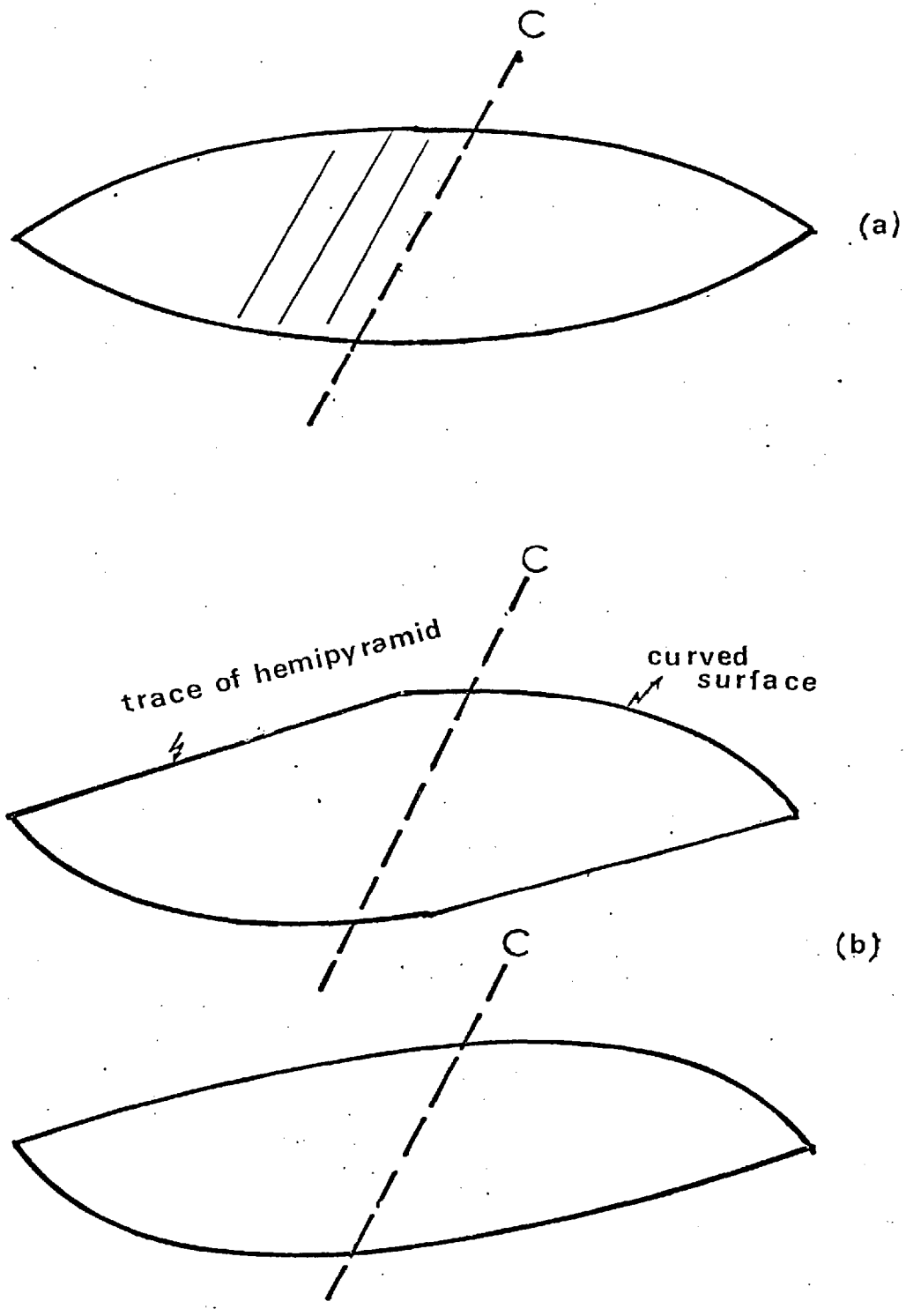


FIG. V.29a,b Schematic diagram showing crystallographic features of discoidal crystals of primary gypsum as seen on 010 cleavage surfaces

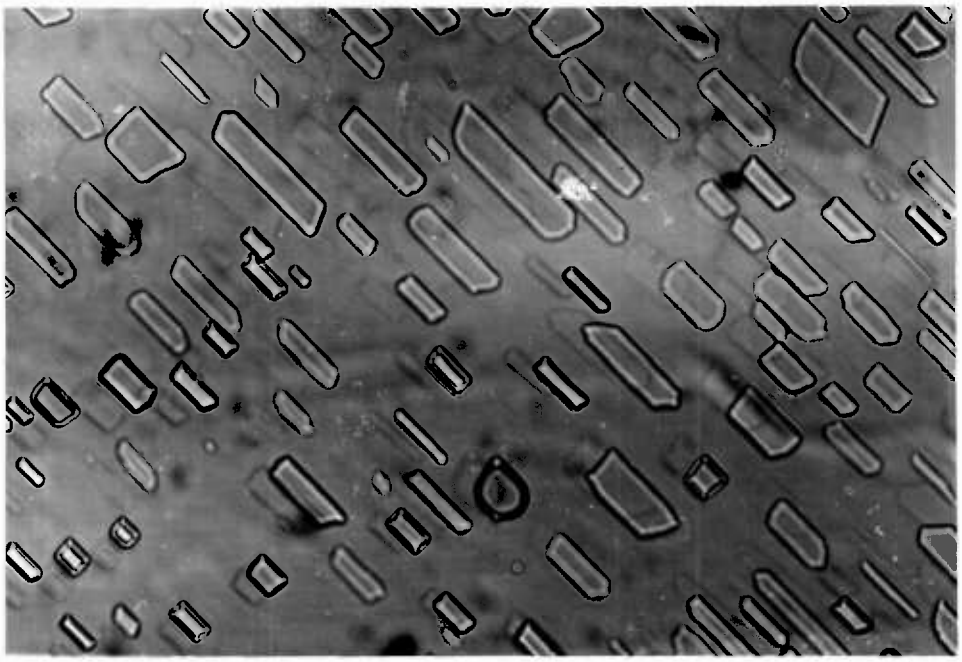


FIG. V.30 Primary brine inclusions in discoidal crystal of primary gypsum:Bozkir Formation.

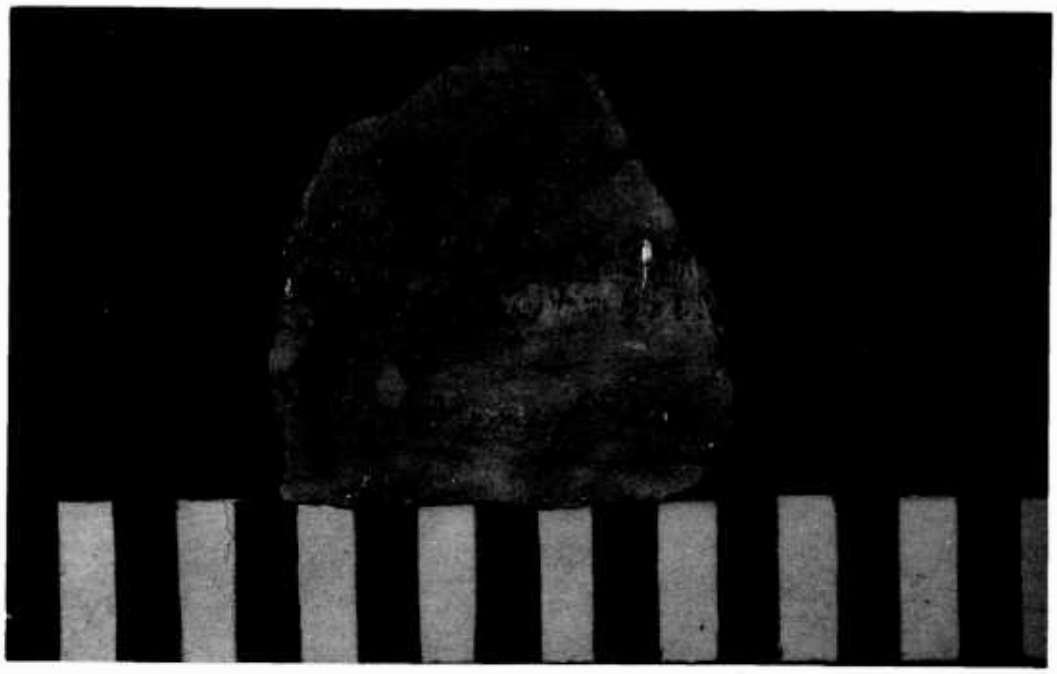


FIG. V.31 Polished slab of the laminar primary gypsum. Note the planar palisade structure.(Scale in cms.)

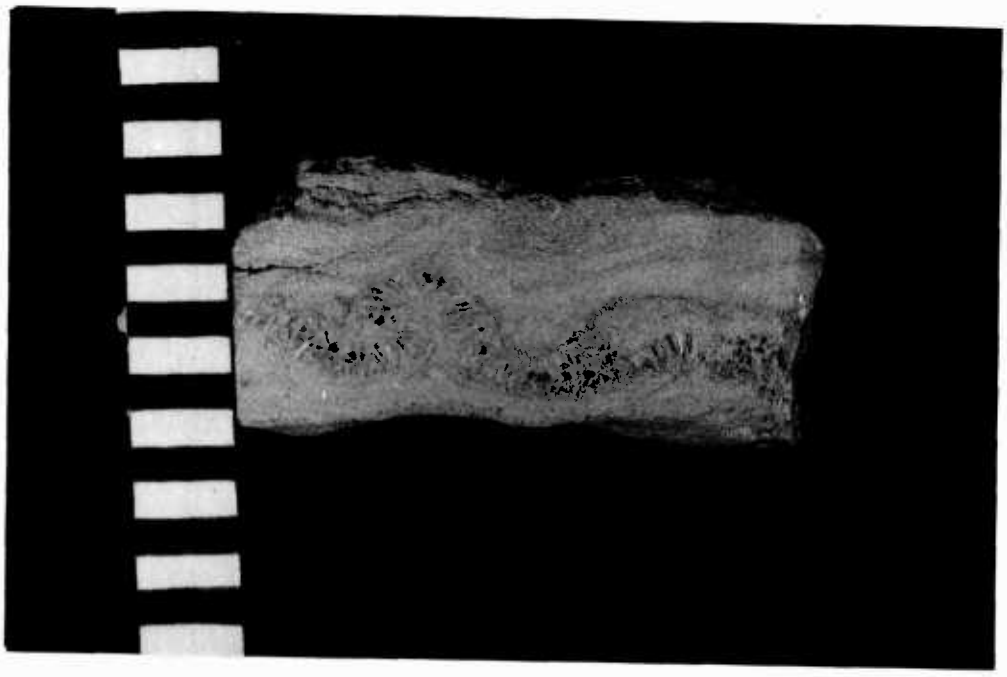


FIG. V.32 Irregular undulose palisade structure.Scale in cms.

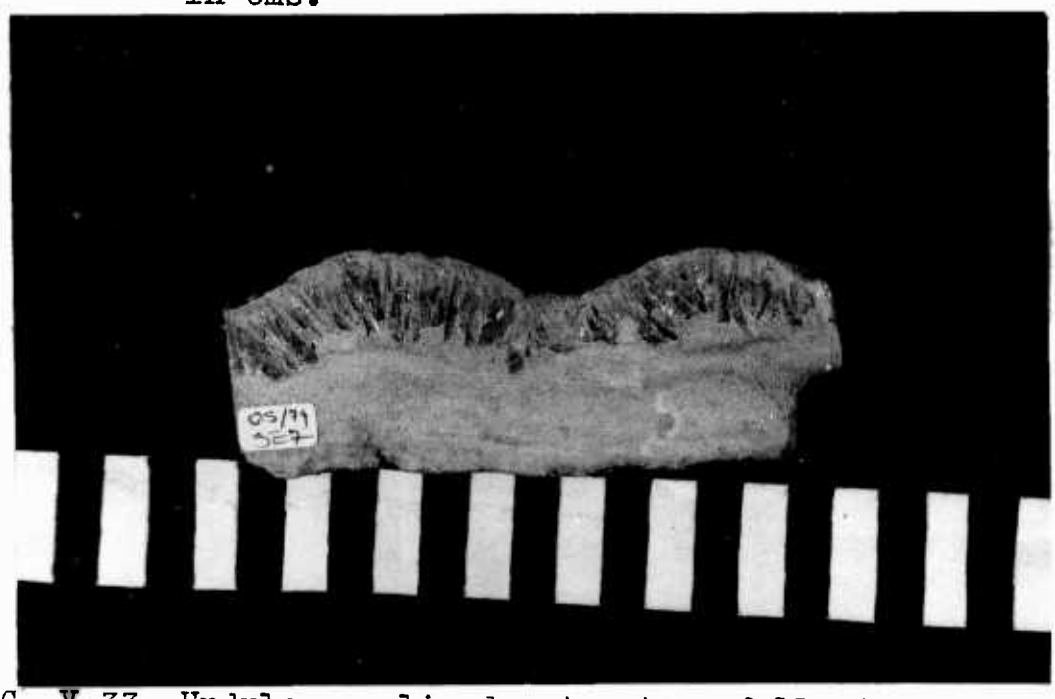


FIG. V.33 Undulose palisade structure following ripple surface.Scale in cms.



FIG. V.34 Large free growth crystals of primary gypsum. Note the zonal arrangement of carbonate inclusions.

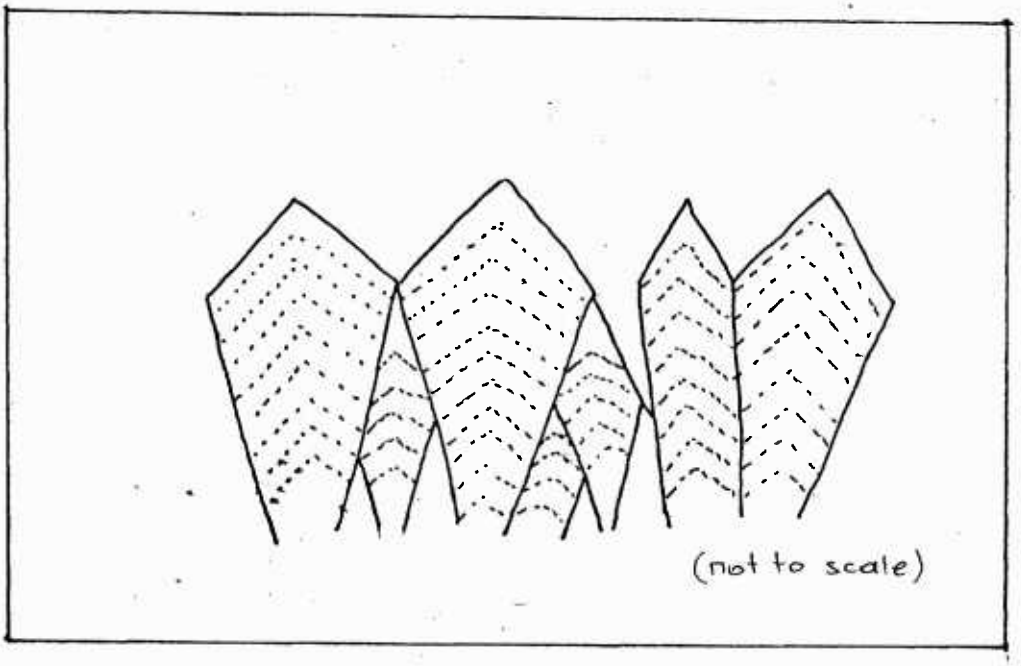


FIG. V.35 Field sketch showing the lateral continuouty of some carbonate zones in adjacent free growth gypsum crystals.

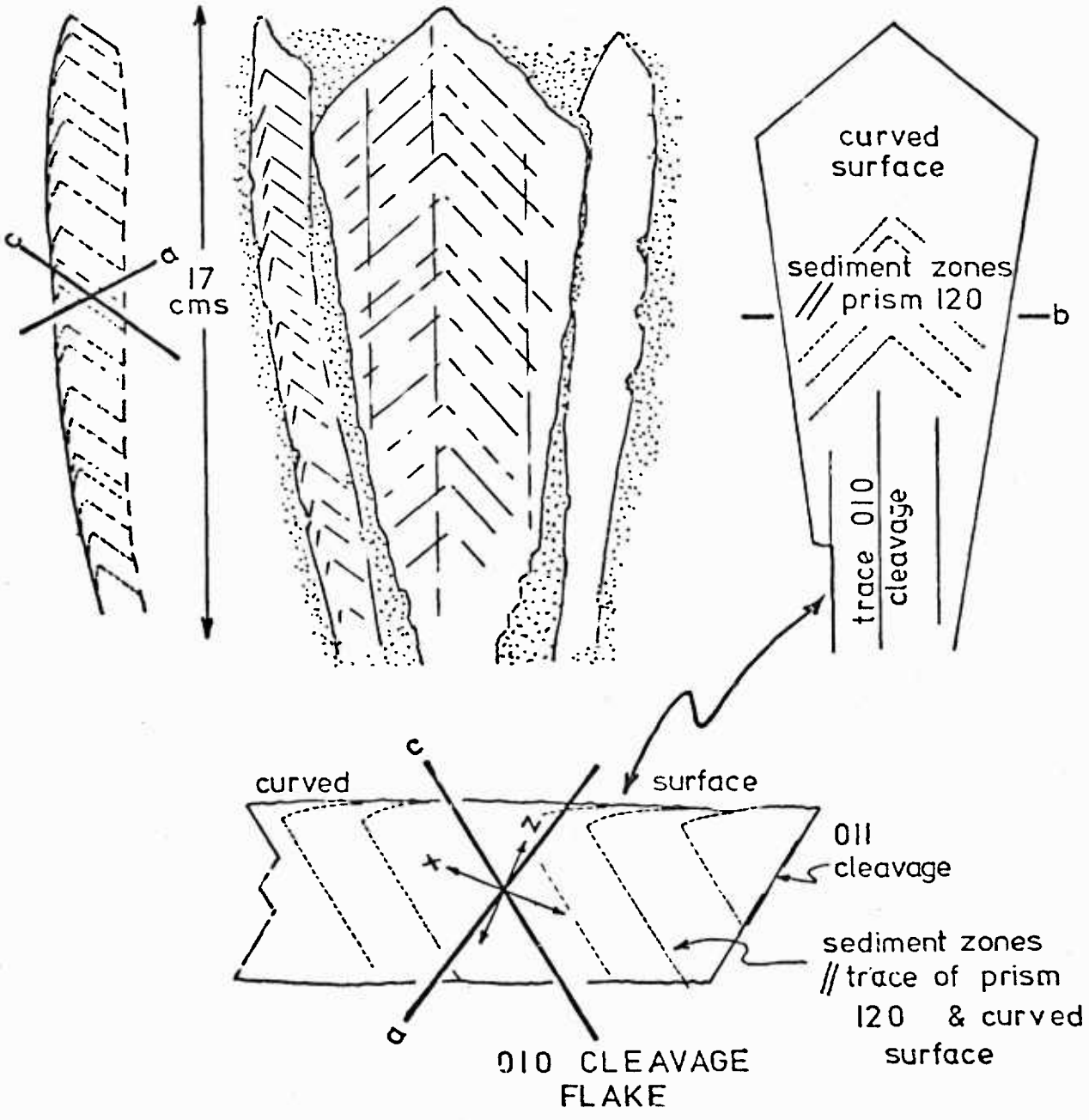
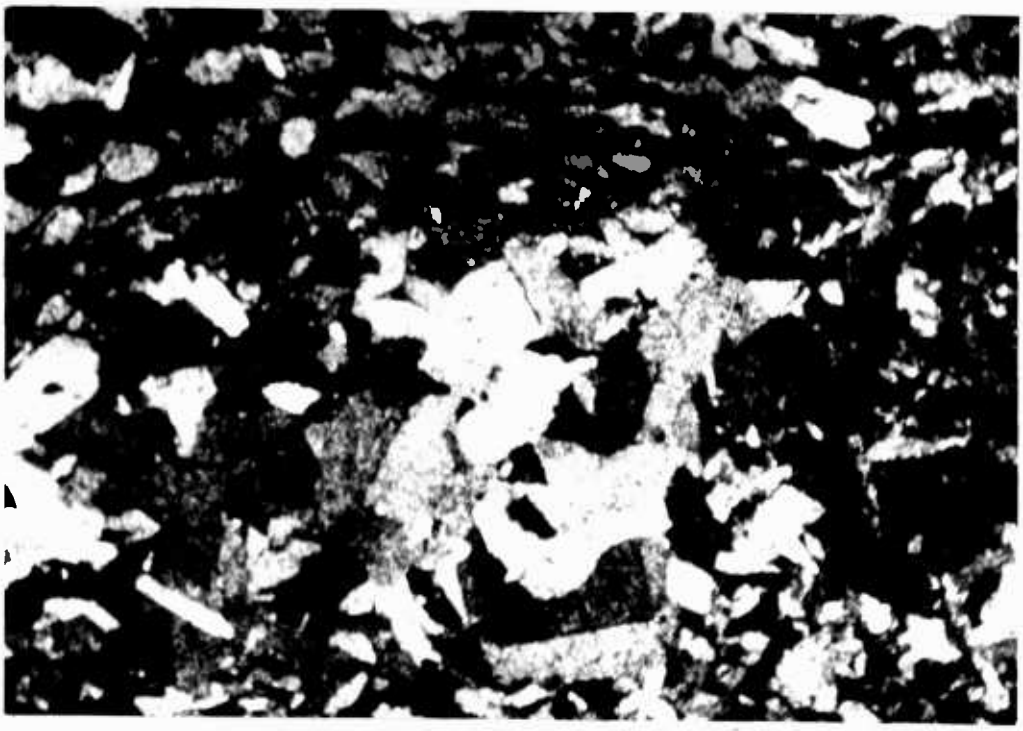


FIG. V.36 Diagram showing crystallographic features of the free growth crystals of primary gypsum.



(×10)

FIG. V.37 Low magnification photomicrograph of a laminar primary gypsum rock.The upper part of the photomicrograph shows the carbonate-rich lamina,while the lower part shows carbonate-free gypsum lamina. Crossed polars.

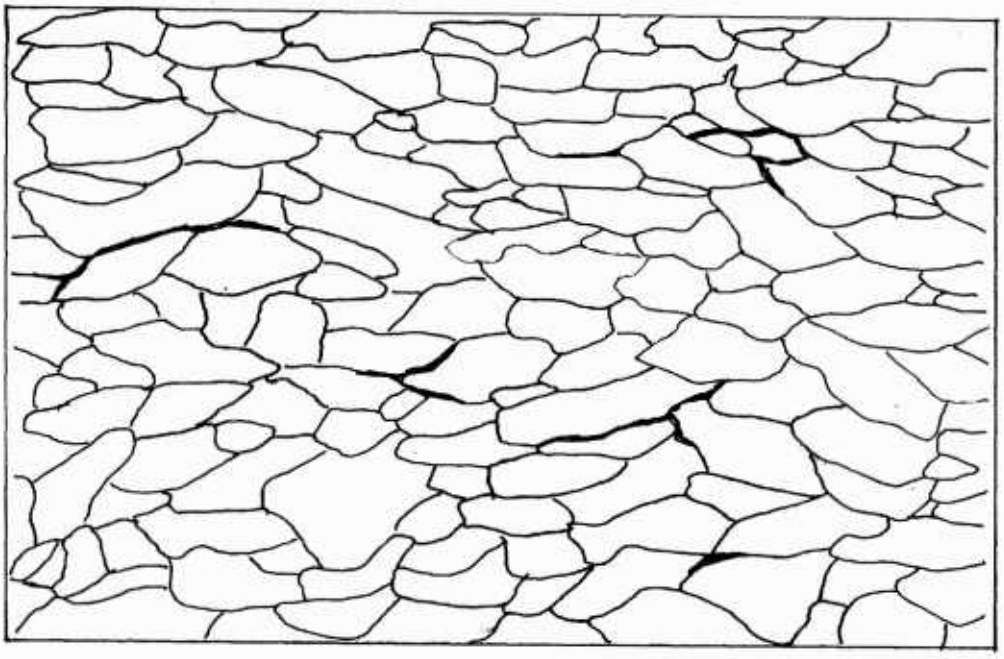


FIG. V.38 Schematic drowing of a thin section of the carbonate-free gypsum lamina cut perpendicular tothe bedding.The crystals are oriented with their long axes parallel to near parallel to the bedding.



FIG. V.39 Photomicrograph of a carbonate-rich lamina which comprises lenceolate-shaped gypsum crystals oriented with their log axes parallel to near parallel tc the bedding. Crossed polars. (×40)

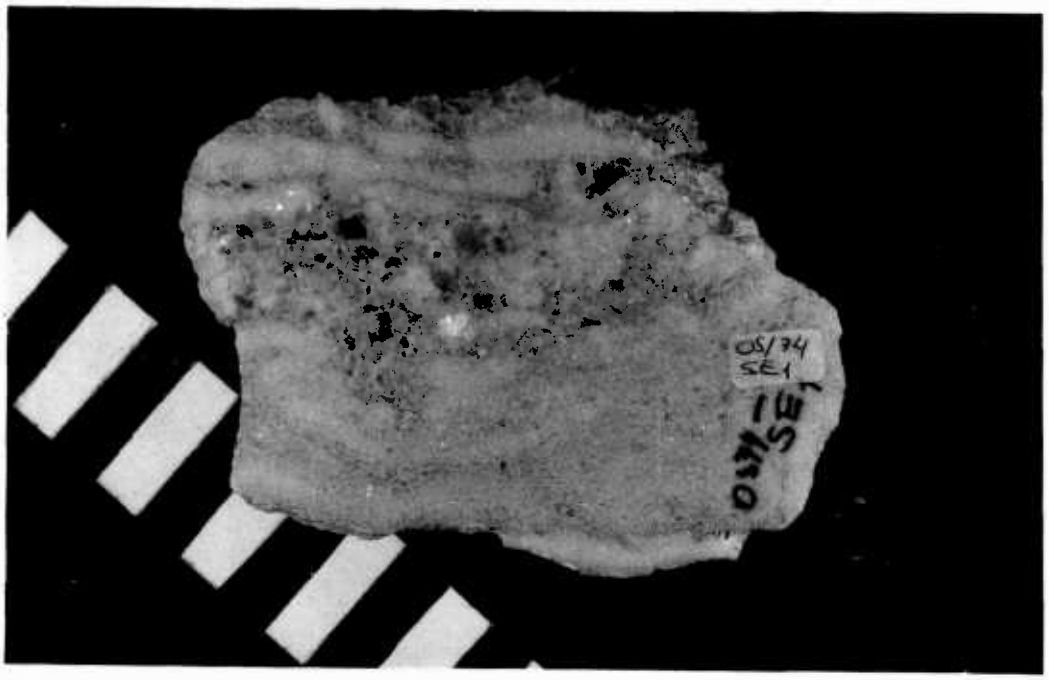


FIG. V.40 Photograph of a polished slab of the laminar in part primary in part secondary gypsum rocks Note the patchy distribution of secondary gypsum(white).Scale in cms.

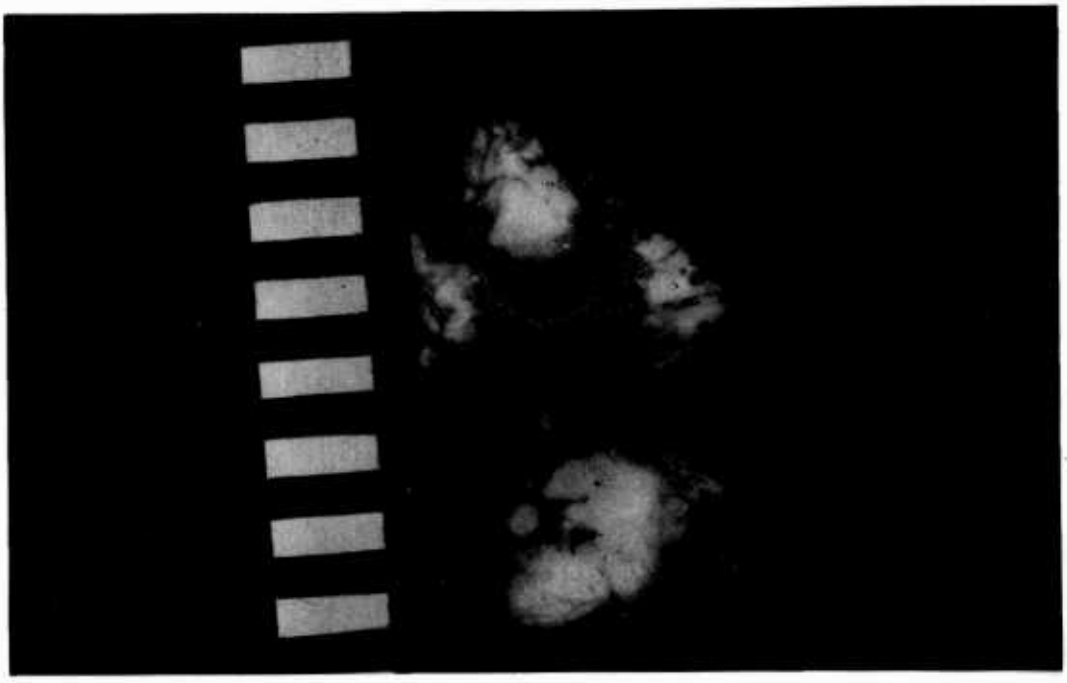
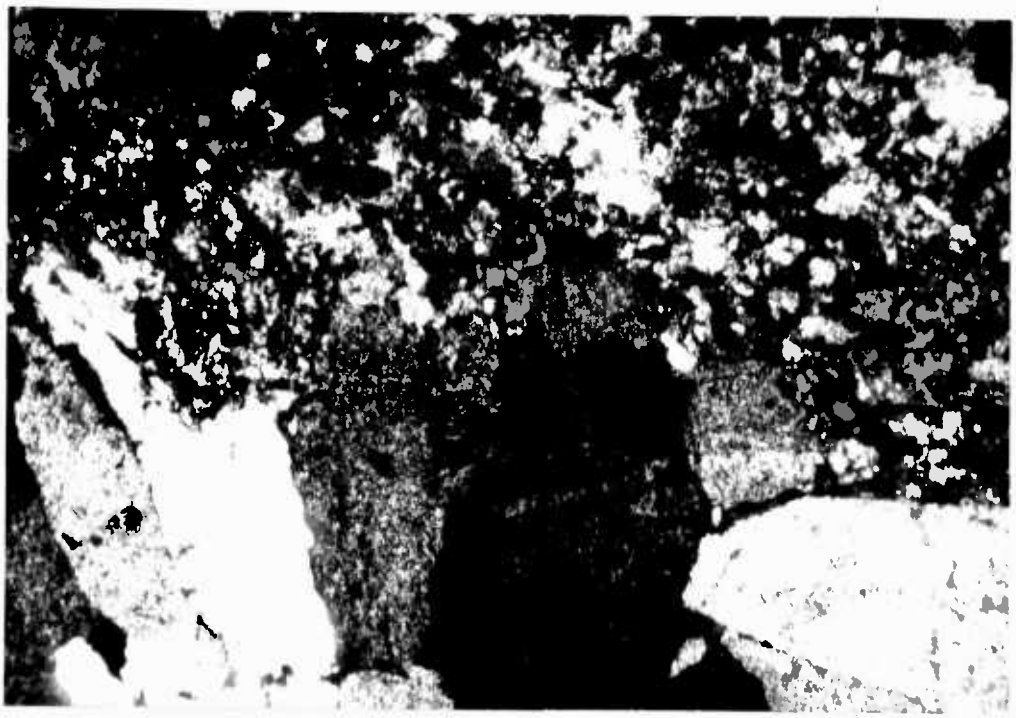


FIG. V.41 Discoidal crystals of primary gypsum in part replaced by anhydrite(now secondary gypsum). Scale in cms.



(×40)

FIG. V.42 Photomicrograph of the laminar in part primary in part secondary gypsum.Note the patchy distribution of the secondary gypsum.Crossed-polars.

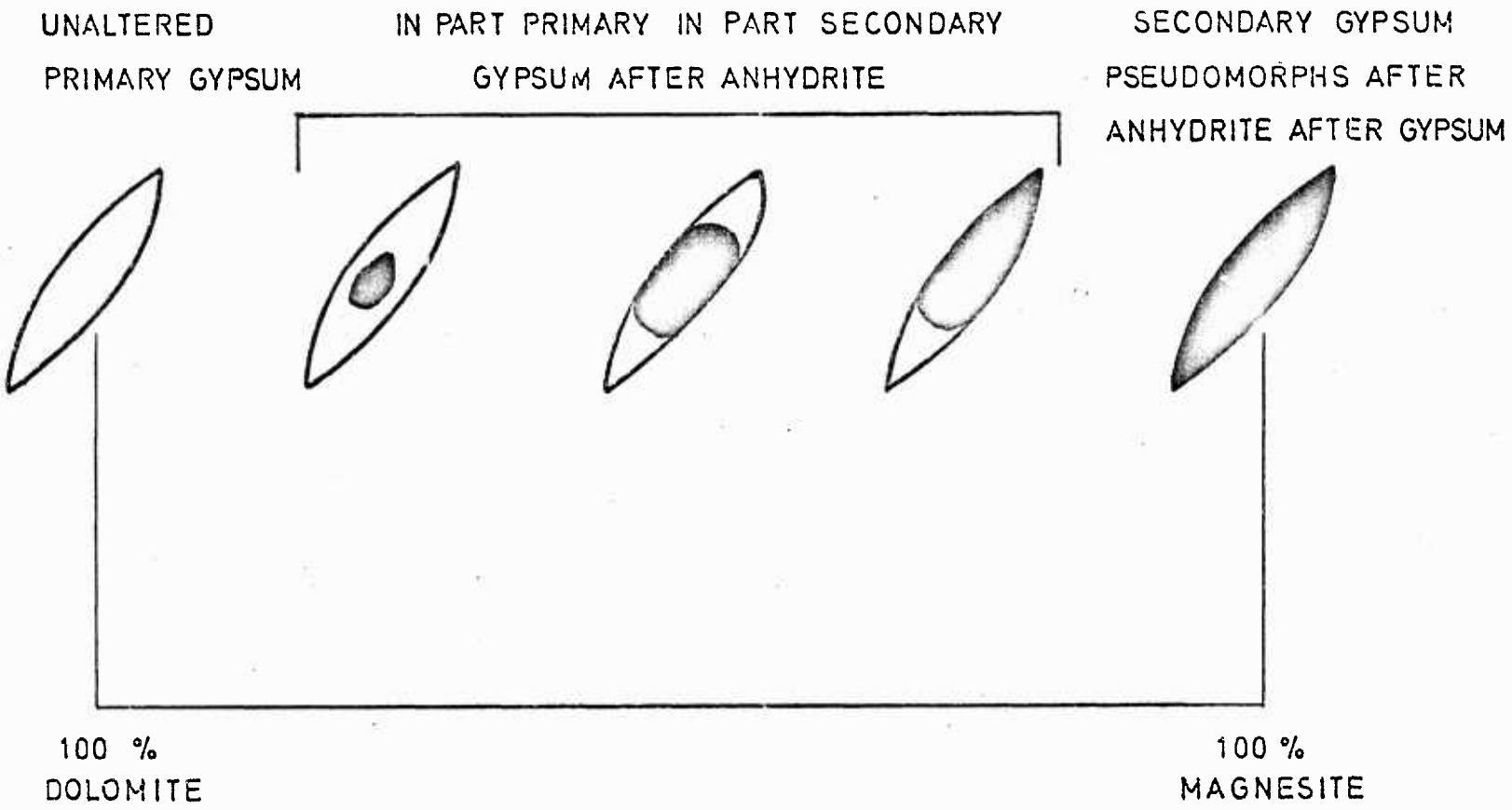


FIG. V.43 Schematic presentation showing the relationship between the ratios of primary gypsum to secondary gypsum and the ratios of dolomite to magnesite in the associated mudstones: Mudstone-Laminar gypsum cycles, with primary and secondary gypsum, Bozkir Formation.

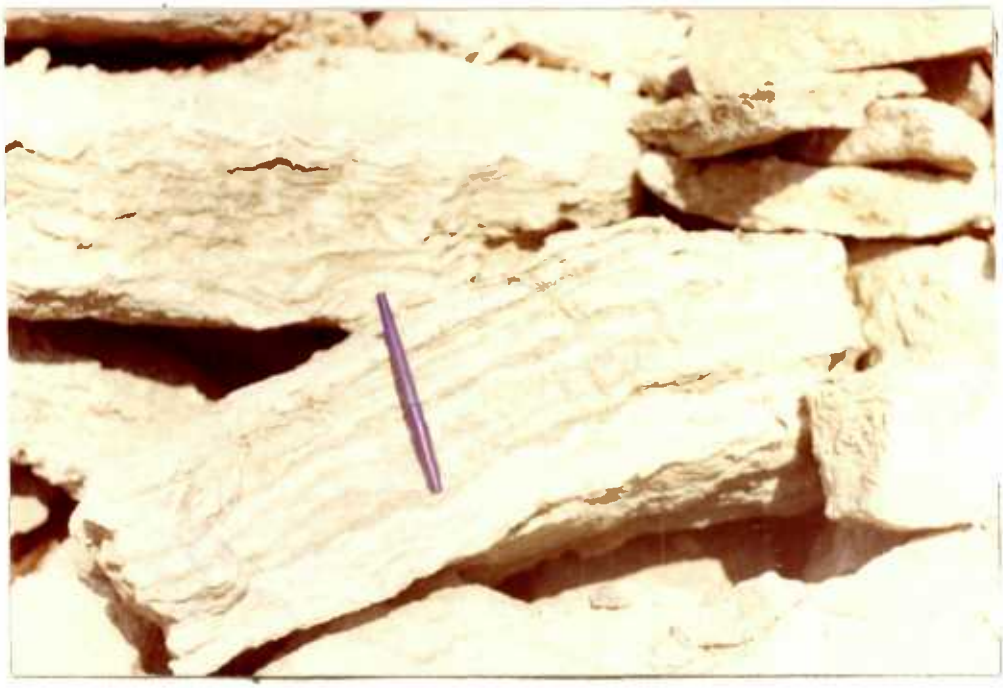


FIG. V.44 Laminar secondary gypsum,fallen block.Note wavy lamination.

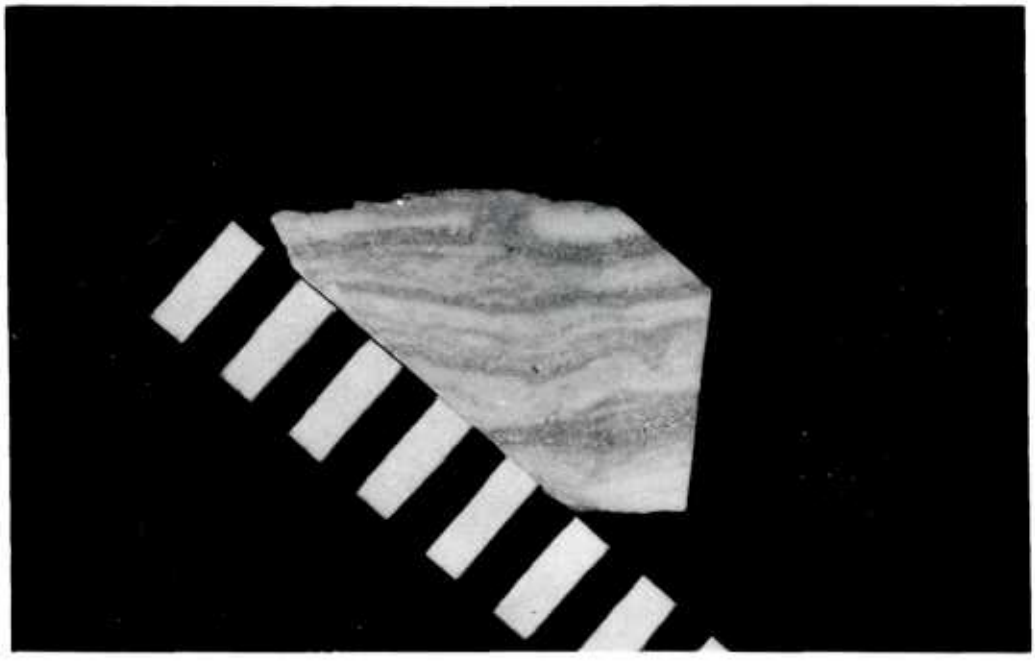


FIG. V.45 Polished slab of the laminar secondary gypsum. Scale in cms.



(a)



(b)

FIG. V.46,a,b Disc-shaped secondary gypsum pseudomorphs after discoidal crstals of primary gypsum.



FIG. V.47 Interpenetrant clusters of secondary gypsum pseudomorphs after discoidal crystals of primary gypsum.Scale in cms.

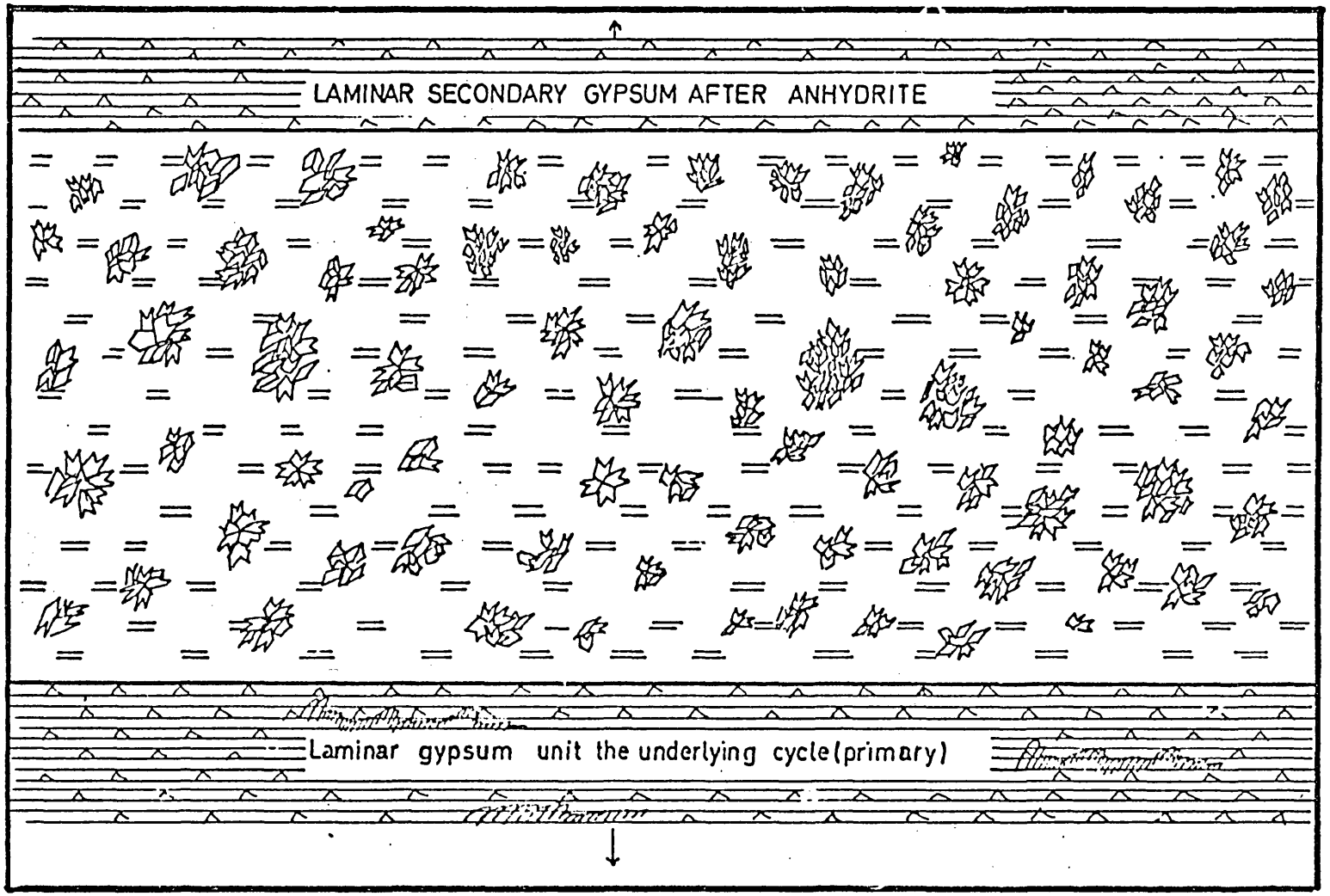
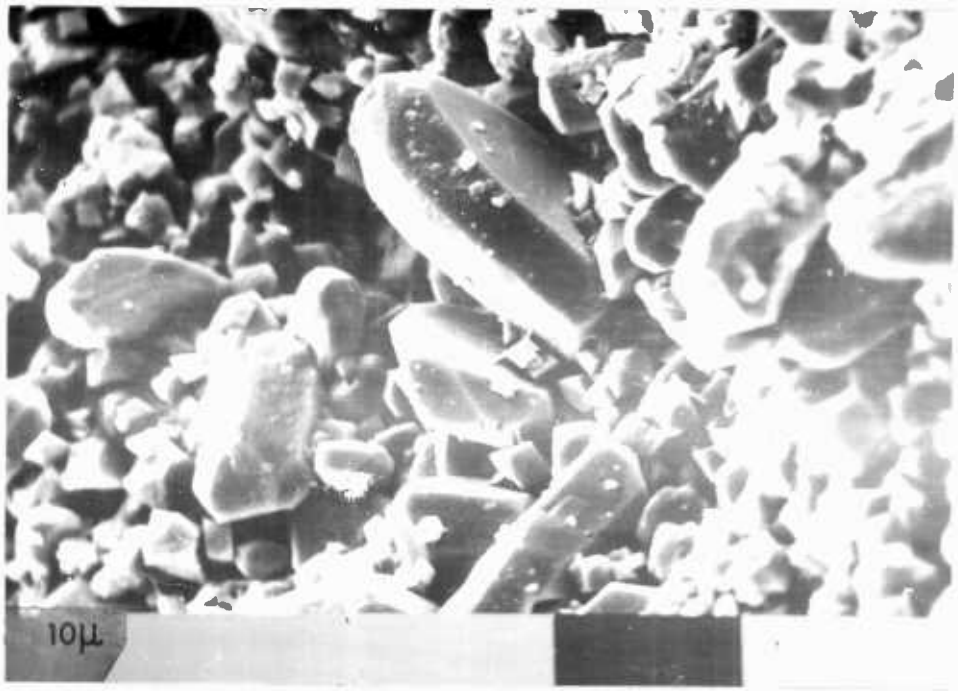
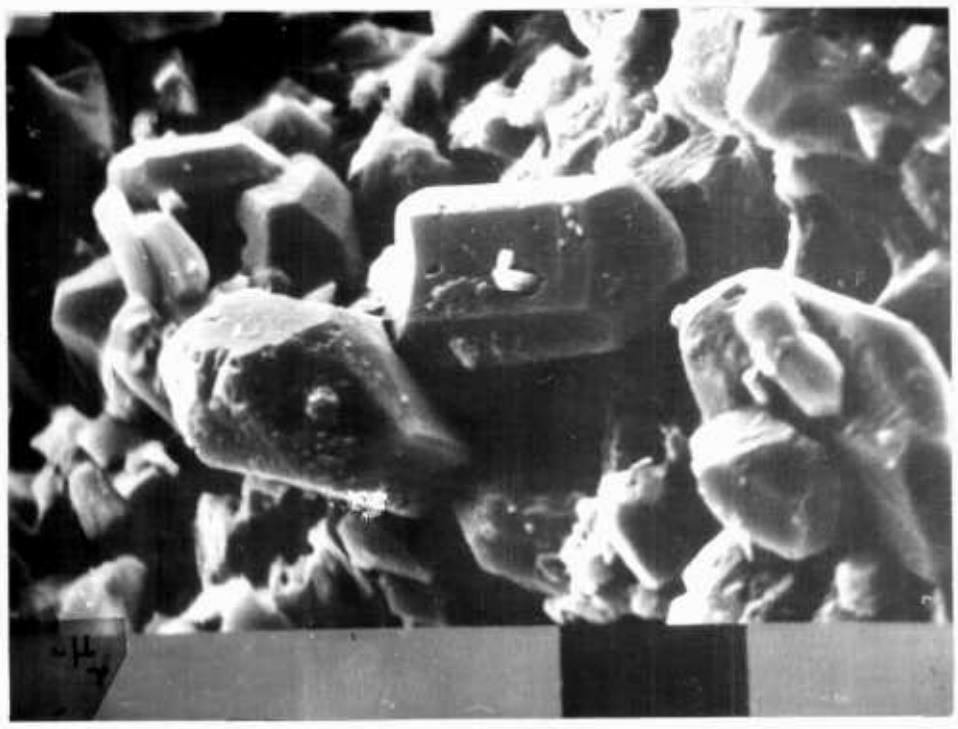


FIG. V.48 Field sketch showing the distributions of the crystals of early diagenetic gypsum after anhydrite in the mudstone unit.

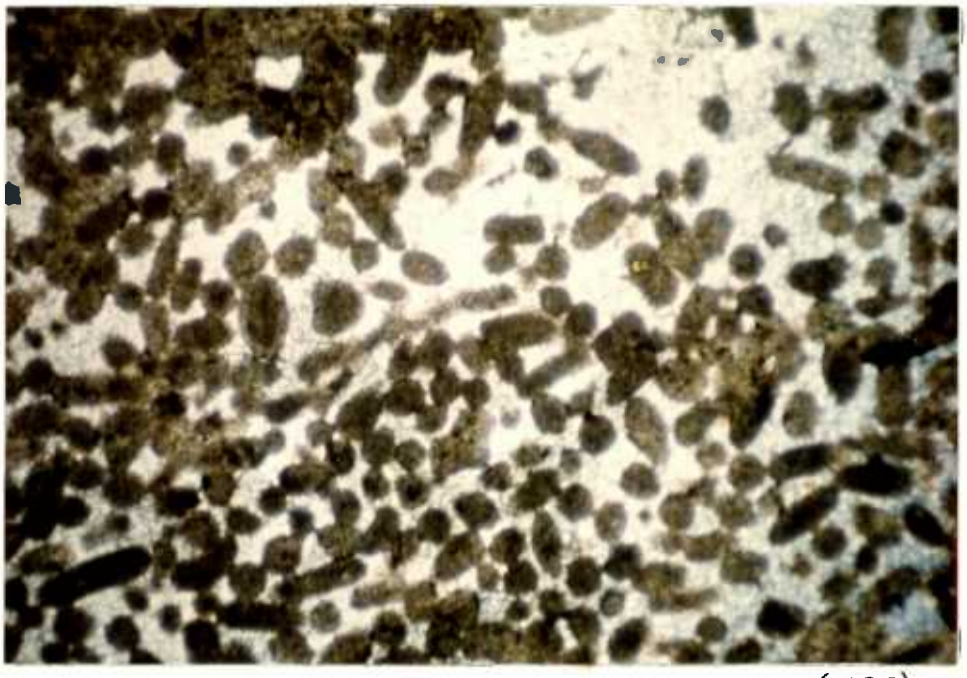


(a)



(b)

FIG. V.49a,b Scanning electron photomicrographs showing celestite crystals in the dolomitic mudstone which carries crystals of early diagenetic gypsum after anhydrite.



(x35)

a

FIG. V.50 Pelletoid grainstone cemented by secondary gypsum after replacement anhydrite. Crossed polars.

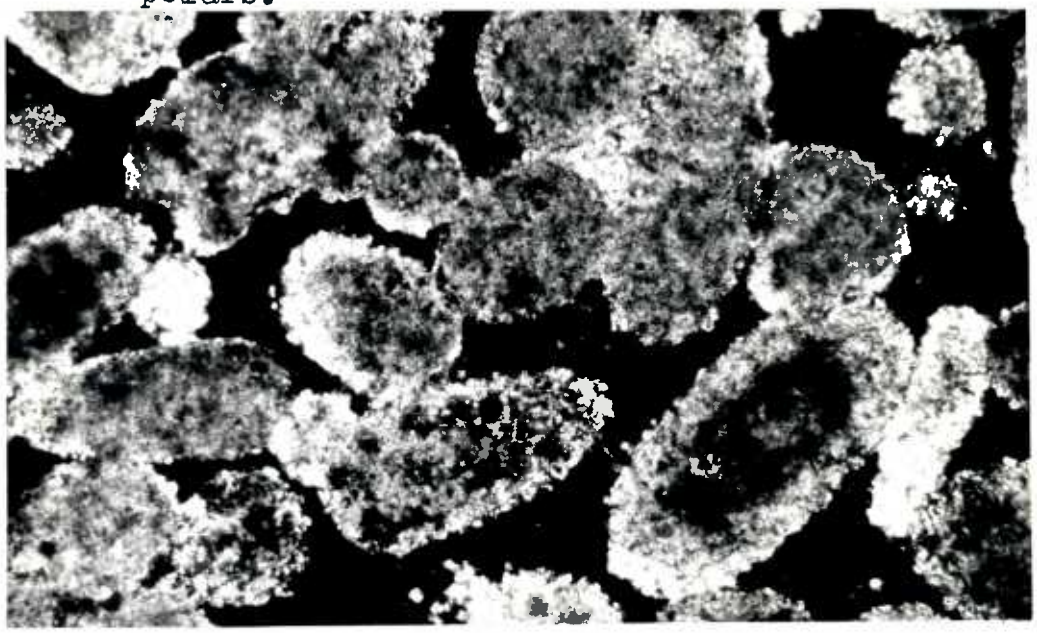


FIG. V.51 Photomicrograph of a pelletoid grainstone cemented by poikilitic gypsum showing fringes of first phase calcite cement of pelletoids, gypsum cement is extingtion position. Crossed polars. (x 85)

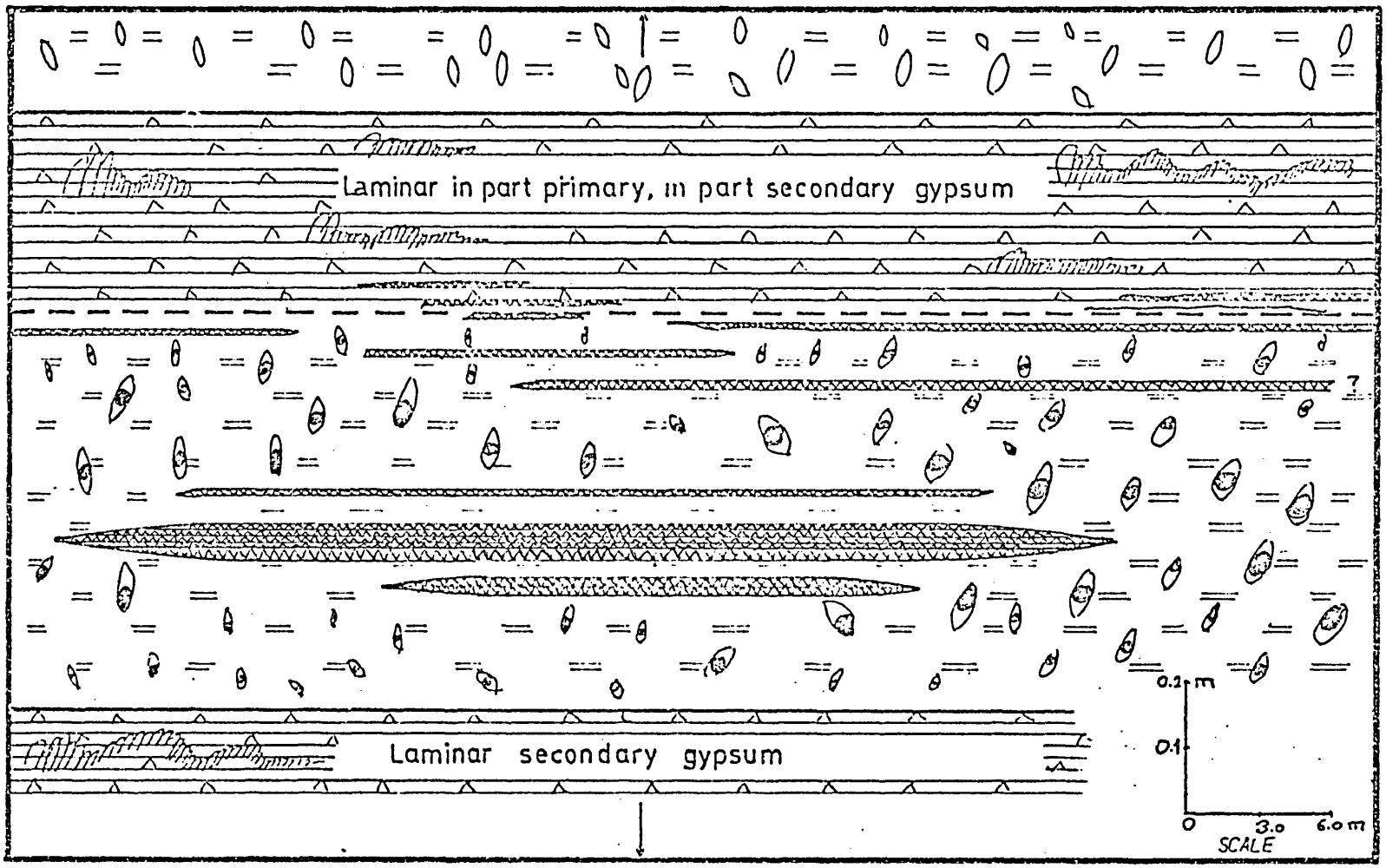


FIG. V.52 Field sketch showing multiple veins of satin-spar gypsum in the mudstone unit of a mudstone-laminar gypsum cycle with primary and secondary gypsum Note the geometry of the veins.

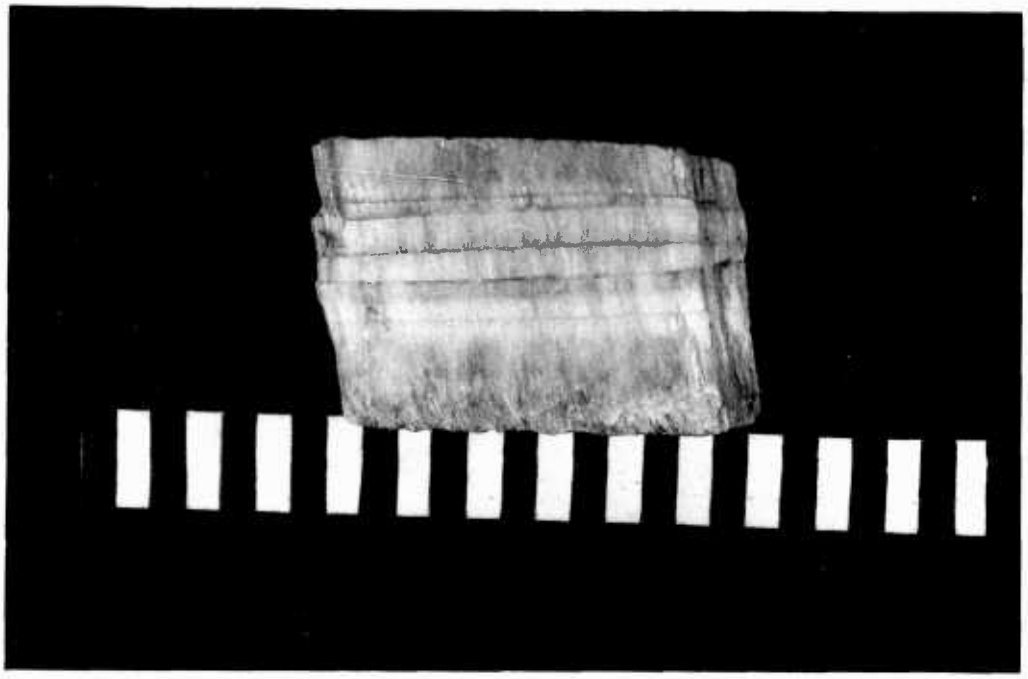


FIG. V.53 Polished slab of a multiple satin-spar gypsum vein. Scale in cms.

CHAPTER VI

PETROLOGY OF SECONDARY GYPSUM ROCKS

VI. 1. INTRODUCTION

Secondary gypsum rocks are gypsum rocks which were produced by hydration of earlier formed anhydrite rocks. The megascopic features of the secondary gypsum rocks and their relationships to the associated lithologies have been described in the previous chapters. This present chapter deals with the petrology of the rocks and possible hydration mechanisms.

Hydration of anhydrite to secondary gypsum is not a simple process and the purpose of the first part of the chapter is to give a summary of previously suggested hydration mechanisms and the physico-chemical controls on the gypsum-anhydrite system.

Secondary gypsum rocks display two main fabric types: porphyroblastic fabrics and alabastrine fabrics. The latter include a wide diversity of sub-fabrics. Although the main fabric names have been generally accepted by most workers, a large number of terms have been used to describe the sub-fabrics of the alabastrine secondary gypsum. The terminologies proposed by various workers are presented and compared with that used in the present study. This review is followed by petrographic descriptions and discussions on the origin of the secondary gypsum rocks of the Bayindir and Bozkir Formations. The latter parts of the chapter deal with the mutual relationships between porphyroblastic and alabastrine fabrics. Finally the microscopic features of the satin-spar gypsum veins are described and their relationships with the secondary gypsum rocks are discussed.

VI. 2. BACKGROUND CONSIDERATIONS

2.1. Hydration mechanism

It was suggested by Holliday (1970) that three mechanisms are possible for hydration of anhydrite to gypsum. They are:-

A. Direct hydration to gypsum (addition of water to the anhydrite crystal lattice).

B. Hydration via intermediate bassanite series (step-wise hydration)

C. Dissolution of anhydrite with concomitant precipitation of gypsum.

According to Holliday (1970), those hydration textures which are characterized by gypsum with ill-defined grain boundaries and irregular extinction reflect imperfectly arranged lattice structure and are likely to have been formed as a result of hydration by direct addition of water to the anhydrite lattice. He suggested that the retention of strontium in the gypsum of the secondary gypsum rocks supports this contention. However, Mossop and Shearman (1973) argued against the possibility that anhydrite could convert to gypsum by direct addition of water to the anhydrite crystal lattice. They stated that "Anhydrite ($CaSO_4$) crystallizes in orthorhombic system (space group amma), whereas, gypsum is monoclinic (space group AZ/a),. The two structures are so completely different that it is difficult to conceive how such a radical lattice reorganization could be accomplished in the solid state" (p. B.147).

The second mechanism is that the hydration of anhydrite to gypsum via bassanite series. It is well known that, on heating in air to about 60°C gypsum slowly loses three-quarters of its water and dehydrates to form hemihydrite ($Ca\ SO_4\ \frac{1}{2}H_2O$). On further heating at higher temperatures (about 100°C), the hemihydrite progressively loses the remainder of the water to form soluble anhydrite ($\gamma Ca\ SO_4$). The intermediate series between hemihydrite and soluble anhydrite is termed the "Bassanite Series".

$Ca\ SO_4\ 2H_2O - 1\ \frac{1}{2}\ H_2O$ (Gypsum)	Heating about 60° ⇌	$Ca\ SO_4\ \frac{1}{2}\ H_2O$ (Hemihydrite)
$Ca\ SO_4\ \frac{1}{2}\ H_2O$ (Hemihydrite)	Heating ⇌	$Ca\ SO_4\ n\ H_2O$ (Bassanite Series)
$Ca\ SO_4\ n\ H_2O$ (Bassanite Series)	Heating ⇌	$\gamma Ca\ SO_4$ (Soluble anhydrite)

Soluble anhydrite ($\gamma Ca\ SO_4$) is not the same mineral as the anhydrite found in sedimentary evaporites. It is hexagonal (Space group c622) and it rehydrates back to gypsum via the bassanite series with addition of water.

Occurrences of hemihydrite, bassanite and soluble anhydrite are limited in nature. Bundy (1956) recorded the presence of hemihydrite in the transition zone between the anhydrite and gypsum in the Mississippian evaporites of Indiana, U.S.A., and soluble anhydrite ($\gamma Ca\ SO_4$) was reported from the Permian evaporites of the Cumberland, northwest England (Arthurton, 1971). However, it has been argued by Mossop and Shearman (1973) that "Hydration of the anhydrite of normal sedimentary rocks to form gypsum in this way would first require the transformation of the $\gamma Ca\ SO_4$ into $\beta Ca\ SO_4$". They pointed out that there is no evidence which indicates the presence of this transformation in the nature.

The third mechanism, dissolution and re-precipitation was proposed by Newland (1941). It involves the dissolution of anhydrite, molecule by molecule, with concomitant precipitation of the calcium and sulphate ions with water to form gypsum. It has been accepted as the most likely process for the natural hydration of anhydrite to gypsum by the majority of workers (e.g. Goodman, 1952; Ogniben, 1957; Ham, 1962; Holliday, 1967, 1970, 1973, 1977; West, 1965; Shearman et.al., 1972; Mossop, 1973; Mossop and Shearman, 1973; Burgess and Holliday, 1974, and Orti, 1974, 1976).

2.2 Physico-chemical controls on the Calcium Sulphate System

2.2-1. Thearmal stability of anhydrite and gypsum

In the early 1900's Van't Hoff et.al. attempted to specify the conditions under which gypsum and anhydrite occur. They found that gypsum is the stable form of the calcium sulphate in pure water below 66°C and they argued that temperatures higher than this favour the formation of anhydrite. They also found that the transition temperature is lowered

to 30°C in the presence of soluble salts, especially sodium chloride.

Posnjak (1938) determined the transition temperature by means of solubility measurements in distilled water and concluded that anhydrite is favoured above 42°C and gypsum is the stable form of the calcium sulphate below that temperature. Later studies by Kelley et. al., (1941) and MacDonald (1953) suggested that the transition temperature in pure water is 40°C rather than 42°C. However experimental work by Hardie, (1967) indicated that it is 60°C.

MacDonald (1953) found that in sea water the transition temperature is 34°C. The effects of sodium chloride on the gypsum-anhydrite transition temperatures as calculated by various workers are shown in figure VI. 1. It has been argued that the presence of other ions can also effect the transition temperature (e.g. Conley and Bundy, 1958; Ostroff, 1964, Hardie, 1967 and Chuft and Choo, 1970).

Studies on the effects of pressure have shown that it only effects the transition temperature slightly, (MacDonald, 1953; Marshal, 1952 and Zen, 1965).

It is clear from the experimental studies summarized above that the maximum temperature below which gypsum is stable is about 42°C. In regions of normal geothermal gradient this temperature should prevail roughly at 900 to 1200 metres depth of burial. (1260 metres; MacDonald, 1953). Murray (1964) found gypsum in borehole cores from 1050 metres below the present ground surface in the Permian San Andres Formation, Dune Field, Crone County, Texas. There are few, if any records of gypsum below that depth. Mossop and Shearman (1973) suggested that gypsum could be present at greater depths where local conditions, such as permafrost, depress the normal geothermal gradient.

2.2.-2. Volume Relations

The unit cells of gypsum and anhydrite are compared in figure VI.2. The unit cell of gypsum is larger than that of anhydrite, but both contain

the same number of molecules. Thus hydration of anhydrite to gypsum should involve an increase in volume. The increase was calculated to be 63% by Allen (1971) who made a direct comparison of the unit-cell volumes of gypsum and anhydrite. An approximate value of 63% for volume increase was obtained by Shearman et.al. (1972) who compared the ratios of the molecular weights to densities of anhydrite and gypsum respectively (Fig. VI.3).

Some early workers (e.g. Pettijohn, 1949; Ogniben, 1957) considered that nodular and enterolithic structures in secondary gypsum rocks formed as a result of the volume increase on hydration of anhydrite, but it has recently been found that these are early diagenetic growth structures and not a function of hydration (West, 1965; Shearman, 1966; Holliday, 1966, 167, 1970; Kinsman, 1966; Butler, 1970; and Mossop and Shearman, 1973). Petrographic studies on many ancient anhydrite and secondary gypsum rocks have revealed that hydration of anhydrite to gypsum is often a volume for volume process (e.g. Goodman, 1952; Bundy, 1956; Ham, 1962; Holliday, 1967, 1970; Mossop, 1973; Mossop and Shearman, 1973; and Orti, 1974, 1976). The lines of evidence which support this view are: the optical continuity between relics of anhydrite crystals enclosed within the secondary gypsum; the presence of gypsum pseudomorphs after anhydrite, and undisturbed sedimentary structures.

The problem which arises is, what happened to the predicted additional volume of gypsum? It has been suggested that where the hydration took place in a 'closed' system (closed apart from the addition of water), the satin-spar gypsum veins represent the additional volume of gypsum (Bundy, 1956; West, 1965; Shearman et.al. 1972; Mossop, 1973; and Mossop and Shearman, 1973). If, however, hydration took place in an open system, then the excess calcium and sulphate ions could have been removed in solution (Mossop and Shearman, 1973).

2.2 - 3. Water Availability

As soon as exhumation brings anhydrite up to levels where rock temperature falls below that of the stability field of anhydrite, hydration becomes possible. However, hydration cannot take place unless water is made available because supply of water is another essential factor for the formation of secondary gypsum rocks. Three possible sources for water were suggested by Mossop and Shearman (1973). These are: (1) Water already present in the pore spaces of the anhydrite rocks: (this is taken to include water present in porous strata which interbedded with the anhydrite rocks), (2) Water from underlying water-bearing formations, and (3) Meteoric water.

Hydration by water which was already present in the pore spaces of the anhydrite and associated lithologies would be expected to take place as soon as the exhumation brings anhydrite rocks up into the stability field of gypsum with respect to rock temperature. Therefore, the transformation takes place under equilibrium conditions (Mossop and Shearman, 1973). They pointed out that the extent of this mode of hydration depends on the amount of the water-filled porosity in anhydrite and associated rocks.

The second is that of hydration by water introduced from underlying water-bearing formations. In some evaporite deposits, such as the Ordovician, Baumann Fiord Formation of Ellesmere Island, Canada, (Mossop, 1973), and the lower Purbeck Evaporites of south and southeast England, (Howitt, 1964), it is the lowermost parts of the anhydrite formations which have been most extensively hydrated to gypsum. Often the upper parts still comprise unaltered anhydrite. In these examples the field relationships indicate that the water was supplied from the underlying water-bearing formations. Usually, where this is the case, satin-spar gypsum veins occur in association with the secondary gypsum rocks. Mossop and Shearman (1973) stated that "In these and similar occurrences, it has

been argued that water made entry into the anhydrite-bearing rocks by hydraulic fracture. The system is believed to have been a closed one, and the additional volume of gypsum produced by hydration of the anhydrite diffused back to the water-filled fractures, where it crystallized out to form the gypsum veins" (p.B149). The stage in exhumation at which the water is introduced to the anhydrite-bearing rocks from below, is important. If the water was introduced during the early stages of exhumation, i.e. as soon as exhumation has taken the rocks out of the stability field of anhydrite with respect to rock temperature, the transformation would take place under more or less equilibrium conditions. On the contrary, if the water was introduced during the late stage of exhumation, the hydration would take place under conditions of disequilibrium (Mossop and Shearman, 1973).

The third possible source of water for hydration is meteoric water; i.e. the hydration was promoted by water introduced from above. In the Castile Formation of Texas and New Mexico, anhydrite has been hydrated to gypsum at outcrop and down to depths of about 70-100 metres from the present day surface, while the underlying parts are characterized by the unaltered anhydrite (Davis and Kirkland, 1970). According to Mossop and Shearman (1973), this is a good example of hydration by water supplied from above. They pointed out that the depth of the hydrated parts of the anhydrite-bearing formations in this mode of hydration is due to the permeability of the rocks. It is also controlled by climatic factors. Hydration by this mode of water supply would be expected to occur under conditions of strong disequilibrium in an essentially open system (Mossop and Shearman op.cit).

2.3. Terminology

Before describing the microscopic features of the secondary gypsum rocks, it is essential to define the terms which will be used. In this chapter the term secondary gypsum is applied to 'any gypsum rock that was derived by hydration of pre-existing anhydrite rocks in the course of exhumation'. This definition excludes the crystals of secondary gypsum with prismatic habit which were formed by hydration of anhydrite during early diagenesis (see chapter V).

Secondary gypsum rocks have two main types of fabric. These are: (i) porphyroblastic fabrics and (ii) alabastrine fabrics. The two differ from one another not only in petrography, but also in their genesis. The subdivision was first made by Ogniben (1957) in his study of the Miocene Sulphur Series of Sicily and has been generally accepted by later workers (e.g. Forbes, 1958; Ham, 1962; West, 1964, 1965; Holliday, 1967, 1970; Mossop, 1973; Mossop and Shearman, 1973; Burgess and Holliday, 1974; Birnboum, 1976; and Orti, 1974, 1976).

Porphyroblastic fabric is generally defined by the following characteristics: coarse crystal size, the presence of corroded anhydrite relics and uniform optical extinction. It probably results from hydration under more or less equilibrium conditions (Mossop and Shearman, 1973).

Alabastrine fabric is a more general term, which includes a wide diversity of secondary gypsum fabric types. Some workers have attempted to sub-divide alabastrine secondary gypsum on the basis of the extinction characteristics, size and shapes and nature of grain boundaries. The various subdivisions which have been proposed are shown in figure (VI.4). Because of the gradations between end-members and intermixing of these even in the area of a single thin section, all fine-grained secondary gypsum rocks will be described as alabastrine in the discussions which follow.

VI. 3. SECONDARY GYPSUM ROCKS OF THE BAYINDIR FORMATION

3.1. Description

Wherever they have been seen exposed to outcrop the gypsum rocks of the Bayindir Formation are wholly secondary and they comprise both porphyroblastic and alabastrine fabrics. Both fabric types can occur side by side in a single specimen (Fig. VI. 5.)

(i) Porphyroblastic fabric

In thin section, crystals of porphyroblastic gypsum are seen to occur, either as isolated crystals, or as aggregates in a groundmass of alabastrine gypsum. They often form narrow selvedges around the periphery of nodules, the central parts of which are alabastrine (Fig. VI. 6). However, it is not unusual to find that some of the smaller nodules are composed entirely of porphyroblastic crystals. Individual porphyroblasts range from 100 to 500 μ up to a few milimetres across. Where present as isolated crystals the porphyroblasts tend to be euhedral (Fig. VI. 7), but in aggregates, they show compromise boundaries and their shapes may vary from thin and needle-like to roughly equidimensional (Fig. VI. 8). The outlines of the individual crystals in aggregates of porphyroblasts vary considerably, once again even within a single specimen some boundaries are consertial and interlocking while others are near linear. Where porphyroblasts lie along side alabastrine fabrics, the junction between the two may be sharp or gradational (Fig. VI.9). The former type leave little doubt that the development of alabastrine fabric post dated the formation of the porphyroblasts (Mossop and Shearman, 1973).

Generally speaking, the porphyroblasts show uniform optical extinction (Figs. VI. 7 , 8 and 9 , but in places, particularly where the boundaries between the porphyroblastic and alabastrine fabrics are gradational the outer parts of the porphyroblasts commonly show a slightly disordered extinction.

Corroded relicts of anhydrite are locally present in some of the porphyroblasts. Their distribution varies from crystal to crystal. In some, the relicts are randomly scattered throughout the crystal either singly or in groups, (Fig. VI.10). In others, they tend to be arranged in groups, either in the central parts of the porphyroblasts or in the outer parts. The presence of these corroded relicts of anhydrite leaves no doubt that the porphyroblasts were replacive in origin. Inclusion of non-evaporitic sediment are present in many porphyroblasts

(ii) Alabastrine Fabrics

The alabastrine fabrics display a wide diversity of sub-types. These range from ill-defined crystals with irregular or undulose extinction at one extreme, to well-defined anhedral crystals with slightly disordered extinction, which interlock with one another in complex fashion, at the other extreme. The latter could be described as granoblastic. All gradations exist between these two end members, but the former is the dominant type throughout the Bayindir Formation. In the lower part of the formation granoblastic fabrics are restricted to areas adjacent to porphyroblasts,

In the upper parts of the formation, where porphyroblasts are absent, granoblastic textures are present, but they occur as vein-like areas in groundmass of the other varieties of alabastrine gypsum.

A photomicrograph of the dominant type of alabastrine fabric of the Bayindir Formation is shown in Figure VI.11. The essential features of this sub-fabric (Type 1 hydration textures of Holliday, 1970) are clearly seen. Firstly, the individual crystals are poorly defined and show irregular and undulose extinction. Secondly, there are large areas which, at first sight, appear to be single crystals, but which on rotation, under crossed-polars break down into masses of sub-crystals, characterized by shadowy grain boundaries (Fig. VI.11,b). Ogniben (1957) used the term "super-individuals" to describe such areas and called the texture "super-individual polarization".

It was mentioned in an earlier chapter that some nodules show a concentric zonation: which superficially resembles liesegang rings. In thin section, under crossed-polars, these nodules are seen to be composed entirely of alabastrine secondary gypsum and the zonation is defined by subtle differences in texture (Fig.VI.12).

(iii) Stratigraphic distribution of the porphyroblastic and alabastrine fabrics.

The general distribution of the porphyroblastic and alabastrine fabrics vertically throughout the Bayindir Formation is presented schematically in Figure VI.13. It can be seen that porphyroblastic secondary gypsum is the dominant fabric type in the lowermost part of the formation. However, porphyroblasts decrease in abundance upwards and are absent in the uppermost parts of the formation. The upwards decrease in porphyroblastic gypsum is accompanied by an increase in the proportion of alabastrine gypsum, which dominates the uppermost parts.

3.2. Interpretation

According to Mossop and Shearman (1973) hydration by water introduced from underlying water-bearing formations leads to production of porphyroblasti fabrics with an associated network of veins of satin-spar gypsum.

The concentration of porphyroblastic gypsum and satin-spar veins in the lower part of the Bayindir Formation suggests that the water which promoted their formation was introduced from the underlying porous Incik Redbeds. This is not to say however that all of the porphyroblasts originated in this way. Some of them may be the products of self hydration. This is suggested by the presence of a few scattered porphyroblasts in the groundmass of alabastrine gypsum in the upper parts of the formation, where satin-spar veins are absent. The presence of these isolated porphyroblasts

can only be explained by hydration by water which was already present in the pore spaces of anhydrite or associated rocks. It is of course impossible to estimate the amount of porphyroblastic gypsum which may have formed by self hydration, relative to the amount of the porphyroblastic gypsum originated by the introduced water.

The gypsum rocks of the uppermost part of the formation are composed entirely of alabastrine secondary gypsum. This suggests that the former anhydrite was hydrated by water introduced from above when the rocks approached outcrop. The presence of the alabastrine gypsum in association with the porphyroblastic gypsum in the lower parts of the formation can also be attributed to the hydration by percolating waters.

A question which arises is that of: when did hydration take place? The presence of a marked unconformity at the top of the formation together with the vertical distribution of the porphyroblastic and alabastrine fabrics suggests that hydration of anhydrite to secondary gypsum may have occurred before deposition of the overlying Kizilirmak and Bozkir Formations. A hypothetical model suggested for hydration of the various parts of the Bayindir Formation is presented schematically in Figure VI. 14.

VI. 4. SECONDARY GYPSUM OF THE BOZKIR FORMATION

4.1. Description

1.1. Gypsum pseudomorphs[1]

On the basis of petrography three types of secondary gypsum pseudomorphs have been recognized. The first consists predominantly of porphyroblastic secondary gypsum with little or no alabastrine gypsum (Fig. VI.15). This

[1]Because of their similar petrographic nature, the gypsum pseudomorphs which occupy the part of the discoidal primary gypsum crystals, and wholly secondary gypsum pseudomorphs are considered together.

type of pseudomorph is mostly found in the lowermost 40-60 metres of the formation. The size of the individual porphyroblasts varies from 200 to 500 μ up to 1 cm. They characteristically carry unreplaced relicts of anhydrite. The distribution of these relicts is similar to those of the Bayindir Formation. The boundaries between the adjacent porphyroblasts vary from place to place: some adjacent porphyroblasts show interlocking crystal boundaries while others are near-linear compromise boundaries. The mudstones in which this type of pseudomorph occurs, contain satin-spar gypsum veins.

The second type of pseudomorph is characterized by the presence of both porphyroblastic and alabastrine fabrics. The porphyroblasts form narrow selvedges around the periphery of the pseudomorphs, while the inner parts are occupied by alabastrine fabric, (Fig. VI. 15). In some pseudomorphs of this type the porphyroblastic rim is not well developed: even so the porphyroblasts tend to occur in the outer parts of the pseudomorphs, (Fig. VI. 16). Where the gypsum is in primary and in part secondary gypsum, porphyroblastic fabrics are also commonly developed in the areas adjacent to the residual primary gypsum. Where they do so, the porphyroblasts are usually in optical continuity with the primary gypsum, (Fig. VI. 17). Other porphyroblasts share all essential features with those of the first type. The alabastrine secondary gypsum is composed mainly of ill defined crystals with irregular and undulose extinction, (Type 1 hyd. textures of Holliday, 1970). In some pseudomorphs well defined crystals with interlocking grain boundaries (granoblastic) also occur; but they are volumetrically insignificant. Where this is the case, the well defined crystals tend to occupy areas adjacent to the porphyroblastic rims. The stratigraphic distribution of this type of pseudomorphs is shown in Figure VI. 18.

In contrast to the first two types, the third type of pseudomorphs contains no porphyroblastic secondary gypsum, but consists entirely of alabastrine secondary gypsum. Figure VI. 19 is a photomicrograph of a thin section of a pseudomorph of this type. These pseudomorphs occur in the upper parts of the formation (Fig. VI.18), and they are closely similar to those of the uppermost parts of the Bayindir Formation.

1.2. Laminar secondary gypsum rocks

Wherever the laminar secondary gypsum rocks are found in the lowermost 40-60 metres of the formation, they are characterized by the predominance of porphyroblastic fabrics over alabastrine fabrics. In the uppermost parts of the formation however, they are composed entirely of alabastrine fabrics, (Fig. VI.20). Thus the distribution of the secondary gypsum fabrics in these rocks are closely similar to that of the pseudomorphs described above (compare Figures VI. 18 and VI. 20).

The microscopic features of both porphyroblastic and alabastrine secondary gypsum fabrics of the laminar secondary gypsum rocks of the Bozkir Formation are closely similar to those in the Bayindir Formation and it is not necessary to redescribe them. However, there is an unusual form of porphyroblastic fabric which merits attention. In some thin sections there are groups of rectangular, square and triangular-shaped optically continuous areas of gypsum which are seperated from one another by a brown coloured carbonate matrix. The gypsum of these areas contains corroded relicts of anhydrite,(Figure VI. 21) and is obviously secondary gypsum. The original crystals were anhydrite which were probably replacive in origin.

4.2. Interpretation

The evidence which appears to be critical to the understanding of the hydration pattern of the Bozkir Formation is as follows:-

1. The satin-spar veins characteristically occur in the lowermost parts of the formation, but they are absent in the upper parts.
2. Porphyroblastic gypsum is the predominant fabric in the lowermost parts of the formation, while the uppermost parts are composed entirely of alabastrine fabrics.
3. The progressive upwards decrease in the proportion of porphyroblastic gypsum is accompanied by progressive increase in the proportion of alabastrine gypsum.
4. There is a positive relationship between the amount of porphyroblastic gypsum and the abundance of satin-spar gypsum veins in the lowermost parts of the formation.
5. After the lowermost 30-40 metres of the formation the satin-spar veins disappear but scattered porphyroblasts in a groundmass of alabastrine gypsum up to about 100 metres from the base are present.

These lines of evidence clearly indicate that the Bayindir and Bozkir Formations both had similar hydration patterns, (compare Figs.VI.14 and 22). However it seems that the amounts of porphyroblasts which resulted from self hydration was greater in the Bozkir Formation than in the Bayindir Formation.

VI.5. MUTUAL RELATIONSHIP BETWEEN PORPHYROBLASTIC AND ALABASTRINE SECONDARY GYPSUM FABRICS.

It has already been mentioned that where porphyroblastic gypsum occurs in association with the alabastrine fabrics, the outlines of porphyroblasts are usually irregular and finger-like extensions of the porphyroblasts penetrate into the alabastrine fabrics. (Fig. VI. 9). In such cases the boundaries between the two fabrics have a gradational appearance (Fig. VI. 9). Examples can be found in both the Bayindir and Bozkir Formations. Most published descriptions of secondary gypsum

rocks mention this relationship (e.g. Ham, 1962; Holliday, 1976, 1970; Mossop and Shearman, 1973; Burgess and Holliday, 1974; and Orti, 1976).

Some workers have argued that these gradational boundaries resulted from recrystallization of the margins of the porphyroblasts in harmony with development of the alabastrine fabrics (Ham, 1962; Holliday, 1967, 1970; Burgess and Holliday, 1974 and Birnboum, 1976). It has been argued that hydration of anhydrite to form porphyroblastic gypsum takes place under more or less equilibrium conditions, whereas alabastrine gypsum is the result of near surface or outcrop hydration under conditions of strong disequilibrium. If such was the case, there is no reason why porphyroblastic secondary gypsum should recrystallize in harmony with the alabastrine fabric. Other authors, however, suggested that these gradational boundaries are original hydration textures, not in any way the result of recrystallization (Mossop and Shearman, 1973; Orti, 1976). Mossop and Shearman (op.cit.) stated that "The phenomenon could arise during hydration where pre-existing porphyroblasts were tending to scavenge the" 'calcium and sulphate ions' "to form overgrowths, but where the rate of growth was too rapid to allow the overgrowths to become properly ordered" (p. B.153).

The present writer examined thin sections cut from cores of the Purbeckian anhydrite rocks of the Walingham borehole, south London. In these cores, the anhydrite has only been slightly hydrated to secondary gypsum; all of which is porphyroblastic. Some of the porphyroblasts have irregular outlines with finger-like extensions which penetrate into the parent anhydrite (Fig. VI.23 a,b). It needs little imagination to picture the fabrics which result if the remainder of anhydrite were to be hydrated to alabastrine secondary gypsum. The boundaries between the porphyroblasts and the alabastrine fabrics would be gradational, and indistinguishable from the so called recrystallization texture (Fig. VI.24 a,b). Thus it is

concluded that some at least of the gradational boundaries between porphyroblastic and alabastrine fabrics in secondary gypsum rocks are simple hydration features (Fig. VI.25)

VI.6 SATIN-SPAR VEINS

Reference has already been made to the presence of horizontal to subhorizontal and vertical to subvertical veins of satin-spar gypsum which occur in the lower parts of the Bayindir and Bozkir Formations and the topmost parts of the Incik and Kizilirmak Formations. They are present in both the secondary gypsum rocks and the associated mudstones.

(i) Microscopic features

Thin sections cut parallel to the length of the gypsum fibres show a fibrous texture in ordinary transmitted light. However under crossed polars it is found that groups of adjacent fibres all go into extinction together (Fig. VI.26). This can be better seen by the use of a sensitive tint. The relationship suggests that the groups of fibres are in effect parts of a single crystal in lattice continuity with one another. Many veins do not show fibrous structure, but comprise blocky crystals of gypsum and gradations can be found between fibrous and non-fibrous veins.

In those secondary gypsum rocks, where the walls of the veins comprise porphyroblastic gypsum, the fibres or the crystals of the veins are usually found to be in optical continuity with the adjacent porphyroblasts (Fig. VI.27).

(ii) Relationship between the satin-spar veins and secondary gypsum rocks

The occurrences of satins-spar gypsum veins in association with gypsum-anhydrite rocks is a common one in many parts of the world (e.g. Richardson, 1920; Bundy, 1956; Forbes, 1958; West, 1956, Aljubouri, 1971; Shearman et.al., 1972; Mossop, 1973; Smith and Moore, 1973; and Burgess and Holliday, 1974).

In the porphyroblastic secondary gypsum rocks themselves there is little or no evidence of any increase in volume, and some workers have suggested that the gypsum of the veins represents the additional volume of gypsum which was generated by the hydration of anhydrite, which is a product of volume for volume replacement of anhydrite by gypsum represented, in part at least, by the gypsum veins (Bundy, 1956; West, 1965; and Shearman et.al., 1972).

However, different explanations have been suggested for the mechanism of emplacement of the veins. One suggestion is that of the mechanical force of crystallization. According to Bundy (1956), the vein walls were separated by the mechanical force of crystallization of gypsum to provide space for the growth of transverse veins. Shearman et.al, (1972) argued that "If the mechanical force of crystallization of the gypsum in the veins were sufficient to open up fractures in the rock, it is pertinent to enquire why the additional volume of gypsum should have migrated from the site of its parent anhydrite. It could equally well have crystallized and have caused expansion in situ" (p. B.149). As an alternative explanation they suggested that where the gypsum veins are present in association with secondary gypsum rocks, the veins originated as hydroulic fractures which were opened up by injection of water from underlying water-bearing formations. The gypsum grows passively in these water-filled fractures (Shearman et.al., 1972 p. B.150). In most instances the gypsum veins are of 'cross-fibre' type, i.e. the individual gypsum fibres extend from wall to wall (e.g. Bundy, 1956; West, 1965, Shearman et.al., 1972, Aljubouri, 1971; and Burgess and Holliday, 1974). Therefore the question which arises is that, if gypsum grows passively in the water filled fractures, how could the fibrous structure be developed? According to Shearman et.al. (1972), the gypsum grew in the water-filled fractures as coarsely crystalline aggregates, sometimes as overgrowths on the porphyroblasts of the walls. During this stage the

the overburden would be supported by the water and the crystals would grow under hydrostatic conditions. However on completion of the vein filling or when the residual water escaped to higher levels, the overburden load will be transferred to the crystals of the veins. The fibrous structure is believed to have developed in response to the superimposition of overburden load.

However it has been argued by Burgess and Holliday (1974) that the origin of satin-spar veins is not directly related to the formation of the porphyroblastic gypsum by water introduced from the underlying water-bearing formations. They found that the amount of satin-spar veins exceeds the total volume of porphyroblastic gypsum and the porphyroblasts were formed later than the formation of satin-spar veins. Burgess and Holliday (1974) concluded that the connate brines could be trapped in the formations by compaction, because of impermeable nature of anhydrite rocks. This entrapment could result in development of hydraulic over pressure. They agreed with Shearman et.al. (1972) from this point, i.e. hydraulic fracture, passive growth of gypsum crystals while overburden is supported by water and development of the fibrous structure when overburden load is transferred to the crystals by escaping of water.

Before discussing the mode of formation of the satin-spar gypsum veins in the area studied, it is necessary to review the field and laboratory observations which have been presented in chapters III and V.

1. The horizontal to sub-horizontal satin-spar veins of gypsum occur abundantly in the basal parts of both the Bayindir and Eski Celtek Formations.
2. In both formations, the number and the thickness of the individual veins decrease progressively upward, and finally disappear in the upper parts.
3. There is a positive relationship between the abundance of porphyroblastic secondary gypsum and the thickness and number of the horizontal satin-spar veins.

4. Both the Bayindir and the Eski Celtek Formations are underlain by porous fluviatile redbeds.

5. In addition to the horizontal to sub-horizontal veins, many vertical to sub-vertical satin-spar veins have been observed. These typically occur in the mudstones which underlay the gypsum units in the lower parts of both formations.

6. In thin section, under the microscope groups of adjacent fibrous gypsum crystals go into extinction together. This suggests that the fibres which go into extinction together were initially one single crystal and fibrous structure was induced.

7. Where the satin-spar veins occur in association with the porphyroblasts, the satin-spar is usually in optical continuity with adjacent porphyroblasts.

On the basis of these lines of evidence it seems unlikely that any mechanism other than that of hydraulic fracture proposed by Shearman et.al., (1972) can satisfactorily explain the various features shown by the satin-spar gypsum veins encountered in both the Bayindir and Eski Celtek Formations. If connate brines were, as suggested by Burgess and Holliday (1974), there should be no relationship between the veins and the distribution of the porphyroblastic secondary gypsum. One would, for example, expect the satin-spar veins should be present in the upper parts of the formation where the secondary gypsum rocks are composed almost entirely of alabastrine secondary gypsum with only a few scattered porphyroblasts.

Some of the satin-spar veins, particularly the thick ones, appear to be multiple. It was suggested by Shearman et.al. (1972) that such multiple veins could be the products of several episodes of water injection. The problem with the mechanism of hydraulic fracture is that of how repeated episodes of hydraulic overpressure were achieved. Seismic pumping (Sibson et.al., 1975) is a likely process.

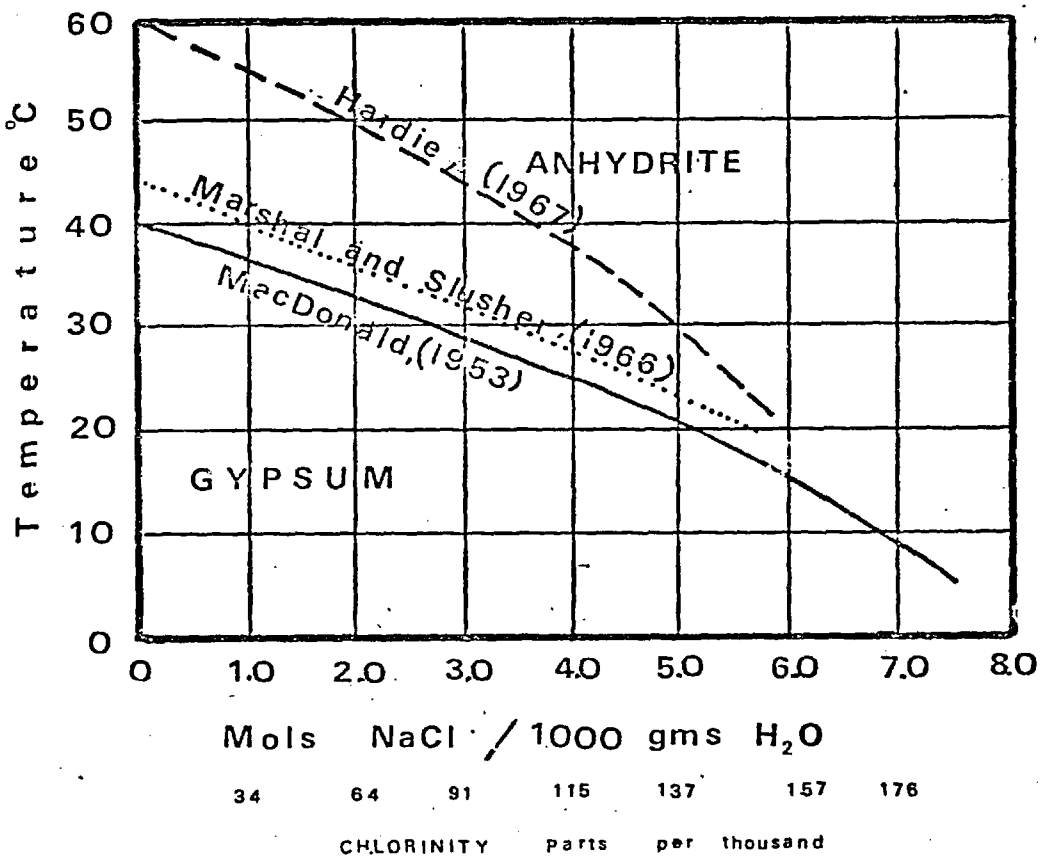


FIG. VI.1 The effect of sodium chloride in solution to the transition temperature of gypsum – anhydrite, at one atmosphere pressure, according to various workers.

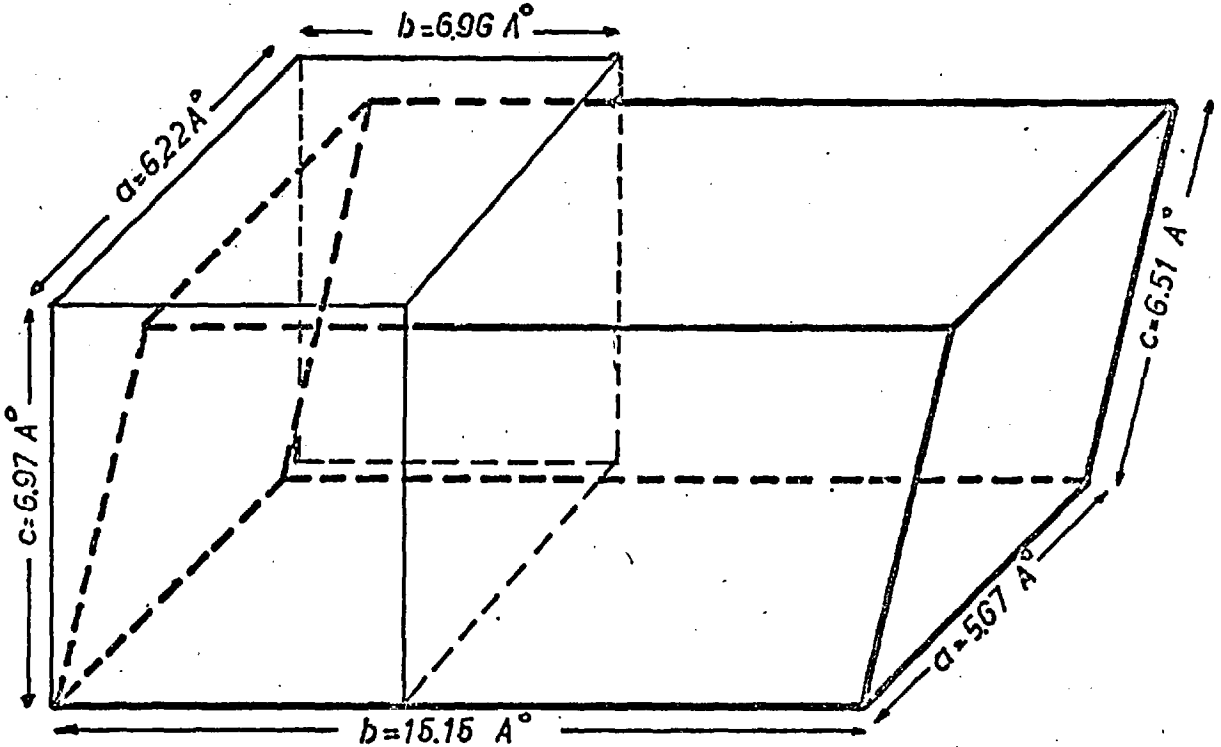


FIG. VI.2 Comparison of unit cell dimensions of gypsum (Thick lines) and anhydrite (Thin lines).(After Bundy, 1956)

	ANHYDRITE		WATER		GYPSUM
	$CaSO_4$	+	H_2O	⟶	$CaSO_4.2H_2O$
Molecular weight	136		36		172
Density	2.899-2.985		1.0		2.314-2.328

$$\text{Volume} = \frac{\text{Mass}}{\text{Density}} \qquad \text{Mass} = \text{Molecular weight}$$

$$\text{Volume} \quad \frac{136}{2.899} - \frac{136}{2.985} \qquad \frac{36}{1.0} \qquad \frac{172}{2.314} - \frac{172}{2.328}$$

	46.9-45.8 Volumes	+	36 Volumes	⟶	74.4-73.9 Volumes
	100 Vol.	+	36 Vol.	⟶	163 Vol.

FIG.VI.3 Volume changes involved in hydration of anhydrite to gypsum (After Mossop and Shearman, 1973)

HOLLIDAY, 1970	ORTI, 1976	MOSSOP and SHEARMAN	PRESENT STUDY
PORPHYROBLASTIC	PORPHYROBLASTIC PORPHYRITIC	PORPHYROBLASTIC	PORPHYROBLASTIC FABRICS
TYPE II HYDRATION TEXTURES (Granoblastic)	GRANOBLASTIC	Granoblastic ALABASTRINE	ALABASTRINE FABRICS
TYPE I HYDRATION TEXTURES	NON-UNIFORM EXTINCTION COMPONENTS		

FIG. VI.4 Comparative table showing the classifications of secondary gypsum rocks according to various workers.

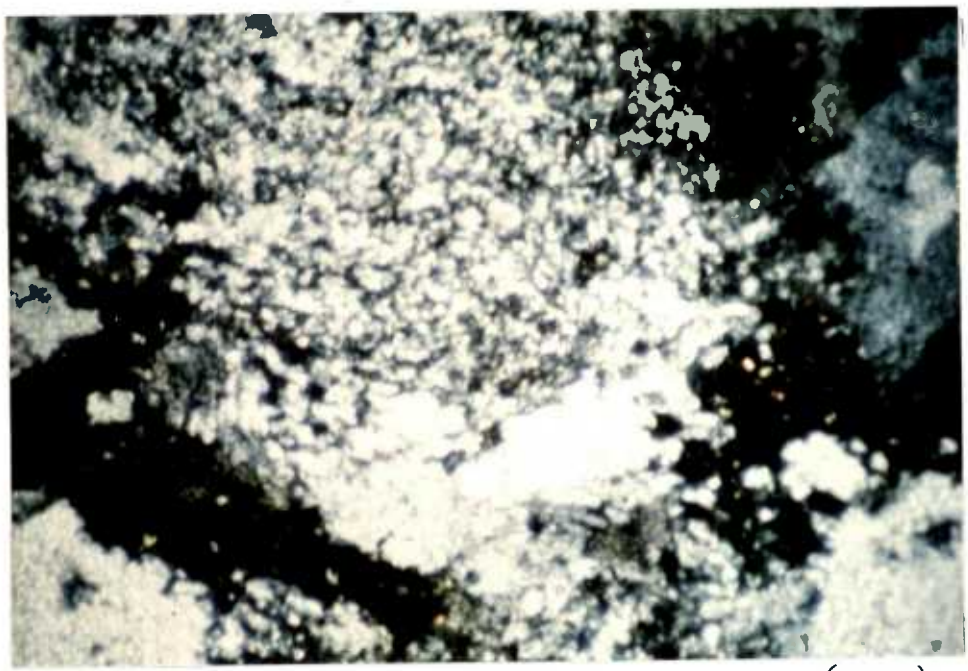


FIG. VI.5 Photomicrograph of a typical secondary gypsum rock of the Bayindir Formation showing porphyroblastic and alabastrine fabrics side by side. Crossed polars.

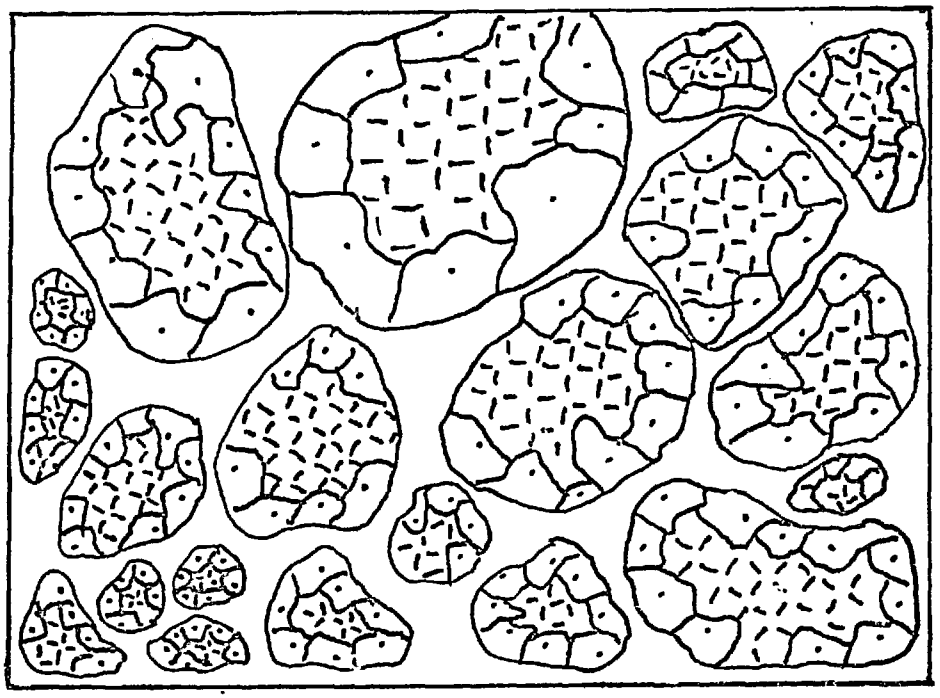


FIG. VI.6 Schematic drowing of a thin section cut from secondary gypsum rocks of the Bayindir Formation.The porphyroblastic fabrics form narrow selvedges around the periphery

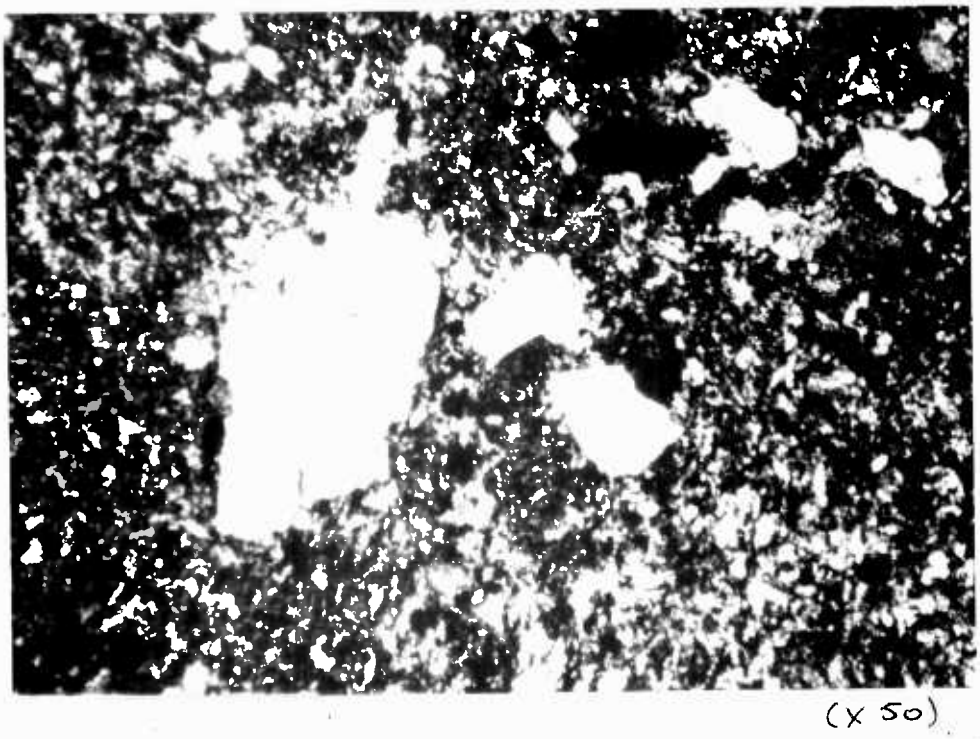
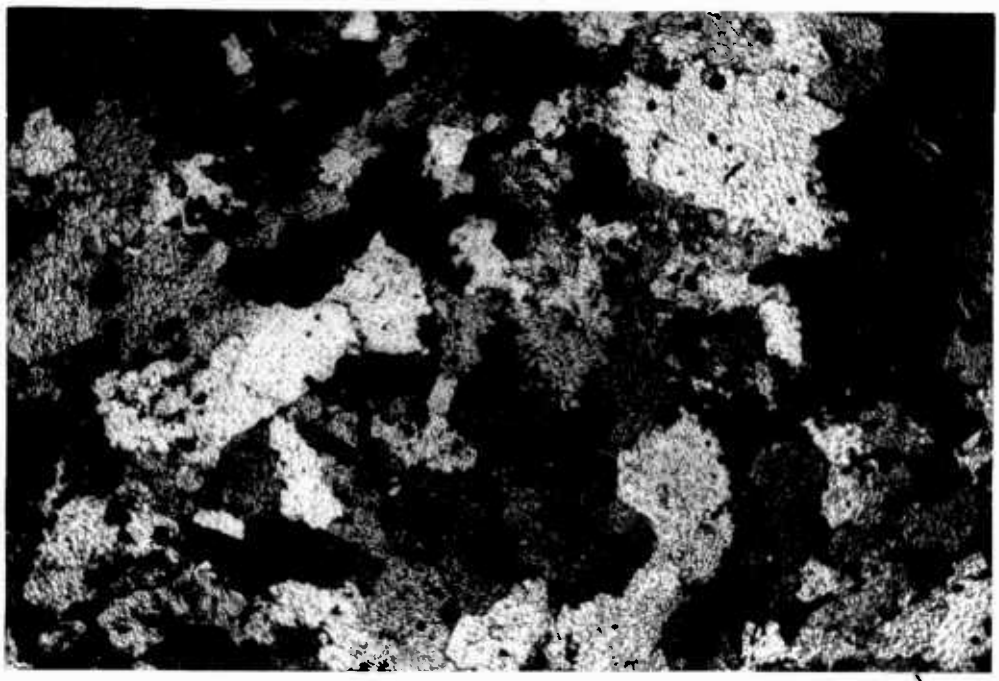
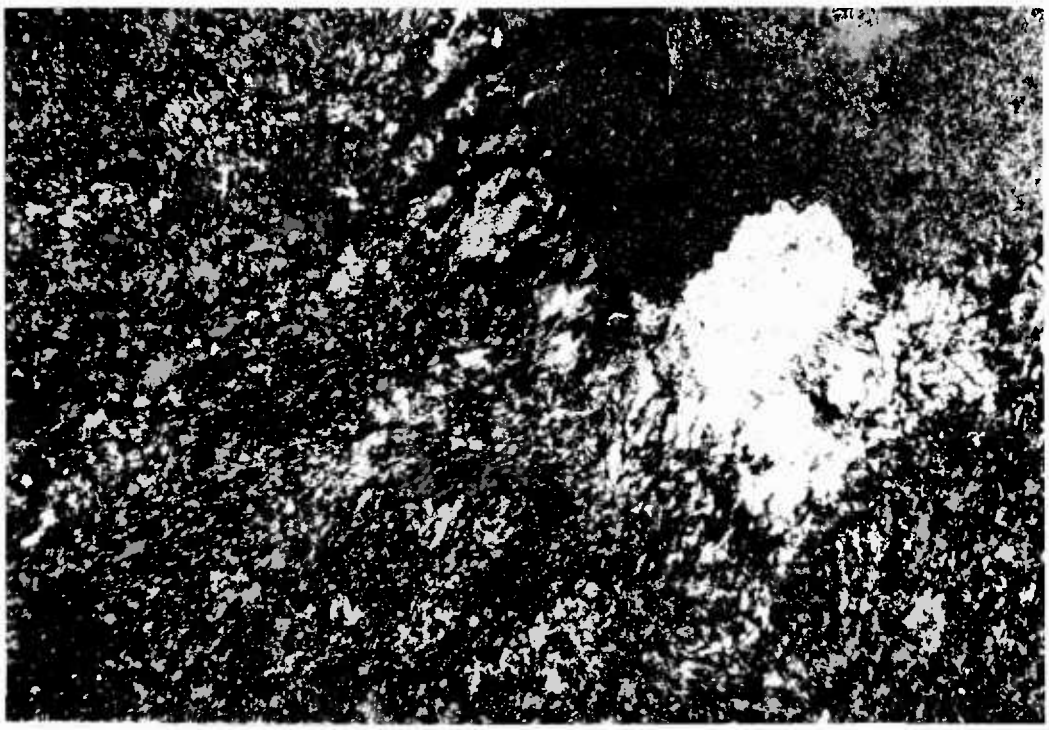


FIG. VI.7 Isolated euhedral porphyroblasts in the groundmass of alabastrine secondary gypsum.Bayindir Formation.Crossed-polars.



(X30)

FIG. VI.8 Aggregates of porphyroblasts.Note the shapes of the individual crystals and the boundaries between them.Crossed polars.



(×40)

FIG. VI.9 Gradational boundary between porphyroblastic and alabastrine fabrics of secondary gypsum. Bayindir Formation.(Crossed polars)

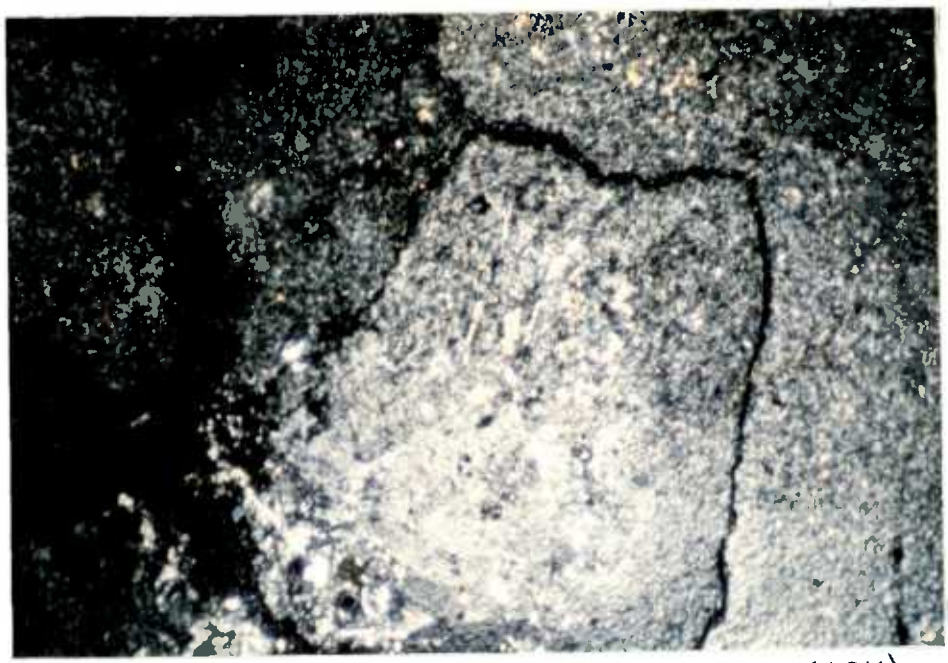
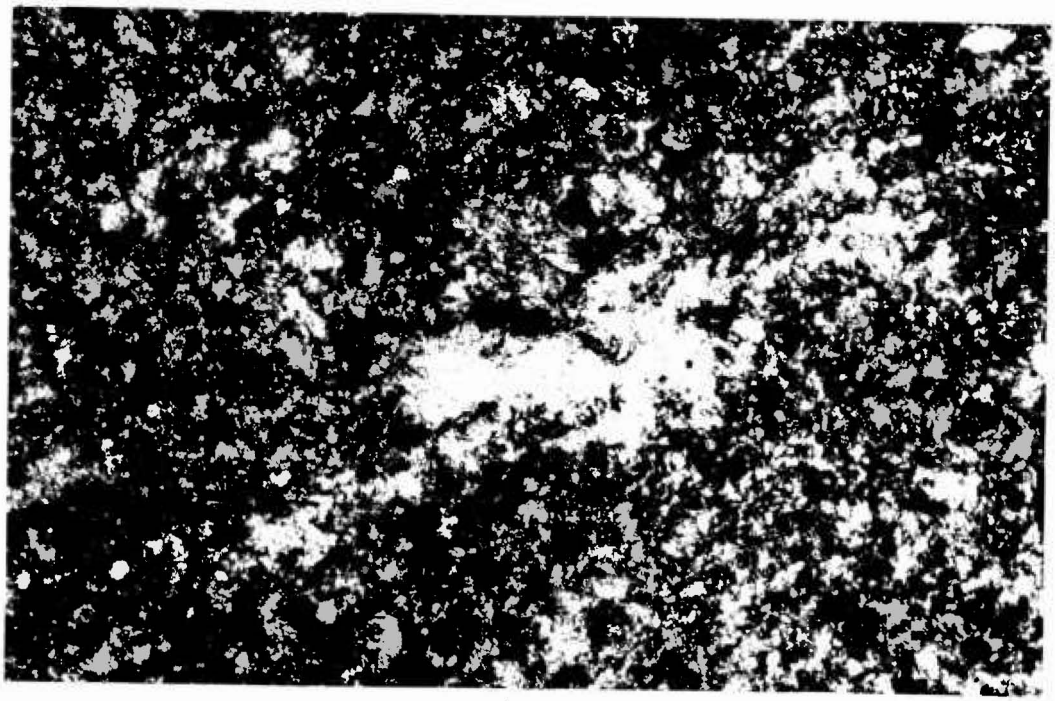
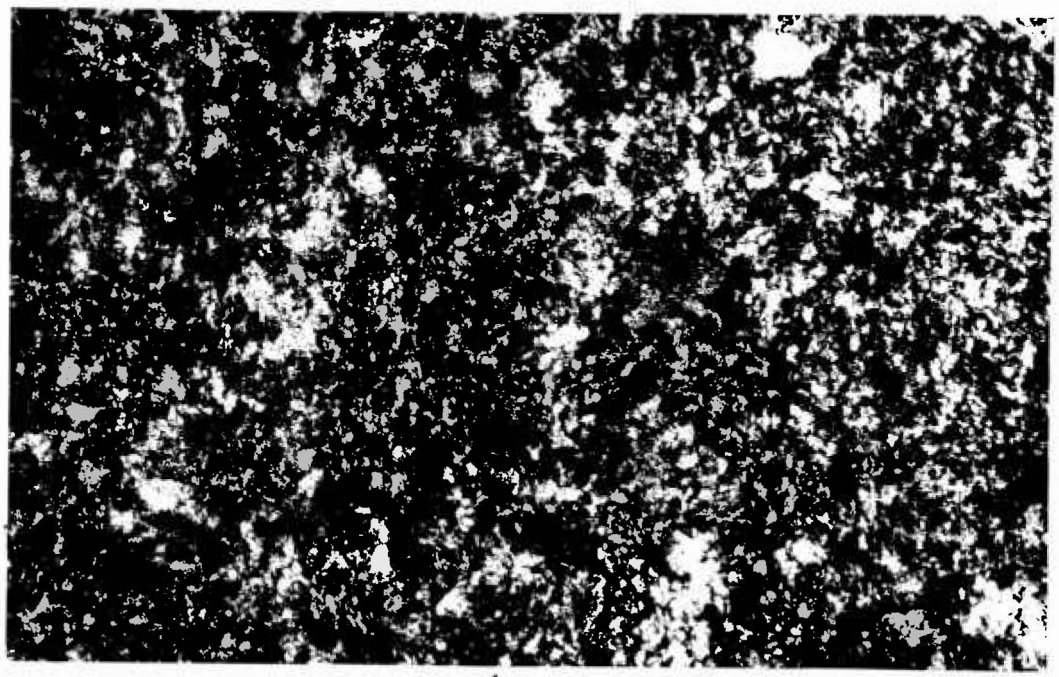


FIG. VI.10 Colour photomicrograph showing corroded relics of anhydrite enclosed in porphyroblastic secondary gypsum:Bayindir Formation.(Crossed polars)



(a)



(b) (x 40)

FIG. VI.11 Low magnification photomicrograph of the dominant type of alabastrine fabrics of the Bayindir secondary gypsum rocks.The individual crystals are poorly defined and show irregular extinction and locally groups of crystals go into illumination which appear to be single crystals(a) but on rotation break down into masses of sub-crystals with shadowy grain boundaries(b).

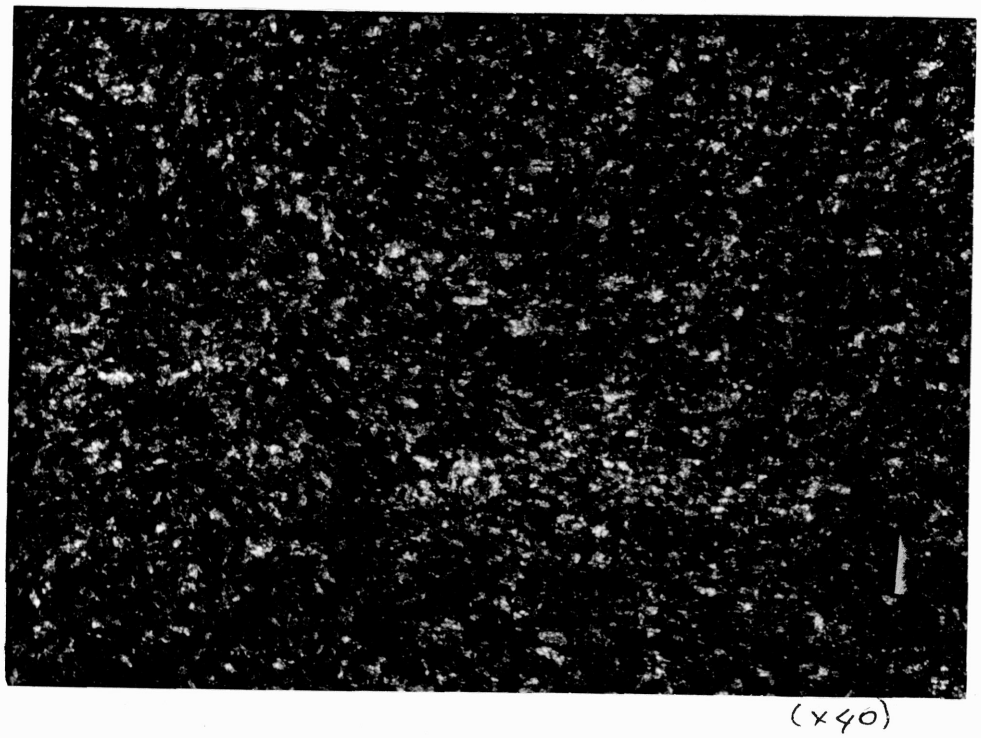


FIG. VI.12 Low magnification photomicrograph of a gypsum nodule which shows concetric zoning,Note the textural difference:Bayindir Formation.(Crossed polars).

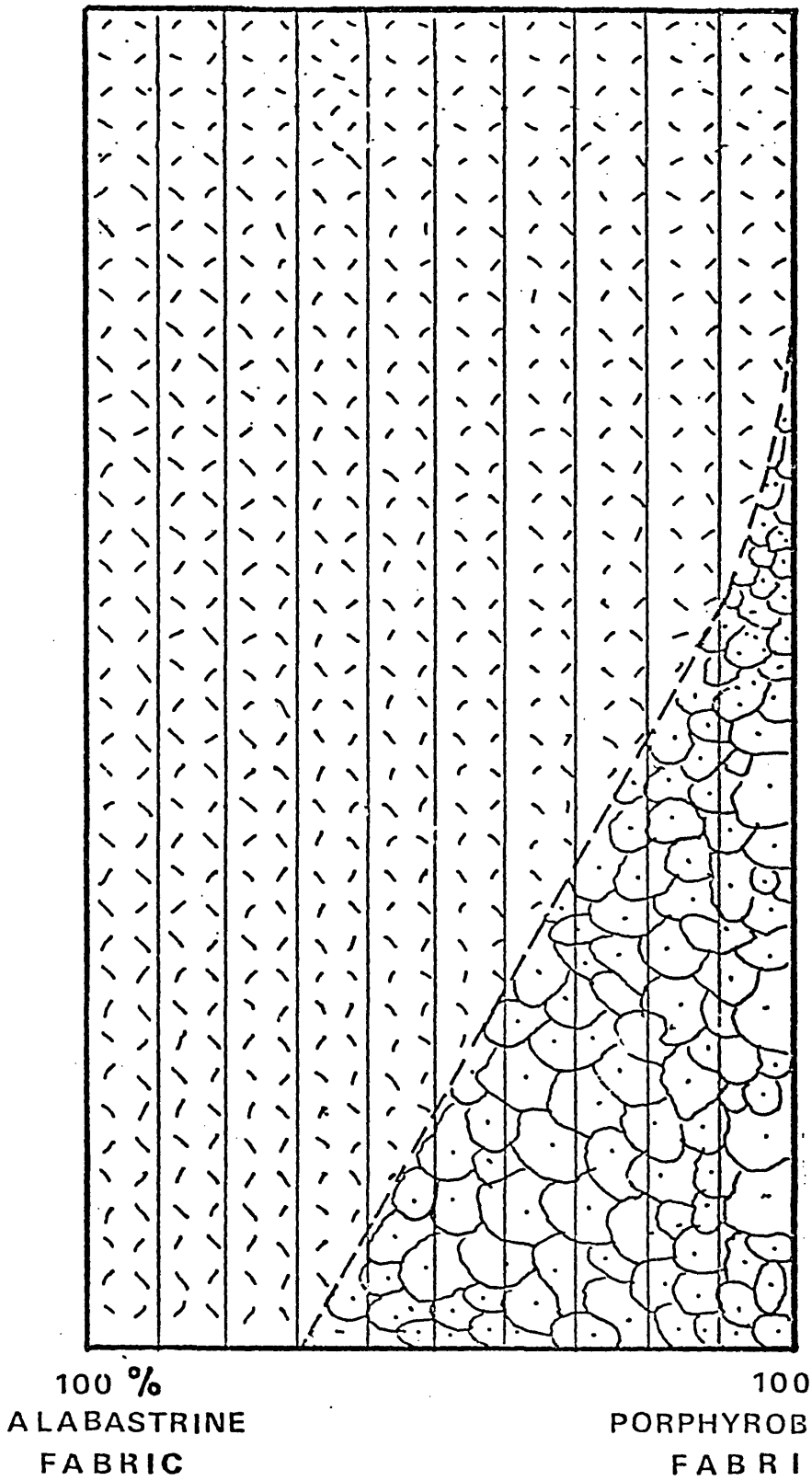
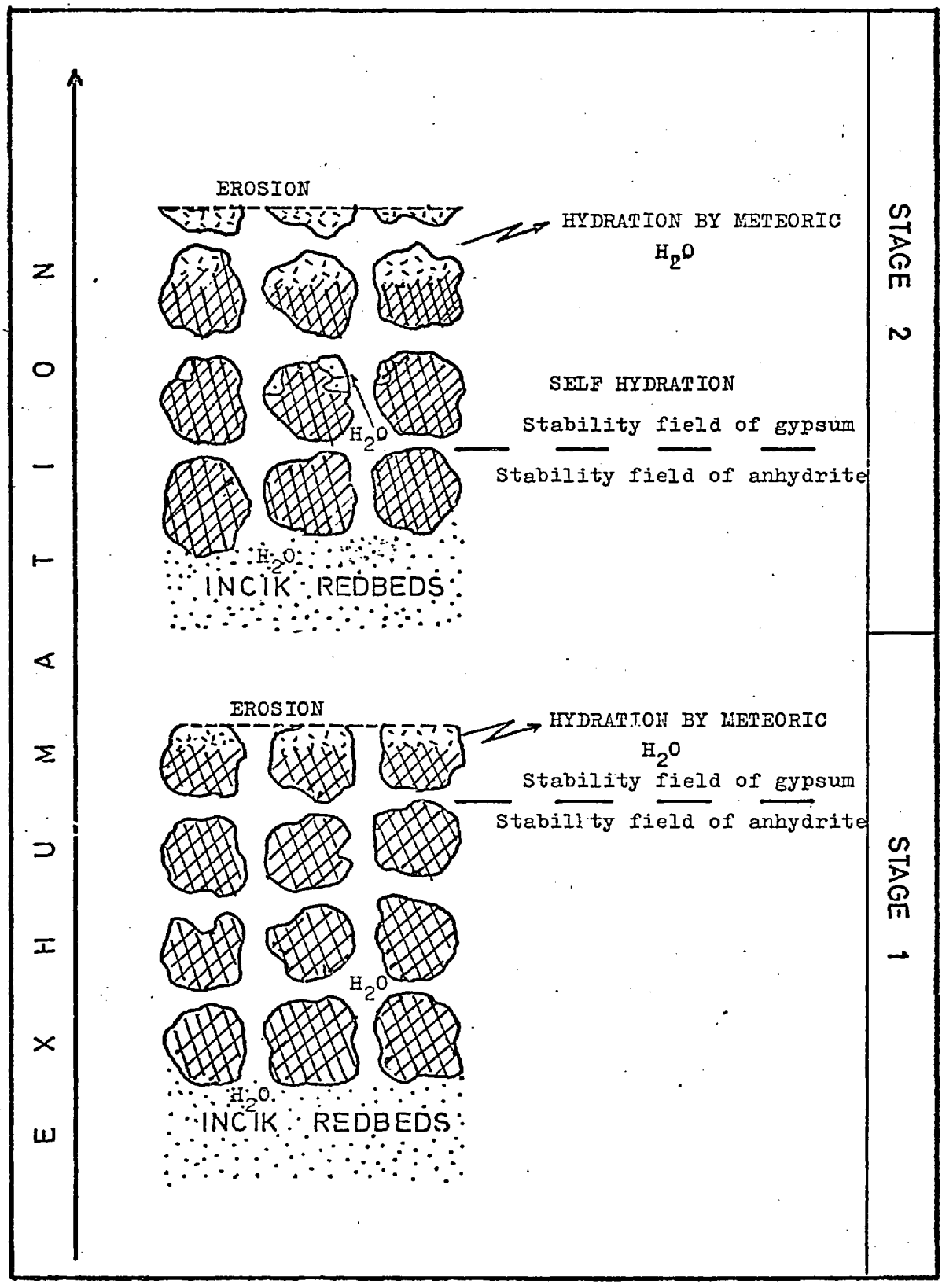
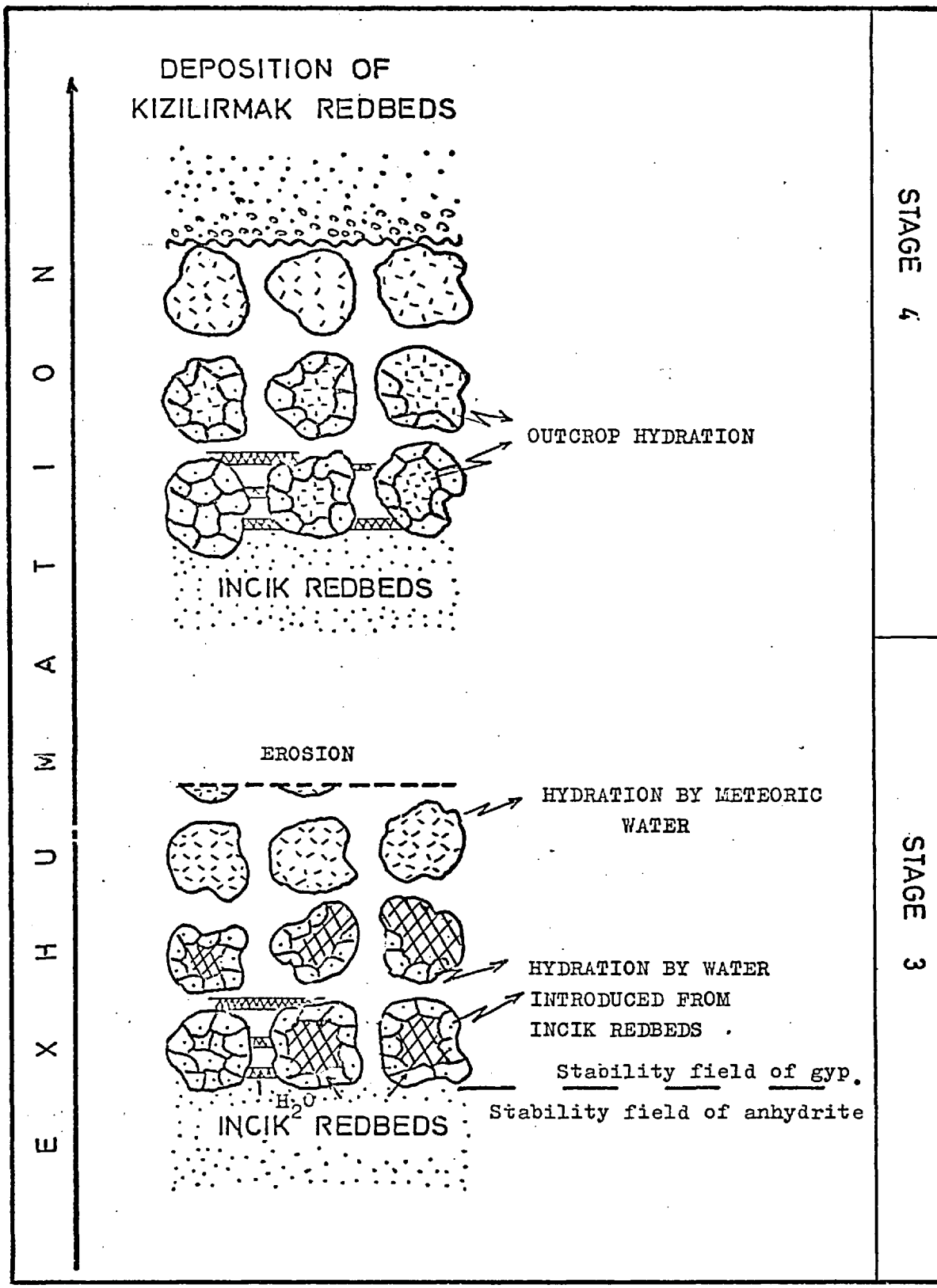


FIG. VI.13 Schematic presentation of the stratigraphic distribution of the secondary gypsum fabrics in the Bayindir Formation.

FIG. VI.14 Schematic presentation of the suggested modes of hydration which effected former anhydrite rocks in the Bayindir Formation.


EXHUMATION
STAGE 2
STAGE 1
EROSION
HYDRATION BY METEORIC
H_2O
SELF HYDRATION
Stability field of gypsum
Stability field of anhydrite
H_2O
H_2O
INCIK REDBEDS
EROSION
HYDRATION BY METEORIC
H_2O
Stability field of gypsum
Stability field of anhydrite
H_2O
H_2O
INCIK REDBEDS


DEPOSITION OF
KIZILIRMAK REDBEDS
OUTCROP HYDRATION
INCIK REDBEDS
EROSION
HYDRATION BY METEORIC
WATER
HYDRATION BY WATER
INTRODUCED FROM
INCIK REDBEDS .
Stability field of gyp.
Stability field of anhydrite
H_2O
INCIK REDBEDS
EXHUMATION
STAGE 4
STAGE 3

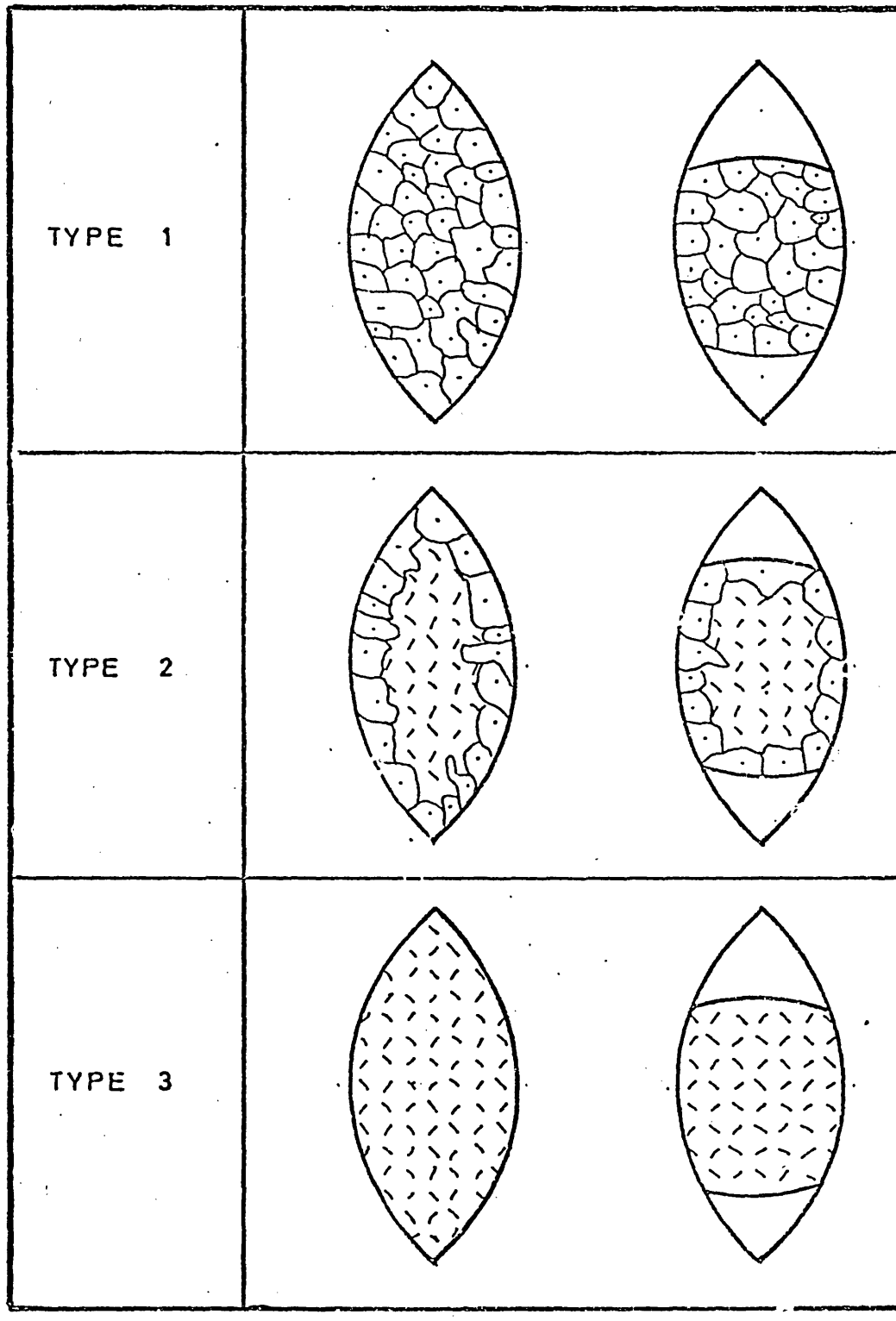
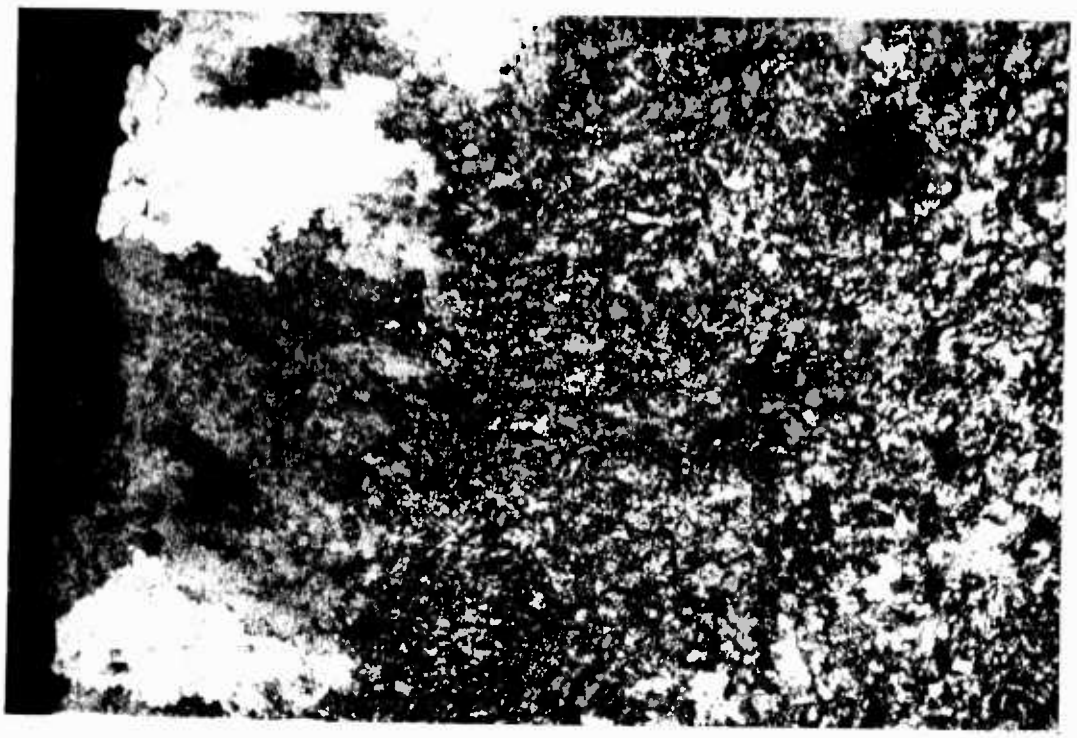


FIG. VI.15 Schematic diagram showing types of secondary gypsum pseudomorphs found in the Bozkir Formation.



(x 30)

FIG. VI.16 Low magnification photomicrograph of the second type of gypsum pseudomorphs. Porphyroblastic fabrics form a selvedge around the periphery of the pseudomorph: Bozkir Formation. (Crossed polars).

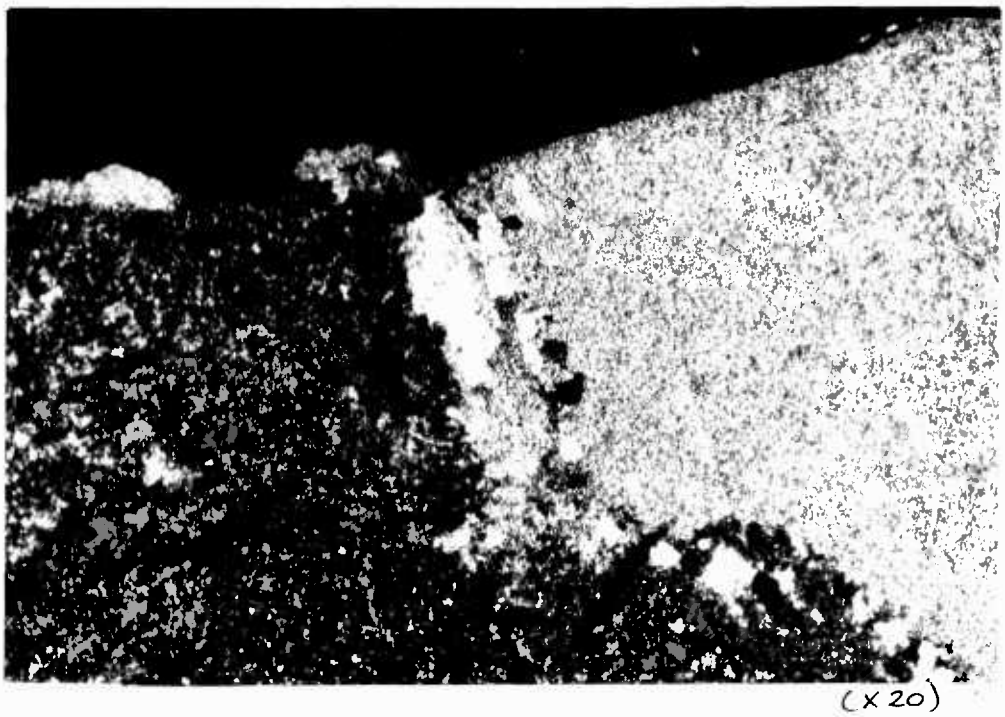


FIG. VI.17 Optical continuity between primary gypsum and porphyroblastic secondary gypsum in the in part primary in part secondary gypsum crystals:Bozkir Formation.(Crossed polars)

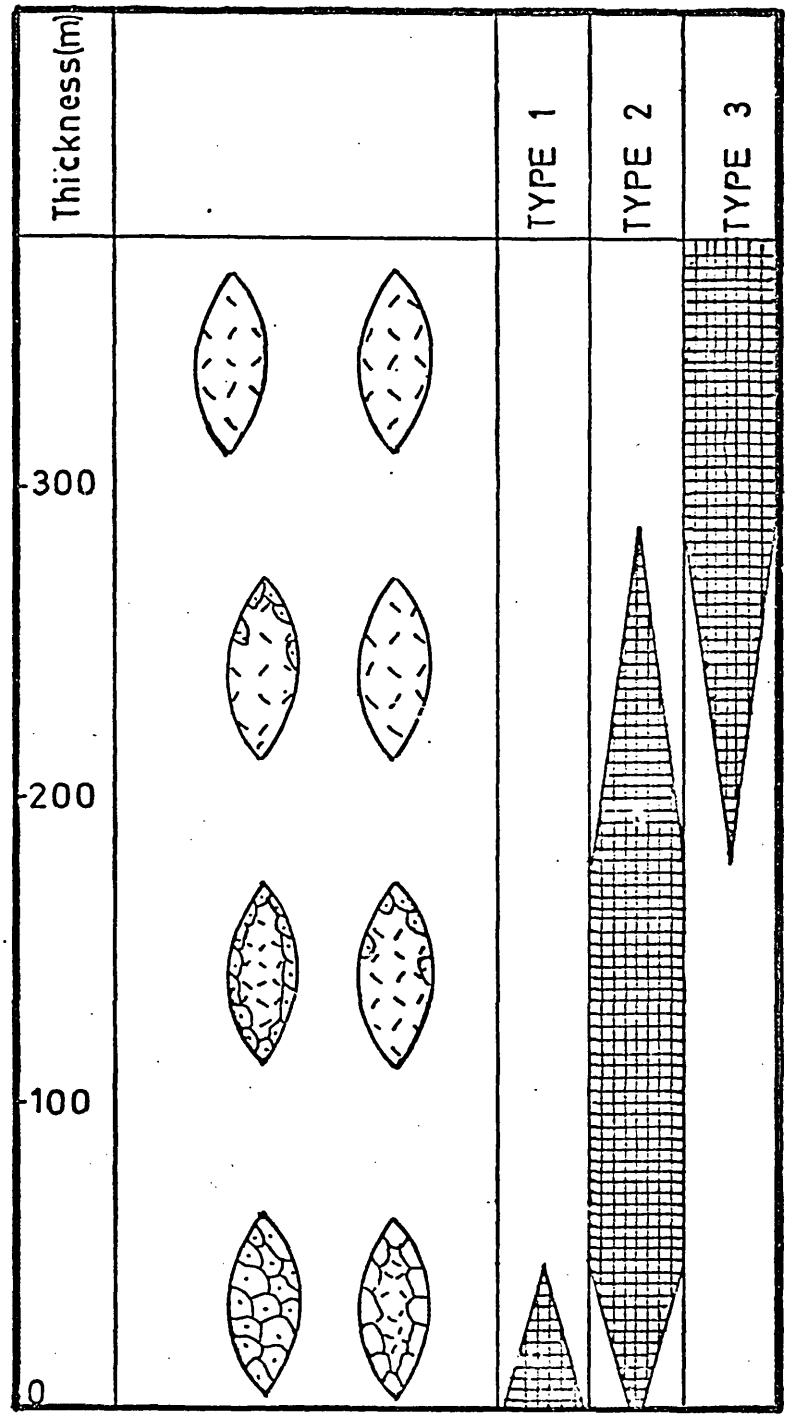
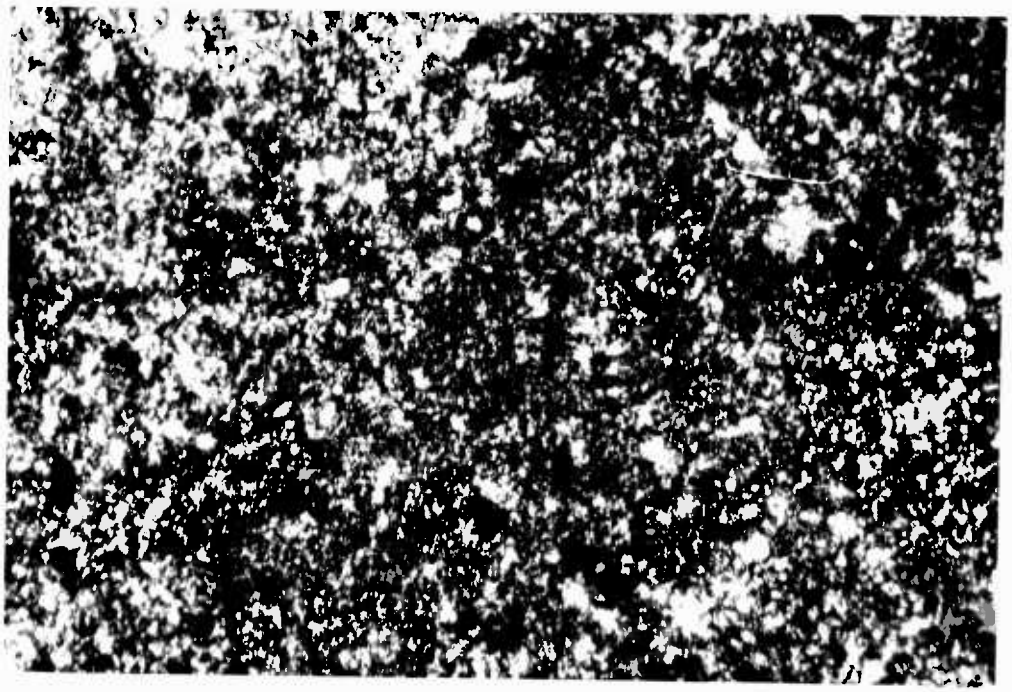


FIG. VI.18 Schematic presentation of the approximate stratigraphic distribution of the various types of secondary gypsum pseudomorphs in Bozkir Formation.



(X 36)

FIG. VI.19 Photomicrograph of the third type of secondary gypsum pseudomorphs: Bozkir Formation.(Crossed polars).

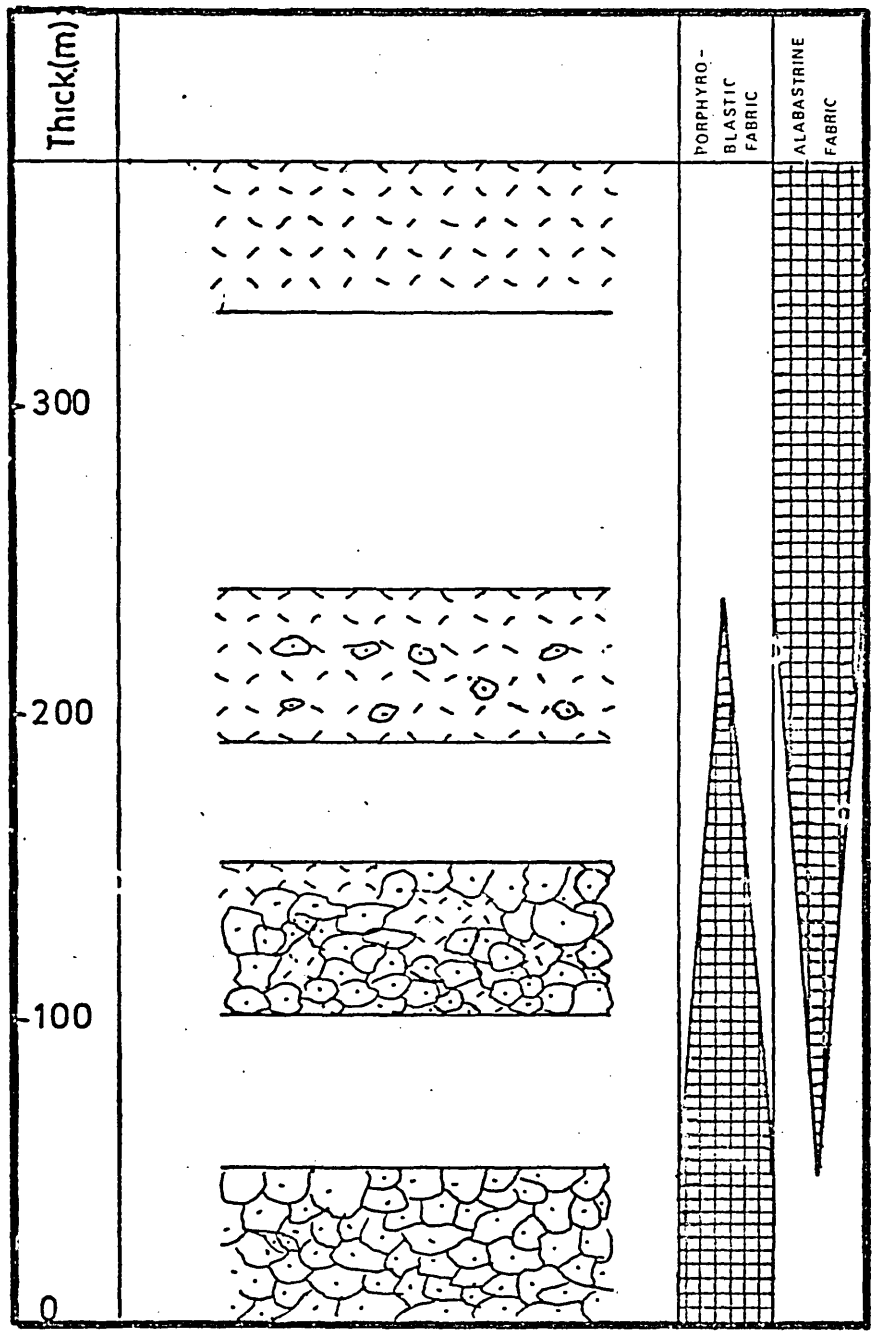


FIG. VI.20 Schematic presentation of the approximate stratigraphic distribution of porphyroblastic and alabastrine secondary gypsum fabrics in the laminar secondary gypsum rocks of the Boz-kir Formation.

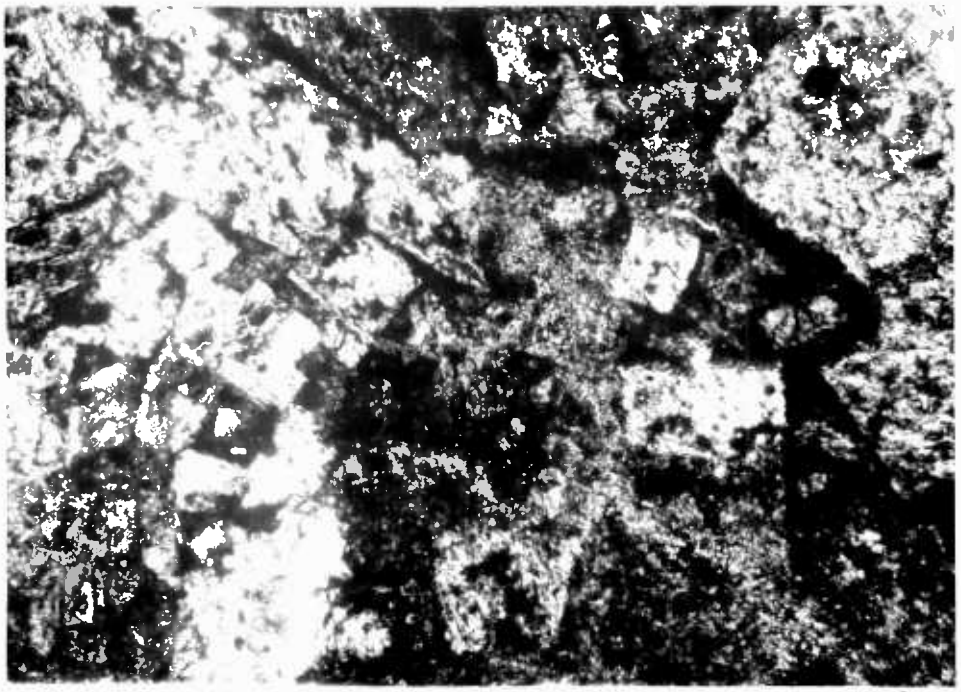


FIG. VI.21 Secondary gypsum pseudomorphs after anhydrite. (Crossed polars)

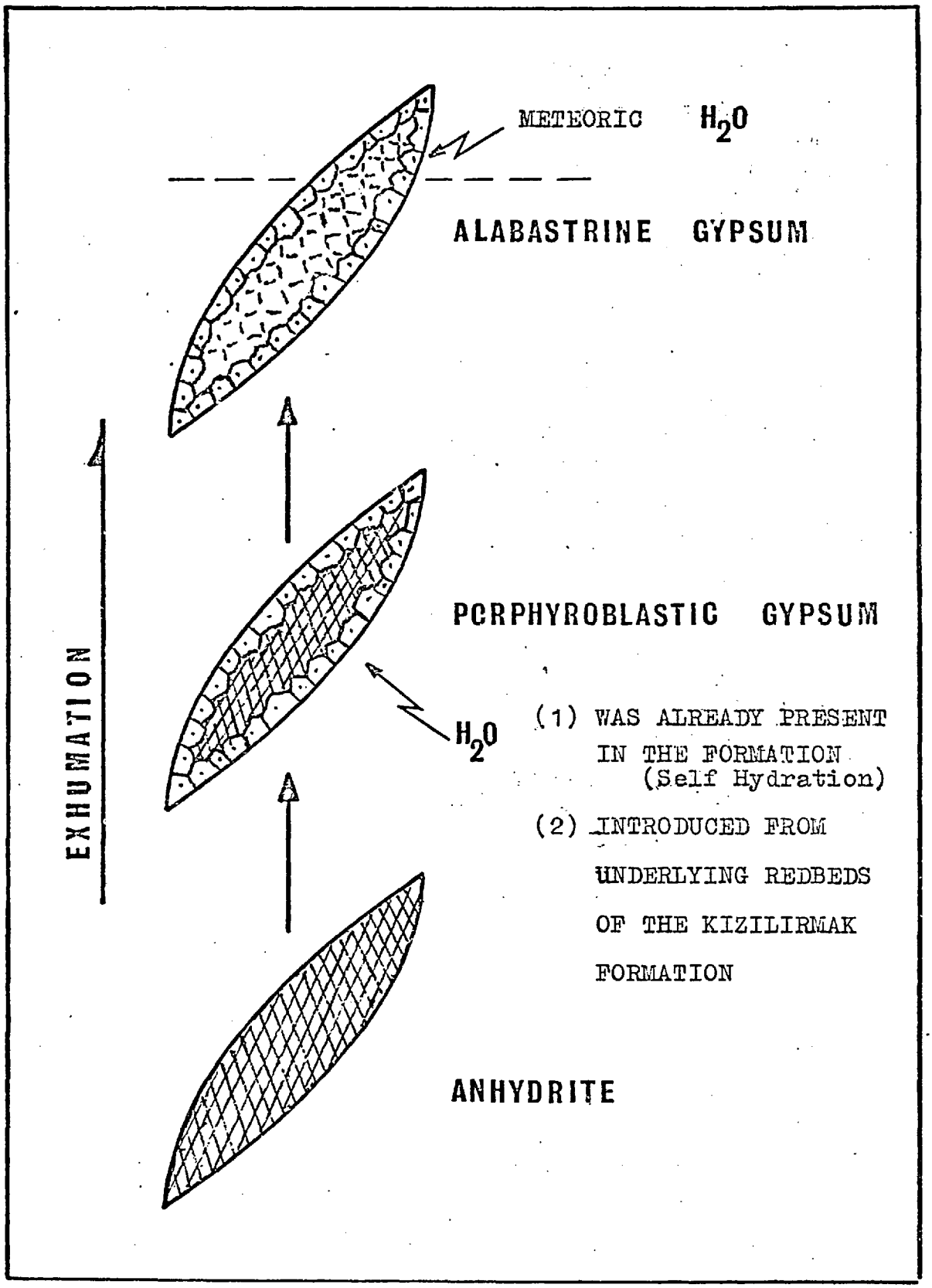
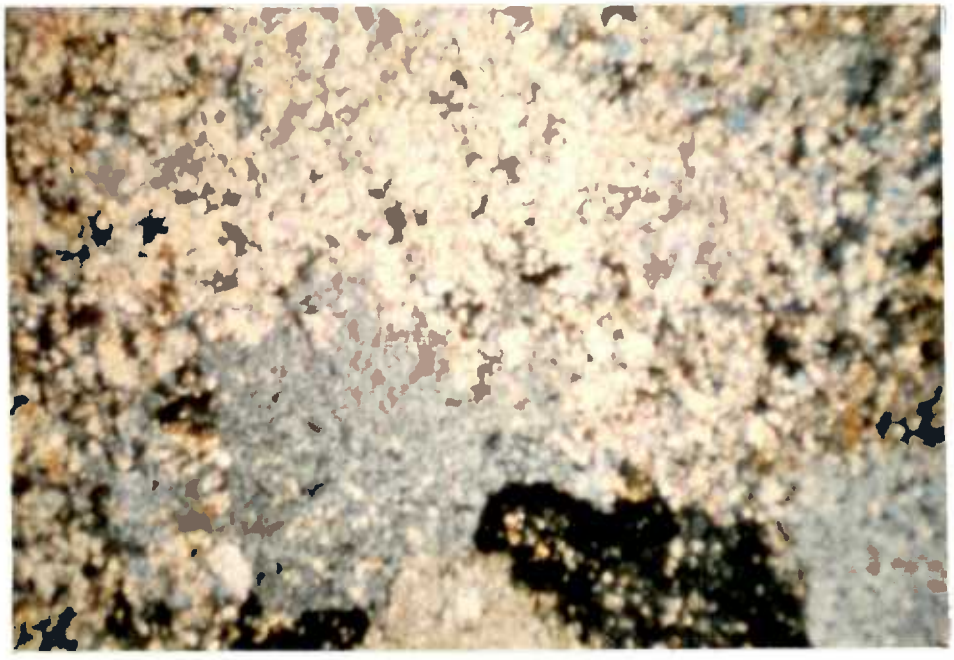


FIG. VI.22 Schematic presentation of the suggested modes of hydration in the Bozkir Formation.

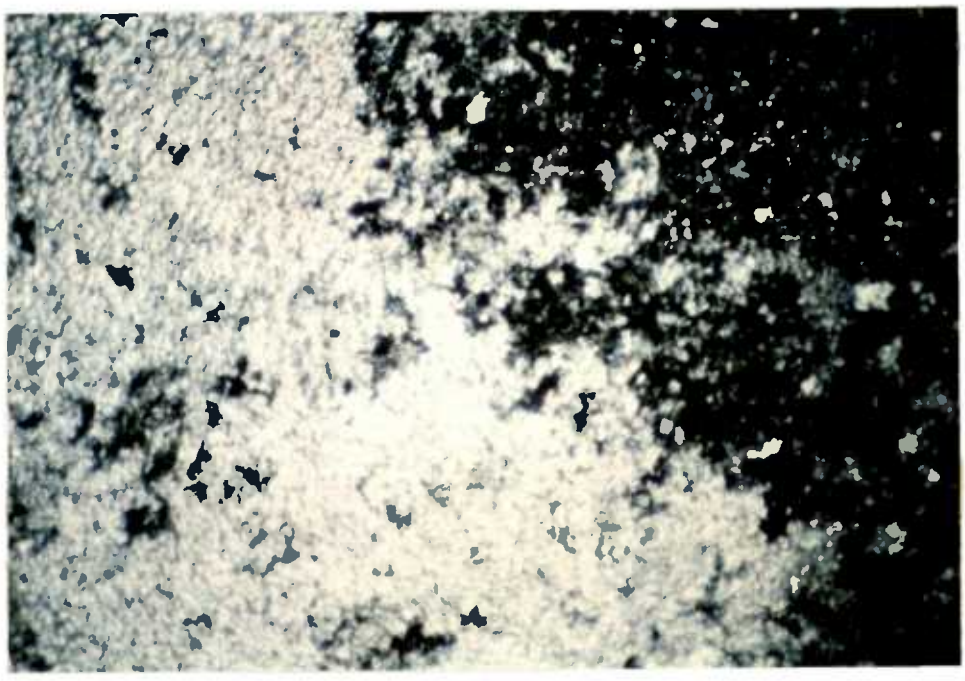


(a)

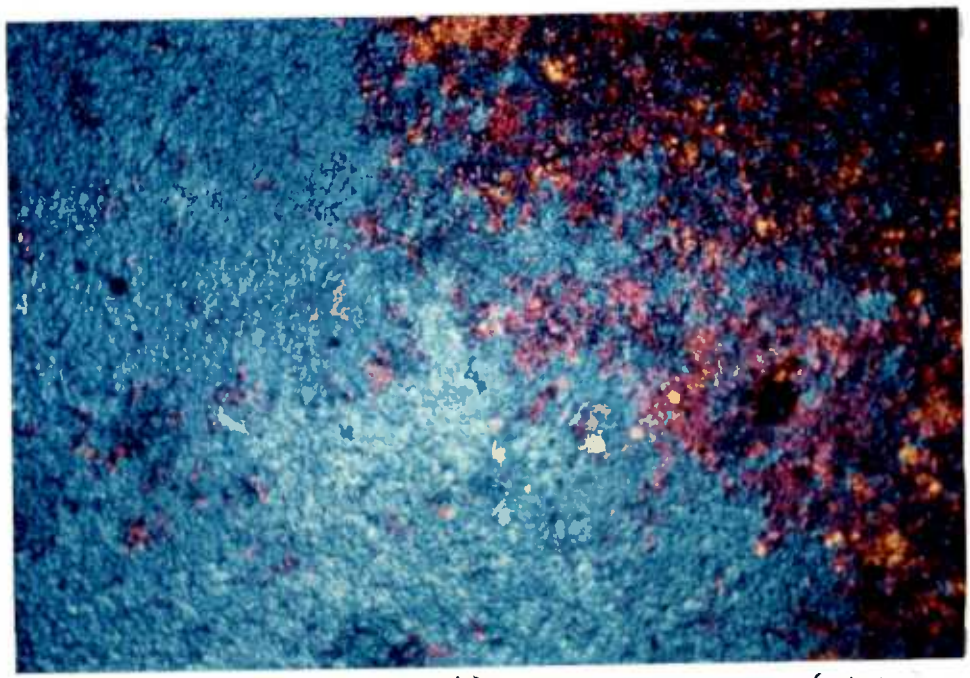


(b) (×40)

FIG. VI.23 Photomicrograph of the Purbeckian nodular anhydrite rocks, partially hydrated to porphyroblastic secondary gypsum, Warlingham borehole, south London. Note the irregular outlines and finger-like extentions of porphyroblasts. (a), Crossed-polars (b), Sensitive tint inserted.



(a)



(b) (X 40)

FIG. VI.24 Gradational boundary between porphyroblastic and alabastrine secondary gypsum fabrics.Note the finger-like extentions of porphyroblast penetrating into the alabastrine fabrics. (a), Crossed polars (b).Sensitive tint inserted.

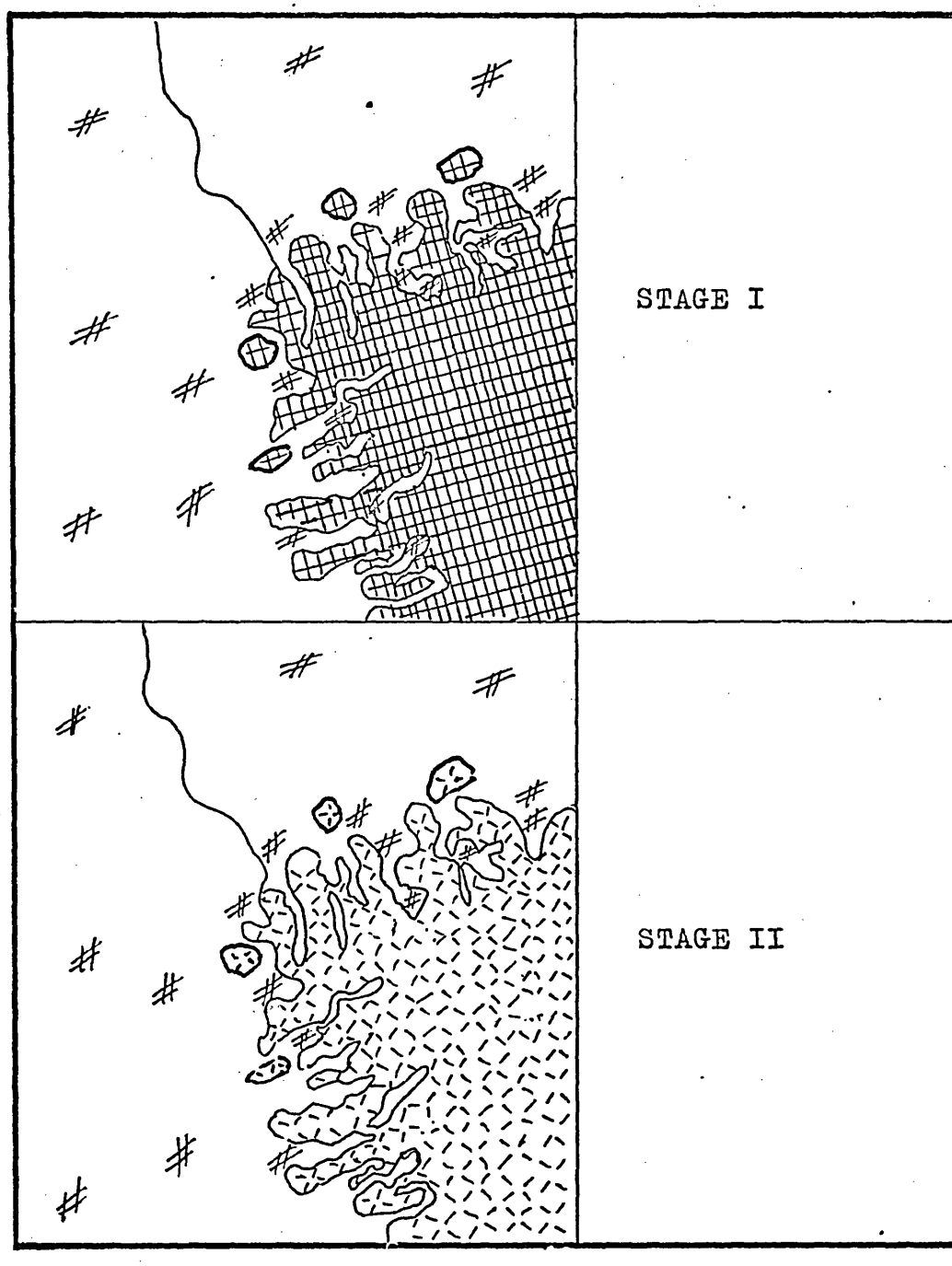


FIG. VI.25 Schematic presentation of the suggested development of gradational boundaries between porphyroblastic and alabastrine fabrics of secondary gypsum.



FIG. VI.26 Photomicrograph of a satin-spar gypsum vein. Note the optical continuity of groups of adjacent fibres. Crossed-polars. (×40)

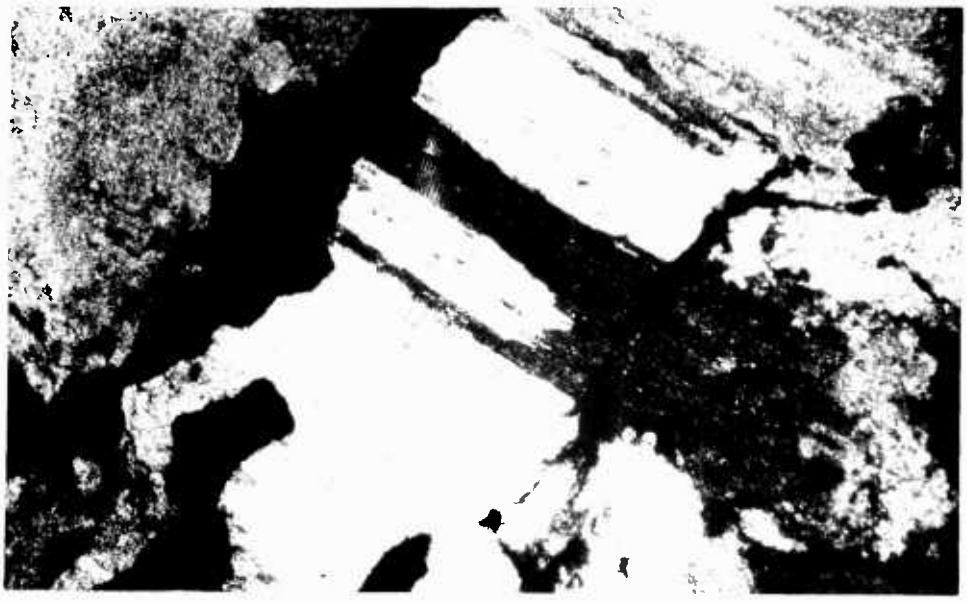


FIG. VI.27 Optical continuity between the fibres of a satin-spar vein and the porphyroblasts adjacent to the vein walls. Crossed-polars. (×60)

CHAPTER VII

SUMMARY AND CONCLUSIONS

Each of the previous chapters had its own conclusions, and it now remains to tie these together.

The sedimentary succession of the Upper Tertiary rocks of the Ugurludag area comprises two continental clastic-evaporite megacycles which are separated by a marked angular unconformity. Each megacycle is characterized by a lower redbed member which passes up gradationally into an overlying gypsum bearing evaporite member (Fig. VIII. 1.)

The Incik Formation, the redbed member of the lower megacycle, is composed essentially of conglomerates, sandstones, siltstones and mudstones present as fining-upward cycles which were probably deposited in a fluviatile environment dominated by meandering streams. An interesting feature of the formation is the presence of three horizons of almost pure clinoptilolite, which formed by alteration of very fine-grained volcanic ash.

The redbeds of the Incik Formation pass up into the evaporitic Bayindir Formation which forms the upper part of the lower megacycle. The lower part of the Bayindir Formation comprises rhythmic repetitions of terrigenous clastics and nodular secondary gypsum rocks. The beds of clastics are cyclic within themselves, being composed of fining-upward cycles of sandstones, siltstones and mudstones. The remainder of the formation is characterized by alternations of laminated calcitic mudstones and nodular secondary gypsum rocks. The evidence obtained from both field and laboratory studies seem to confirm the conclusion of most previous workers that the formation was deposited in a continental environment It is uncertain whether the sulphate ions of the calcium sulphate minerals were obtained from pre-existing sulphate bearing formations, pyrite deposits, marine derived groundwaters or volcanic sources. The secondary gypsum rocks have both porphyroblastic and alabastrine fabrics. Porphyroblastic fabrics dominate in the lower part of the formation where they are associated with satin-spar veins. The upper part is composed almost entirely of alabastrine

secondary gypsum.

The presence of anhydrite relicts in the gypsum porphyroblasts of the nodular gypsum rocks indicates that the nodules were originally composed of anhydrite. The complete absence of evidence of any traces or even hint of primary gypsum suggests that the anhydrite nodules grew 'de novo' without any gypsum precursors.

Deposition of the lower megacycle was followed by an episode of tectonism which involved uplift, folding and thrusting of the sediments of the lower megacycle and older formations. This was succeeded by widespread erosion before the deposition of the upper megacycle commenced in an intermontane playa lake complex. It is suggested that the hydration of anhydrite of the Bayindir Formation to secondary gypsum took place during this interval.

The Kizilirmak Formation, the clastic member of the upper megacycle, is mainly made up of fining-upward cycles of conglomerates, sandstones, siltstones and mudstones, but there is some gypsum in the upper parts. This formation represents the marginal fluviatile facies of the playa lake complex.

The succeeding Bozkir Formation overlies and interfingers with the Kizilirmak Redbeds and is made up of rhythmic repetitions of gypsum-bearing mudstone laminar gypsum cycles. These rocks were the deposits of the lacustrine part of the complex. Unlike the Bayindir Formation, the evaporites of the Bozkir Formation clearly originated as gypsum. In some cycles this gypsum remained unchanged, but in others it was altered in part or wholly to anhydrite when the playa dried out. This early diagenetic change was accompanied by diagenetic replacement of dolomite by magnesite in the mudstones. The various early diagenetic changes and the subsequent hydration of the anhydrite to secondary gypsum are summarized schematically in Figure VII. 2.

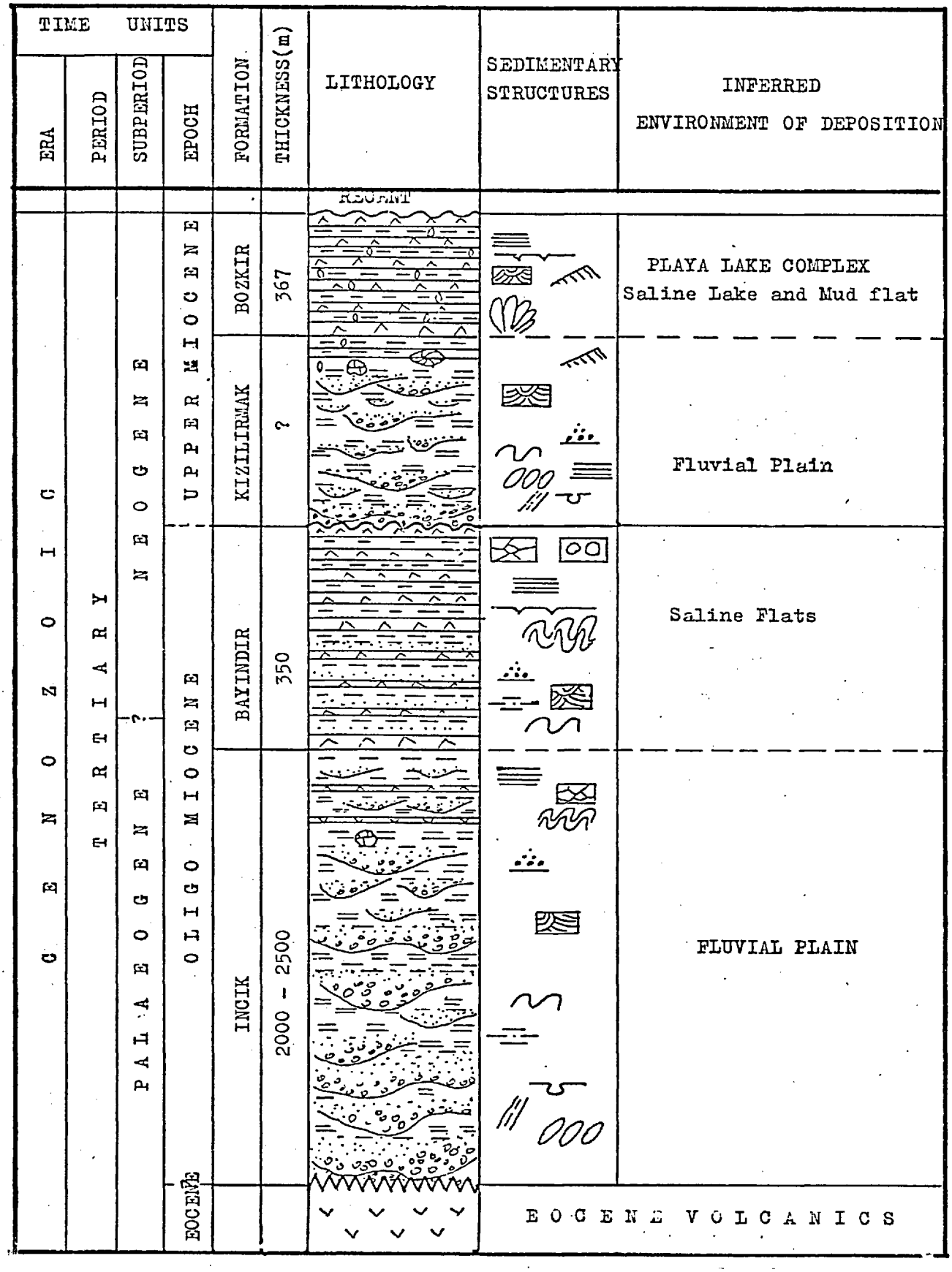
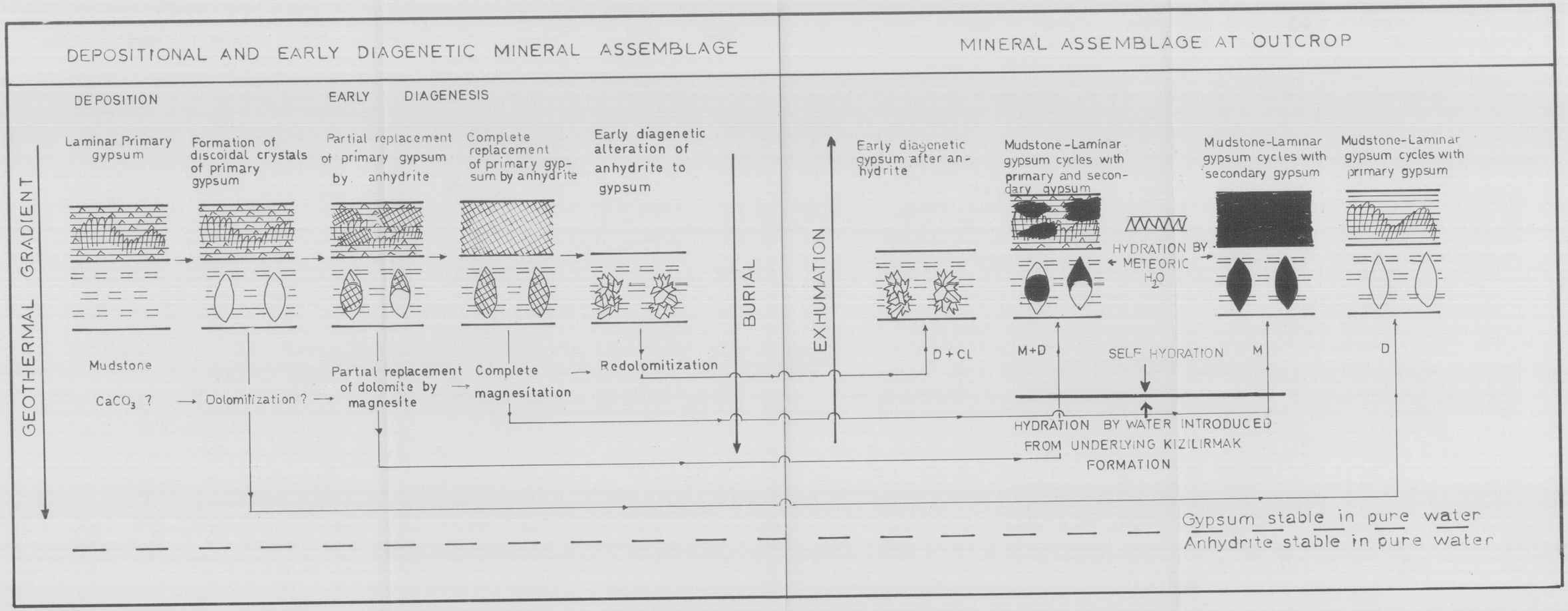


FIG. VII.1 A summary of lithofacies and depositional environments of the Upper Tertiary redbed-evaporite megacycles in the Ugurludag area of the Cankiri-Corum Basin.

FIG. VII.2 Summary of early diagenetic changes and subsequent modes of hydration in the Bozkir Formation.


DEPOSITIONAL AND EARLY DIAGENETIC MINERAL ASSEMBLAGE
MINERAL ASSEMBLAGE AT OUTCROP
DEPOSITION
EARLY DIAGENESIS
GEOTHERMAL GRADIENT
Laminar Primary gypsum
Formation of discoidal crystals of primary gypsum
Partial replacement of primary gypsum by anhydrite
Complete replacement of primary gypsum by anhydrite
Early diagenetic alteration of anhydrite to gypsum
BURIAL
EXHUMATION
Early diagenetic gypsum after anhydrite
Mudstone-Laminar gypsum cycles with primary and secondary gypsum
Mudstone-Laminar gypsum cycles with secondary gypsum
Mudstone-Laminar gypsum cycles with primary gypsum
HYDRATION BY METEORIC H_2O
Mudstone
$CaCO_3$?
Dolomitization ?
Partial replacement of dolomite by magnesite
Complete magnesitation
Redolomitization
D+CL
M+D
SELF HYDRATION
M
D
HYDRATION BY WATER INTRODUCED FROM UNDERLYING KIZILIRMAK FORMATION
Gypsum stable in pure water
Anhydrite stable in pure water

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APPENDIX I

LOG OF THE TYPE SECTION OF THE BOZKIR FORMATION

0.00-1.60	1 cycle with primary gypsum.
1.60-3.75	1 cycle with secondary gypsum.Satin-spar veins
3.75-4.75	1 cycle with primary and secondary gypsum.Satin-spar veins.
4.75-5.55	1 cycle with secondary gypsum.Satin-spar veins.
5.55-6.85	1 cycle with primary gypsum.
6.85-9.40	1 cycle with secondary gypsum.Satin-spar veins.
9.40-9.95	3 cycles with primary and secondary gypsum.Satin-spar veins.
9.95-10.95	2 cycles with primary gypsum.
10.95-13.00	1 cycle with primary and secondary gypsum,satin-spar veins.
13.00-14.40	1 cycle with primary gypsum.
14.40-14.95	1 cycle with primary and secondary gypsum,satin-spar veins.
14.95-19.65	5 cycles with secondary gypsum,satin-spar veins.
19.65-19.72	1 cycle with primary gypsum.
19.72-19.80	1 cycle with secondary gypsum.
19.80-19.93	2 cycles with secondary gypsum.
19.93-20.05	2 cycles with primary and secondary gypsum.
20.05-31.50	8 cycles with primary gypsum
31.50-32.30	1 cycle with primary and secondary gypsum,satin-spar veins.
32.50-40.75	6 cycles with primary gypsum.
40.75-46.60	4 cycles with secondary gypsum,satin-spar veins.
46.60-49.60	1 cycle with primary and secondary gypsum,satin-spar veins.
49.60-50.20	1 cycle with secondary gypsum.
50.20-51.00	1 cycle with primary and secondary gypsum.
51.00-51.35	1 cycle with secondary gypsum.
51.35-56.80	4 cycles with primary and secondary gypsum.
56.80-60.50	7 cycles with primary gypsum.
60.50-63.75	1 cycle with secondary gypsum.

220.40-221.15	1 cycle with primary and secondary gypsum.
221.15-223.10	3 cycles with primary gypsum.
223.10-223.50	Light brown mudstone with discoidal crystals of primary gypsum,up to 3 cms. across.
223.50-224.15	Cross-bedded,fine-grined sandstone cemented by poikilitic gypsum.
224.15-232.40	6 cycles with primary gypsum.
232.40-235.40	1 cycle with secondary gypsum.
235.40-241.80	5 cycles with primary and secondary gypsum.
241.80-267.00	Covered
267.00-268.35	1 cycle with primary and secondary gypsum.
268.35-271.90	2 cycles with primary gypsum.
271.90-273.00	1 cycle with primary and secondary gypsum.
273.00-289.50	9 cycles with primary gypsum.
289.50-289.80	1 cycle with secondary gypsum.
289.80-294.40	4 cycles with primary and secondary gypsum.
294.40-301.50	8 cycles with secondary gypsum.
301.50-303.90	2 cycles with primary gypsum.
303.90-305.75	1 cycle with primary and secondary gypsum.
305.75-331.00	17 cycles with primary gypsum.
331.00-332.70	1 cycle with primary and secondary gypsum.
332.70-336.45	2 cycles with secondary gypsum.
336.45-338.90	11 cycles with primary and secondary gypsum.
338.90-349.50.	4 cycles with secondary gypsum.
349.50-351.85	1 cycle with primary gypsum.
351.85-352.60	2 cycles with primary and secondary gypsum.
352.60-353.05	Light olive gray mudstone with discoidal crystals of primary gypsum.
353.05-353.50	Very fine-grained cross-laminated sandstone cemented by poikilitic gypsum.
353.50-354.90	1 cycle with primary and secondary gypsum.
354.90-363.00	6 cycles with primary gypsum.
363.00-365.50	Covered
365.50-367.00	2 cycles with primary gypsum.

63.75-65.75	1	cycle with primary gypsum.
65.75-82.50	6	cycles with primary and secondary gypsum.
82.50-91.00	21	cycles with primary gypsum.
91.00-91.15	1	cycle with secondary gypsum.
91.15-91.40	2	cycles with primary and secondary gypsum.
91.40-91.48	1	cycle with primary gypsum.
91.48-96.60	4	cycles with primary and secondary gypsum.
96.60-128.50	19	cycles with primary gypsum.
128.50-131.20	1	cycle with secondary gypsum.
131.20-137.75	4	cycles with primary and secondary gypsum.
137.75-141.80	1	cycle with primary gypsum.
141.80-144.35	3	cycles with primary and secondary gypsum.
144.35-146.35	1	cycle with secondary gypsum.
146.35-154.50	4	cycles with primary and secondary gypsum.
154.50-157.00	1	cycle with primary gypsum.
157.00-158.90	1	cycle with primary and secondary gypsum.
158.90-165.50	5	cycles with secondary gypsum.
165.50-167.30	1	cycle with primary and secondary gypsum.
167.30-188.70	11	cycles with primary gypsum.
188.70-191.40	3	cycles with primary and secondary gypsum.
191.40-193.65	1	cycle with secondary gypsum.
193.65-194.65	1	cycle with primary and secondary gypsum.
194.65-201.15	2	cycles with primary gypsum.
201.15-202.55	1	cycle with secondary gypsum.
202.55-208.90	4	cycles with primary and secondary gypsum.
208.90-217.60	33	cycles with primary gypsum.
217.60-217.85	4	cycles with primary and secondary gypsum.
217.85-218.05	1	cycle with secondary gypsum.
218.05-218.30	1	cycle with primary gypsum.
218.30-219.10	3	cycles with primary and secondary gypsum.
219.10-220.40	2	cycles with secondary gypsum.

APPENDIX II

X-RAY DIFFRACTION ANALYSIS

X Major

\+ Minor

\- Trace

A. BAYINDIR FORMATION

SAMPLE No.	Constituent minerals				LOCATION OF SAMPLE
	CALCITE	QUARTZ	FELDSPAR	CLAY MIN.	
OS/75/ 101	X	X	+	+	Yeniyapan Dere, near the village of Yeniyapan
OS/75/ 102	X	X	+	+	" " "
OS/75/ 119	X	+	+	+	The Kiziltepe Section
OS/75/ 124	X	+	+	+	The Ceeltepe Section
OS/75/ 127	X	+	+	+	" " "
OS/75/ 128	X	X	+	+	" " "
OS/75/ 129	X	+	+	+	" " "
OS/75/ 130	X	+	+	-	" " "
OS/74/ N_5-E_2	X	X	+	+	The Bestepe Section
OS/74/ N_3-E_2	X	+	-	+	" " "

B. KIZILIRMAK FORMATION

SAMPLE No.	Constituent minerals							Type of gypsum	LOCATION OF SAMPLE
	CALCITE	DOLOMITE	MAGNESITE	QUARTZ	FELDSPAR	CLAY MIN.	GYPSUM		
OS/75/ 166	X	+		X	+	+	+	P	The Esekcitepe Section
OS/75/ 222			X	+	+	-	+	S	The Kskayasi Section
OS/75/ 300	X			X	+	+			Guydumdere
OS/75/ 309	X	+		+	+	-	+	P	The Kepeztepe Section
OS/75/ 342	X			+	+	-			" "
OS/74/ 201	+	X		+	+	+	+	P	The Kuskayasi Section
OS/74/ SE_2-B	X	+		+	+	-	+	P	The Kepeztepe Section
OS/74/ SE_2-2	X			+	+	-			" "
OS/74/ SE_3-3	X			X	+	+			" "

C. BOZKIR FORMATION

SAMPLE No.	Constituent minerals						Type of Gypsum	LOCATION OF SAMPLE
	DOLOMITE	MAGNESITE	QUARTZ	FELDSPAR	CLAY MIN.	CELESTITE		
OS/75/164		X	+	-	-		S	The Pesiktepe Section
OS/75/178		X	X	+	+		S	Ambarci Tarlalari
OS/75/179	X	+	+	-	-		PS	" "
OS/75/181	+	X	+	-	-		PS	" "
OS/75/188	X		+	-	+		P	" "
OS/75/193	X		X	+	+		P	" "
OS/75/194	X		+		-		P	" "
OS/75/198		X	+	-	+		S	" "
OS/75/213	X		+	+	-	-	P	The Tozluburun Sec.
OS/75/216	X		+	+	+		P	" "
$OS/75/T_1-1$	X		+	+	+	-	P	" "
$OS/75/T_1-12$	X		+	-	+		P	" "
$OS/75/T_1-13$	X		X	+	+		P	" "
$OS/75/T_2-3$	+	X	X	+	+		PS	The Tuzlanintepe Sec.
$OS/75/T_2-5$	X		+	-	-		P	" " "
$OS/75/T_2-6$	X	+	+	+	+		PS	" " "
$OS/75/T_2-7$	X		X	+	-		P	" " "
$OS/75/T_2-8$	X		+	-	+		P	" " "
$OS/75/T_3-2$	X	+	X	+	+		P	The Ambartepe 1 Sec.
$OS/75/T_3-4$	X		+	-	+		P	" " "
$OS/75/T_3-5$	X		+	+	+		P	" " "
$OS/75/T_3-9$	X		+	-	+		P	" " "
$OS/75/T_6-2$		X	+	+	+		S	The Kizlarcukuru 2 Sec.
$OS/75/T_7-2$	X		+	+	-		P	The Kirkoy Section
$OS/75/T_7-5$	X	X	+	-	+		PS	" " "
$OS/75/T_7-7$		X	+	+	+		S	" " "

SAMPLE No.	Constituent minerals						Type of Gypsum	LOCATION OF SAMPLE
	DOLOMITE	MAGNESITE	QUARTZ	FELDSPAR	CLAY MIN.	CELESTITE		
OS/75/T_9-11	X		+	–	–	+	EDS **	The Kayayol Section
OS/75/T_9-12	X		+	+	–	+	EDS	" " "
OS/75/T_{11}-3		X	+	+	+		S	The Acioz Section
OS/75/T_{12}-2	X		+	–	+		P	The Kumceltek 2 Section
OS/75/T_{12}-4	X		+	+	+		P	" " "
OS/75/T_{12}-8	X		+	–	–	–	P	" " "
OS/75/T_{12}-10	X		+	–	+		P	" " "
OS/75/255	X		+	+	+		P	Ambarci Tarlalari
OS/75/256	X	X	+	+	+		PS	" "
OS/75/257	X		X	+	+	–	P	" "
OS/75/259	X		+	+	+		P	The Type Section
OS/75/260		X	+	–	+		S	" " "
OS/75/262		X	+	+	+		S	" " "
OS/74/200		X	+	–	+		S	" " "
OS/74/202		X	+	+	+		S	" " "
OS/74/204		X	+	–	+		S	" " "
OS/74/210		X	+	+	+		S	" " "
OS/75/286	X		+	+	–		P	The Guydumdere Section
OS/75/291		X	+	–	+		S	" " "
OS/75/292		X	+	–	–		S	" " "
OS/75/293	+	X	+	+	+		PS	" " "
OS/75/294	+	X	+	–	–		PS	" " "
OS/75/295		X	+	+	+		S	" " "
OS/75/275		X	+	–	+		S	" " "
OS/75/246***	C	A	L	C	I	T	E +	GYPSUM***

* Gypsum is not included

** Early diagenetic gypsum after anhydrite

** Pelletoid grainstone cemented by gypsum

APPENDIX III (In rear pocket)

GEOLOGICAL MAP AND CROSS-SECTIONS OF THE UGURLUDAG AREA

III.1 Lagend

III.2 CORUM G 32 C_3 Sheet

III.3 CANKIRI H 32 b_2 Sheet

III.4 CANKIRI H 32 b_1 Sheet

III.5 CORUM G 32 C_4 Sheet

III.6 Geological Cross-sections

GEOLOGICAL MAP OF THE UGURLUDAG AREA

Legend

T_{bo} BOZKIR FORMATION

T_k KIZILIRMAK FORMATION

T_{ba} BAYINDIR FORMATION

T_i INCIK FORMATION

T_{ev} EOCENE VOLCANICS

T_{ef} EOCENE FLYSCH

SMof OPHIOLITES

DIP OF BEDDING

30/ Normal

78/ Overturned

— Vertical

LANDSLIDE

ROAD

STREAM

VILLAGE

I — I Geol. Section line

T Tepe (Hill)

Y Yayla (High Plateau)

FORMATION BOUNDARY

1 Observed

2 Probable

THRUST FAULT

1. Observed

2. Probable

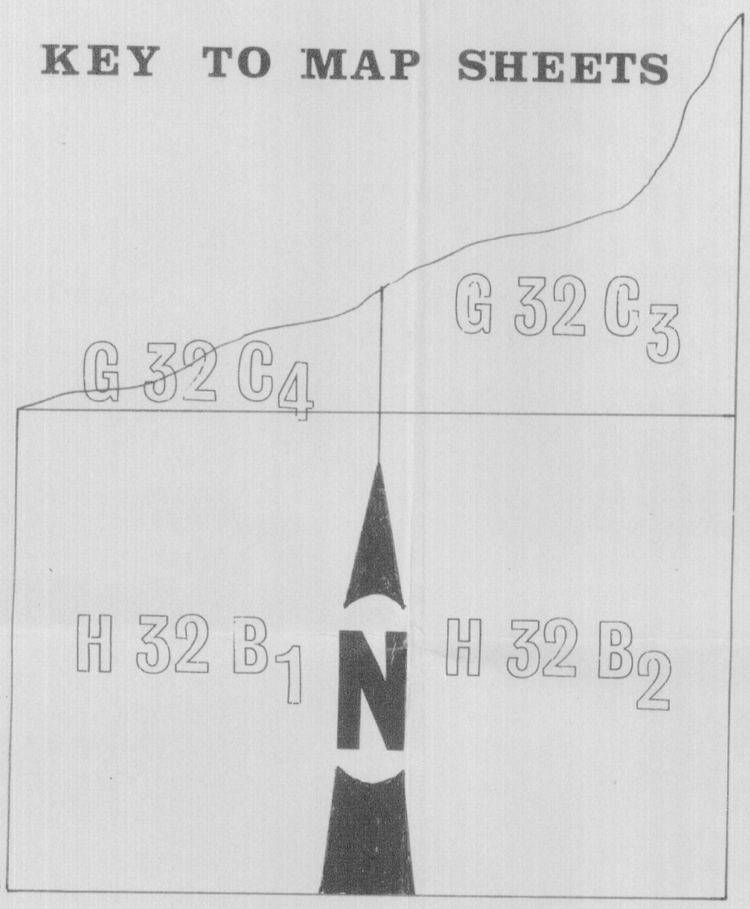
STRIKE-SLIP FAULT

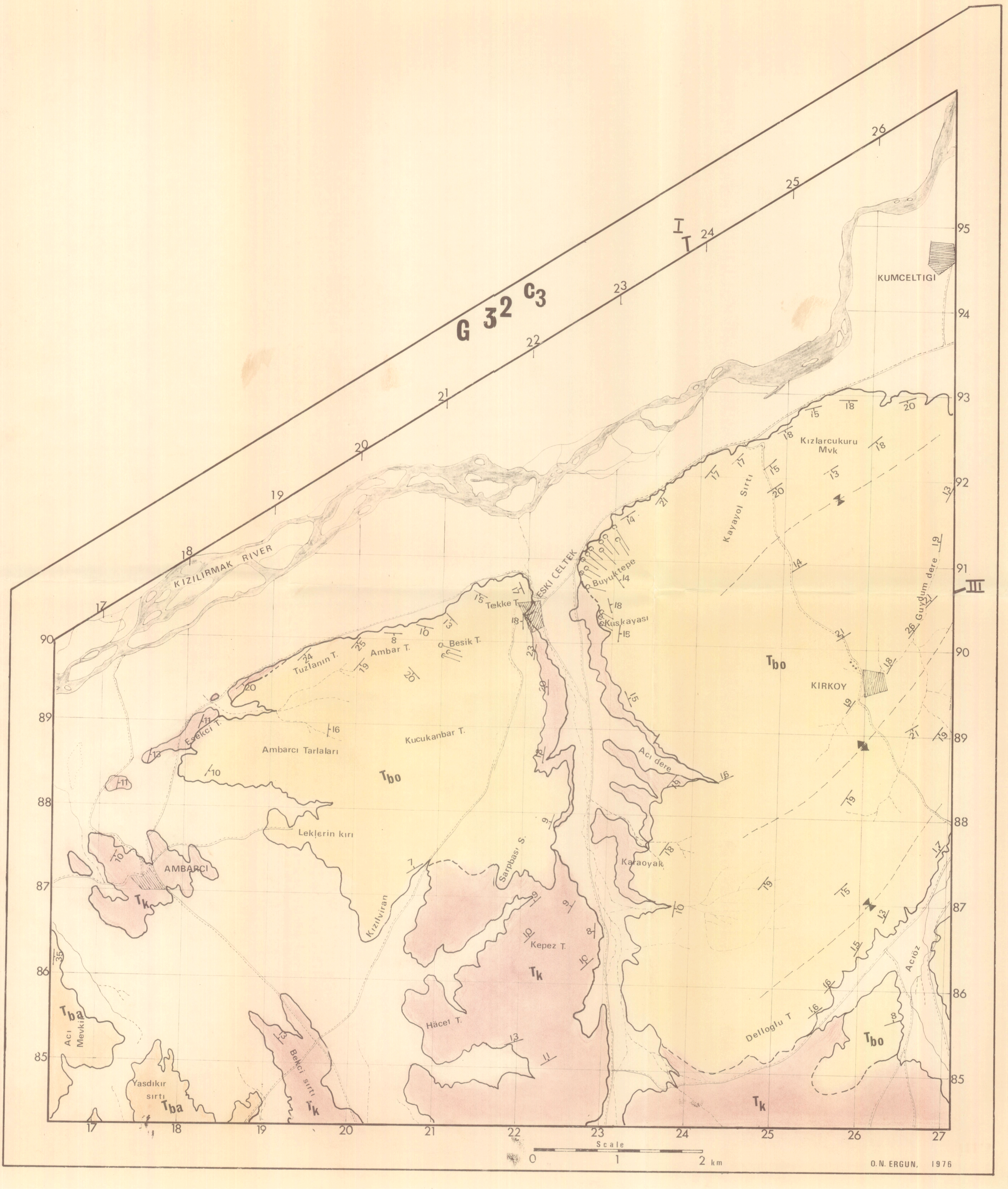
UNCONFORMITY

ANTICLINE

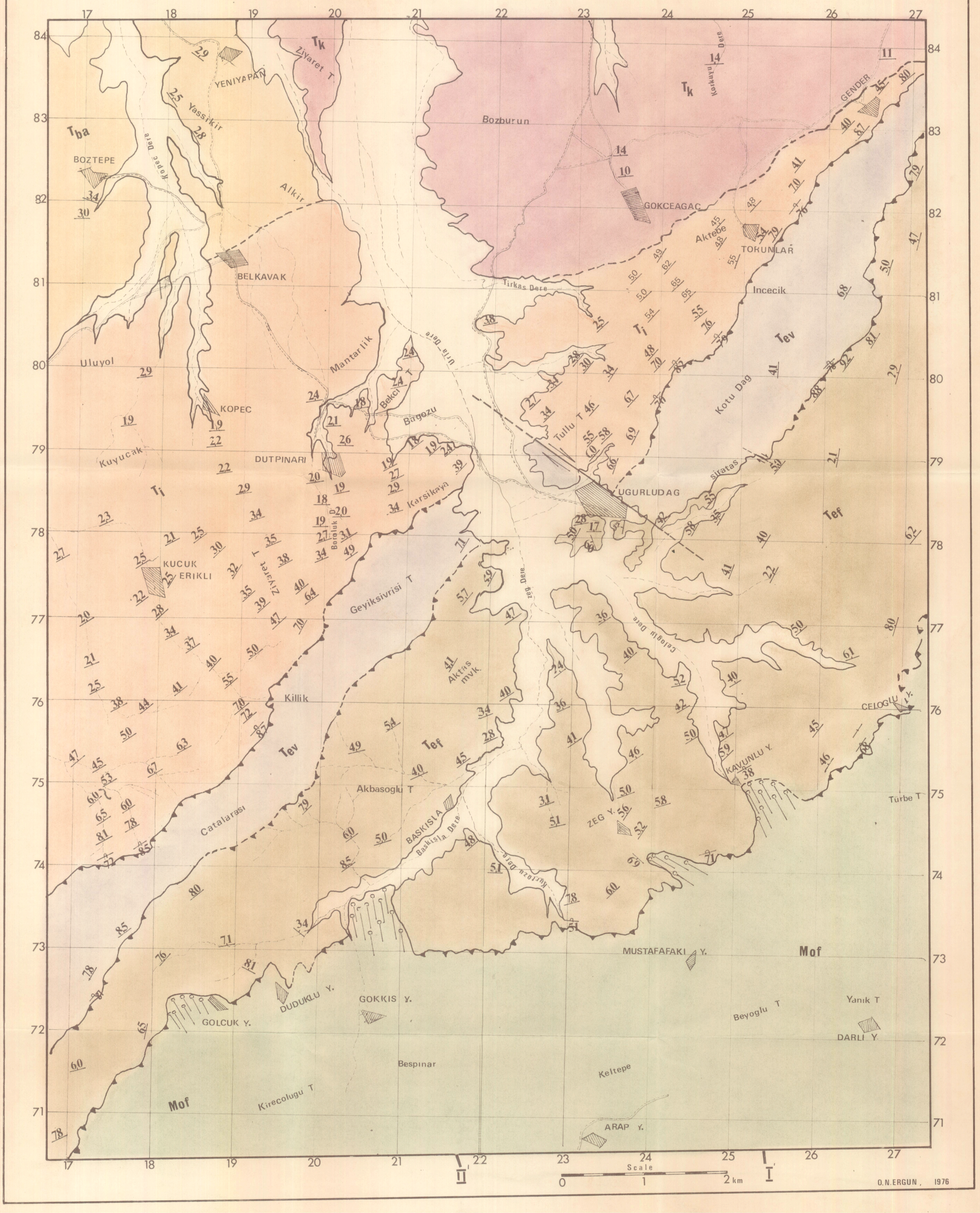
SYNCLINE

KEY TO MAP SHEETS




G 3 2 C3
I
I
KIZILIRMAK RIVER
ESKI CELTEK
KUMCELTIGI
KIRKOY
AMBARCI
Kızlarcukuru Mvk
Kayayol Sırtı
Guydum dere
Buyuktepe
Kuskayası
Tekke T.
Besik T.
Ambar T.
Tuzlanın T.
Ambarcı Tarlaları
Kucukanbar T.
Esekci T.
Leklerin kırı
Kızılviran
Sarpbası S.
Kepez T.
Hacet T.
Karaoyak
Aci dere
Delloglu T
Acioz
Bekci sırtı
Yasdıkır sırtı
Aci Mevkii
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Tk
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O.N. ERGUN, 1976

H 32 b_2

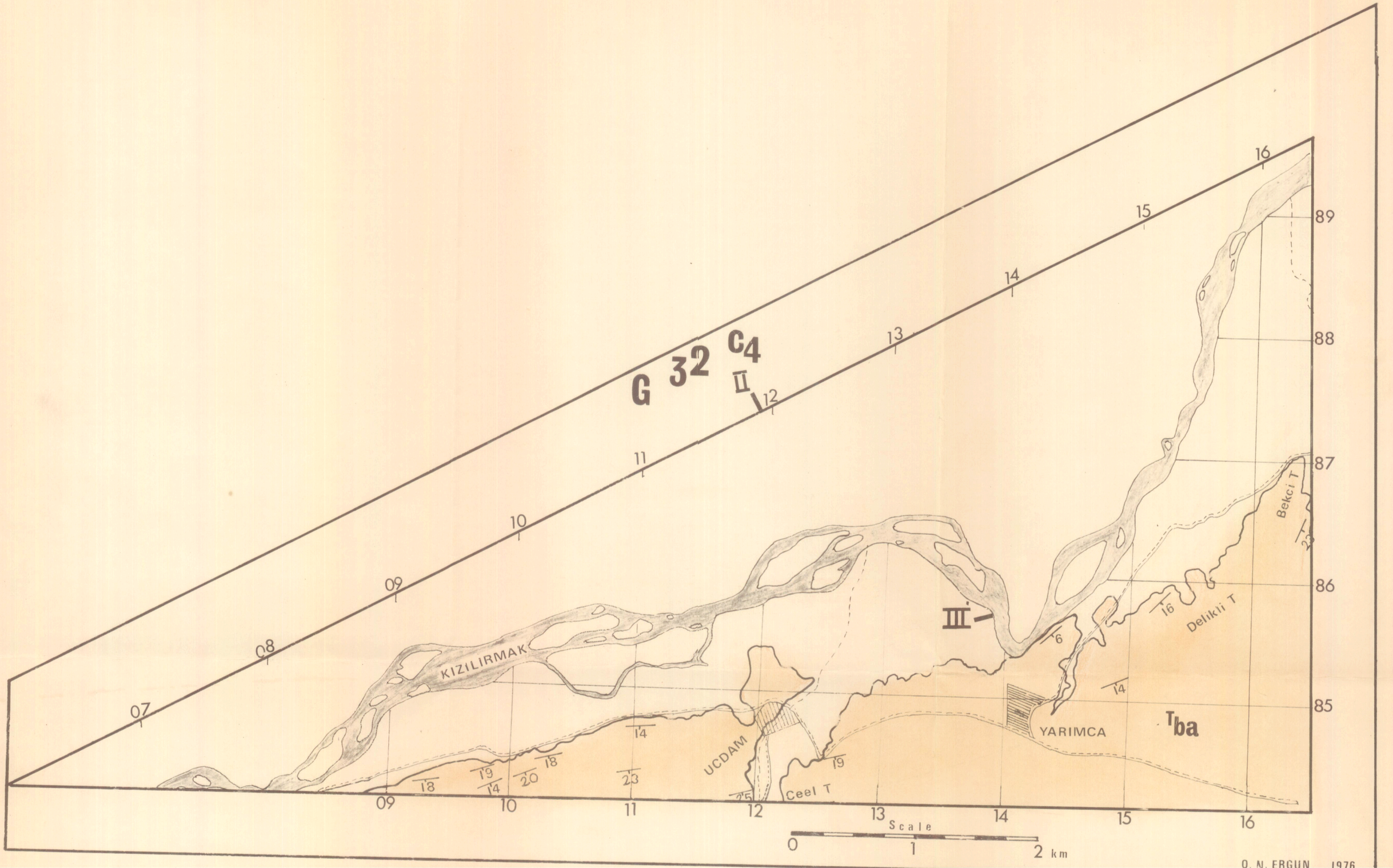

Tba
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Tev
Tef
Mof
BOZTEPE
YENIYAPAN
Yassikir
Kopec Dere
Alkir
BELKAVAK
Ziyaret T
Bozburun
Koruluvu Dere
GENDER
GOKCEAGAC
Aktepe
TOKUNLAR
Incecik
Tirkas Dere
Mantarlik
Urla Dere
Bekci T
Bagozu
KOPEC
Uluyol
Kuyucak
DUTPINARI
Tullu T
Kotu Dag
Sitatas
UGURLUDAG
Karsikaya
Boroluk Dere
KUCUK ERIKLI
Ziyaret T
Geyiksivrisi T
Zeg Dere
Celoglu Dere
Aktas mvk.
Killik
CELOGLU Y.
KAVUNLU Y.
Türbe T
Catalarası
Akbasoglu T
BASKISLA
Baskisla Dere
Kurtozu Dere
ZEG Y.
MUSTAFAFAKI Y.
DUDUKLU Y.
GOKKIS Y.
GOLCUK Y.
Beyoglu T
Yanik T
DARLI Y.
Bespinar
Kirecolugu T
Keltepe
ARAP Y.
II
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1
2 km
O.N.ERGUN, 1976

H 32 b_1

KARAKISIK
Kızıltepe
Büyük kızıl T
Dortyol
Armut T
T_{ba}
K kısık T
Tuzlupınar dere
MEHMETALI CIFTLIGI
TUGLU
Kumluk T
Tılkideligi T
Canak T
Tahtabacak T
IRICE MAH
Yazı T
KALENDEROGLU
Ceel T
Karatas T
Kırklar T
Kızılgervis T
Yaglı T
Kustepesi
Ziyaret T
Beştepe
Düzcedere
Acroluk
T_i
Kartal T
Kayatuzu T.
Balkaya T
Cetel T
Yelekkaya T
Adamölen T.
Tepetarla T
Sağca T
Höyük T
BUYUK ERIKLI
Ince T
Kozakkaya T
Bekci T.
Baklalık T.
KARAEVLIYA
Cakıl T.
Korkuyu T
T_{ev}
Karakaya
UCGLUK
Cakil T
Bostepe
Boztas T
Agacabork T

Scale
0 1 2 km

O.N.ERGUN, 1976



O. N. ERGUN 1976

GEOLOGICAL CROSS SECTIONS OF THE UGURLUDAG AREA

