Geochemical investigation of granitic rocks of Liberia

GEOCHEMICAL INVESTIGATION OF LIBERIAN GRANITIC ROCKS

by

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ABSTRACT

The aim of this project was two-fold: to characterize the geochemistry of the granitic rocks of the country; and to relate these geochemical characteristics to the possibility of rare-metal mineralization in those rocks.

Samples of these rocks, which are of Pre-Cambrian age and underlie most of the country, were taken from three main areas: (1) the northwest region (centred at about $8^{o}00'N$, $10^{o}00'W$) where both massive and foliated granites are the major rock types; (2) The Grebo Town Area (centred at about $6^{o}30'N$, $9^{o}32'W$), where pegmatite lenses (believed to contain cassiterite mineralization) and granitic gneisses are enclosed by metasedimentary schist complex; and (3) the Cestos Batholith area (centred at about 5° 50'N, $8^{o}57'W$), where quartz diorite and granitic gneisses are the major rock units.

In total 334 samples were collected in the proportions of 185 from the Northwest region, 47 from the Grebo Town Area, 61 from the Cestos Batholith area and the rest were collected along a corridor in the north-central region between Totota and Konia on the Voinjama-Monrovia highway.

Subsamples of 0.1g of these samples were digested in a mixture of hot $HClO_4$, HF, HNO_3 and analysed for twenty-five major and trace elements (Li, Na, K, Rb, Be, Mg, Ca, Sr, Ba, Al, La, Ti, V, Cr, Mo, Mn, Fe, Co, Ni, Cu, Ag, Zn, Cd, Pb, and P) by inductively coupled plasma atomic emission spectrometry. Duplicate samples and reference materials included in the sample batches indicated satisfactory analytical accuracy and precision. To aid the interpretation process of the geochemical data thus obtained, thin sections from sixty randomly selected hand specimens were also studied microscopically.

To facilitate detailed data interpretation, a number of modern univariate and multivariate statistical techniques have been used to obtain histograms, normal probability plots, graphical plots, ridge regressions, MTree plots, means, medians, standard deviations, minima, maxima and boxplots.

The available data suggest that although all of the rocks under investigations are granitoids, ranging from true granite through granodiorite to quartz diorite with a mean of granodiorite, they exhibit regional as well as local chemical and petrographic characteristics. The Cestos Batholith and the associated granitic gneisses are more calcium rich than the Northwest granites and the associated gneisses. This is in agreement with the result of the microscopic examination which has shown that samples from the Northwest granites are generally granodioritic, whilst those from the Cestos Batholith area are quartz dioritic. The general deficiency of mafic elements such as Mg, Fe, and Ca in the rocks of Grebo Town area, as indicated by the geochemical data, is also in agreement with the microscopic study which has indicated that these rocks are relatively pegmatitic.

Most of the trace and minor elements (e.g. Rb, La, Cr, Ni, Pb, Cu, and Co) in almost all of the suites have very wide ranges of concentrations. In addition, Mo, Ag, Cr, and Cd were commonly found to be below their analytical detection limits in all samples except those from the Cestos Batholith.

The Grebo Town Area suite is the richest in the granitophiles (Rb, K and Li) and the most impoverished in the granitophobes Mg, Ca and Sr. It can therefore be considered as the most differentiated among the granitic rocks being studied.

In general, the geochemical data are not indicative of rare-metal mineralization in the granites of Liberia, but the Grebo Town area may be considered for further work.

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PRESENTATION OF THE THESIS

This thesis is divided into 10 chapters and a number of appendices. Following The Introduction in Chapter 1, the physiography of Liberia is briefly described in Chapter 2, whilst the regional geology is given in Chapter 3. The geology of the three main areas sampled is dealt with individually in greater detail in Chapter 4. In Chapter 5, a short review of the chemical, petrochemical and petrological properties of granitic rocks as related to their mineralization potential is presented, followed by the description of the sampling, analytical and data processing techniques in Chapter 6. Chapter 7 is devoted to the petrography of the areas investigated. The chemical data of the four areas sampled are interpreted and discussed individually in Chapter 8, whereas the regional geochemistry is dealt with in Chapter 9, where the areas are compared among themselves, and then as an entity with other PreCambrian granites elsewhere in the world. Chapter 10 provides an overall discussion and tentative conclusion of the project as a whole. Also in this chapter are presented few recommendations/suggestions for further work. Finally, appendices are given for the interested reader.

CHAPTER 1

INTRODUCTION

1.1 GENERAL STATEMENT

Geochemistry has made great progress in the area of mineral exploration and has been especially useful in places such as the tropics where soil overburdens are usually very thick, making conventional geological methods of mineral exploration less effective when used alone. From this point of view, Liberia provides an ideal situation for the application of geochemical methods to the search for concealed and disseminated ores.

1.2 OBJECTIVES OF THE RESEARCH

The main objectives of this project are: (1) to determine the geochemical characteristics of the granitic rocks of Liberia; and (2) to relate these attributes to their mineralization potential. To do this the project has been planned to include representative samples of all of the granitic rocks, both massive and foliated,throughout the country.

This project also forms a part of the general programme of the regional scale reconnaissance mineral and geological exploration being carried out at present by the Liberian Geological Survey. It is hoped that the results will help to shed more light on the mineral resource potential of the country.

1.3 PREVIOUS WORK

1.3.1 General Statement

Until after the sixties, the need for comprehensive hard rock geochemical investigation for mineral exploration purposes remained largely unresolved (Rose et al., 1979; Govett, 1983) in many parts of the world, particularly in the developing countries. There is now enough data from both the western world and the U.S.S.R. to show that rock geochemistry is a powerful tool in the hands of the expert, and can be successfully used to elucidate geochemical features that can be related to mineralization potential. This has been demonstrated, for example, in Australia, Saskatchewan, Ontario, the Yukon, Idaho and elsewhere (Levinson, 1974; Hawkes and Webb, 1962). A regional scale study may not be adequate to delineate a specific potential target, but may define larger geochemically favourable metallogenic provinces where it may be worthwhile to concentrate future efforts for particular ore types. It might also show the relationship between the bedrock lithology and certain elements (James, 1965; Olade, 1975; Imeokparia, 1980, 1981; Hesp, 1974).

For granitic rocks, more investigations continue to be directed towards the establishment of genetic or spatial relationships between the rock types and the ore metals, especially tin, molybdenum, tantalum, tungsten, uranium, thorium and niobium, which have

been collectively referred to as rare-metals by Russian workers (Moseley, 1981). The presence (or absence) of these elements in addition to certain other trace elements at certain levels of concentration in granitoids has been used as a criterion in distinguishing barren and ore-bearing varieties (Banerjee et al., 1982; Boissary-Vinau and Roger, 1980; Bradshaw, 1967; Flinter, 1970; Imeokparia, 1982).

Attempts have also been, and continue to be made to utilize the concentration of major elements in discriminating mineralized granites (sensu latu) from unmineralized ones. But this approach has not proved very useful, at least on its own, as many controversies among researchers remain unresolved. For instance, Flinter et al. (1972), Hesp (1971), Tischendorf (1977), Hesp and Rigby (1975) and Cuney (1978) are all somewhat agreed that higher silica content in these rocks signifies possible rare-metal mineralization potential. On the other hand, opponents who have either directly or indirectly expressed doubt about this theory include Hosking (1965); Singh and Ahmad (1974) and Thompson (1977). Controversies of similar nature surround the use of other major constituents (CaO, TiO_2, MgO and K_2O). However, it appears to be the general concensus of concerned workers now that various combinations of these elements among themselves and with some trace elements can be effectively used as guides to ore-bearing potential of the granitoids.

By corollary, petrological features have been

used as exploration tools in granitic terrains (Hesp, 1974 and Tischendorf, 1977).

In addition to the use of trace and major elements as guide in mineral exploration in granitic terrains, geophysical properties such as gravity and magnetic anomalies have also been used (Plant et al., 1980).

The literature abounds with many instances in which geochemical investigation, either alone or in combination with other methods has been successfully applied in many parts of the world to the detection of the ore-bearing potential of granitic rocks (e.g. Imeokparia, 1982; Garnett, 1971; Olade, 1980; Govett, 1983; and Stemprok, 1979). The low density of outcrops in Liberia makes this method particularly suitable.

CHAPTER 2

PHYSIOGRAPHIC FEATURES OF LIBERIA

2.1 GENERAL STATEMENT

Liberia is a tropical country, and has a total area of about 43,000 square miles. It is centred at about $6^{o}30'N$ and $9^{o}25'W$, and is bounded on the south by the Atlantic Ocean. It lies at the southern tip of the West African shield which is generally known as the Guinean Shield (Fig. 1).

2.2 RELIEF AND ELEVATION

Along the coast, the country is rolling, but becomes progressively more rugged throughout the interior. Elevations reach about 1400 metres at Mt. Wutivi in Lofa County (Figs.2 & 3). Local relief is quite variable, especially in the hinterland.

2.3 CLIMATE AND VEGETATION

Liberia receives more than 450 centimetres of rainfall yearly, most of which comes mainly between the middle of May and the middle of October. This alternates with a dry and hot season, with temperatures rising not infrequently to $80-90^{o}F$. Humidity is generally high near the coast even during the middle of the dry season, whereas humidity is less pronounced most of the time in the hinterland. The climate has promoted

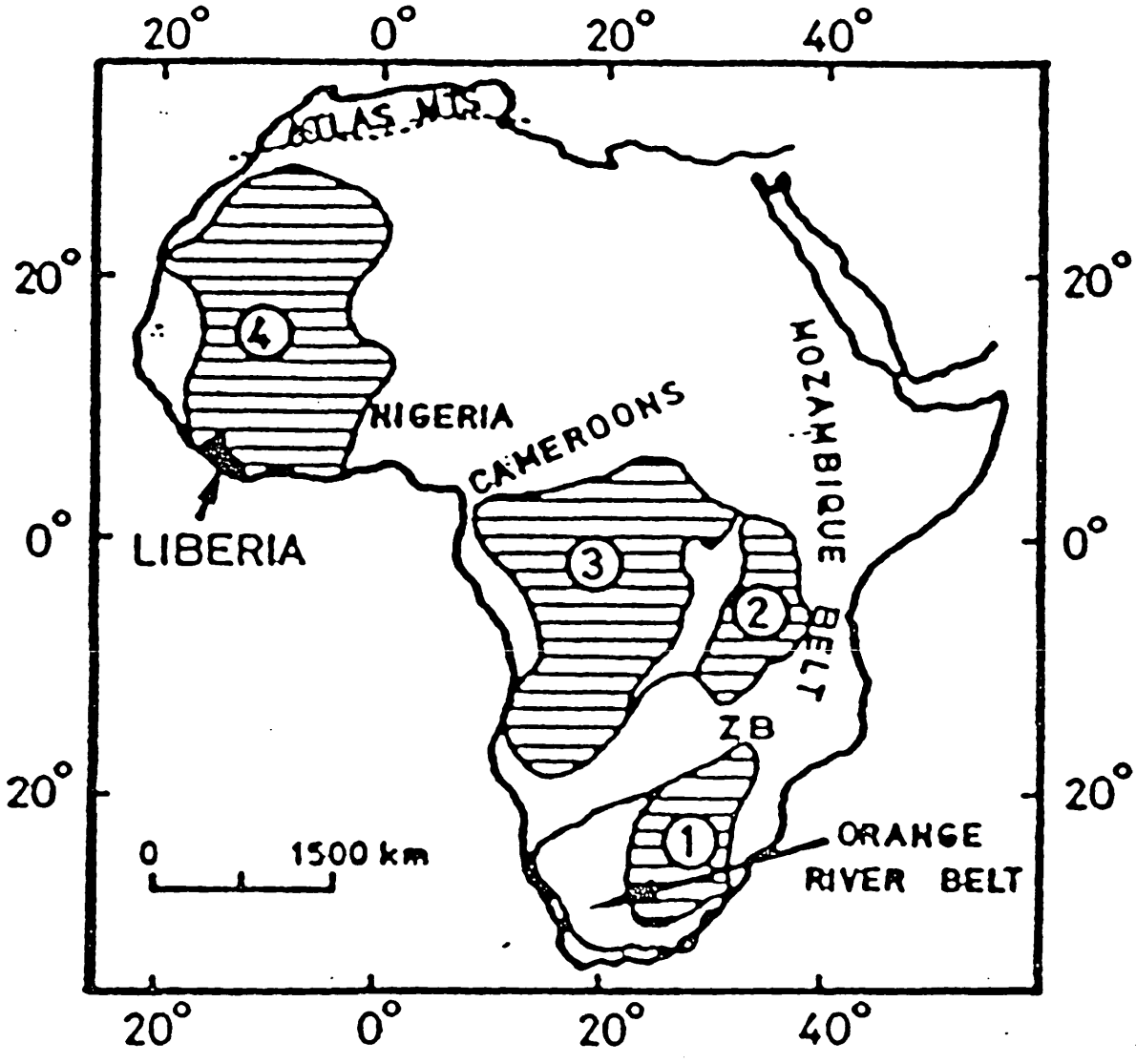


Fig.1. Geologic index map showing the geological setting of Liberia relative to the major cratons in Africa. Area 1, Kalahari-Zambabwe craton; areas 2 and 3, Tanzania and Angola cratons, respectively; and area 4, West African craton (or Guinean Shield). Mozambique, the Orange River, and the Zambezi (Z.B.) mobile belts are also shown.

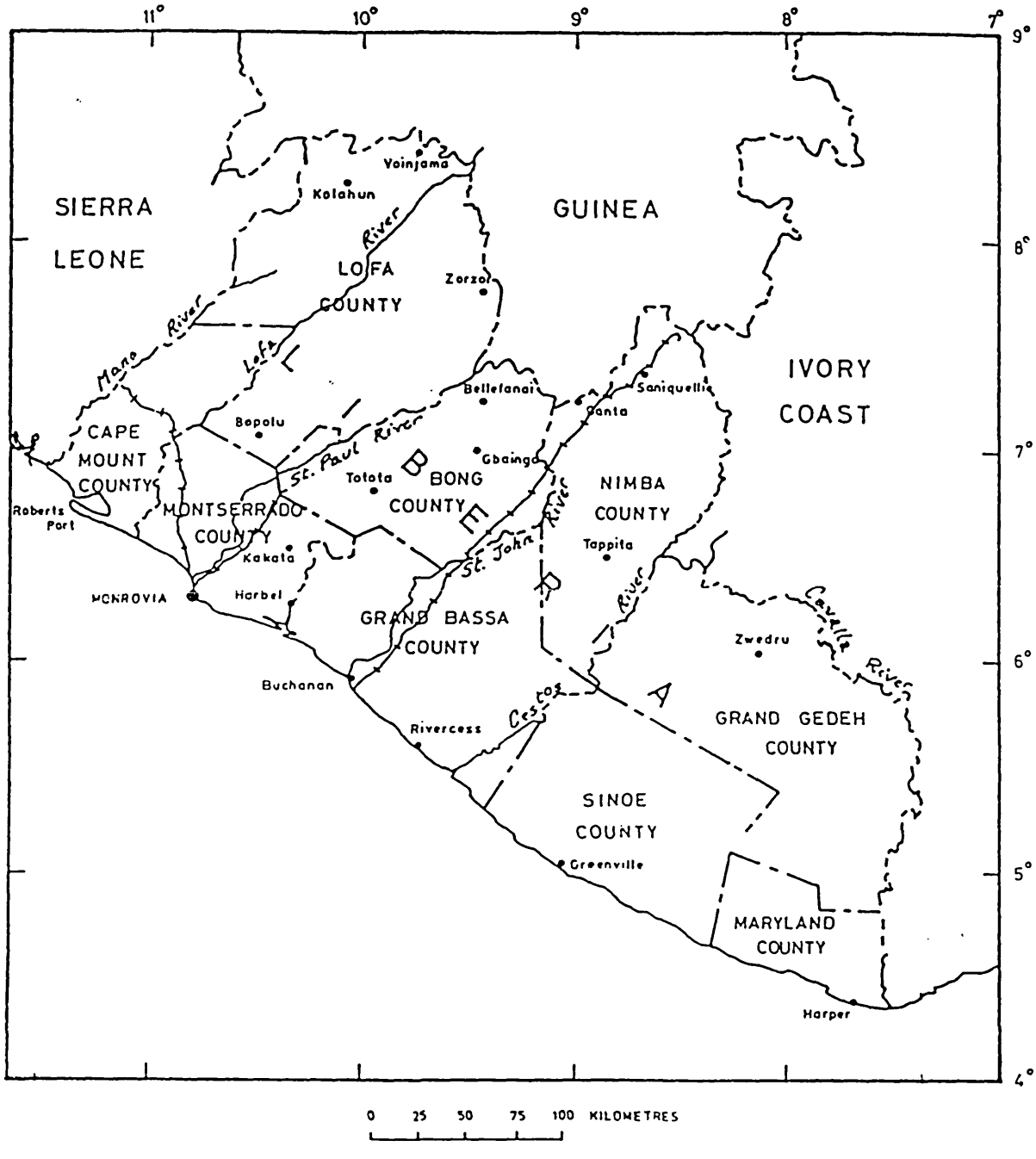


Fig.2. Major towns, cities, and the counties of Liberia

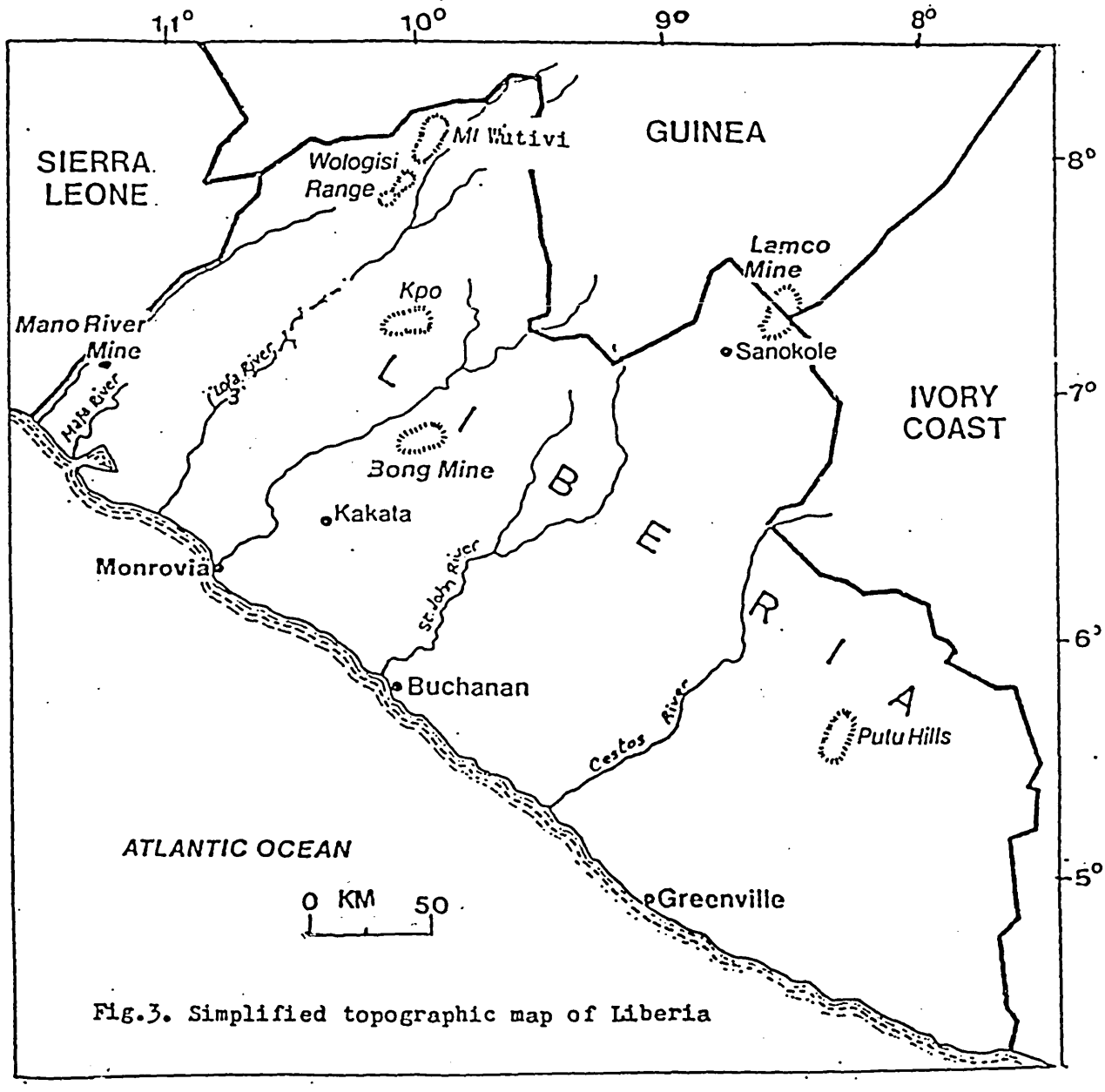


Fig.3. Simplified topographic map of Liberia

the development of dense tropical rain forest vegetation, which blankets most of the country.

2.4 OVERBURDEN

The combined effect of the high temperature, heavy tropical rainfall, and dense forest cover has had great influence on rock weathering. It encourages extensive chemical weathering, which in turn produces enormously thick overburden of lateritic soils and saprolite. Fresh outcrop is sparse.

2.5 DRAINAGE

With the exception of the small coastal strip with an average width of about 10km, the landscape is characteristically dissected by a complex network of closely spaced streams or rivers most of which have narrow and discontinuous floodplains, especially in the hinterland. These streams generally flow southwest, parallel to the regional trends of the country rocks. Cascades or rapids are numerous in most of these rivers, and are caused by the ridges of swarms of dolerite dykes which chiefly trend obliquely to the normal southwest flow direction. The presence of large floodplains and/or meandering rivers are rare phenomena in Liberia, except in the coastal area, e.g. in the vicinity of Monrovia and Buchanan.

2.6 ACCESSIBILITY

Laterite-surfaced highways are the chief means of access to most of the major towns or settlements in the country. Traverses are generally taken from these along jeep trails to places from where the traverses can be continued along footpaths or hunter trails. River traverses by means of small rubber boats or wooden canoes have sometimes been used to conduct geological and/or mineral exploration surveys along parts of rivers such as the Cavalla, Dube, Lofa, St John, and St Paul. Light single engine aircrafts have sometimes also been employed to reach otherwise unaccessible places of geologic or mineral exploration interest.

CHAPTER 3

3. GEOLOGY OF LIBERIA

3.1 INTRODUCTION

Most of our knowledge of the geology of Liberia is of reconnaissance nature and results from the efforts of three main groups.

A team of USGS geologists worked alongside geologists of the Liberian Geological Survey during a U.S. Agency for International Development programme called GERA (Geological Exploration and Resources Appraisal) from 1964 to 1972. Maps at various scales, the most comprehensive being the 1:250,000 ten folio series, and other geologic documents, resulted from this programme.

Results have also been obtained from foreign and local geologists employed by various exploration and mining companies in the country, viz: the former Diamond Mining Corporation of Liberia whose major activities were concentrated along the lower Lofa River basin and vicinity; the former W.H. Muller Company Mineral Exploration Division, which conducted a mineral exploration programme in eastern Liberia from 1968 to 1972; the now defunct Liberia Mining Company; Liberian American-Swedish Minerals Company which is exploiting the Nimba iron ore deposit (lat.$7^{o}32$ and long.$8^{o}25$); the

Bong Mining Company, mainly owned by German interests and mining the iron deposit of the Bong Range (lat. $6^{o}51'$ and long. $10^{o}15'$); and the National Iron Ore Company (NIOC) which is basically owned by Liberians and the Liberian government and mines the Mano River iron ore deposit (lat. $7^{o}18'$ and long. $11^{o}16'$).

Geologists of the Liberian Geological Survey, who conduct their own geologic mapping and mineral exploration programmes in addition to monitoring the activities of both foreign and local mineral exploration and mining companies, have also made substantial contributions in this regard. More recently,minor contributions to the knowledge of the geology of Liberia have been made by geologists of the Coastal Liberia Uranium Company, which carried out a uranium exploration programme in few selected areas in Central Liberia, and geologists of the UN Revolving Fund Minerals Project who conducted mineral exploration reconnaissance in the eastern third of the country.

The following summary of the geology of Liberia is mainly based on reports by: White and Leo (1969, 1970); White (1971a, 1971b, 1972); Jones and Stewart (1970); Thayer et al (1974); Tysdal (1978); Behrendt and Wotorson (1970, 1971, 1974) and Force (1983) among others.

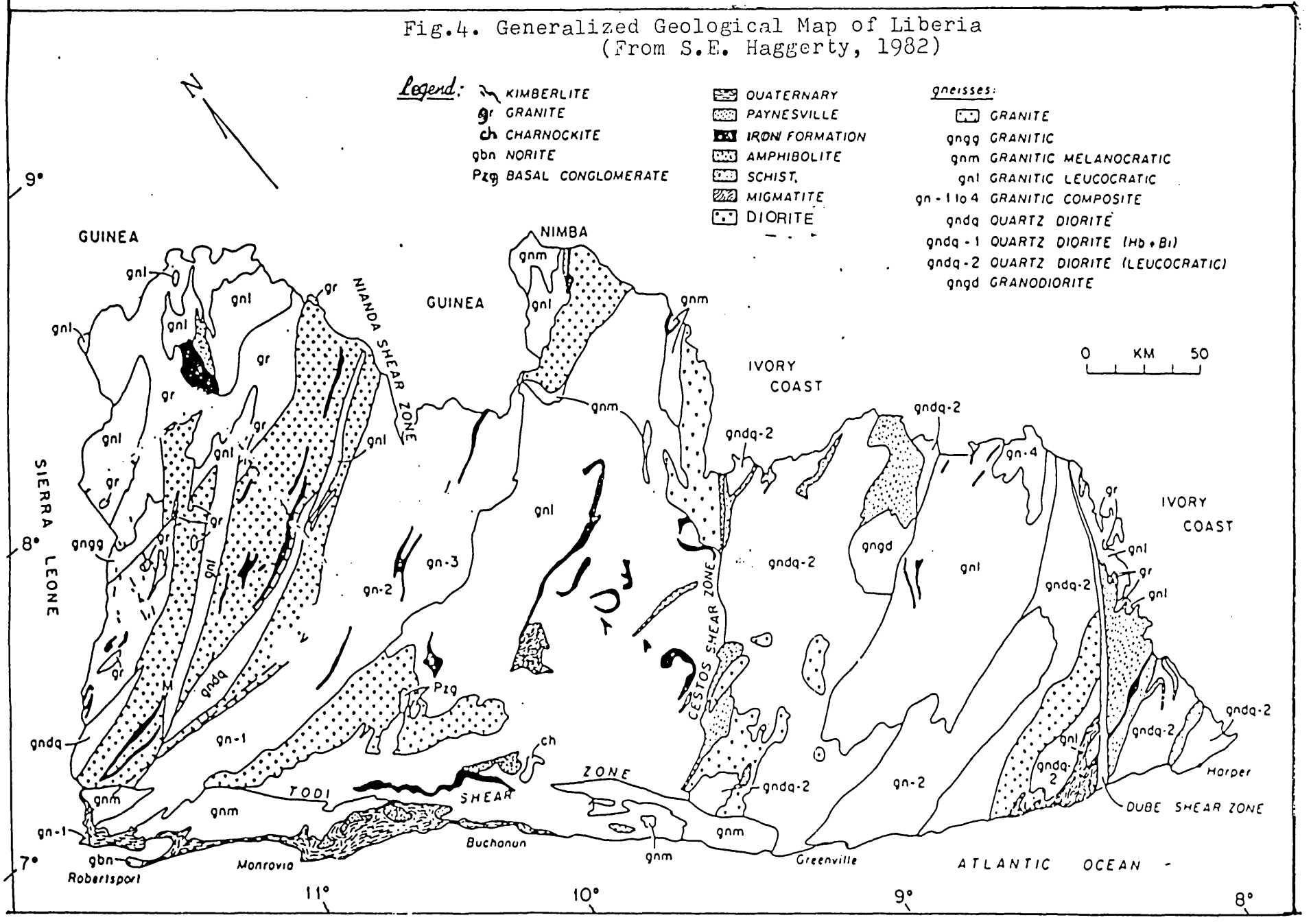
3.2 REGIONAL GEOLOGY (See map in pocket at rear)

3.2.1 Rock Types and their Distributions

The study of the geology of Liberia is difficult primarily because of the poor accessibility to the remote parts of the country and the poor exposure of the bedrock geology by the dense rainforest vegetation and thick lateritic soil cover, all of which are related to the humid tropical conditions. About 90% of the information on the geology of the country, particularly the fraction from the GERA project, was acquired from photo-interpretation from aeromagnetic, aeroradiometric and gravity data obtained from earlier geophysical surveys. Nevertheless, the information is reliable, as has been demonstrated in the few places where ground-check has been carried out.

Nearly all of the territory of Liberia is underlain by Precambrian crystalline rocks, which range in age from 3,400m.y. to 550m.y. (Figs. 4,5). The main groups of these crystalline rocks are: (1) an older basement complex which comprises composite gneisses, granulites and migmatites; (2) a meta-volcano-sedimentary complex consisting of amphibolites, amphibolitic schists, undivided schists and iron (both silicate and oxide) formations; and (3) a younger basement or intrusive complex embracing pegmatites, massive and slightly foliated granites and granodiorite, charnockite, diorite, metadolerite, norite, ultramafics, and

Fig.4. Generalized Geological Map of Liberia
(From S.E. Haggerty, 1982)



gabbro) (Table 1). These divisions are more or less time-stratigraphic in nature, but for the sake of discussion the rocks may be conveniently grouped on the basis of mineralogical composition and/or genesis. Along the coast lies a narrow and discontinuous strip of beach and fluvial deposits of unconsolidated material and sandstone of Paleozoic age.

3.2.2 The Crystalline Basements

Most of the basement rocks (i.e. the Older and Younger complexes) of the country are granitic and it is these which form the subject of this investigation. They include the massive and slightly foliated granites and granodiorites, diorite, tonalite, charnockite, migmatites and gneisses. Mineralogically, these granitic rocks consist dominantly of quartz, microcline, plagioclase (with An content up to about 50%), microperthite, with varying and small amounts of biotite and/or hornblende. Sphene, zircon, apatite and magnetite are the common accessory minerals. Pyroxenes are rare (except in charnockite). Quartz is an ever-present constituent and may reach up to 60% in some cases. Tonalite and tonalite gneisses with andesine and a higher proportion of mafic minerals have been reported in many parts of the country (White, 1970; Jones and Stewart, 1970). Scattered shows of trondhjemite have also been described (Sangmor, personal communications; Seitz, 1977).

TABLE 1 MAIN GROUPS OF THE CRYSTALLINE ROCKS IN LIBERIA

3 Younger Basement or Intrusive Complex

- Pegmatite
- Granite and granodiorite massive slightly foliated
- Charnockite
- Diorite
- Metadolerite
- Norite/gabbro
- Ultramafic

2 Metavolcano - Sedimentary Complex (or Super Group)

- Amphibolite
- Amphibolite schist
- Schist, undivided
- Composite unit - comprising schist, amphibolite, quartzite and local iron formations
- Itabarite
- Quartzite

1 Older Basement Complex (or Continental Crust)

- Composite gneiss - well foliated, granite to quartz diorite in composition
- Granulites - mainly found along coast
- Migmatites

The northwestern region of the country is extensively underlain by large massive granites although smaller granites occur elsewhere. These rocks are medium-to coarse-grained, unfoliated or only slightly foliated (Leo and White, 1969; Jones and Stewart, 1970; Newhouse et al, 1944). Excellent exposures appear as domes (inselbergs) which are barely covered with savannah-like vegetation. Such exposures are uniquely confined to the extreme northwest of the country, around the Zorgor, Voinjama and Kolahun areas. Their inhomogeneous composition and their lack of sharp, cross-cutting contacts with the surrounding gneisses does not suggest an intrusive origin. Essential minerals comprise quartz, microcline, and oligoclase, although plagioclase may have an An content of up to 50%, thus giving rise to the dioritic and tonalitic varieties. Biotite is the chief mafic mineral, although subordinate amounts of hornblende may be encountered occasionally. These mafic minerals often occur as segregates or clusters, while the feldspars occur not uncommonly as phenocrysts (Seitz, 1977). Accessory minerals include sphene, apatite, zircon, Fe-oxides (magnetite, ilmenite and haematite) and secondary epidote and chlorite. Textures are typically allotriomorphic/hypidiomorphic granular. Perthitic and myrmekitic intergrowths are not uncommon.

The surrounding granitic gneisses in the northwestern region and elsewhere in the country share most of the petrographic features of the massive granites, except for the textural aspects. They indicate moderate to extreme shearing strained quartz and bent laminae in plagioclase crystals are strongly suggestive of deformation in these rocks, which range up to upper amphibolite facies. Migmatites and augen and injection gneisses are included within this group on a structural basis.

Pyroxene to hornblende facies granulite occurs along the coastline of the country, with a width of about 15 miles and a length of about 60 miles from northwest of Monrovia to the Sierra Leone border, beyond which it probably continues as the Kasila "Series". Other outcrops, in addition to units not mappable at reconnaissance scale, occur: (1) near the Guinean border, central north of Liberia ($7^{o}38'N/8^{o}35'W$; $6^{o}48'N/8^{o}25'W$); and (2) southeast of Monrovia ($5^{o}20'N/9^{o}30'W$). The metamorphic grade ranges from pyroxene granulite to hornblende granulite facies. Augite, hypersthene, and calcic plagioclase are the main mineral constituents, but hornblende, biotite and scapolite are commonly present in subordinate quantities (Leo, 1968; White, 1969), and the granulites along the coast are more melanocratic. Both metasedimentary granulites and mafic granulites of igneous origin

have been postulated (Leo, 1968; Jones and Stewart, 1970).

3.2.3 Amphibolites and Schists

Bands of amphibolites and lenses of schists which are generally too small to be mapped at reconnaissance scale interlayer the major crystalline basement complexes. The schists include pelitic as well as graphitic types, and the largest mappable unit occurs east of Zwedru. The wide range of mineralogical composition is a reflection of the many types of sedimentary rocks (which included sandstone, greywackes, cherts and conglomerates) from which these schists were derived. Usually biotite and quartz are present in association with other common aluminium silicates (sillimanite, kyanite, andalusite) and staurolite, and the association of the schist bands or lenses with the occurrence of iron formations (Fe-silicate or oxide facies) has been well established in Liberia.

Amphibolite bands are widespread. They are principally composed of quartz, plagioclase, and hornblende, with or without substantial amounts of other amphiboles, such as the actinolite-tremolite series, anthophyllites, and cummingtonite. These bands trend NE concordantly with the enclosing gnessic and/or granitic basements. Leo and White (1967) and Onstat and Dorbor (1981) favour a sedimentary origin (paragenesis) for most of these rocks. But as such a conclusion is based mainly

on mineralogy and field relationships (structures), chemical investigation would provide additional helpful evidence.

3.2.4 Basic and Ultrabasic Intrusives

Basic and ultramafic intrusive rocks are widely distributed throughout the basement complexes of the country. Diabase (or dolerite) intrusions are the commonest, and occur both as sills and dykes. The sill variety is typically restricted to the coastal region in and around Monrovia and Harper ($4^{o}26'N/7^{o}45'W$), where it is essentially structureless, or nearly so. The diabase occurs as dykes in three distinct bands: coastal; central; and northern. Both the coastal and central bands trend parallel to the coast (NW/SE) whereas there is a great deal of variation within the northern band as to the trend: (1) E-W in the Voinjama area; (2) SE-NW south of Kolahum; and (3) N-S near and north of Zorzor and north of the intersection of the LAMCO railroad and $7^{o}N$ parallel. The evidence from field observations, metamorphic effects on some of the dykes in the northwest (Voinjama/Zorzor/Kolahum area), geophysical anomalies, and a few radiometric age determinations), strongly suggests that not all of the dykes were derived from one magma at the same time. The coastal intrusions are of Jurassic age; central ones are of Silurian age and the east-trending ones in the Voinjama/Zorzor/Kolahun area are of Pre-cambrian age. Mineralogical

differences also exist among the three sets of dolerite dykes. Although they all contain calcic plagioclase, the northern occurrence is more tholeiitic and more pyroxene deficient than those of the coastal and central belts.

Outcrops of ultramafic rocks are not uncommon, but are usually too small to be mapped individually at regional scales. Consequently, they are invariably included within more broadly defined groups. Besides the known single large outcrop at the confluence of the Lofa and the Yambesi Rivers (c. $7^{o}12'N/10^{o}45'W$) about 80 miles northwest of Monrovia, there are several smaller but mappable units elsewhere in the country. Sangmor and Dorbor (1978) mapped one such unit during a geologic and mineral exploration investigation programme in the vicinity of the village of Gondoja. The outcrops generally display strong schistosity towards the contacts with the enclosing granitic gneisses, but become progressively massive inwards, suggesting that these bodies were either emplaced before or during the regional metamorphism of the surrounding granitic rocks. Varieties include serpentinite, dunite, peridotite and pyroxenite, with straightforward mineralogy.

Very little is known about the few scattered occurrences of gabbro and norite in the country. Most of the gabbro outcrops are considered as coarser facies of the dolerite dykes. Almost all outcrops of this rock type cannot be mapped at reconnaissance scales individually. The mineralo-

gical composition is very similar to that of the dolerite, and so the coarser texture may only be an indication of their cooling history. Norite occurs in two localities: Robertsport, where it is in the form of an elliptical plug ($\sim 6^{o}42'N/11^{o}28'W$); and four miles west of the intersection of the LAMCO railroad and the Ganta-Scalepea highway ($7^{o}08'N/9^{o}00'W$) about seven miles south of Ganta, Nimba County. The norite body at Robertsport exhibits indications of retrograde metamorphism such as kelyphitic texture, and is more garnetiferous than the one in Nimba County. Calcic labradorite, hypersthene, and augite are the main mineral constituents, but the Robertsport outcrop is more melanocratic.

3.2.5 Kimberlites

Several short, thin kimberlite dykes and plugs have been observed and mapped in the western region of the country (White and Leo, 1969; Brendht and Wotorson, 1972; Leurie, 1967; Hargety, 1979). These are of late Jurassic to early Cretaceous age and trend north to northwest, thus sometimes obliquely transecting the foliation of the enclosing granitic gneisses. The economic potential of these kimberlites has not been fully assessed, but they are believed to be connected with the alluvial diamonds which are mined in westernmost Liberia and eastern Sierra Leone. One possibility in this regard may be that the present level of erosion has now reached close to the base of the larger

kimberlite dykes or plugs whose erosion served as the source of the present alluvial diamonds.

3.2.6 Sedimentary Rocks

Outcrops of unmetamorphosed sedimentary rocks of Devonian and Tertiary ages occur along the coast between Buchanan and Monrovia. The outcrops are discontinuous, but may extend as far as the border between Liberia and Sierra Leone. Sandstone, which is the predominant variety, is intercalated with arkoses, siltstones, mudstones, and conglomerates to a varying degree. Questionable carbonatized and silicified plant fragments have been observed in these rocks (Jones and Stewart, 1970). The largest of these formations is the fine-grained (0.05-0.40mm) Paynesville sandstone which occurs on the eastern outskirts of Monrovia. It is composed of well rounded quartz grains and is locally strongly cross-bedded at steep angles. The formation generally dips gently toward the sea and has a known maximum thickness of about 70ft. Other units of unmetamorphosed sedimentary rocks include the Lower Cretaceous Farmington River Formation and Tertiary Edna sandstone, both of which outcrop between Monrovia and Buchanan.

3.2.7 Geochronology

Data from radiometric dating of both mineral separates and whole rocks (Hurley et al., 1970, 1971; Hedge et al., 1975), geological investigation and geophysical surveys (Behrendt and Wotorson,

1974) have provided ample information on the geochronology of the Liberian rocks. Based on this information, the crystalline rocks of Liberia fall into three age provinces (Fig.5): (1) The Liberian age province (ca 2700m.y.) which covers more than two-thirds of the country, and extends westward into Sierra Leone, northward into Guinea and northwestern Ivory Coast (three anomalous values of 3000, 3200 and 3450 m.y. occur in the southwest corner of this province (Hedge et al., 1975); (2) the Eburean age province (ca 2000m.y.) which covers the easternmost region of the country and extends into the Ivory Coast; (3) the Pan-African Age province (ca 550m.y.) which occupies the western two-thirdsof the coast, extends into Sierra Leone to the west and is fault-bounded against the Liberian and Eburean age provinces by the Todi shear zone.

The widely distributed dolerite dykes and sills and the kimberlite dykes and plugs in the west are Triassic to Cretaceous in age. The sedimentary units are also of Devonian to Tertiary age (see section 3.2.6).

3.2.8 Structure

The poor exposure of outcrops makes the study of geological structures extremely difficult. However, in places where exposures are good, structural features such as folds, faults, joints and shears can be observed. It is worth noting here that each of the age provinces (Liberian,

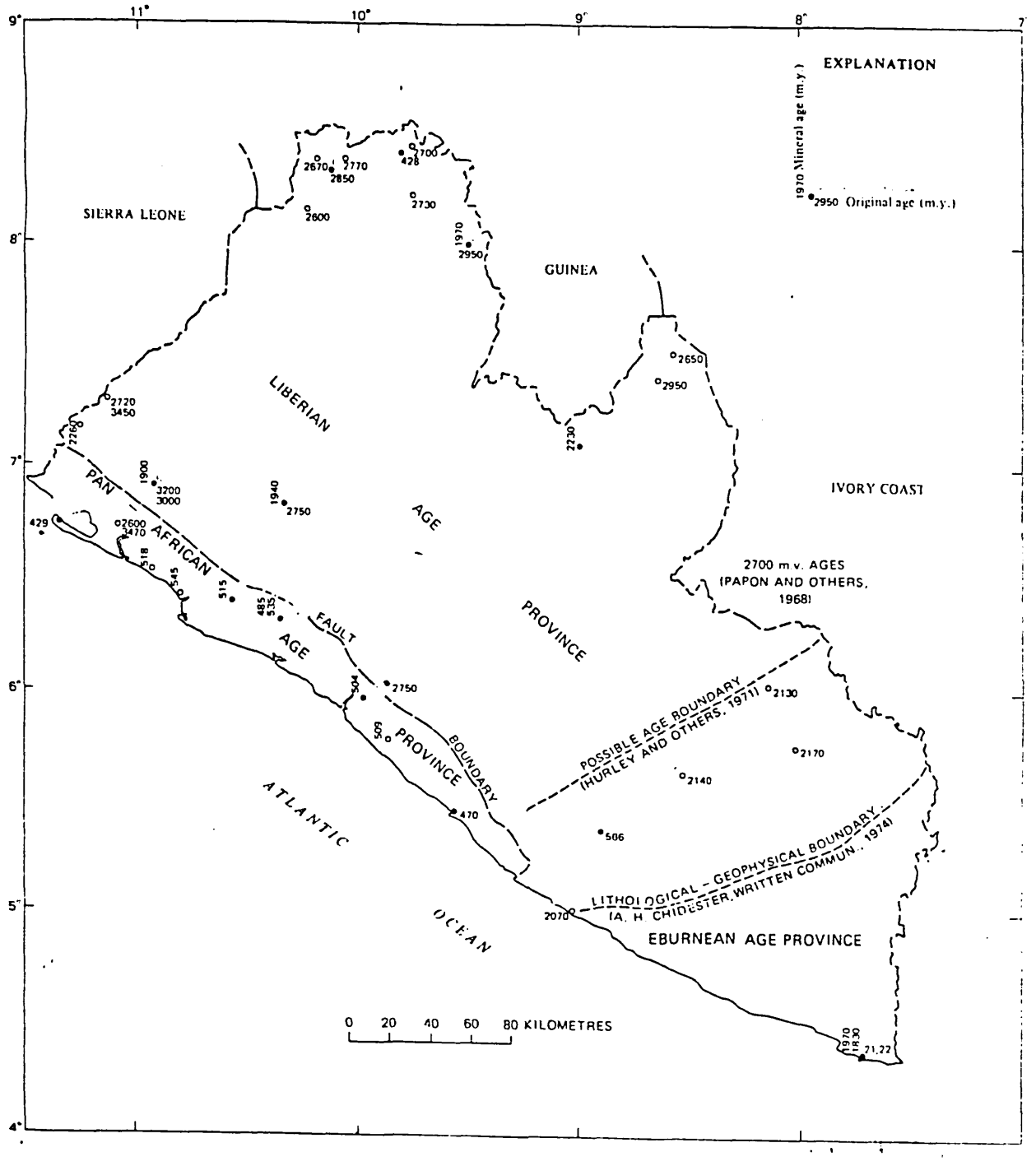


Fig. 5. Map of Liberia showing age distributions in each age province. Solid circles indicate data from Hedge et al. (1975); open circles, data from Hurley et al. (1970). Except for a few K-Ar mineral ages on essentially unmetamorphosed igneous rocks, horizontally written ages are whole-rock Rb-Sr ages and are believed to represent approximate age of the rock; vertically written ages are mineral ages believed to reflect later thermal effects.

Eburnean, and Pan-African) represents a separate tectonic episode (Behrendt and Wotorson, 1974). The structural trends vary from one province to another, and within each province. Thus, the general trend of foliation and regional strike in the Liberian province is northeast; in the Eburnean province, east to northeast; and in the Pan-African province, northwest. Dips in the three provinces are normally high (45° and upward). In each of these provinces, parallelism of planar features over large areas may be indicative of uniformity of deformation on a regional scale, but some linear features such as mineral orientation, rodding, bent twin laminae in plagioclase observed under the microscope, and microscopic folds which plunge at varying angles (with different orientations) locally, are strongly suggestive of multiple deformations. This is a characteristic feature of most Pre-cambrian terrains. Force (1981),for example, working in the Mt Nimba-Sanokole area, observed four phases of folding in the rocks of the area (Fig. 6).

Several faults and fault zones have been deduced from aerial photographs and geophysical maps. For example, a large fault was observed from aerial photographs and aeromagnetic maps in a section of the Lofa River south of Weasua, where related shear zones were also identified (Leo and White, 1969). Such shear zones or faults, most of which trend northeast with nearly vertical dips are conspicuous throughout Liberia,

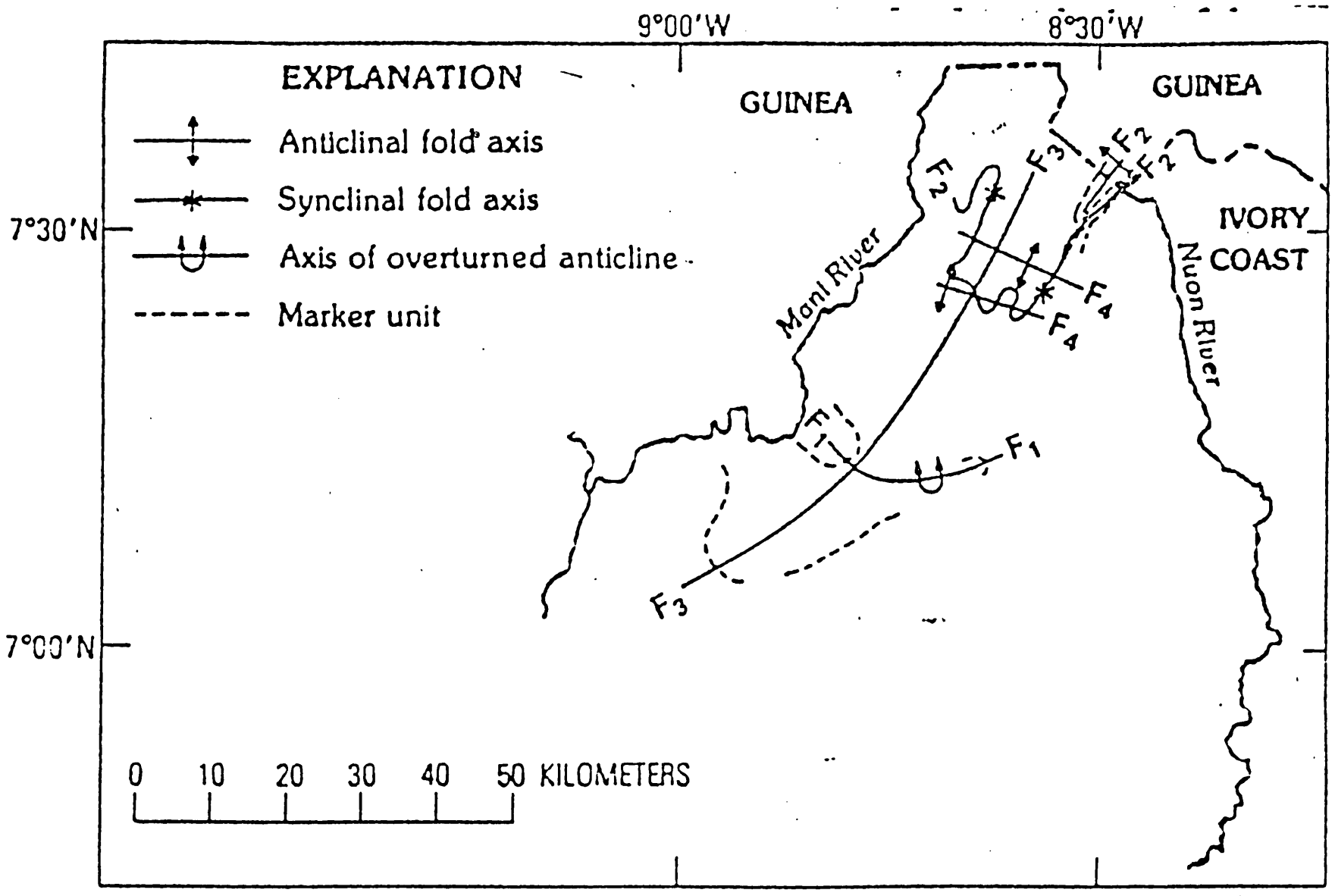


FIGURE 6.—Distribution of folds of different ages in the Mt. Nimba-Sanokole area. F_1 and F_4 are oldest, but they apparently formed separately, and their relative ages are unknown. (from Force, 1983)

and include the Cestos shear zone and the St John shear zones. The courses of most or all of the major rivers and streams are controlled by such fracture or shear zones. Two prominent thrust faults have also been recognised in northeast Liberia, and at least three joint systems have been observed in some parts of the country.

The trends of the diabase and kimberlite dykes are oblique to the foliation of the enclosing gneissic rocks, and are indicative of fracture systems which might postdate the gneissic structure and certainly predate the emplacement of the dykes.

3.2.9 Known Mineralizations

Iron ore, alluvial gold and diamond deposits have remained the principal economic minerals in Liberia since their initial discoveries between 1933 and 1937 by the Holland Syndicates (Shannon and Sangmor, 1982 and G.K. Massaquoi, personal communication), (even though the existence of gold and iron was previously known to the natives who mined and used the metals for trading). Since the 1930's reconnaissance geological investigation and mineral exploration programmes by both local and foreign geologists have found deposits or mineral occurrences of barite, kyanite, phosphate, clays, silica sands, heavy mineral beach sands, bauxite, and manganese (Fig. 7), but these remain uneconomic at the present time.

Base metal mineralization (chalcopyrite, galena, bornite, sphalerite and chalcocite) has been

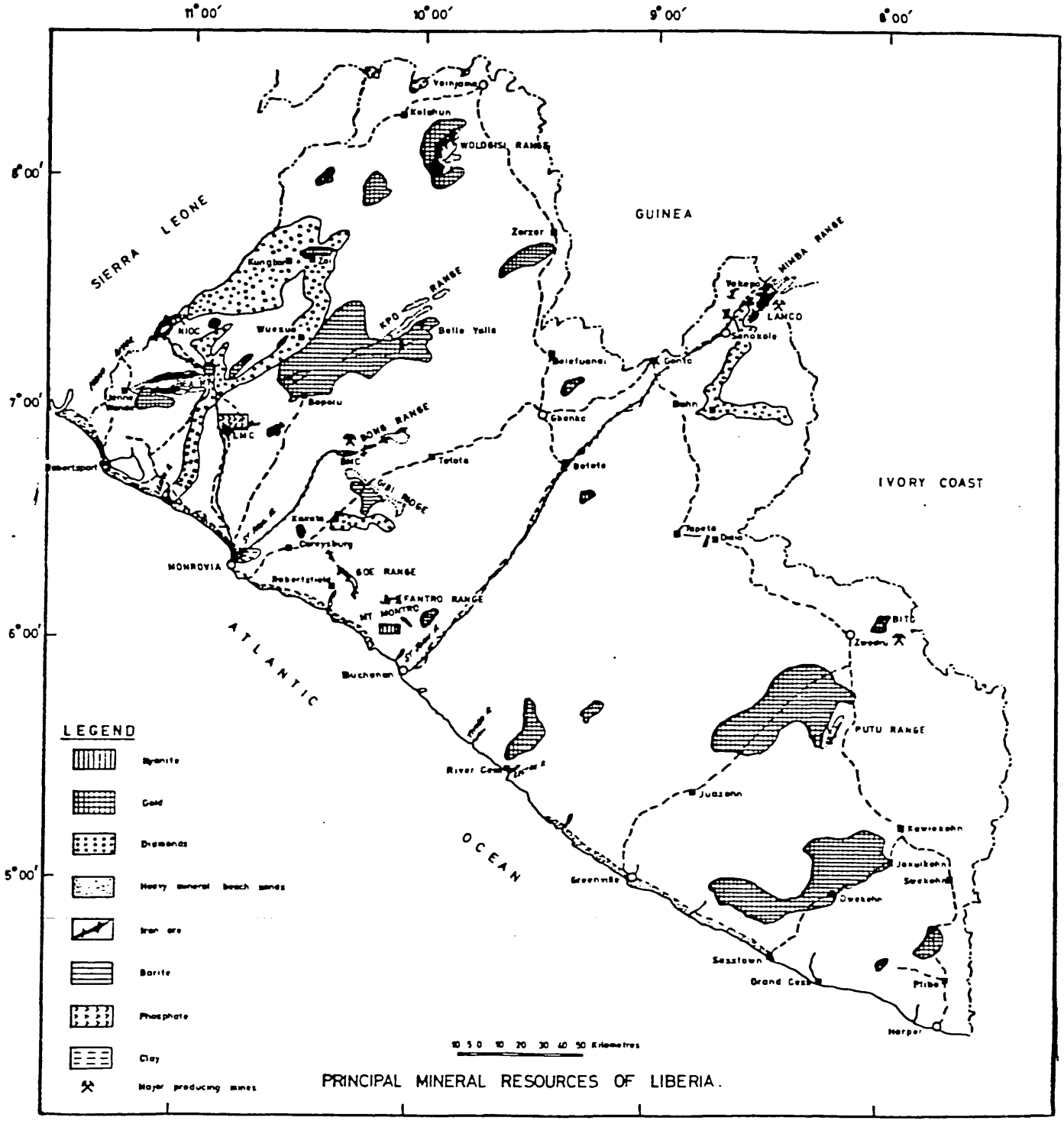


Fig. 7. Principal Mineral Resources of Liberia
(From E H Shannon and S S Sangmor, 1982)

reported in the Gboya creek and Galena creek area (Johnson and Cooper, 1971) and in the Gondoja, Cape Mount area (Batteham, 1976; Sangmor and Dorbor 1981). The latter place is one of the two localities where the occurrence of primary gold has been well established. The gold is disseminated in pegmatitic quartz veins which have intruded into the amphibolite and ultramafic (pyroxenite, hornblendite, dunite and peridotite) country rocks. Tungsten mineralization (scheelite) has also been observed here.

Primary gold has also been found 20 miles northeast of the township of Zwedru, Grand Gedeh County, associated with quartz veins enclosed in a country rock of amphibolite schists (Sherman, personal communication, 1978). Petrographic and ore-microscopic studies (S.P. Srivastava, personal communications, 1978) suggest that the gold also occurs as intergrowths with sulphide minerals (chiefly arsenopyrite) in the enclosing schists.

Tin mineralization (cassiterite) in the lower portion of the St John shear zone ($6^{o}30'N$, $9^{o}32'W$) was first recognized in 1961 (Offerberg and Tremaine, 1961). This mineralization was confirmed in 1969 in active stream sediments south of the village of Grebo Town. This and subsequent similar confirmations culminated in the UNDP Minerals Survey Project geochemical investigation of the area in 1971-1972 (UNDP Technical Report No. 4).

3.3 PREVIOUS GEOCHEMICAL EXPLORATION IN LIBERIA

3.3.1 General Statement

It is very regrettable that despite attempts by several organizations to conduct regional or reconnaissance geochemical prospecting in Liberia, no efforts have been made to date to investigate the geochemical features of the dominant rock types and their mineralization potential.

Against this background, it is, however, appropriate to summarize the geochemical prospecting activities of the major organizations (most of which are foreign) which include: (1) The Liberian Geological Survey; (2) joint Liberian and U.S. Geological Survey; (3) UNDP Minerals Survey; (4) W.H. Muller Company, Mineral Exploration Division; (5) Coastal Liberia Uranium Limited; (6) Liberian-Swedish American Minerals Company (LAMCO); (7) Preussag Metal Exploration (Pty) Limited. Majorareas investigated by some of these organizations are shown in Fig. 8.

3.3.1.1 Liberian Geological Survey

In its capacity as the nation's main mineral exploration agency, the Liberian Geological Survey has always made it a routine matter to incorporate some geochemical methods in exploration programmes. In general, soils, stream sediments and a few grab samples of rocks have been collected randomly and analysed during geological mapping and mineral exploration programmes throughout the country. As a result of this approach, geochemical data from

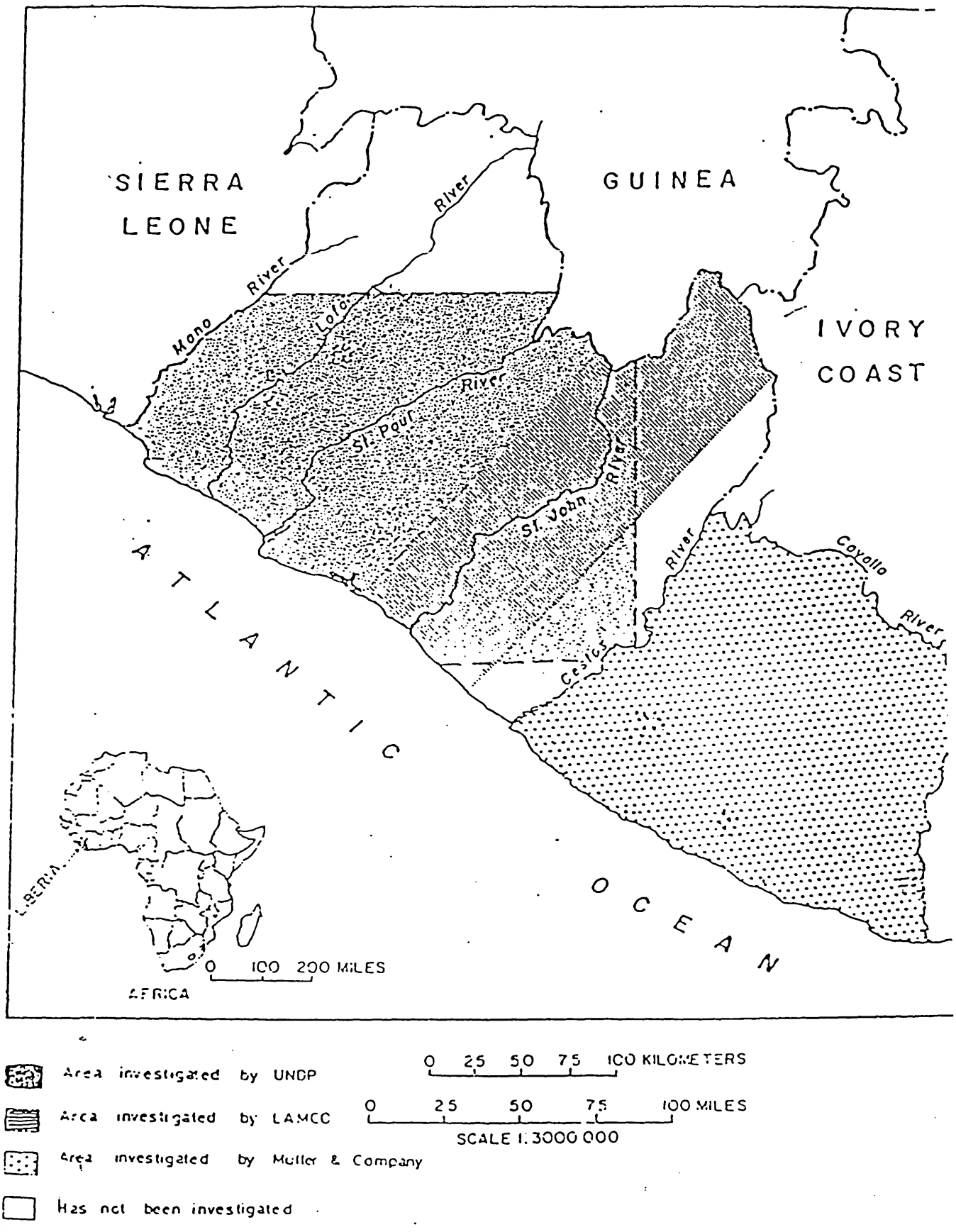


Fig.8. Three major areas where geochemical prospecting had been carried out previously.

this source are at best sketchy and inconclusive, and cannot be used to evaluate the geochemical features or mineral potential of any areas thus investigated.

3.3.1.2 The Liberian and U.S. Geological Surveys

During the course of the GERA (Geological, Exploration and Resources Appraisal) exploration programme by these two Surveys (1965-1972), two areas were specifically investigated using geochemistry in conjunction with geological methods. These were: (a) the Gboya-Galena creek area; and (b) the Sam Davis creek area. They were investigated to test the suitability of simple geochemical methods of exploration in the country.

The country rock in the Gboya creek Galena creek area, which lies southwest of Tawalata (centred at about $7^{o}20'N$ and $10^{o}18'W$), Lower Lofa County is granitic gneiss intercalated with sericite-quartz schist. A shear zone striking $N70^{o}E$, parallel to the regional strike, had indicated sulphide mineralization of Pb, Cu, Zn, and Fe. Pits and trenches were dug to the bedrock up and downstream from the confluence of the creeks across the shear zone. Geochemical soil samples (which formed more than 95% of the samples collected) were then taken from the upper horizon and at close intervals from the surface down to the bedrock in each pit and trench. The few rock samples taken were mainly floats. Total cold extractable (CX) metal contents were determined in the field, and further analysis in the laboratory

of those samples which indicated 10ppm or more CX metal contents gave results ranging from 16 to 7000ppm combined lead, copper and zinc.

The Sam Davis Creek prospect, at which the Liberia Mining Company had done some prospecting in the early 1940's or late 1930's (Thayer et al., 1974), is situated about three miles NE of Gondoja (centred at about $7^{o}15'N$ and $10^{o}50'W$), Cape Mount County. Here disseminated grains of galena, pyrite, sphalerite, and chalcopyrite were found in pegmatitic quartz veins enclosed in coarse-grained amphibolite, pyroxenite, and peridotite. In addition to soil samples taken in a random fashion from the upper horizon throughout the area, (weathered) rock samples were also taken from the walls of the old trenches and an old adit. Cold extractable heavy metal was determined in the field with values ranging from 6 to 116ppm. Analysis in the laboratory indicated the following results: 100-600ppm Cu; 12-500ppm Pb; 200-1000ppm Zn. Ten fresh rock samples from the same area (but not from the adit or trenches) were collected and sent to the chemical laboratory of the Korea Institute of Mineral and Geoscience by personnel of the Liberian Geological Survey during a geologic mapping and mineral exploration programme in 1978. Results from these samples showed the following:- 200-600ppm Cu; 0.50-16.0g/t Au; 170-725g/t Ag; 200-18000ppm Pb; 100-21500ppm Zn; 1300-1400ppm Ni and 600-1500ppm Cr. Values of 1.50ppm Mo and 400ppm W were detected only in one sample.

3.3.1.3 UNDP Mineral Survey Project

This covered an area of about 16,000 square miles (just over a third of the area of the country). The main area of the project lies between $5^{o}50'$ and $7^{o}35'$ north, $9^{o}00$ west and the national boundary between Liberia and Sierra Leone. Geochemical samples were collected along available highways, jeep trails, footpaths and near suitable confluences of tributaries with larger streams. Altogether 4254 samples were collected in the following proportions: soil, 65%; stream sediment, 24%; rock, 4%; and heavy mineral, 7%. Soil samples for the initial regional surveys were collected at about 800 metre (0.5mi) intervals; rock samples were taken whenever encountered and found appropriate for chemical and/or petrographic analysis; stream sediment and heavy mineral concentrate samples were obtained from secondary and other minor creeks in nine major basins at a density of approximately one sample per forty km^2 ($15.4mi^2$). During a second phase of the project a number of smaller areas including the GreboTown mineralization area (centred at about $6^{o}30'N$ and $9^{o}32'W$) and the Cape Mount norite plug (centred at about $6^{o}40'N$ and $11^{o}35'W$) were selected and subjected to more detailed geochemical investigation, with results as follows:- soil: 0-115ppm Cu; 6-100ppm Ni; 0-125ppm Zn; stream sediment: 1-66ppm Cu, 0-150ppm Pb; 2-115ppm Zn; 0-180ppm Ni; 0-110ppm Co; 0-3000ppm Cr; rock: 20-50ppm Cu; 25-100ppm Zn; 10-125ppm Ni.

These results were consistent with those of the first phase (UNDP Technical Report 3, 1972).

3.3.1.4 Muller and Company Exploration Division

This work was carried out in the eastern third of the country (centred at about $5^{o}30'N$, $8^{o}10'W$). Altogether 25,725 geochemical samples were collected, of which 20,000 were soil samples, 2,325 rock samples, and 3,400 heavy mineral concentrates. Lithology is quite variable in this area, ranging from acid to ultramafic rocks and the geochemical results vary accordingly. For example, the soil samples contained: 800-45000ppm Cr; 200-36000ppm Cu; up to 1000ppm Zn; 1600-10000ppm Ni; up to 1200ppm Co; up to 570000ppm Mn; and up to 550000ppm Al. Concentrations determined in fresh rocks included: up to 2500ppm Cr; 1620-3300ppm Cu; 400-660ppm Zn; and 800-12000ppm Ni (Muller Exploration Liberia, 1970).

3.3.1.5 Others

Also contributing to this limited information, but on smaller scale, are: (1) The Liberian-Swedish-American Minerals Company which carried out a reconnaissance geochemical investigation along their railroad track from Buchanan to Yekepa; (2) the UNDP Revolving Fund Mineral Exploration Programme, currently working in the eastern third of the country; (3) Coastal Uranium Limited, which conducted uranium exploration in the scattered region of the country from 1977 to 1982; and (4) Preussag Metal Exploration (Pty) Limited, which carried out a brief reconnaissance geochemical exploration programme at

the Sam Davis Prospect (previously mentioned) in 1976.

Reports of all of these investigations are on file at the Liberian Geological Survey in Monrovia.

CHAPTER 4

GEOLOGY OF AREAS STUDIED

4. INTRODUCTION

Although it may appear from the preceding chapter that Liberia is mainly underlain by granites, which are relatively uniform, the differences that exist between each of the granitic areas studied (Fig.9) requires description in order to aid geochemical data interpretation.

4.1 GEOLOGY OF THE NORTHWEST GRANITES

The geology of the area which includes the Northwest granites and the associated gneisses, schists and other rock units of lesser extent, has been studied at reconnaissance level by Thayer et al. (1974), Leo and White (1969), Behrendt and Wotorson (1974), Jones (1967) and Seitz (1977), among others. Fig.10 shows the general geology of the area. It is an area of prime interest to this investigation as it is the only region in the country known to contain large exposures of massive granitoids in addition to the foliated varieties.

4.1.1 The Massive Granitic Rocks

These range in mineralogical composition from alkali granite to quartz diorite and trondhjemite. Textures are variable, but are mostly equigranular to porphyritic, medium-to coarse-grained. The

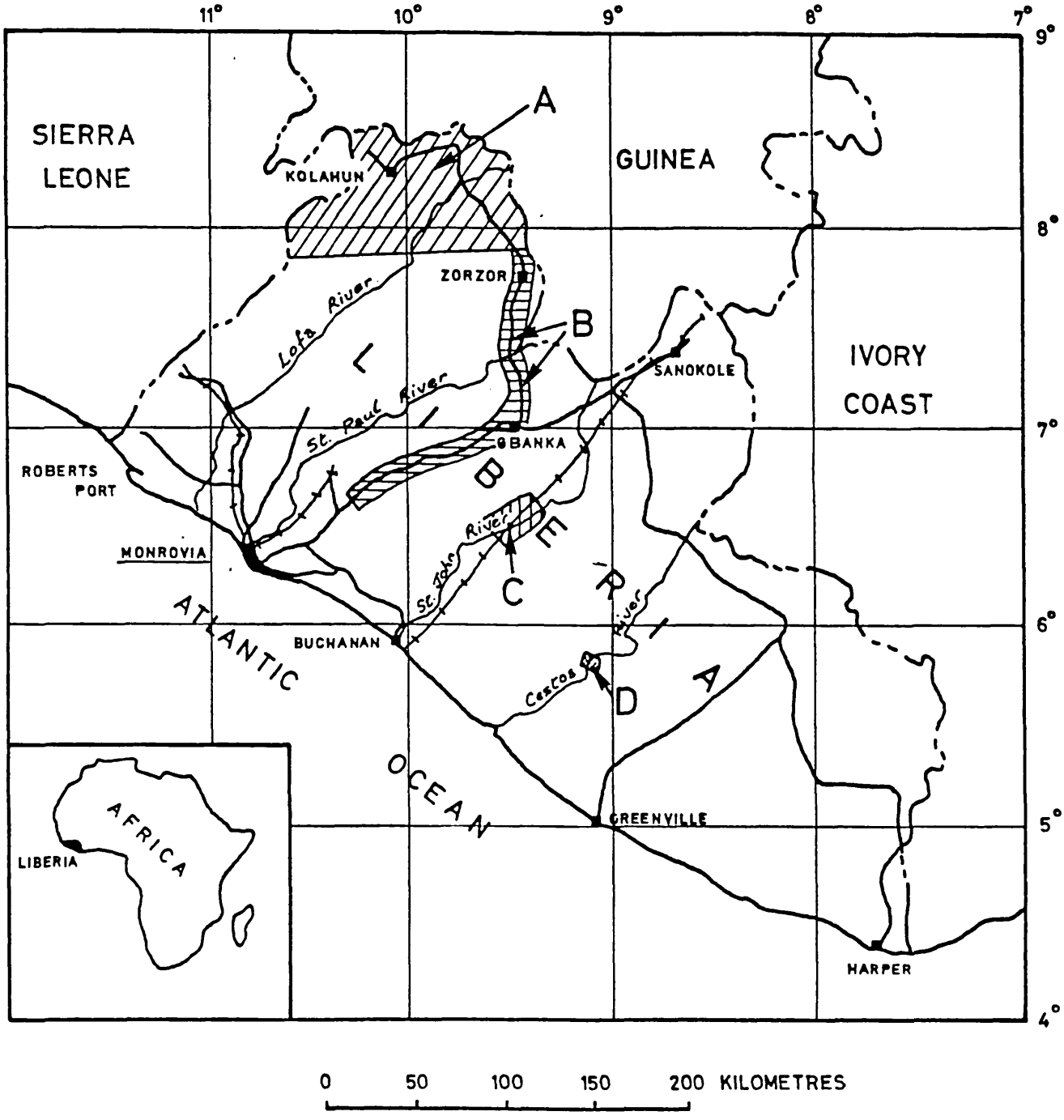
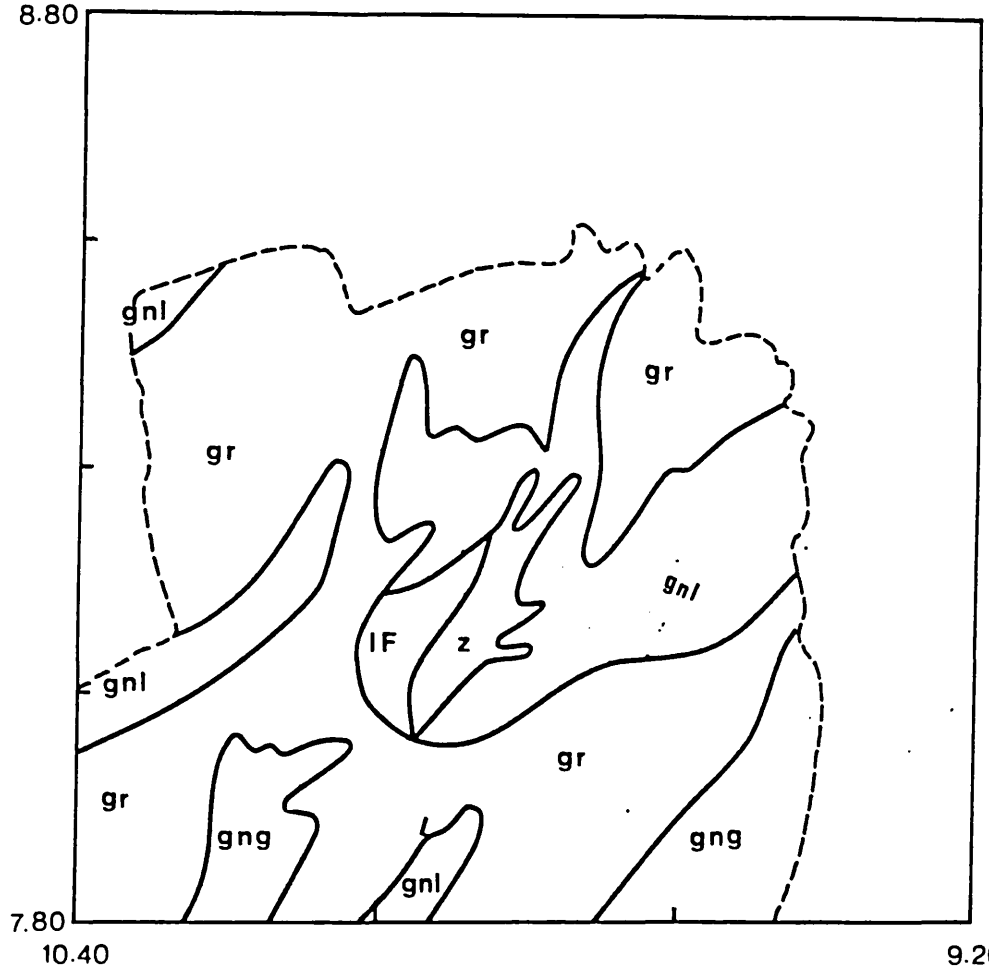


Fig. 9. Index map showing the areas sampled for the present project:

(A) Northwest Granites and associated gneisses
(B) North Central Corridor
(C) Grebo Town area
(D) Cestos Batholith area



gr	Massive or slightly foliated granite
gnl	Leucocratic granitic gneiss
gng	granitic gneiss
IF	Iron formation (oxide and silicate facies)
Z	Composite unit, amphibolite, schist, etc.

Fig 10. Generalized geologic sketch map of the Northwest Granites and associated gneisses (after Seitz, 1977); Approximate scale 1:750,000 (slightly distorted for compatibility with computer generated maps presented subsequently).

colour is usually grey, but pink colouration due to K-feldspar may be locally conspicuous, especially in the large exposures of the area. Quartz, microcline, and plagioclase (albite/oligoclase) are the chief modal minerals. Horblende is subordinate to biotite, both generally occurring as clots or segregates and the accessory minerals include sphene, apatite, monazite and zircon.

4.1.2 Granitic and Leucocratic Gneisses

No attempt is made to separate these two units, for as far as is known to the writer, there is hardly any difference between them, except in terms of colour index. They are mineralogically very similar to the massive granites. Differential layering of biotite and/or hornblende usually crudely defines a general northeast foliation. Feldspar augens and phenocrysts occur locally, and lithological variations within short distances are not uncommon, especially where large exposures are available.

4.1.3 Schists, Iron Formations, Amphibolites and Dolerite Dykes

Occurrences of schists, iron-formations, amphibolites and dolerite dykes interlayer the massive and foliated granitic rocks. The schists have amphibolite - facies mineral assemblages consisting of quartz, biotite, plagioclase chlorite, muscovite and other aluminium silicate

minerals. Higher metamorphic grade facies, such as sillimanite-containing pelitic schists, may be locally encountered.

The iron-formations in this area have been exhaustively treated by White (1973) and Seitz (1977). The oxide facies of this unit has high economic potential (see section 3.2.9).

The amphibolite bands are generally concordant, trending parallel to the strike of the enclosing gneisses, but cross-cutting relationships have also been observed in some cases, suggesting that amphibolites of both igneous and sedimentary origin may be present (White,1973).

The diabase or dolerite dykes, common throughout the country, are here mostly of tholeitic composition and generally strike east-west. Meta-dolerite dykes have also been observed in few places, suggesting that there have been at least two periods of fracturing, followed by emplacement of the dolerite dykes. A basalt outcrop has been found about three miles south-west of Voinjama on the Voinjama-Kolahun highway. Ultramafics have also been observed in the Wologisi Range.

Major fault and foliation trends in the granitic gneisses are predominantly northeast, although small scale faults may trend otherwise. Folds are mostly observable in the iron-formations and schists, particularly in the Wologisi Range. The E-W trending dolerite dyke swarms strongly suggest a major east-west trending fracture system.

Nowhere has any sharp contact between the gnessic and the massive granitic unit been observed. Where observed, the contact shows as close interfingering or (crudely) gradual transitions between the gneissic and massive granites. Similarity in age (Hurley et al., 1971; Hedge et al., 1975) and the level of radioactivity of both the massive granites and the gneisses are suggestive of a genetic association with the possibility that anacetic effects obliterated metamorphic effects in the massive granitoids.

4.2 GEOLOGY OF THE CESTOS BATHOLITH

The Cestos Batholith lies in a shear zone along the Cestos River about 60 miles southeast of Buchanan, Grand Bassa County. Fig. 11 is a geologic map of the area. Both the batholith and the surrounding granitic gneisses and schists are Pre-Cambrian and fall in the Liberian age province (ca.2.7b.y.) (Hurley et al., 1971). Tysdal (1977) and others have carried out geologic investigation as well as mineral exploration programmes in this area.

The rock types of the area include quartz diorite diorite gneiss, leucocratic gneiss, melanocratic gneiss, composite gneiss,schists, with minor amounts of quartzite, amphibolite and iron-formations; plagioclase, quartz, and K-feldspar, decreasing in that order, are the main mineral components. Hornblende is the main characterizing mineral, and biotite and

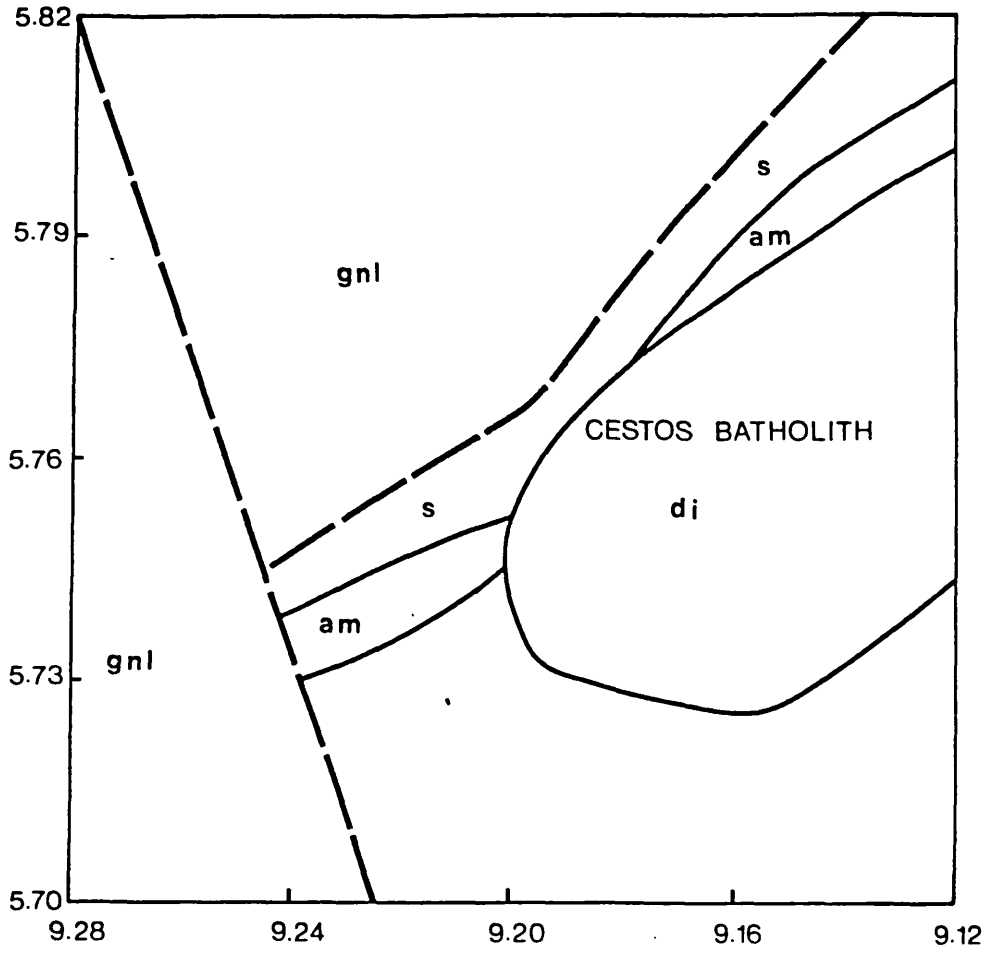


Fig 11. Generalized geologic sketch map of the Cestos Batholith area (after Tysdal, 1977); approximate scale 1:375,000 (slightly distorted for compatibility with computer generated maps presented subsequently).

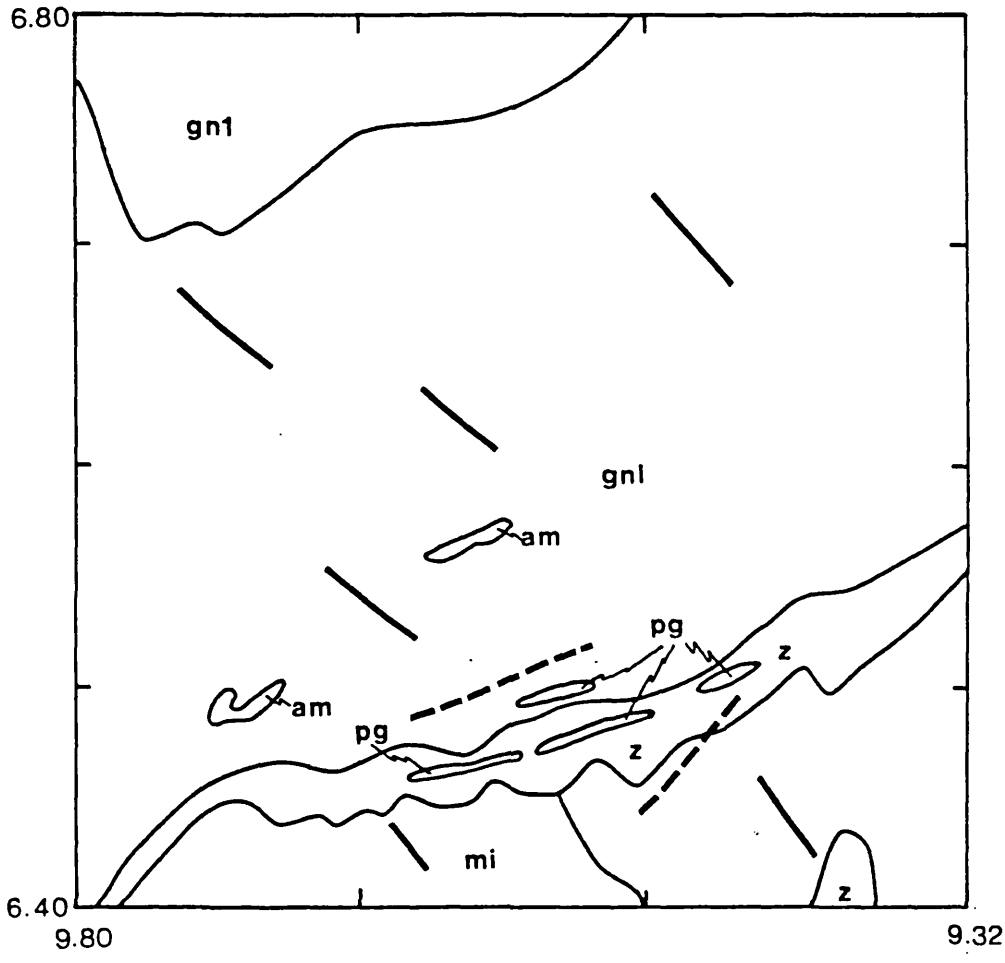
(secondary) muscovite are also present. Pyroxenes, garnets and sphene constitute the accessory mineral suite.

Most of the rocks in this area have been affected by shearing and faulting (as may be observed in the river and stream channels) and the Cestos Batholith is no exception. On casual inspection hand specimens from the batholith may appear to display massive texture, but careful examination of good exposures in the field shows that foliation may be well pronounced where the batholith comes into contact with the surrounding rocks.

4.3 GEOLOGY OF THE GREBO TOWN AREA

The geology of the Gbanka quadrangle (Folio of the Gbanka Quadrangle, Liberia Map I-776-D), containing an occurrence of tin mineralization, has been established by Force and Dunbar (1977), White and Leo (1970) and Behrendt and Wotorson (1974), but our knowledge of the geology is largely due to the work of an UNDP Minerals Survey Project team which conducted a mineral exploration programme there in 1971-1972 (UNDP Technical Report No. 4,1972). Fig. 12 presents the local geology of the area.

Thin lenses or veins of granular pegmatites are associated with the main rock types (schists, granitic gneisses and migmatites) of the area. These veins and lenses trend NE, parallel to the strike of foliation of the enclosing rocks.



gn1 Composite granitic gneiss with subordinate amphibolite

gnl Leucocratic gneiss

am Amphibolite

pg Pegmatite lenses

z Composite unit of schist, amphibolite and iron formation (silicate and oxide facies)

mi Migmatite

Fault

Dolerite

Fig 12. Generalized geologic sketch map of the Grebo Town area (after Force and Dunbar, 1977); approximate scale 1:500,000 (slightly distorted for compatibility with computer generated maps presented subsequently).

Shearing is not uncommon in most of the pegmatite lenses or veins as the area as a whole forms part of the St John shear zone.

The enclosing schists are rich in quartz, muscovite and other aluminium silicate minerals. The gneisses range from granite to quartz diorite in mineralogical composition. The pegmatite veins contain K-feldspars (mainly microcline), plagioclase, quartz and micas (chiefly muscovite) as the main minerals. Accessory minerals include magnetite, tourmaline, rutile, zircon, pyrite and epidote. Cassiterite has also been reported from these veins.

The area contains several faults which generally trend NE, parallel to the regional strike of the St John shear zone.

No radiometric age dating has been carried out, but it may be assumed that the major rock types of this area are of Pre-Cambrian age since they form part of the Pre-Cambrian (c a.2.7.b.y.) Liberian age province. On the other hand, the dolerite dykes which transect the major rock types and pegmatite lenses or veins in a northwest-southeast direction are probably of Jurassic age (Hurley et al., 1971).

4.4 GRANITES AND GRANITIC GNEISSES ALONG THE NORTH-CENTRAL CORRIDOR

This corridor covers the section between Totota township (Bong County) and Konia settlement (Lofa County) along the Monrovia-Voinjama highway

(Fig. 9). The geology is diverse as the corridor was sampled as a traverse along the highway. In general, however, the lithology and structural relations are similar to those of the Northwest Granites and Gneiss (Fig.10).

CHAPTER 5

REVIEW OF THE CHEMICAL, PETROCHEMICAL AND PETROLOGICAL FEATURES OF GRANITIC ROCKS AS GUIDES TO MINERALIZATION

5. INTRODUCTION

Whilst it is beyond the scope of this work to deal exhaustively with this topic, it is relevant to briefly summarize the chemical, petrochemical and petrological features of granitic rocks as guides to their mineralization potential. Such features have been known and studied for decades, and were recognized, for example, by Werner in the 18th century. According to Moseley (1981), early students of this subject were Daubree and Beaumont in the 1840's, Cotta, Dalmer, Ferguson and Bateman, and Westveld. Recent workers in this area of scientific investigation include Hosking (1962), Ratigan (1960), Ginsburg (1972), Stemprok and Skov (1974), Tischendorf (1973, 1977), Tischendorf et al. (1971), Howarth et al. (1981), Plant et al. (1980), Simpson et al. (1979), Ishihara (1980,1981), Stemprok (1979), Imeokparia (1982, 1983, 1984), Hudson and Art (1983), Rankin et al. (1981), Pokalov (1982), Bradshaw (1967), Juniper and Kleeman (1979), Ishihara et al. (1981), Govett (1983), Olade (1971,1980) and Olade and Fletcher (1976). Despite the fact that terms like rare metals or rare elements, metallization, metalliferous, metallized , mineralization, and specialised

granites abound in the literature of exploration geochemistry today, there seems to be sometimes some confusion as to the exact meanings of some of them. It is therefore relevant to make some explanatory notation here. The terms "rare metals" or rare elements are used here to include all those lithophile elements - Sn, W, Be, Li, Mo, Ta, Nb, and Rb - which are generally associated with late-stage crystallization of granitic melts. Similarly, the term metallization (and also metallized or metalliferous) is taken here to mean the "high primary concentrations of metals predominantly in silicate minerals" (Plant et al., 1980), whereas mineralization is meant to imply the formation of these metallic elements into discrete ore minerals. On the other hand, specialized granites are here defined as granitoids which are relatively enriched in a particular metallic element or a group of such elements as opposed to the Clarke values in similar or related intrusives

5.1 CHEMICAL FEATURES

5.1.1 General Statement

There is now an ample amount of evidence to show that, despite minor differences of opinion, the degree of evolution of a particular pluton

type (and any associated mineralization) is indicated by the major- or trace-element geochemistry (Govett, 1983). The underlying factor for this line of thought is that as crystallization of a magma proceeds, some elements have the tendency to be incorporated into the early-formed minerals (or rocks) while others prefer to accumulate in the residual fluid and become incorporated into more evolved suites at later stages. Naturally, rocks formed at the various stages of evolution will display distinct major-or trace-element geochemistry. Thus the granitic rocks or granitoids, which are usually considered to be more evolved, are in general enriched in the granitophile elements (e.g. K, Rb, Ba, Li) or some high field-strength elements (e.g. Ta, Nb, Be) and the volatiles (F, B, Ce) but depleted in the granitophobe ones (e.g. Mg, Cr, V and Ca). This process of enrichment or depletion is governed by several chemical parameters such as electronegativity, ionic potential, the ionic radius and ionic effects (Goldschmit 1937; Ahrenes, 1965, 1962; Krauskopt, 1967; Mason, 1966).

5.1.2 Major Element Concentrations and Ratios

The use of the major element concentrations in granitoids as a guide to their mineralization potential remains one of the areas of active research and controversy today. Claims of success in the use of these elements as a guide in exploration programmes for the rare elements in

granitic terrains are abundant. Others dispute these successes. For it is clear that this controversy has been with exploration geologists and geochemists since the days of Westerfield who is said to have stated in the late 1930's that the main chemical composition of tin-bearing granites did not differ markedly from that of non-stanniferous, ordinary biotite granites. An opposite view was expressed in the late 1940's by Edwards-Caskin and others, who claimed that tin granites from New South Wales and Tasmania were 'conspicuously' silica-rich (Tischendorf, 1977).

One recent worker who has come out as a strong supporter of Westerfield's idea is Hosking (1965). He cites the tin deposits of Bolivia and Portugal as examples of instances in which SiO_2 content is not necessarily higher than that of the normal or barren granites in the same areas. Moseley (1981) mentions the Dartmoor granite in the Cornubian tin province as an example of a granitic body which is highly silicic but almost unmineralized, to emphasize the problem associated with the use of this parameter. Others who have echoed Westerfield's view in recent time include Ratigan (1963) and Singh and Ahmad (1974).

On the other hand, it appears that most workers in this field of investigation during the last two or three decades now share Edwards-Caskin's view on the enhancement of silica contents in mineralized granitoids (Hesp, 1971; Flinter, 1972; Groves, 1972; Boyle, 1974; Hesp and Rigby, 1975; Cuney, 1978;

Stemprok, 1979; Ewers and Scott, 1977).

Similar controversy also surrounds the use of K_2O as a guide to mineralization in granitoids. For instance, whilst several workers agree with Mason and MacDonald (1981), Howarth et al. (1981) and Plant et al. (1980), that enhancement of K_2O is noticeable in mineralized granitoids, Tischendorf (1977) in a major survey appeared to be taking a different opinion. He concluded that differences in the contents of this element in specialized and normal granitoids may not be particularly obvious.

From the preceding paragraphs it is obvious that there is considerable divergence of opinion on the usefulness of the geochemistry of these elements, especially silicon, as guides for mineral exploration in granitic terrains. This apparent lack of general agreement on the usefulness of the geochemistry of these two elements in this respect must be evaluated on the basis of factors such as geological setting, number of samples used and petrological features (Boyle, 1974; Stemprok et al. 1977; Imeokparia, 1980; Moseley, 1981; Govett, 1983).

The usefulness of other major elements for this purpose appears even more difficult to assess for the differences in concentration of components such as CaO, TiO, FeO, Fe_2O_3 and MgO between mineralized granites and unmineralized are usually highly insignificant in most places (Tischendorf, 1977; Stemprok et al. 1977).

Ratios such as (Na+K): (Ca+Mg) and (Na+K): Fe (Govett, 1983), and K_2O:Na_2O (Boyle, 1974) have also been employed as means of discriminating between tin-mineralized and unmineralized granites (for tin mineralization has been the most investigated thus far) with varying degree of success. However, the use of major element concentrations by themselves has not proved unequivocal, but it may be of great assistance in combination with the results of other methods.

5.1.3 Trace Elements

5.1.3.1 General Statement

The abundance and inter-element relationships among the trace elements have also been extensively used in discriminating mineralized granites from the unmineralized ones. The usefulness of these elements, which include Sn, Li, Rb, W, Mo, Be and F and Cl, rests on the principle that their content "in each rock type is likely to appreciably vary due to various factors" (Beus and Gregorian, 1977, in Moseley, 1981). Some of these factors, which could be geological, chemical, petrological, or physical, have already been mentioned at the beginning of this chapter.

5.1.3.2 Tin and Other Element Concentrations

Most of the investigation on rare elements and their usefulness as geochemical exploration tools in granitic terrains has been in connection with Sn mineralization (Moseley, 1981; Govett,

1983). This is understandable, as the concentration of the element itself can be used to assess its mineralization potential in granitoids. Thus, it is now agreed among most workers that tin-mineralized granitoid intrusions are generally characterised by higher amounts of the metal as opposed to lower amounts in barren granitoids(Barsukov, 1957; Hesp and Rigby, 1975; Ivanova, 1963; Tauson and Kozlov, 1973; Beus and Sitnin, 1968; Lenthall and Hunter 1977; Govett, 1983). Olade (1980) specifically emphasizes that high tin variance is another important characteristic of tin-mineralized granitoids.

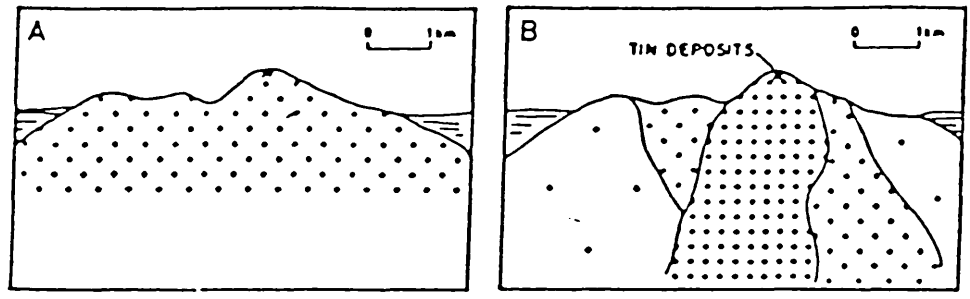
On the other hand, Chauvis(in Moseley,1981) cites the tin mineralization in Britanny as an instance where the granitoids hosting tin mineralization contain lower contents of tin than unmineralized granitoids. Other instances of arguments against the theory of higher tin contents in tin-bearing granites, such as by Hosking (1962), using tin mineralization in Malaysia and Cornwall as examples, have already collapsed (Singh and Ahmad, 1974 and Hosking, 1971).

The evidence for higher tin-contents in mineralized granitoids is overwhelming. Nevertheless, because of the fact that actual values are difficult to assign as values vary from one locale to the other (Table 2), other factors such as degree of evolution of granitoids concerned, their internal geochemical variability and geological settings must be taken into consideration (Moseley, 1981). Taylor (1979) has diagrammatically summed up the geological aspect of this problem (Fig.13).

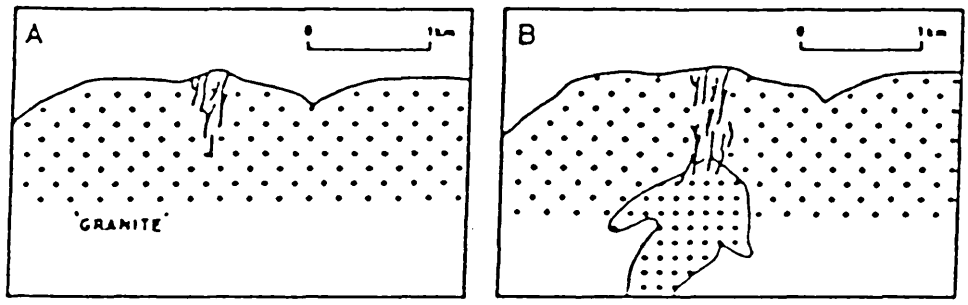
Table 2

The Sn-content in specialized granites according to several authors and the proposed average without the data by Aubert (1969), Burnol (1974a), Ganev (1964), Leutwein (1965), Tugarinov - Kovalenko (1973) (in ppm) (from Tischendorf (1977)

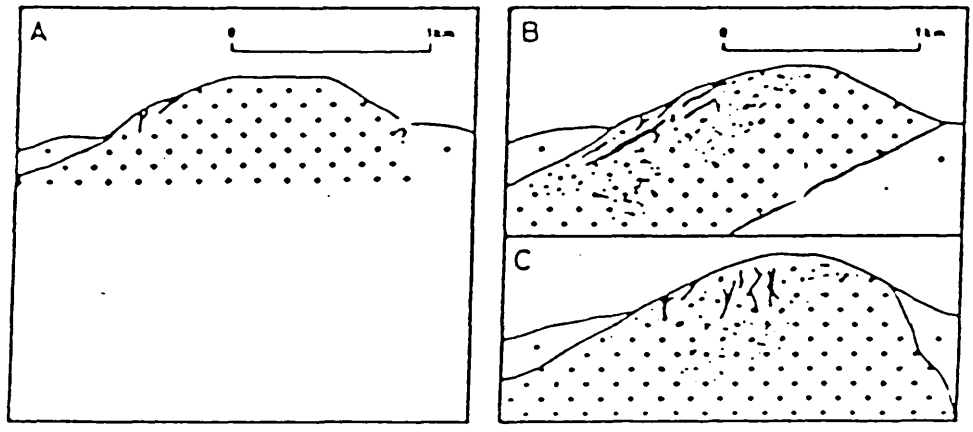
Authors	Specialized granites	Normal granites
Aubert (1969) Montebras	56—158 (Ø 80)	—
Echassiere	93—245	—
Barsukov (1964)	10—37	3—5
Barsukov (1974)	16—37 (Ø 26)	2—4.5
Barsukov - Pavlenko (1956)	16—30	<5
Beus - Sitnin (1968)	15±4 (>20)	5±1
Bräuer (1970)	20—60	3
Burnol (1974b)	90—285	—
Charoy (1972)	7—35 (Ø 15)	—
Flinter - Hesp - Rigby (1972)	8—20	—
Ganeev (1964)	24—667	—
Govorov et al. (1970)	11—12	6.5—8
Groves (1972)	31—61	—
Groves (1974)	15—45	—
Haapala (1974)	5—100 (Ø 58)	—
Hall (1973)	5—79	—
Hesp (1971) after Rattigan	5—45 (Ø 16)	2—5
Hesp (1974)	20—80	—
Hesp - Rigby (1974)	27.0	3.8
Ivanova (1963)	16—32	<5
Jarchovský (1974)	32±3	—
Klomínský - Absolonová (1974)	33—39	—
Kozlov (1974)	9.4—28	—
Kuzmin et al. (1970)	4.2—12.3	—
Lange et al. (1972)	10—80	—
Legeido (1969)	4.2—7.4	2.0—6.5
Legeido (1972)	2.4—7.8 (Ø 7.1)	3.5—4.1 (Ø 3.9)
Leutwein (1965)	113	—
Lugov (1968)	10—20	—
Nedashkovskii - Narnov (1968)	6—24	—
Neiva (1972)	20—100	—
Phan (1965)	30	8
Rattigan (1963)	20	2—5
Rub in Lugov et al. (1969)	10—60	1—7
Rub - Koptev - Dvornikov (1970)	10—60	3—5
Rub et al. (1974)	15—25	—
Rudakova (1973)	10—80	—
Sattran - Klomínský (1970)	25—30	2.5—4



Tin bearing granitoids initially assumed homogeneous (A) are subsequently shown to be multiphase (B).



A tin bearing granitoid? (A) is subsequently shown to be the host to the true parent (B).



Even when a tin bearing granite is clearly outlined (A), the tin distribution may be anisotropic, varying both laterally and horizontally.

Fig.13. Problems relating to sampling and interpretation of data relating to geochemical specialisation of granitoids (Part 1).

(Taylor, 1979)

Lithium has also been extensively studied in relation to fractionation and possible mineralization in granitoids, and it is now generally accepted that it is enriched in mineralized granitoids (Beus and Sitnin, 1968; Hesp, 1971; Beus and Gregorian, 1977; Howarth et al., 1981; Plant et al., 1980; Flinter et al., 1972; Govett, 1983; Smith and Turek, 1976; Levinson, 1980; Tauson and Kozlov, 1973; Ishihara et al., 1980; Imeokparia, 1980). Table 3 is a compilation of values of this element in specialized granitoids according to various authors. Despite this apparent general consensus on its enrichment in highly fractionated (and therefore possibly mineralized) granitoids, the role of Li in the mineralizing process is not yet quite clear (Tischendorf, in Stemprok et al., 1977). In consideration of the characteristic co-enrichment of lithium and fluorine, Bailey (1977) has suggested that Li may be facilitating mobility of certain elements in granitoid melts, a role for which fluorine is well known.

Two other trace elements whose enrichments in mineralized or specialized granitoids have been successfully used as exploration tools are fluorine and rubidium (Barsukov, 1957; Sheraton and Labonne, 1978; Bailey, 1977; Tischendorf, 1977; Imeokparia, 1980, 1982; Govett, 1983; Hesp, 1974). Many workers believe that most rare-metals are carried as fluorides to be concentrated and precipitated during the late stage of the emplacement of a granitoid intrusion. Table 4 is the data on the abundance of this

Table 3

The Li-content in specialized granites according to different authors and proposed averages (in ppm)

Authors (See Tischendorf,(1977) for source publication)	Specialized granites	Normal granites
Aubert (1969) Montebras	407—1203	—
Echassiere	955—1329	—
Beus - Sitnin (1968)	80±20 (>100)	37±6
Bräuer (1970)	400—1000	70—150
Burnol (1974b)	535—1315	—
Carron de la Roche (1974)	>60 (Ø 120)	<60 (Ø 45)
Fiala (1968)	200—675	—
Groves (1972)	150—400	—
Groves (1974)	50—300	—
Haapala (1974)	50—500	—
Hall (1973)	20—3000	—
Jarchovský (1974)	700±25	—
Klomínský - Absolonová (1974)	279—465	—
Kovalenko - Kuzmin et al. (1971)	90—340 (Ø 190)	—
Kozlov (1974)	84—300	—
Kuzmin et al. (1970)	86—330	—
Lange et al. (1972)	200—900	—
Leutwein (1965)	861—1025	—
Phan (1965)	100	35
Rub et al. (1974)	240—810	—
Rudakova (1973)	45—130	—
Sattran - Klomínský (1970)	450	—
Tauson (1974)	200—250	—
Eastern Transbaikalia average	97	
Tischendorf (1970)	410±150	—
Tischendorf et al. (1972)	430	40—60
Tugarinov - Kovalenko (1973)	183	—
Zalashkova - Gerasimovskii (1974)	76—265	—
Zoubek - Tauson et al.		
Erzgebirge	340	—
Transbaikalia	80	56
proposed average	400±200	
Bohemian massif	450±100	
Central Massif of France	950±200	
all other regions	220±100	

Table 4

The F-content in specialized granites according to different authors and the proposed average (in ppm)

Author (See Tischendorf (1977) for source publication)	Specialized granites	Normal granites
Aubert (1969) Montebras	1530—3810	—
Echassiere	2630—3389	—
Bräuer (1970)	2000—5000	250—500
Burnol (1974b)	3100—5560	—
Charoy (1972)	640—1808 (Ø 945)	—
Fiala (1968)	5000	—
Fuge - Power (1968)	1395	—
Groves (1972)	3100—10200	—
Haapala (1974)	8000	—
Hall (1973)	460—12200	—
Jarchovský (1974)	8000 ± 300	—
Klomínský - Absolonová (1974)	2300—4700	—
Kovalenko - Kuzmin et al. (1971)	2800—4700	—
Kozlov (1974)	2000—3000	—
Kuzmin et al. (1970)	2800—3600	—
Lange et al. (1972)	3500—8400	—
Legeido (1969, 1972)	1400—3300	500—1500
Odikadse (1971)	1000—2000	650— 700
Rub et al. (1974)	3000—4000	—
Rudakova (1973)	1100—1900	—
Shcherba (1968)	800—6000	—
Shcherba et al. (1973)	1800—2000	—
Tauson (1974) East Transbaikalia	1200—2000	700
average	3000	800
Tauson et al. (1968)	2500—3000	
Tischendorf (1970)	4300 ± 2000	—
Tischendorf et al. (1972)	5100	500—640
Tugarinov - Kovalenko (1973)	1300—4600 (Ø 3100)	—
Zalashkova - Gerasimovskii (1974)	2100—3000	
Zoubek - Tauson et al. (1972)		
Erzgebirge	3400	—
Transbaikalia	2700	500
proposed average	3700 ± 1500	

element in specialized granitoids as determined by various workers.

The enrichment of rubidium in relation particularly to potassium, as indicated by the K/Rb ratio in mineralized granitoids, is well known and has been used as an exploration tool in many places (Plant et al., 1980; Sheraton and Black, 1973; Allman-Ward, 1982; Govett, 1983; Sheraton and Lebonne, 1973). Both Rb and K increase with fractionation, but due to its larger ionic size Rb generally becomes more concentrated in highly fractionated granitoids. Under extreme conditions of fractionation such as is necessary in the mineralization processes of most rare-metals (especially Sn), the K/Rb ratio may fall below the normal range of 150-300 (Govett, 1983).

Data on the use of the contents of other rare-metals (W, Mo, Be, Ta and Nb) as guides to their mineralization in granitoids are sparse, and information is sometimes conflicting. For instance, while Tischendorf (1977) reports that Ivonnova (1963) and Barsukov (1964, 1974) found tungsten and molybdenum content in general, to be same in both mineralized and unmineralized granitoids, other workers, including Garrett (1971) and Flinter et al. (1972) have noted increases in W and Mo contents in mineralized granites (Tables 5 and 6). Similar controversies surround the use of the contents of other rare-metals in assessing their mineralization potential in grani-

Table 5

The W-content in specialized granites according to different authors and the proposed average, without the data by Aubert (1969), Burnol (1974b) and Ganeev (1964) (in ppm)

Author	Specialized granites	Normal granites
Aubert (1969)	15—174	—
Barsukov (1964)	1.6—2.7	1.6—2.7
Beus - Sitnin (1968)	5±1 (>4)	2±0.3
Burnol (1974b)	20—163	—
Ganeev (1964)	20—200	—
Govorov et al. (1970)	3—5	1.5—2
Ivanova (1963)	<1.2—2	<1.2—2
Kovalenko - Kuzmin et al. (1971)	1—5	—
Kozlov (1974)	2—5.9	—
Rub - Koptev-Dvornikov (1970)	2.2	1.8
Rudakova (1973)	2	—
Shcherba (1968)	8—30	—
Shcherba et al. (1973)	4.4—7.0	—
Stemprok (1971)	13—28	—
Tauson (1974) East Transbaikalia	4.9—10	—
Tauson (1974) average	4.1	1.5
Zoubek - Tauson et al. (1972)		
Erzgebirge	14	—
Transbaikalia	4.7	1
proposed average	7±3	

(Tischendorf, 1977)

Table 6

The Mo-content in specialized granites according to different authors and the proposed average, without the data Ganeev (1964) and Shcherba (1968) (in ppm)

Authors	Specialized granites	Normal granites
Barsukov (1964)	1—1.4	1—1.4
Ganeev (1964)	1—28	—
Govorov et al. (1970)	3—10	2—2.5
Ivanova (1963)	1.1	<1—1.2
Kovalenko - Kuzmin et al. (1971)	0.8—2.0	—
Shcherba (1968)	5—40	—
Shcherba et al. (1973)	1.5—3.7	—
Tischendorf (1970)	3.9±1	—
proposed average	4±2	

(Tischendorf, 1977)

toids (Tischendorf, 1977; Olade, 1980; Govett, 1983; Plant et al., 1980; Lenthall and Hunter, 1977). On the whole, however, it would appear from these studies that values over the Clarke in addition to high variance are good indicators of mineralization in granitoids. For instance, working in northern Nigeria, Olade (1980) found that Nb showed a two-fold increase from barren hornblende granites to mineralized granites. Some of the controversies surrounding the use of these elements as guides for rare-metal prospecting stem from their low levels of concentration in geological materials in general. Therefore as analytical methods for these elements have been and continue to be improved, their usefulness as prospecting tools is bound to become clearer.

5.2 ELEMENT RATIOS

5.2.1 General Statement

Using element ratios to assess the degree of evolution, and thus the ore-bearing potential, of granitoids is proving to be a versatile tool. The elements involved in a particular ratio have either a sympathetic (isomorphous) or antipathetic relation at one point or another during normal crystallization. The choice of any of these ratios depends on many factors. Beus and Grigorian (1977) are inclined to think that "the most informative ratios are those which are based on elements whose migration tendencies (such as those of Mg and Li)

are in opposing directions during crystallization of a magma". Other workers (e.g. Sheraton and Black, 1973) take different approaches.

5.2.2 Selected Ratios

Many element ratios have been used to characterize granitoids in terms of ore-bearing potential. Among those that have been generally used with some degree of success are: U/Th, K/Rb, K/Ba, Ba/Rb, K/Sr, Ba/Ca, K/Na, Ca/Sr, Mg/Ti, Mg/Li, TiO_2/Ta, Li x1000/K, K/Pb, Li/Zn, Sn/F.

One or more of these ratios have been used by various workers (Tauson and Kozlov, 1973; Plant et al., 1980; Tischendorf, 1977; Smith and Turek, 1976; Imeokparia, 1979; Moseley, 1981; Strong et al., 1974; Groves and McCarthy, 1978; El Bouseily and El Sokkary, 1975; Sheraton and Black, 1973; Beus and Sitnin, 1968; Beus and Gregorian, 1975; Imeokparia, 1981; Bailey, 1977) to determine the stage of fractionation of granitoids, and therefore their possible rare-metal mineralization. The'cut-off values" of some of these parameters are given by Moseley (1981). Thus, for example, values of < 100, ≤ 0.5, < 100 for K/Rb, Ba/Rb and Mg/Li, respectively, are considered as signals for a high degree of fractionation and/or mineralization in granitoids.

Relationships between some trios of both trace and major elements have also been used to assess the degree of fractionation (and hence the mineralization potential) of granitoids. Such a relationship may be used to discriminate mineralized

granitoids (Figs. 14 & 15).

5.3 PETROCHEMICAL FEATURES

5.3.1 General Statement

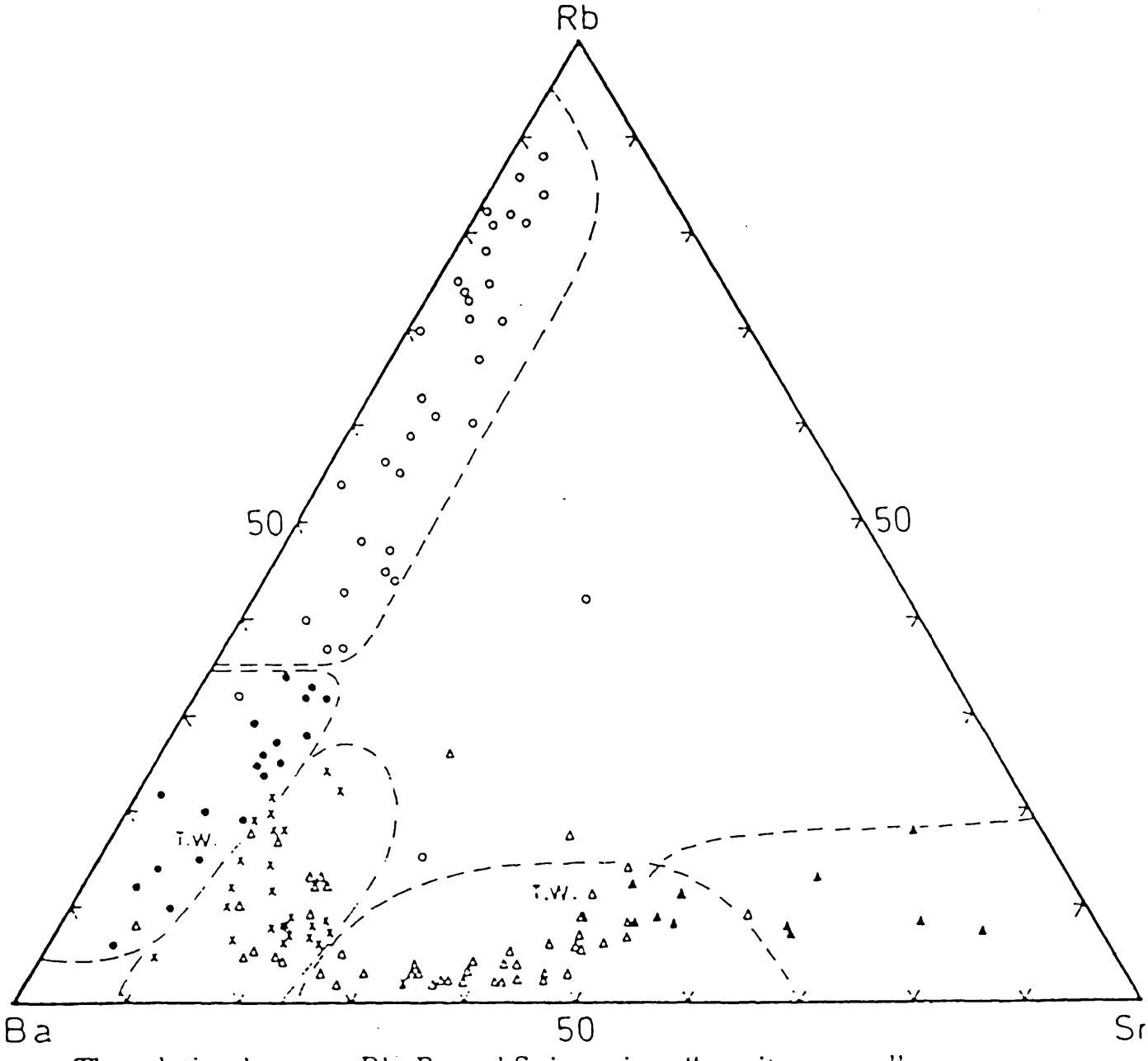
Several workers have attempted to use certain petrochemical properties as guides to rare-metal mineralization in granitoids. Each individual worker seems to place more emphasis on one or the other of these properties. Here, however, only a summary of some of these properties will be given.

5.3.2 I-type/S-type and Magnetite Series/Ilmenite Series Schemes

These two schemes of classification of granitoids are relatively new, but have been widely accepted in the scientific world since they were first introduced by Chappell and White (1974) and Ishihara (1975) respectively. Although the two systems are not the same, they overlap in some respects (Takahashi et al., 1980).

5.3.3 I-type/S-type

The chemical, mineralogical and other criteria of these "two contrasting granitic types" (White and Chappell, 1974) are given in Table 7. Inspite of some minor controversies, it is now generally accepted that the I-type granitoids are derived from igneous source material (or a source lying within or close to the mantle) whereas the S-type granitoids are believed to have originated within the continental



The relation between Rb, Ba and Sr in various "granite groups". ▲ = diorites; ◬ = quartz diorites—granodiorites; X = anomalous granites; • = normal granites; o = strongly differentiated granites; ◬ T.W. = high-Ca granites; • T.W. = low-Ca granites (Turekian and Wedepohl, 1961).

Fig. 14 (From El Bouseily and El Sokkary, 1975)

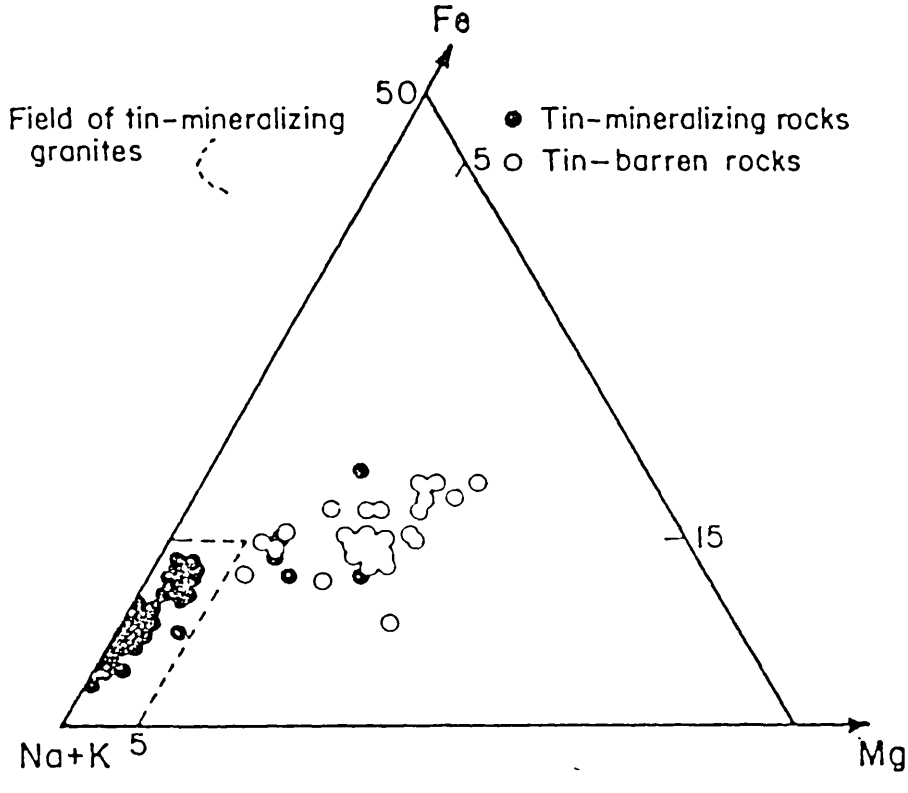


Fig.15. System Na+K—Fe—Mg for New England granites.

(Juniper and Kleeman, 1979)

I-type	S-type
Relatively high sodium, Na_2O normally $>3.2\%$ in felsic varieties, decreasing to $>2.2\%$ in more mafic types	Relatively low sodium, Na_2O normally $<3.2\%$ in rocks with approx. 5% K_2O, decreasing to $<2.2\%$ in rocks with approx. 2% K_2O
Mol $Al_2O_3/(Na_2O + K_2O + CaO) < 1.1$	Mol $Al_2O_3/(Na_2O + K_2O + CaO) > 1.1$
C.I.P.W. normative diopside or $<1\%$ normative corundum	$>1\%$ normative corundum
Broad spectrum of composition from felsic to mafic	Relatively restricted to high SiO_2 types
Regular inter-element variation within plutons; linear or near-linear variation diagrams	Variation diagrams more irregular
Hornblende common. Sphene common. Mafic (igneous) inclusions common	Muscovite more common. Monazite, biotite, cordierite and garnet present. Metasedimentary xenoliths
Low initial $^{87}Sr/^{86}Sr$ ratios (<0.708)	High initial $^{87}Sr/^{86}Sr$ ratios (>0.708)
Linear isochrons	Scatter of isochronic points
Normal range of $\delta^{18}O$ values (6-10°/oo, SMOW)	Enriched in ^{18}O ($\delta^{18}O$ values about 10 °/oo, SMOW)
Commonly intrude S-types in composite batholiths	Earlier than I-types in composite batholiths

TABLE 7 Characteristics of I-type and S-type Granitoids (Moseley, 1981)

crust and show more compositional irregularity (White and Chappell, 1977). Chappell and White (1974) have associated porphry Cu-Mo mineralization with the I-type granitoids and Sn mineralization with the S-type granites.

5.3.4 Magnetite Series/Ilmenite Series

The main characteristics of these "series" are shown in Table 8. Several workers (including Shibata and Ishihara,1974; Saskaki and Ishihara, 1979, 1981; Ishihara, 1971b, 1979b; Takahasi et al (1980); Ishihara and Terashima, 1977a) have contributed to the knowledge of these series. The Magnetite Series is comparable in origin to the I-type of Chappell and White, but the Ilmenite Series is composed of both the I-type and S-type (Ishihara, 1981). Ishihara (1977, 1981) postulates that the Magnetite Series granitoids are hosts to major sulphide mineralization whereas the Ilmenite Series are associated with cassiterite and wolframite mineralization.

5.3.5 Other Petrochemical Features

Other petrochemical properties of granitoids have been recognized and used by other workers as mineral exploration tools. For example, Plant et al., (1980) were able to relate magnetic and gravity anomalies to metallization in some of the late discordant Caledonian granites of northern Scotland. Copper and molybdenum mineralization was later confirmed in some of these same granites (Moseley, 1981). Similarly, Simpson et al., (1979) related

TABLE 8 DISTINGUISHING CHARACTERISTICS OF THE MAGNETITE SERIES AND ILMENITE SERIES (FROM ISHIHARA, 1981)

	Magnetite Series	Ilmenite Series
1.	Magnetite content $> .10\%$	Magnetite and ilmenite contents $< .10\%$
2.	Magnetic susceptibility $> 1 \times 10^{-4}$ em u/g	Magnetic susceptibility $< 1 \times 10^{-4}$ em u/g
3.	Bulk Fe_2O_3/FeO ratio > 0.5	Bulk Fe_2O_3/FeO ratio < 0.5
4.	A positive $\delta\,^{34}S$ value and low ^{18}O value	A negative $\delta^{34}S$ value and high ^{18}O value
5.	Depletion in lithophile elements	Enrichment in lithophile elements
6.	Accessory magnetite (0.1 - 2 vol. %), ilmenite, haematite, pyrite, and chalcopyrite.	Accessory ilmenite, pyrrhotite, graphite, (monzonite, garnet) and muscovite.
7.	Biotite with high Fe_2O_3/FeO and low refractive index.	Biotite with low Fe_2O_3/FeO and high refractive index.
8.	Intrusive sequences in which Fe/(Fe+Mg) for amphiboles, and biotite decreases with decreasing SiO_2 content of the host rocks.	Intrusive sequences in which Fe/(Fe+Mg) for amphiboles and biotite increases with increasing SiO_2 content of the host rocks.

uranium mineralization in the British Isles to deep, large negative Bouguer anomalies and other geophysical properties. Direct relationships between magnetization and metallization in granitoids have also been noted elsewhere (Pecherskiy, 1965; Ishihara, 1981 ; Stemprok, 1979; Ryabchikov, 1978).

5.4 PETROLOGICAL FEATURES

5.4.1 General Statement

The close relationship between the chemical and (mineralogical) petrological characteristics of rocks is a well known phenomenon, but there is little doubt that these petrological features can be of tremendous value by themselves in estimating the mineralization (or metallization) potential of granitoids. Despite the lack of complete agreement among workers (Barsukov, 1957; Hesp and Rigby, 1972; Raguin, 1965) some of the petrological features or characteristics have been used to discriminate mineralized granitoids from barren ones in various parts of the world (Tischendorf, 1977 ; Gotman and Rub, 1981).

5.4.2 Modal Composition

Some workers have used the modal composition to differentiate between highly fractionated, and hence probably mineralized, granitoids from the unmineralized ones. Flinter et al. (1972), for example, applied this means in Australia to distinguish between mineralized granitoids and

unmineralized ones. Table 9 shows modal composition of some specialized granitoids.

5.4.3 Intrinsic Features

Intrinsic characteristics of some minerals have also been used as exploration tools for rare-metal mineralization in granitoids. For example, during the late stage of crystallization of a magma, quartz has the tendency to collect more fluid than at earlier phases. The fluid inclusions thus collected may cause the quartz to show undulatory extinction which is interpreted by most workers as indicative of extreme fractionation with attendant high mineralization potential (Tischendorf, 1977). The role of some species of micas (e.g. protolithionite, lithionite and zinnwaldite) as exploration tools can similarly be ascribed to their ability to concentrate and carry volatile elements which most workers consider as indicators for mineralization processes (Stemprok, 1979).

5.4.4 The Relationship between Biotite and Hornblende

As far as mineralization processes are concerned, biotite and hornblende are generally considered to be antipathetic, on the grounds that mineralized granites usually are more biotite-rich and hornblende-poor than unmineralized ones. Smith and Turek (1976) use examples from different parts of the world to illustrate this point. They state that the mineralized granites in Cornwall, Indonesia, Erzgebirge, Brazil, Malaya and Nigeria are biotite and/or

Table 9

Modal composition of specialized granites according to several authors

Authors	*qz*	*af*	*pl*	*am*	*lm*	*acc*
Aubert (1969), Burnol (1974a)	20—40	15—35	20—50	1—5	5—10	
Exley - Stone (1964)	28—38	19—34	17—36	3—9	2—6	1—2
Grigoriev - Dolomanova (1964)	35—41	23—35	23—29	1—7	—	—
Groves (1972)	30—38	15—33	25—50	0—4	0—7	0—4
Kovalenko - Kuzmin et al. (1971)	38	26	23	3	—	—
Lange et al. (1972)	34—36	28—40	20—30	3—4	1—2	1—2
Rub et al. (1964)	28—33	36—49	10—25	1—4	—	1—2
Shcherba et al. (1973)	34—36	39—44	15—23	1—2	1—3	1
Sobolev (1971)	29—36	28—47	15—32	1—6	—	—
Stemprok - Sulcek (1969)	41	29	24	4	—	—
Zhilinskii (1959)	33—39	30—40	19—28	1—6	—	—
proposed average	36 ± 3	33 ± 6	25 ± 3	3 ± 1	3 ± 2	1

(Tischendorf, 1977)

muscovite-bearing, whereas the related but unmineralized granitoids are mainly hornblende-rich.

The exact role played by biotite in the mineralization processes of the rare-metals in general, and of tin in particular, is too controversial and involved to attempt to speculate on here. However, several hypotheses have been put forward on this subject, (Rattigan, 196 ; Barsukov, 1957; Dmitriyer et al., 1968; Bradshaw, 1967; Odikadze, 1967; Roedder, 1977; Hesp, 1970, Simpson et al., 1979; Flinter, 1971; Flinter et al., 1972; Govett, 1983). Attempts to try to use other ore element variations in biotite to identify mineralized granitic intrusions have not been entirely successful (Govett, 1983).

5.4.5 Accessory Minerals

The importance of accessory minerals as indicators of metalliferous or mineralized granitoids has been known at least since the early part of the century (Tischendorf, 1977; Bowden and Jones in Stemprok et al., 1978). Accessory minerals commonly considered as indicators of highly differentiated and hence possibly mineralized granitoids are shown in Table 10. (Note that minerals containing two of the most important volatiles (F,B) are highly ranked). These accessory minerals are thought to be the carriers and concentrators of the rare metals during the last stage of evolution of a granitic magma. Therefore their presence may be

Table 10

Schematic grouping of accessories appearing in specialized granites according to literature data

Very important accessories, typical for specialized granites	Topaz, fluorite, tourmaline, cassiterite, columbite-tantalite, beryll
Less frequent accessories, typical for specialized granites	Orhite, titanite, thorite, xenotime, monacite, apatite
Accessories appearing in specialized and normal granites often influenced by processes of assimilation	Andalusite, cordierite, sillimanite, dumortierite, garnet
Non-typical acessories appearing in specialized and normal granites	Magnetite, ilmenite, pyrite, rutile, anatase, zircon, epidote, hornblende

(Tischendorf, 1977)

indicative of possible mineralization.

5.4.6 Hydrothermal Alteration

Recognition of hydrothermal alteration processes such as tourmalization, sericitization, kaolinization, silification/greissenization and albitization may be used as guides in mineral exploration in granitic terrains. Several workers (Stemprok, 1979; Allman-Ward, 1982; Sminov, 1976; Tischendorf, 1977; Govett, 1983) have described this as a valuable exploration tool, although each one tends to consider one particular process as more useful. Allman-Ward (1982), for instance, thinks that tourmalinization is the better indicator of the tin mineralization in S W England.

As a whole, these processes represent a late/post-magmatic stage where the chances of the rare-metals being concentrated to form deposits are enhanced (Stemprok, 1979).

CHAPTER 6

SAMPLING, ANALYTICAL AND DATA PROCESSING TECHNIQUES

6. INTRODUCTION

The choice of appropriate sampling procedures and dependable analytical techniques are basic requirements for any geochemical research and/or exploration project, for these two phases usually have great influence on the final success. To meet these requirements the following were taken into consideration.

1) The choice of the kind of geologic material to be sampled.

2) Selection of sample localities to ensure that representative samples were obtained.

3) Amount of material to be collected at each sampling locality.

4) Effective sample attacks and analytical methods/procedures.

5) Means of data quality control.

6.1 SAMPLING TECHNIQUES

The combined effects of luxuriant vegetation and thick soil overburden in a tropical country like Liberia make lithogeochemical sampling a very difficult task. To these factors may be added the problem of inaccessibility due to the numerous river systems (basins) and rough terrain. Generally, there is scarcity of bedrock exposure and when and if encountered, obtaining fresh material may not be

easy. Throughout this phase of the project, it was found that outcrops exposed in deep valleys along rivers and streams were not very useful, as these rocks were generally affected by shearing and other disturbances to a measurable degree. This is in complete contrast to the great usefulness of these river traverses for geological investigation. As a result, most of the samples used in this study were collected along the existing highways, jeep trails foothpaths and hunter trails. The choice of sampling points or localities was often governed by factors such as accessibility and the degree of probability of obtaining fresh and representative samples of the granitic rocks.

As part of the preparation for the field work the chances of encountering an outcrop or a group of outcrops in a particular place were assessed through the use of previous knowledge of topographic expressions or features. The presence on geological maps of dip and strike symbols, which are certainly the result of previous geologic reconnaissance in a particular part of a highway, jeep trail or footpath, was also of great help in this regard. Sometimes traverses along newly constructed logging trails proved fruitful; they occasionally helped to narrow the gaps between some sampling points which would otherwise be very large.

Thus sampling in the field was done at random spatial locations but with some organized or advanced planning. Excellent exposures were often expected

along the highways and jeep trails at points where topographic highs were observed. In such places the bedrock, if present, had been blasted to facilitate the construction of the highway which in turn made it easier to obtain fresh samples. Realizing that these rocks are possibly heterogeneous, it was sometimes necessary to collect several samples at various points, around an outcrop. Quarries opened and used for highways and domestic construction were also extensively used whenever encountered, and these provided another means of easily collecting fresh samples. In some instances, jeep trails were followed as far as they extended. This type of traverse contributed greatly, as some of them sometimes ended within reasonable walking distances of fresh outcrops.

In the Grebo Town area and the Cestos Batholith area (in the Cestos Shear Zone) hunting trails were extensively used. In the Grebo Town area a few outcrops were also sampled along the railroad and a logging trail. In the Cestos area, outcrops were generally small, bouldery and isolated. Fresh samples were only obtained from topographic highs. Although some of the outcrops appeared bouldery and discontinuous to the eye, they were certainly not boulders, as they could be shown to be the same as the altered but still identifiable rocks in the river valley below.

In total 334 rock samples were collected: 185 from the Northwest Granites and associated gneisses (NWG); 61 from the Cestos Batholith and the associated gneisses (CB); 47 from the Grebo Town area (GTA); and 41 along the highway between Totota and Konia. Weights of samples varied from about 300 to 500g .

6.2 ANALYTICAL TECHNIQUES

6.2.1 Sample Preparation

After obtaining a hand specimen from each sample for future reference, the remainder was crushed to less than 10mm in a jaw crusher at the Bong Mining Company's facilities in Liberia. To avoid carry-over contamination at this stage, the crusher was thoroughly dusted out and cleaned with a lint-free cleaning cloth after the crushing of each sample. Furthermore, a clear colourless quartz crystal about the size of the average ordinary sample was crushed and retained after every ten or fifteen samples in order to monitor any carry-over contamination from sample to sample.

After crushing and properly mixing, each sample was twice poured through a two-slot Jones separator. After the second pouring through the separator, the process was repeated with the "catch" from one side only, and one of the "catches" at this time was put into a separate paper bag and labelled with the same serial number as used in the field, while the other was added to the initial "catch" and also labelled with same original serial number.

Each of the one-quarter aliquots was reduced to about 70g in the chemistry laboratory of the Liberian Geological Survey. The remainder of each of these one-quarter aliquots, the three-quarter aliquots and the hand specimens were being retained at the Liberian Geological Survey in Monrovia for future reference.

In order to demonstrate that proper sub-sampling had in fact been achieved at the crushing stage, a 70-g aliquot was also taken from every twentieth three-quarter aliquot for a reproducibility test. These were then air-freighted along with the normal 70-g aliquots to the laboratories of the Applied Geochemistry Research Group, Imperial College (London). All of these sample aliquots were then pulverized to 200 mesh, using a Tema mill with an agate pot.

It was found unnecessary to pulverize all of the 70g of each sample (as this could require that each sample be pulverized in two separate portions before being combined), and only about 70-80% of each of the 70-g samples was pulverized. This again inevitably required that it be demonstrated that this sub-sampling procedure at this stage could not possibly have an adverse effect on the final analytical results. Six samples were thus randomly chosen, each one was split into approximately two equal portions ($\sim$ 35-g each) and pulverized to 200 mesh. This batch of twelve(12) samples was included in the reproducibility test batch, details of which are described in Appendix A. In general the reproducibility was good for most

of the elements, especially the major elements; however, some of the duplicate pairs of samples used in the test did not indicate satisfactory reproducibility for the trace elements Cr, Pb, and Ni. The poor reproducibility shown for these trace elements may be mainly attributed to (i) the usual low concentrations of them and, (ii) their poor (highly erratic dispersal) distribution patterns in the rock type under investigation. Added to these factors may also be the failure of the sample attack used to effectively and completely decompose some of the accessory minerals (spinels for Cr and Ni, for example) in which these trace elements may occur.

6.2.2 Analysis

Three hundred thirty-four samples were analysed for twenty-five major and trace elements (Li, Na, K, Rb, Be, Mg, Ca, Sr, Ba, Al, La, Ti, V, Cr, Mo, Mn, Fe, Co, Ni, Cu, Ag, Zn, Cd, Pb, and P) by digesting 0.1g sub-samples in a mixture of hot concentrated nitric acid, hydrofluoric acid, and perchloric acid (HNO_3+HF+$HClO_4$) to yield a dry residue which was then subsequently leached into 6M HCl. The resulting solution was made up to volume with de-ionized water and directly nebulized into the inductively coupled plasma atomic emission spectrometer (ICPAES), one of the main analytical instruments used by the Applied Geochemistry Research Group.

Details of the analytical procedures are given in Appendix II.

6.3 METHODS OF ANALYTICAL QUALITY CONTROL

In any geochemical exploration or research project, the quality of the final data is assessed in terms of two basic parameters, namely: accuracy and precision. The term accuracy is defined as the nearness of a result (x_i) or of the arithmetic mean of a set of results ($\bar{x}$) to the true value (μ). Since the true value cannot be determined, the average or arithmetic mean of a large number of measurements obtained by reliable analysts using a variety of analytical methods is used. Such a value has been referred to by some workers as the preferred, usable or accepted value (Thompson, 1983). On the other hand, precision is the agreement of a set of results among themselves. In geochemistry this parameter is often defined as $P = (2S / \bar{x}).100\%$, where S is the standard deviation indicating that it is related to the coefficient of variation. This definition implies P is constant over the analytical range used. The parameter is also more or less heavily dependent on random errors which are very often unavoidable (Fritz et al., 1979).

In accordance with practice at the Applied Geochemistry Research Group laboratories, relative precision and accuracy were used to monitor variation within each batch; variation between batches; and overall variation. To achieve this

goal, Departmental reference materials; duplicate samples; and reagent blanks were used.

6.3.1 The use of Departmental Reference Materials to Monitor the degree of accuracy

In line with practice at the AGRG laboratories, house reference materials were used throughout this study in every batch of samples analysed. Two different reference materials (HRM1 and HRM2) were used and one or the other is inserted after every ten samples (and treated like the ordinary samples) throughout the analysis of a particular batch. This method of inserting the reference materials prevents or minimizes the introduction of bias in the estimation of the accuracy which would result if all were put at the end or at the beginning of the analysis. These reference materials are mixtures of derivatives of geologic substances which have been prepared to represent wide spectrum of chemical matrices.

Figs. 16 and 17 present the results obtained for the reference materials HRM1 and HRM2, respectively, for all the batches analysed throughout this study. In these figures, the accuracy for each element can be considered good, as the mean and the accepted or preferred values are similar and fall within the $\bar{x}\pm 2S$ range. The detection limit for Rb which is the highest among the trace elements, also falls within the $\bar{x}\pm 2S$ range for HRM1 whereas Ag, Cd and Mo were not detected.

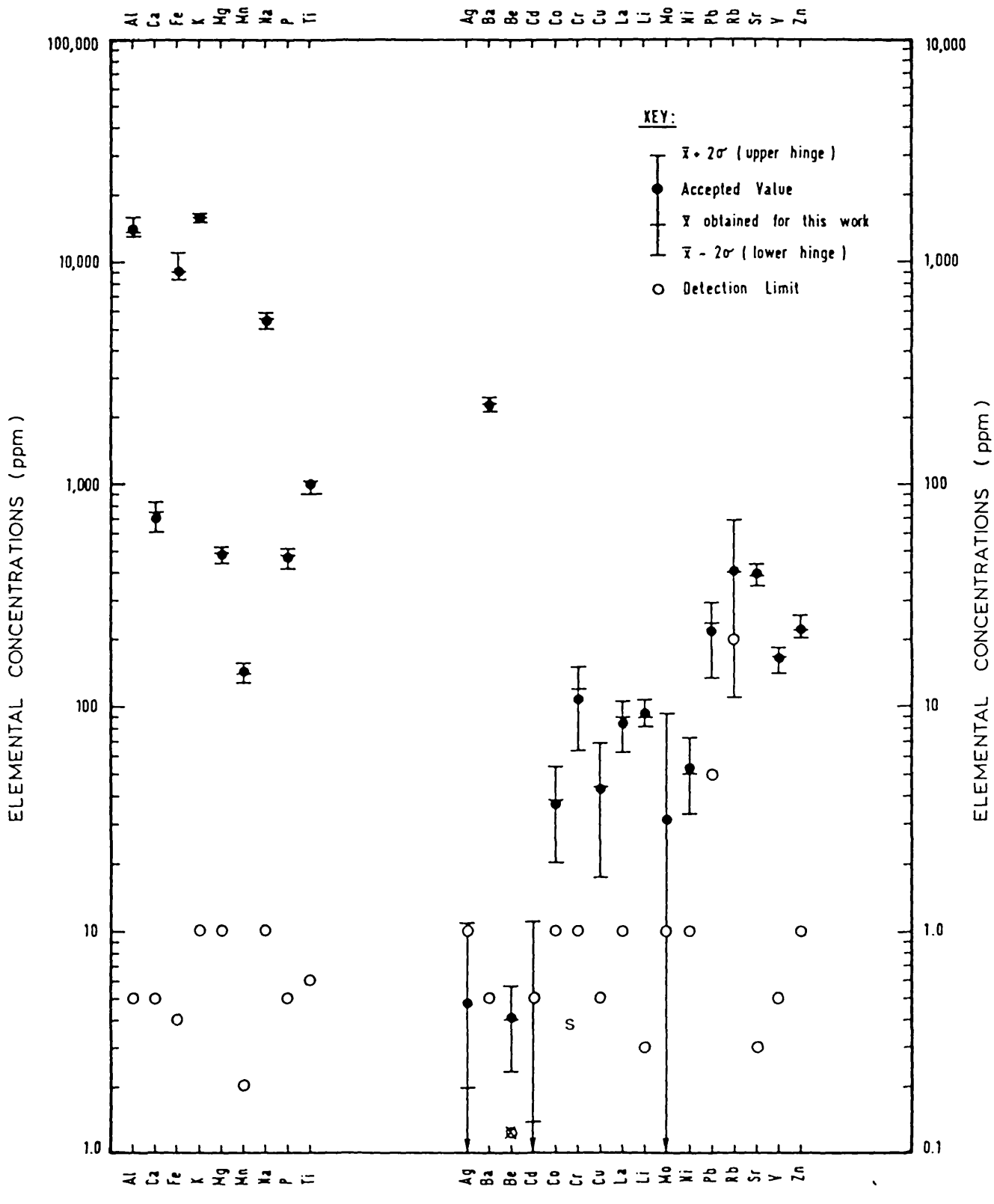


Fig.16. The degree of accuracy as indicated by reference material HRM1.

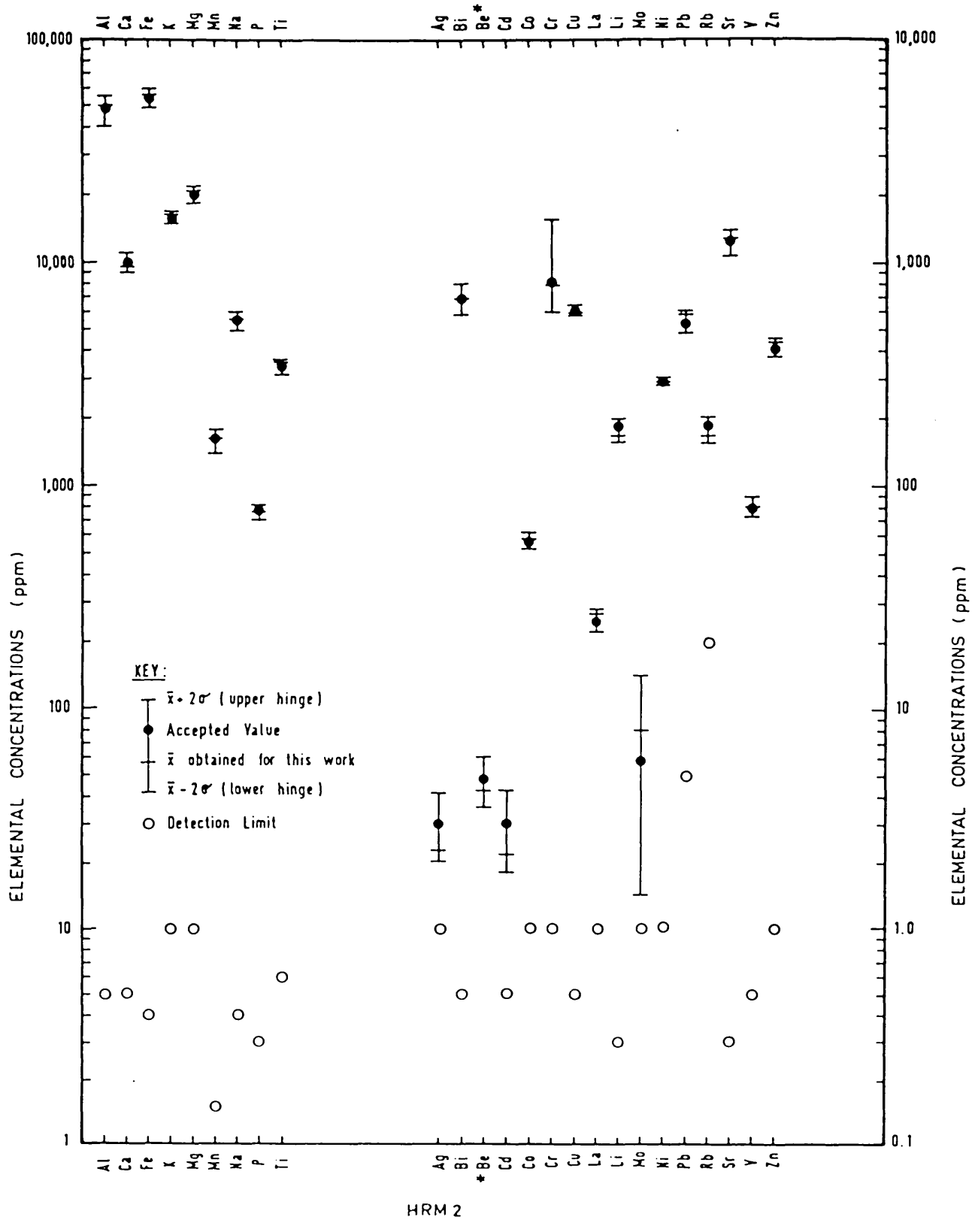


Fig.17. The degree of accuracy as indicated by the reference material HRM2.

6.3.2 Using duplicate samples to measure the overall precision

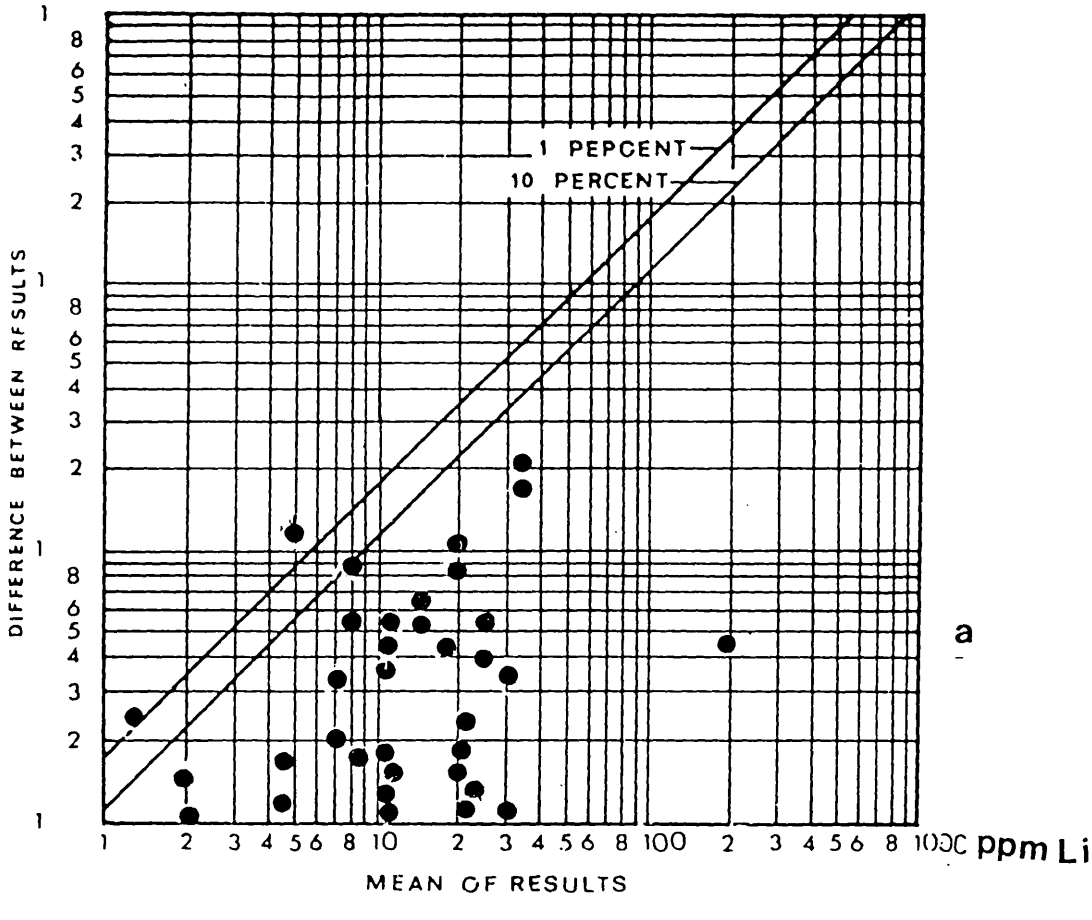
A set of duplicate sub-samples was dispersed randomly throughout each batch during analysis. These sub-samples usually make up about 10% of the batch and are taken through every step of the analytical procedure.

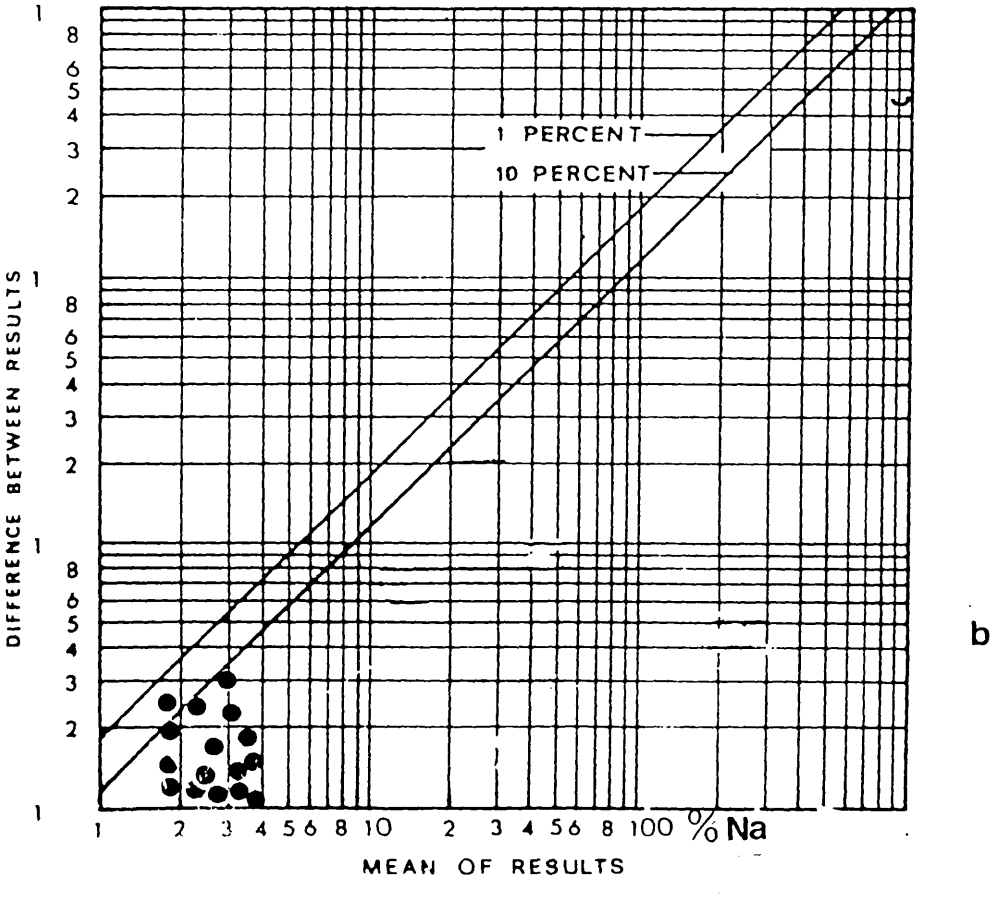
The precision was ascertained or tested using a standard control chart proposed by Thompson and Howarth (1973,1976) and Howarth and Thompson (1976). This methodology involves the calculation and subsequent plotting of values of the absolute difference (x_I x_2) between each pair of duplicates against its mean ($(x_1 + x_2)/_2$) for each element determined. The precision determined by this method is evaluated as a function of the level of concentration of each element in the sample and should therefore be more helpful than estimating precision from multiple analysis of reference materials.

Generally this method of evaluating the precision becomes more meaningful when the level of concentration of analyte is equal to or greater than four times the detection limit. If this condition is not met, it becomes difficult to evaluate this parameter, as there is bound to be too much fluctuation.

Figs. 18a - 18f show the precisions obtained for a selected number of elements determined in this study. The precisions for almost all of the elements (with the exception of Ag, Mo, Cr, Cd and

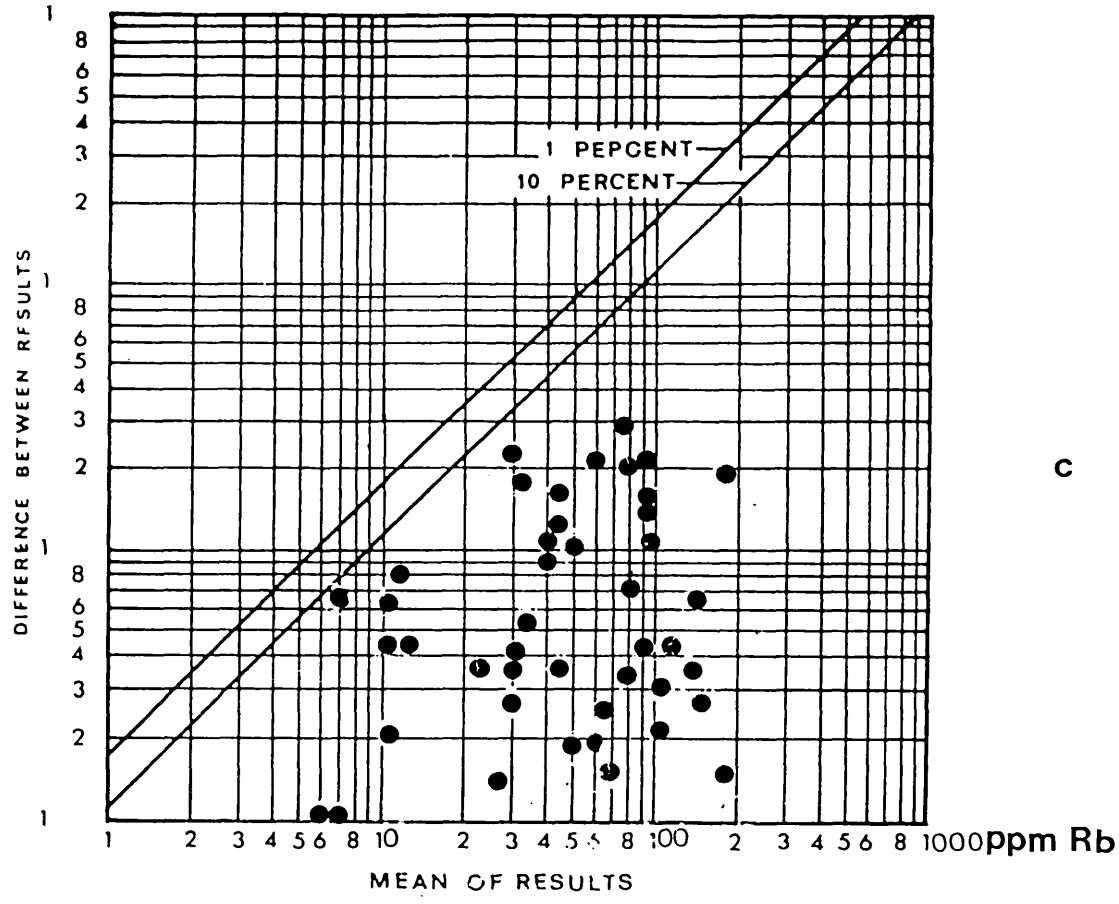
Fig.18(a-f). Precision control charts for duplicate samples for a selected number of elements.





PRECISION CONTROL CHART FOR DUPLICATE RESULTS

In a set of duplicate measurements on many samples where for each sample the precision of measurement is 10 per cent at the 95 per cent confidence limit (i.e. $\sigma/\mu = 0.05$) the indicated proportion of points will fall above the diagonals. The scale of the means must be 10 times greater than the scale of the differences



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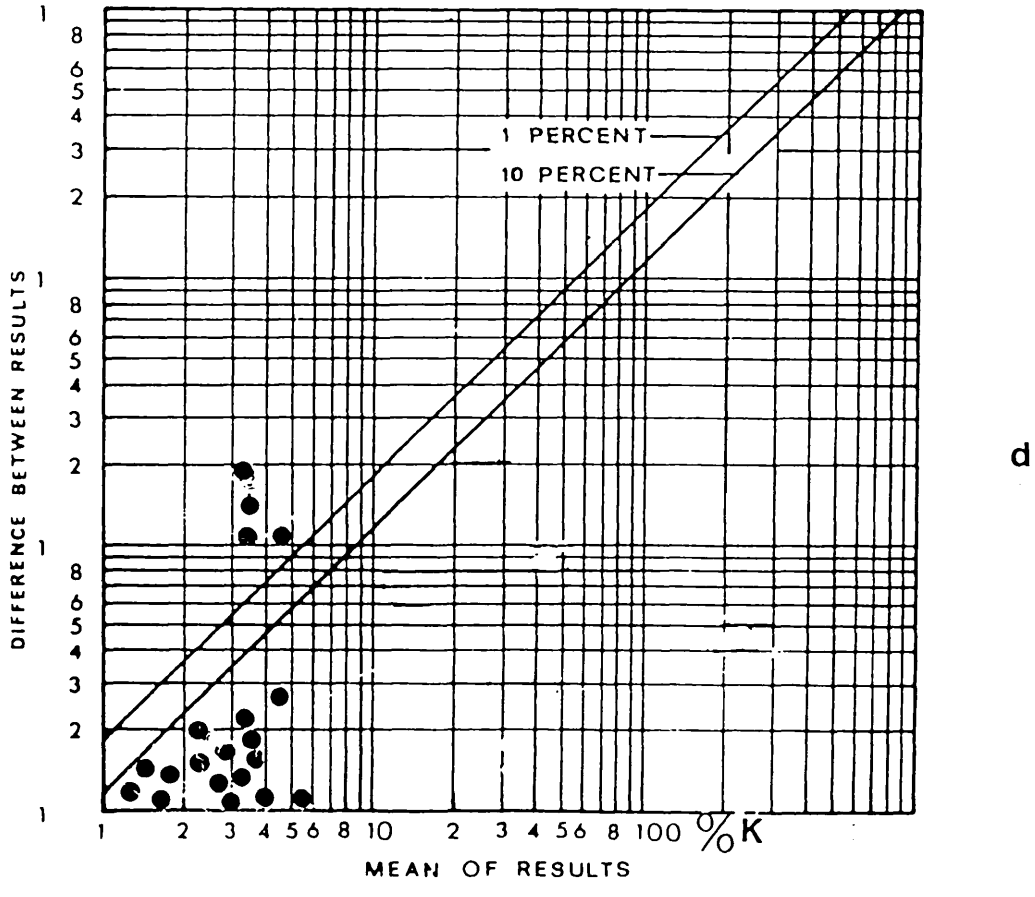
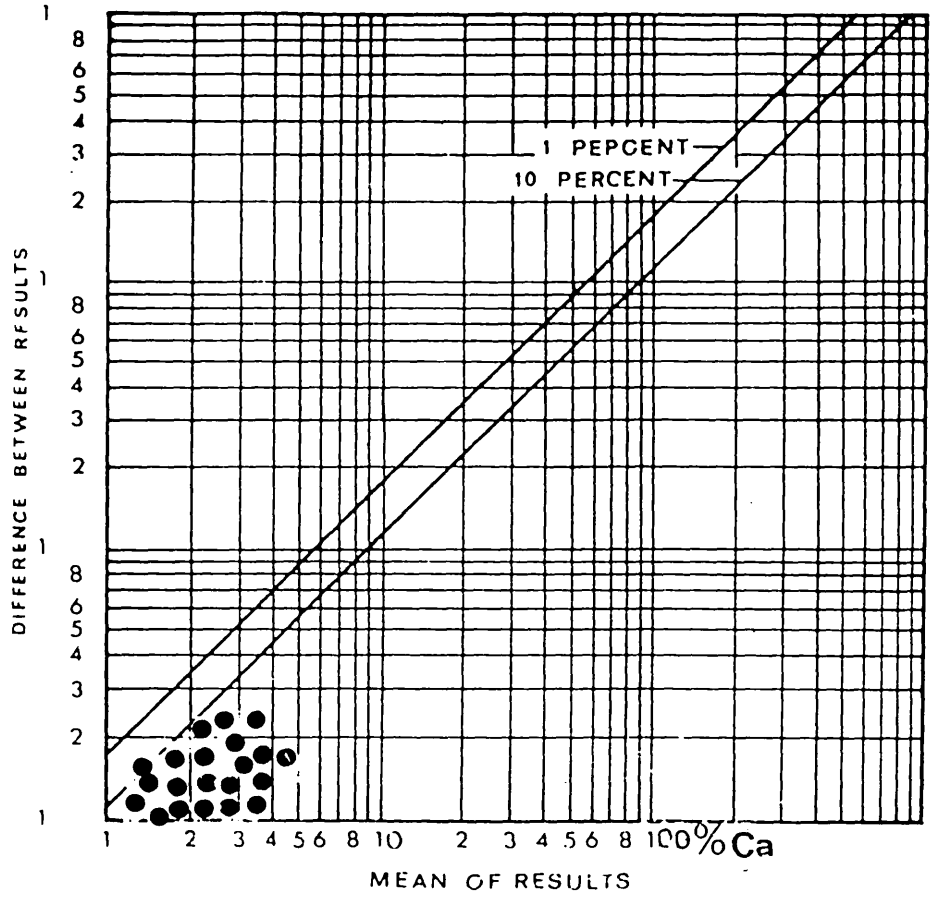


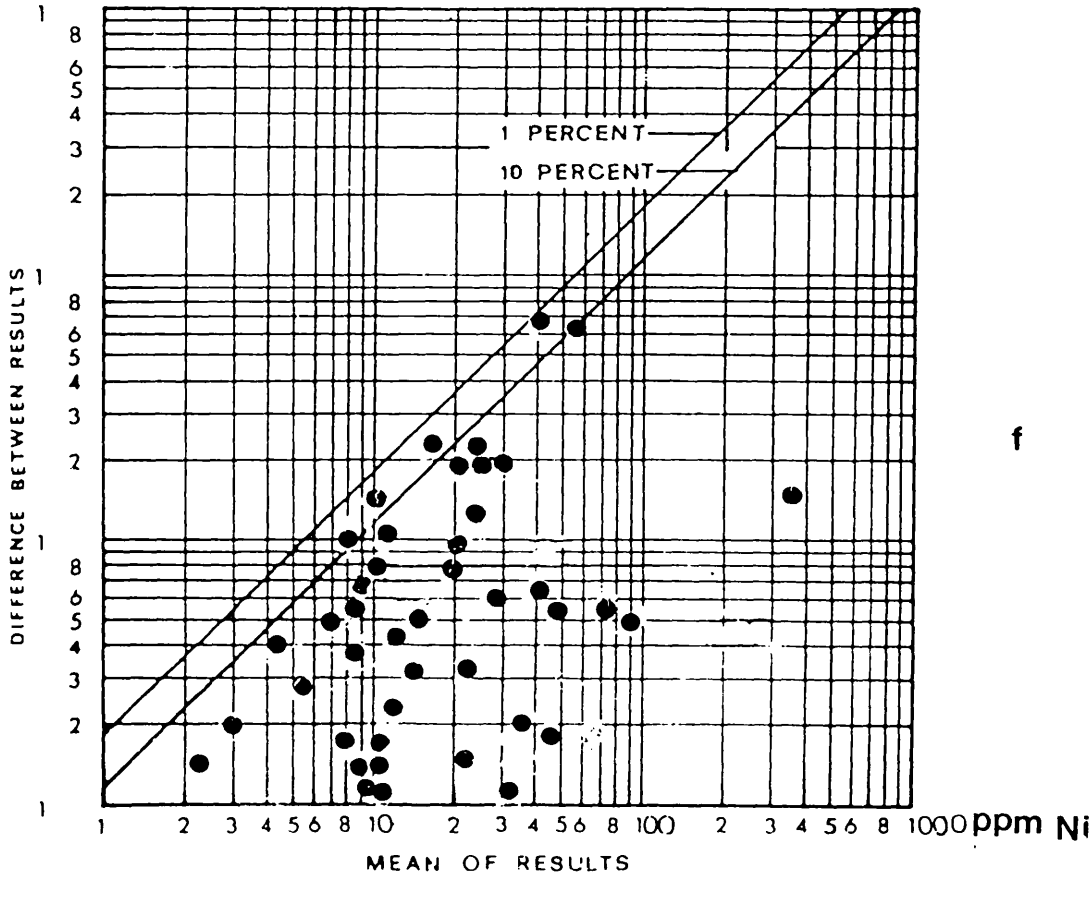
d

PRECISION CONTROL CHART FOR DUPLICATE RESULTS

In a set of duplicate measurements on many samples where for each sample the precision of measurement is 10 per cent at the 95 per cent confidence limit (i.e. $\sigma/\mu = 0.05$) the indicated proportion of points will fall above the diagonals. The scale of the means must be 10 times greater than the scale of the differences.



e



f

PRECISION CONTROL CHART FOR DUPLICATE RESULTS

In a set of duplicate measurements on many samples where for each sample the precision of measurement is 10 per cent at the 95 per cent confidence limit (i.e. $\sigma/\mu = 0.05$) the indicated proportion of points will fall above the diagonals. The scale of the means must be 10 times greater than the scale of the differences.

Ni) are within the 10% limit accepted by the AGRG laboratories. The cause of the poor precisions for Ag, Mo, Cr and Ni may be mainly attributed to their low levels of concentration (being very close to their respective detection limits) in the rocks under investigation.

6.3.3 Assessing Possible Contamination by use of Reagent Blanks

In addition to determining relative accuracy and precision, it is also necessary to determine how much contamination might have been introduced throughout the analytical procedure. Contamination may occur during the sample preparation stage (weighing, digestion) or through carry-over from the analytical instrument or equipment. Impurity in reagents may also cause contamination. To monitor the contamination from such sources, reagent blanks, forming about 4% of the solutions to be analysed were randomly included in each batch at the weighing stage, and were treated in the same fashion as the ordinary samples, duplicates, and reference materials throughout the analytical procedure.

As an illustration, results obtained from reagent blanks of batch E1008 are shown in Table11. The overall result is good as eighteen of the analytes are below their detection limits in the reagent blanks (see Figs.15 and 16 for the detection limits). Of the remaining seven elements

TABLE 11 BLANK SUBTRACTION VALUES

Li	BELOW DETECTION LIMIT
Na	12.055
K	BELOW DETECTION LIMIT
Rb	BELOW DETECTION LIMIT
Be	BELOW DETECTION LIMIT
Mg	BELOW DETECTION LIMIT
Ca	BELOW DETECTION LIMIT
Sr	BELOW DETECTION LIMIT
Ba	1.094
Al	59.732
La	BELOW DETECTION LIMIT
Ti	BELOW DETECTION LIMIT
V	BELOW DETECTION LIMIT
Cr	2.178
Mo	BELOW DETECTION LIMIT
Mn	BELOW DETECTION LIMIT
Fe	BELOW DETECTION LIMIT
Co	BELOW DETECTION LIMIT
Ni	1.562
Cu	1.454
Ag	BELOW DETECTION LIMIT
Zn	3.968
Cd	BELOW DETECTION LIMIT
Pb	BELOW DETECTION LIMIT
P	BELOW DETECTION LIMIT

only Al, Zn and Cr show values well above their detection limits of 5, 1, and 1ppm, respectively. In such cases where the concentration is higher than the detection limit, the value is deducted from that found in the ordinary samples, duplicates and reference materials. The difference thus obtained is considered to be a close estimate of the true value.

6.4 DATA PROCESSING TECHNIQUES

To facilitate data analysis and final interpretation, both univariate and multivariate techniques have been selectively applied. The main objective of using these techniques is to be able to visualize the behaviour and inter-relationships of the elements in the data. Computer programmes normally used by the Applied Geochemistry Research Group have been applied to the data to obtain basic statistics (means, variance, minima and maxima), maps, box-plots, scatter plots, ternary diagrams, histograms, Kleiner-Hartigan "Trees", normal probability plots, and correlation coefficients and to perform ridge regression. Most of these data processing techniques are relatively familiar and thus interpretation of results are usually straight forward. However, it is relevant to briefly comment on the ridge regression and the Kleiner-Hartigan graphic tree techniques, since

they are relatively new data analysis methods in exploration geochemistry.

(a) The Ridge Regression Technique

According to Howarth (1984) "there seems to be a general consensus of opinion that the ridge regression technique is a useful tool to use with ill-conditioned data, particularly when the number of predictors is large, even if only used as an additional guide to the best subset of variables for later re-analysis by least squares". Thus the use of this technique in combination with probability plots of regression residuals can overcome many of the problems encountered when using the classical least squares methods of regression. For example, it reduces the tendency for some of the more important predictors to be masked, or misleading importance attached to some elements owing to the inherent correlation between predictor elements in a geological situation. The predictors are assumed to be "independent" (i.e. uncorrelated) in the classical least squares regression solution which may lead to erroneous estimation of their true regression coefficients.

Based on the foregoing considerations this technique was applied to each of the four data subsets of this project using the nine major elements Al, Ca, Fe, K, Mg, Mn, Na, P and Ti as the predictors and the trace elements Be, Li, Rb, Sr, Ba, Mo, Cu, Zn and Pb as the dependent variables. Each of the selected dependent

variables was individually regressed on the nine independent variables in each case, and a ridge trace, a residual probability plot and the residuals were obtained.

The ridge trace is used to show the relative importance of each of the independent elements as a predictor of the behaviour of a particular dependent variable. It is obtained by plotting the standardized regression coefficients of the predictors as a function of the ridge constant k (a constant added to the diagonal elements of the correlation matrix to produce better estimators of the regression coefficients). In such a case the best positive predictor element lies farthest on the positive side of the zero coefficient, whereas the most important negative predictor element lies farthest on the negative side of the zero coefficient (i.e. the predictive importance (negative or positive) of each major element is directly proportional to its distance from the zero coefficient). An example of the ridge traces and residual probability plots from each of the data subsets are shown in Figs.19 - 21, and are in turn referred to and/or briefly discussed in the appropriate sections of Chapter 8.

(b) The Kleiner-Hartigan Tree Method

This method for the graphic display of multi-dimensional data developed at Bell Laboratories (Kleiner and Hartigan, 1984), and improved at the Applied Geochemistry Research Group, Imperial

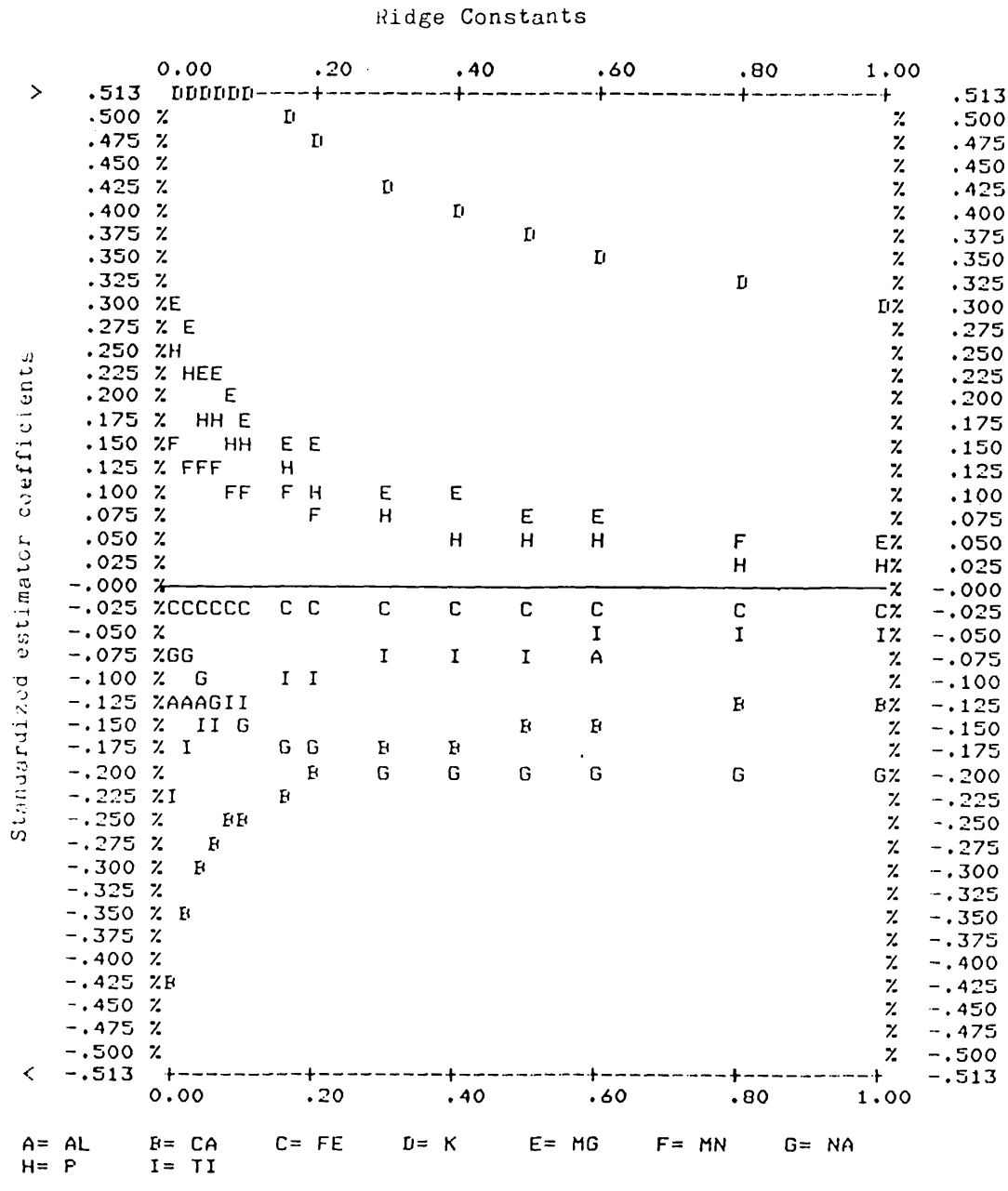
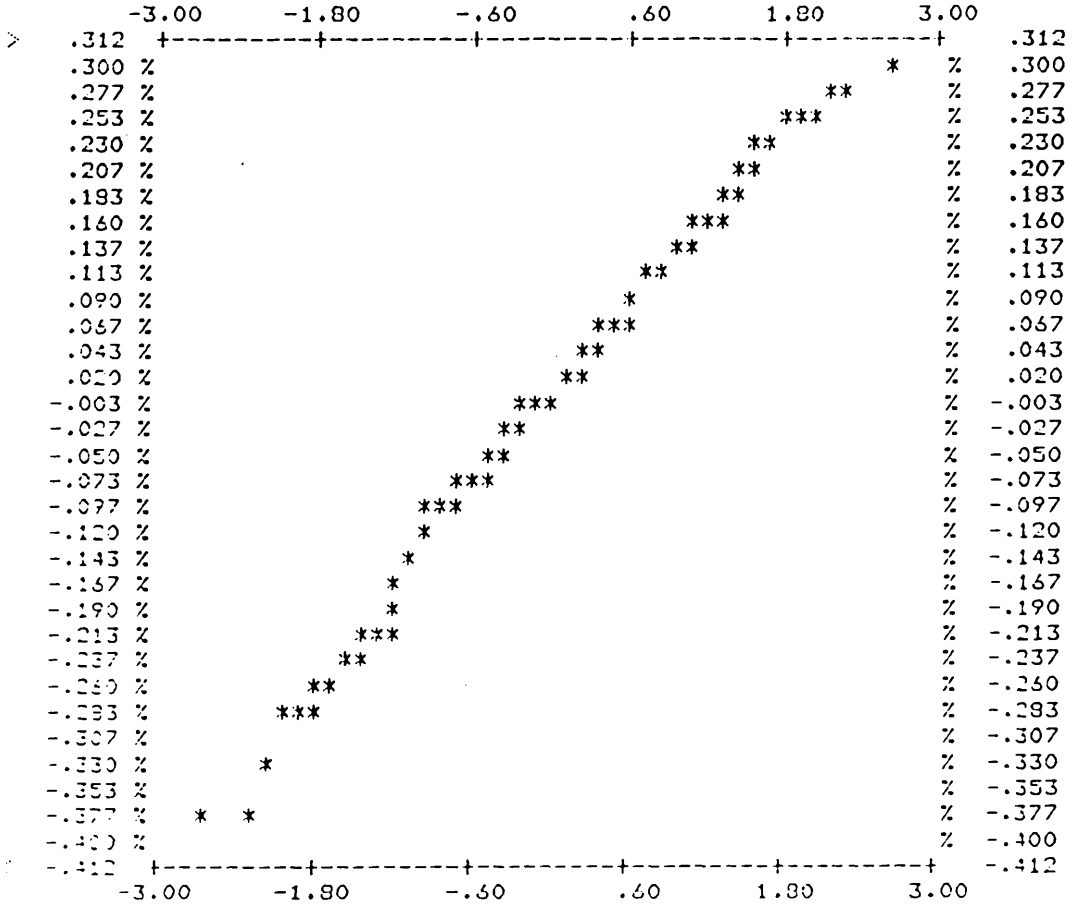


Fig.19a. The ridge trace for b as an example of the ridge trace for the selected trace elements from the Northwest granite and associated gneiss data.



SMALLEST RESIDUALS		LARGEST RESIDUALS	
4566	-.38768	4563	.29113
4633	-.38001	46150	.28706
4581	-.32592	4562	.26808
46650	-.29214	4461	.26040
4663	-.27973	4561	.25282
4503	-.27553	4548	.25123
4482	-.26985	4463	.24537
4693	-.25916	4646	.22327
4666	-.23971	4474	.21949
4552	-.23476	4723	.21699
4702	-.23243	4667	.21048
4664	-.22553	44750	.19864
4442	-.22281	45550	.18642
47140	-.21322	4523	.18065
4711	-.20755	4674	.17122

Fig.19b. The residual normal normal probability plot for Rb as an example of the normal probability plots for the selected trace elements from the Northwest Granite data.

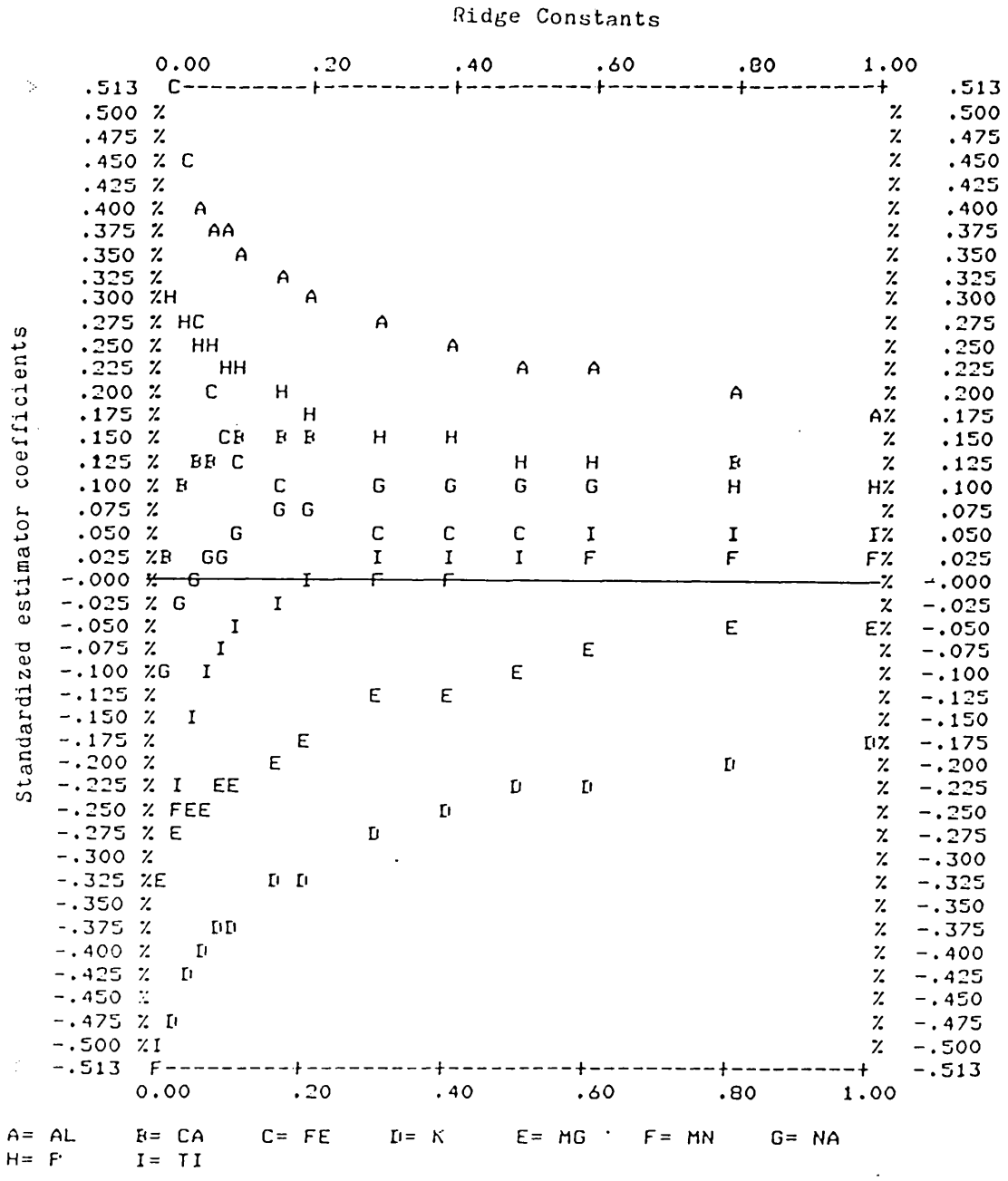


Fig.20a. The ridge trace for Be as an example for the ridge traces for the selected trace elements from the North Central corridor data.

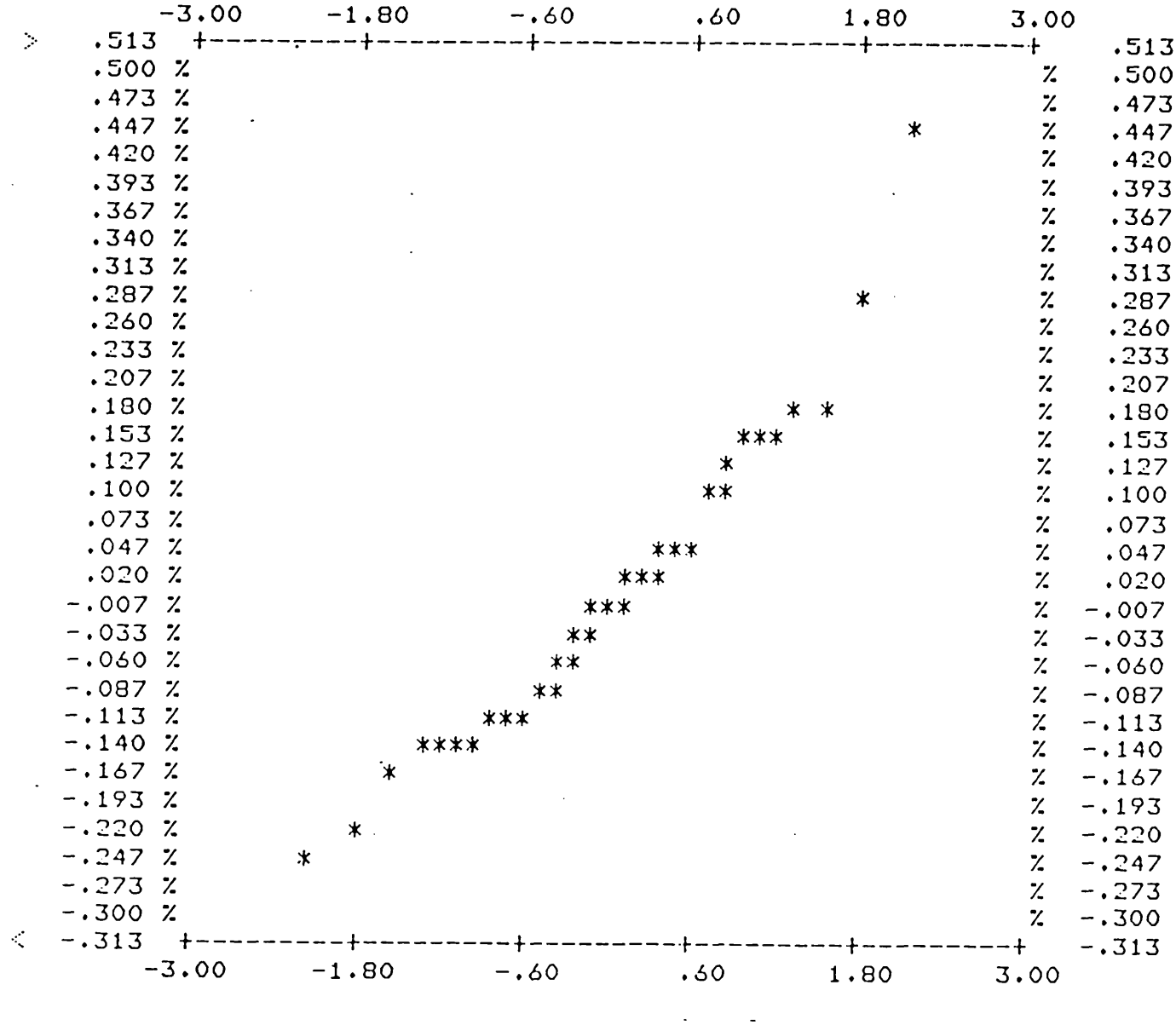


Fig.20b. The residual normal probability plot for Be as an example of the residual probability plots for the selected trace elements from the North Central corridor data.

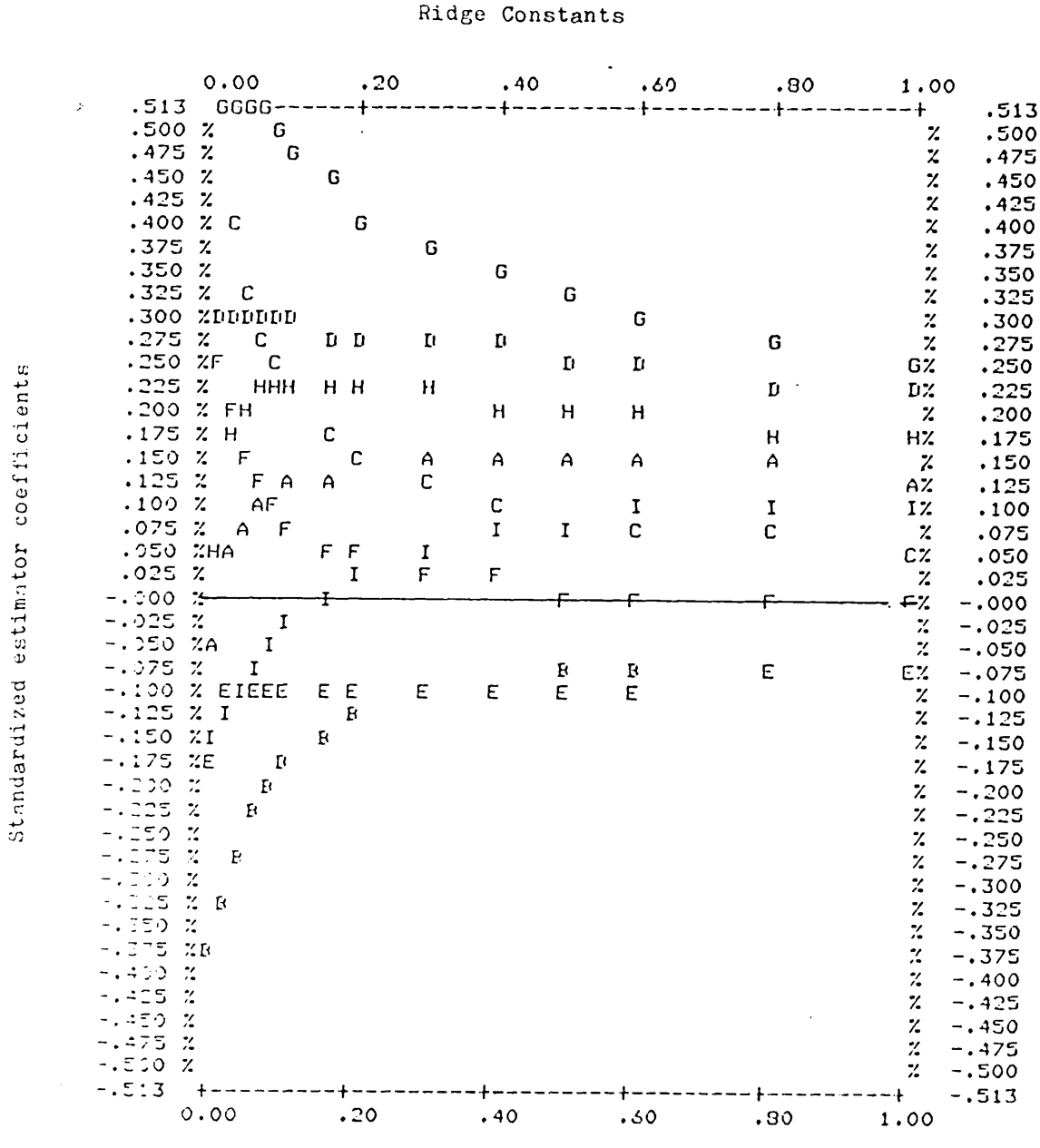
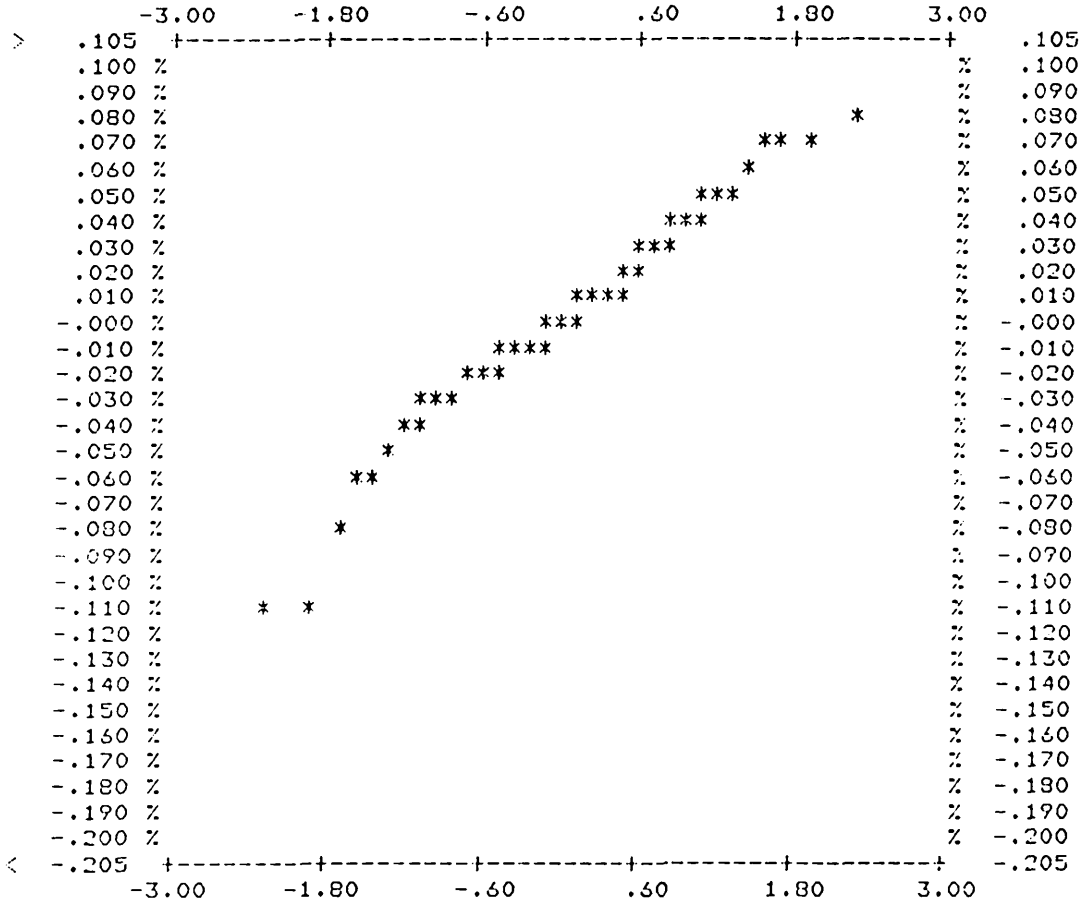


Fig. 21 The ridge trace for Be as an example of the ridge traces obtained for the selected trace elements determined in the Cestos Batholith area suite.

Fig.21b. An example of the normal probability plots obtained for the selected trace elements determined in the Cestos Batholith area suite.



SMALLEST RESIDUALS		LARGEST RESIDUALS	
5064	-.11074	5051	.08331
5061	-.10502	4924	.06762
5014	-.08498	4902	.06686
4883	-.06446	50050	.06655
5022	-.06395	4934	.05845
5063	-.05496	5012	.05457
5033	-.03875	5052	.05138
5043	-.03569	5002	.05105
4911	-.03404	4882	.04450
5024	-.02938	5016	.04101
4926	-.02808	4892	.03642
4992	-.02660	50150	.03206
4931	-.02461	5011	.02889
4894	-.02331	4994	.02728
5053	-.02165	5001	.02538

College, has been used for the display of the compositions of the data sets. Each variable in a given sample has the same position in the Tree as defined by a template (Fig.22 for a typical example) based on a dendrogram (see Chapter 8) for the correlation matrix defined over all the samples. The dendrogram therefore shows the hierachial clustering of the variables in the "tree". The strength of this grouping or clustering as represented in the diagram as compared with the original correlation matrix is indicated by the cophenetic correlation coefficient (a measure of degree of goodness-of-fit). The length of each branch in the "tree" is proportional to the concentration of the variables above it.

Maps showing the "trees", and figures showing the dendrograms and templates for each data subset are given and discussed in the relevant sections in Chapter 8.

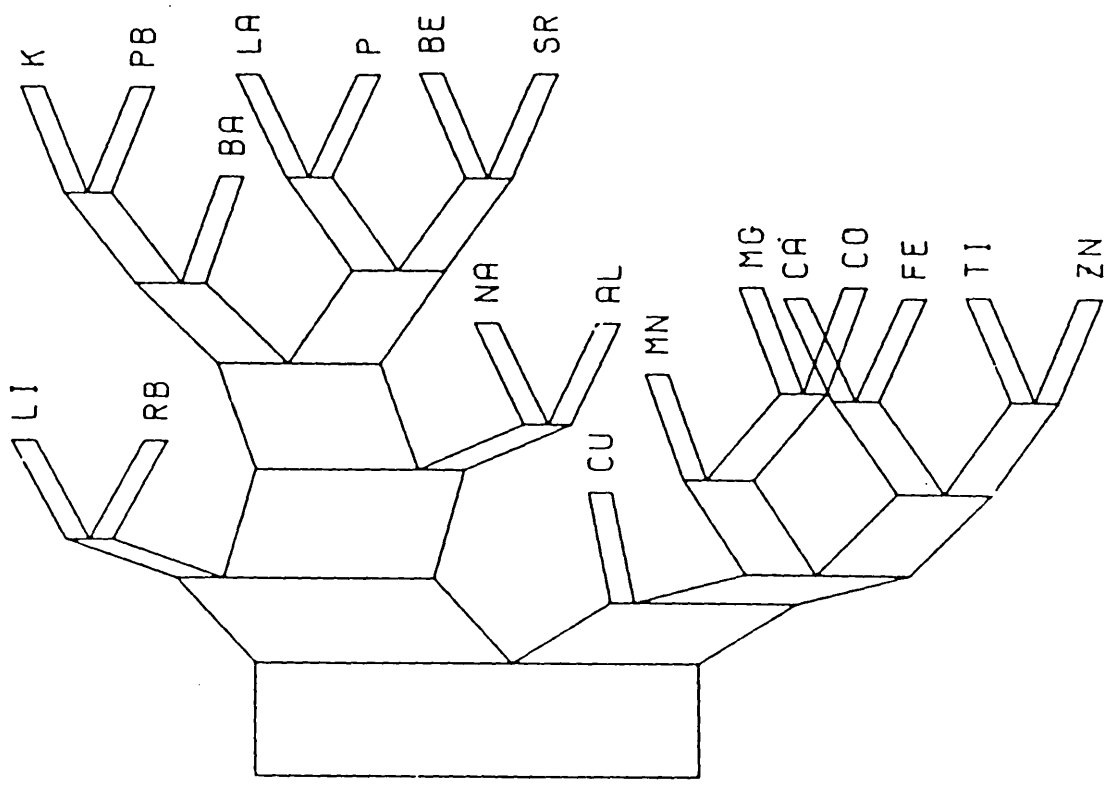


Fig.22. A typical template showing the relative positions of the elements in a Kleiner-Hartigan "Tree".

CHAPTER 7

PETROGRAPHY

7.1 INTRODUCTION

The term "granitoids" as used in this study applies to all rocks which range from alkali granites to quartz diorite. In other words, the classification used here is based mainly on the relative proportions of quartz, plagioclase and alkali feldspar. Non-genetic field classifications such as massive granites, foliated granites, quartzo-feldspathic gneisses and migmatites have been used for descriptive purposes in some places, but should not be interpreted as implying compositional variations. The petrography of rocks from the individual areas is first treated separately,(with the exception that the granites and granitic gneisses along the corridor in the north central region are included with the North-west granites and the associated granitic-gneisses, since they are all petrographically similar.) Table 12 summarizes the distinctive mineralogical features of the individual suites, and the close similarity between the North-west suite and that from the north central region is evident.

7.1.1 The Northwest Granites and the Surrounding Gneisses

The Northwest Granites and the surrounding

TABLE 12 SUMMARY OF DISTINCTIVE MINERALOGICAL FEATURES OF REPRESENTATIVE SAMPLES OF THE SUITES STUDIED. AVERAGE MODAL COMPOSITION HAS BEEN RECALCULATED TO 100%

	1	2	3	4
K-feldspar	24	26	41	14
Plagioclase	43	42	23	50
Quartz	22	23	28	18
Biotite	7	6	4	8
Muscovite	1	1	1	1
Hornblende	1	1	1	6
Others*	2	1	2	3
	100	100	100	100

Note: (1) Northwest granite, n = 27; (2) North Central Corridor (traverse), n = 6; (3) Grebo Town Area, n = 10; (4) Cestos Batholith Area, n = 10.

* These include mainly the accessory minerals such as apatite, zircon, and sphene.

granitic gneisses (NWG) constitute the largest continuous granitic body in the country. Macroscopically, the rocks are leucocratic to mesocratic, generally medium to coarse grained. Dark or dusty grey colouration is very common among the massive to the slightly foliated varieties of these rocks, although pinkish coloured massive varieties may be locally present. The pink colouration is attributed to potassium feldspar. Locally biotite and/or hornblende occur as clots or segregates; augens or porphyroblasts of plagioclase feldspars are also not uncommon in the foliated granites.

Under the petrographic microscope, the rocks of this region generally exhibit allotriomorphic to hypidiomorphic granular to porphryloblastic texture. Foliation is usually marked by the orientation of biotite flakes or weakly so by elongated quartz grains in the gneissic facies. Polyphase metamorphism in some gneissic specimens is indicated in most cases by two or more orientations of biotite flakes. The rocks are made up of K-feldspars, plagioclase feldspars, quartz, biotite ($\pm$ muscovite), and a suite of accessory minerals including epidote minerals, sphene, iron oxides, apatite, zircon and chlorite (Table 13).

The predominant K-feldspar is microcline (Table 13), which is usually perthitic especially when it occurs in the massive variety of granites, although non-perthitic types are occasionally encountered. Orthoclase is the only other K-feldspar and both together may constitute up to 40 to 50% by

volume, with a general average of less than 40%. Where alteration is evident, the K-feldspars always alter to clay minerals (sericitization/ muscovitization).

Plagioclases (An_{5-17}) occur as large laths. They usually form up to 60% of the volume of the specimen, averaging around 40%. Antiperthites are not uncommon. The plagioclase feldspars almost always show some degree of saussuritization/ epidotization. This epidotization process may be the direct result of hydrolysis of anorthite in the plagioclase, as advocated by Marmo (1971), where he thinks the equation for the reaction is represented as:

$$4(CaO,Al_2O_3.2SiO_2)+7H_2O$$

Anorthite water

$$\rightarrow 4CaO.3Al_2O_3.6SiO_2.H_2O+SiO_2+2Al(OH)_3$$

Zoisite Quartz Gibbsite

The epidote content varies from accessory to a major component in few cases. Another feature of these plagioclase feldspars is the presence of bent twin laminae, which are indicative of deformation. Associated with both potassium and plagioclase feldspars are the myrmekitic intergrowths (of quartz) in these rocks, which may be due to reactions at the contacts between the two different types of feldspars Philip, 1973).

Quartz is the third major mineral constituent of these rocks. It usually forms about 20% by volume of the specimen. It occurs interstially in the feldspars, especially where the specimen is

massive. In the gneissic or foliated varieties, it may occur granulated or strained, with undulatory extinction.

Biotite is the main ferromagnesian mineral in these rocks, and may reach up to 10 to 15% by volume. It ordinarily marks the foliation direction in the foliated granites or gneisses. It appears as dirty green flakes under the microscope, and is pleochloric in different shades of greenish brown. Green mica (fuchiste) was observed in one instance (Sample DO442). Some biotite flakes show bent cleavage direction, another indication of deformation.

Muscovite may be present in these rocks up to about 2 to 3% by volume, but it appears to be mostly secondary, after biotite and/or K-feldspars.

Hornblende can at best be described as uncommon in these rocks, except in one instance (Sample DO449), where it was found to be about 10 to 20% by volume.

The accessory minerals of this suite include epidote minerals, chlorite (mostly after biotite), apatite, zircon (often enclosed in biotite flakes), iron oxides (mostly magnetite, Sample DO457), sphene (sometimes twinned), staurolite (rare, DO467), and carbonate, up to 1% (after plagioclase; Sample 470).

7.1.2 Grebo Town Area

The granitoids of this area include pegmatite, aplite, migmatite, pegmatite granites, and granitic gneisses. They are massive to gneissic, fine to

medium to coarse grained, leucocratic. They show more indication of granulation (they form part of the St John Shear Zone); some poikilitic textures can be observed. Phenocrysts of feldspars, measuring up to 10cm in length, are not uncommon. Sometimes tourmaline crystals up to 4cm in length may be observed, mostly associated with quartz. Blocks of muscovite can be found also in some strongly weathered sections of the pegmatite.

Here the rocks also show allotriomorphic to hypidiomorphic granular to granoblastic textures under the petrographic microscope. Most of the rocks indicate certain degree of metamorphic effect or shearing in this area. Direction of foliation is indicated, where present, generally by the orientation of biotite/muscovite flakes or strained quartz. K-feldspars, plagioclase feldspars and quartz comprise the main minerals of these rocks, as in the case of the Northwest Granites (Table 12).

Orthoclase is also subordinate to microcline in these rocks, though more abundant here than in the NWG, and both of them are perthitic, with orthoclase being more microperthitic. Sericitization is observed, and ranges from slight to moderate in these K-feldspars, which make up about 20 to 65% by volume in these rocks.

Plagioclase feldspars are usually sodic and may comprise up to 60% by volume in a few cases (Sample DO4784), but are mostly below 30%. Saussuritization is less pronounced in these rocks.

Sample DO4822 shows a zoned structure with calcic core. Myrmekites at the contacts between these plagioclase feldspars and the K-feldspars are not uncommon. As in the NWG,bent twin lamellae are also observed in a few of the plagioclase crystals.

Quartz, which may be as much as 35 to 40% by volume, occurs mainly in granulated or strained form, and hence exhibits undulatory extinction; some occur as inclusions in the feldspars.

Biotite is less abundant in these rocks than in the NWG with a maximum of about 10%. It is generally brown in colour, and its bent flakes are again interpreted here as indications of deformation, as are the granulated and sheared quartz crystals. Also some of the biotite flakes show two directions of foliation, indicating polymetamorphism (Sample DO4843). Muscovite is more abundant in these rocks, reaching a maximum of about 5% by volume. Hornblende (brownish green in colour) was observed in one case only (Sample DO4803).

Iron oxides (mostly magnetite), apatite, chlorite, sphene, epidote, zircon, almandine and tourmaline (Schorl) occur as the accessory minerals.

7.1.3 The Cestos Batholith Area

The rocks of this area are grey-green to dark, massive to gneissic, medium to coarse grained. They generally range from diorite to quartz diorite in mineralogical composition. Crushing and granulation effects are obvious in most samples, except those from towards the centre of the batholith, and

foliation is commonly defined by the streaks of biotite or hornblende. The rocks are composed of plagioclase feldspars, quartz, potassium feldspars, hornblende, and biotite. The accessory minerals include sphene, epidote, apatite, magnetite and allanite.

The plagioclase feldspar, which is usually 40 to 50% by volume, is often heavily saussuritized to the extent that it sometimes becomes poikilitic with the inclusions of epidote. Twin laminae are sometimes bent, indicative of deformation in this area, as in the other areas discussed. Inclusions of K-feldspars in plagioclase feldspar crystals were noted in Sample D04892.

Quartz is generally either simply elongated or crushed to form elongated trains; usually it thus has wavy extinction; it may form about 20% by volume of the rock. The granulated form may be recrystallized around the feldspars. The K-feldspars (both microcline and orthoclase) are quantitatively less important in these rocks as they usually make up less than 15% by volume. Crystals are often interstitial to the plagioclase crystals, and microcline perthites predominate over the orthoclase.

Hornblende and biotite are the main ferromagnesian minerals in these rocks, with the former appearing more abundant in this suite but still generally subordinate to biotite. They show varying degrees of chloritization, and their alignment usually defines the foliation direction in the gneissic varieties of these rocks. Biotite flakes are sometimes riddled with pleochloric haloes, which may be sites of zircon

inclusions.

The accessory mineral suite here is similar to that of the NWG series, although the individual minerals are somewhat more abundant. Epidote, for example, may even be considered as a major constituent in some samples (DO 5001, D04933), and in one instance may be primary (Sample D04892). Sphene has also been found in greater amounts here, and one crystal observed measures about 0.74x1.8mm (Sample 4892), while another displays multiple twinning (Sample D04921).

TABLE 13 MODAL COMPOSITION OF THE SUITES STUDIED. (I) NORTHWEST GRANITES; (II) THE NORTH CENTRAL TRAVERSE; (III) GREBO TOWN AREA; (IV) CESTOS BATHOLITH AREA

AREA 1		MODAL MINERALOGY								REMARKS
Sample No.	Rock Type	K-spars	Plag	Qtz	Hblde	Bt	Musc	Others	Accessory or Secondary	
D04425	Qtz Diorite	5	50-60	25	-	15	2		Ep,Ap,Zir,Carb, Chl,Sph,fuch, Fe-oxide,Cord.	Medium to coarse grained, bent twin planes in some plag. crystal. Mesocractic.
4431	Qtz Diorite	5	40-50	20	-	10	3		Ap,Zir,Fe-oxide	
4435	Qtz Diorite Gneiss	5	60-20	20	-	20			Ap,Zt,Ep,Mon Chl.	Well foliated; medium-grained; seriatized.
4442	Gneissic Qtz Diorite	15	50	20	-	4	2		Sph., Ap,Chl., Ep,Mgt,Ser.	Medium to coarse grained; moderately foliated.
4446	Qtz Diorite Gneiss	15	60	20	-	3	1		Chl., Ap,Mgt.	Equigranular; foliation not obvious in hand specimen K-spar is micro-perthitic muscovite after biotite.
4471	Granodiorite Gneiss	5	60	20	-	15	1		Ep,Ap,Mgt	Myrmeketic, foliation is marked, by orientation of biotite flakes which are dirty greenish.
4481	Granodiorite	25	40	15	-	10	4		Mgt,Ep,Chl.,Ap, Zir,Carb.	Massive, leucocratic, granular,allotriomorphic texture;antiperthic, contains myrmekites.
4482	Hornblende Granite	30-40	20	25	5	3	-		Ep,Ap,Mgt,Carb, Zir,Sph,Chl., Sericite.	Pinkish grey coloured; hblde/biotite are clots; hblde is greenish under microscope; saussuritization and sericitization are obvious
4493	Granodiorite	5-10	40-50	15	10-20	-	-		Ep,Chl.,Op, Carb,Sericite	Coarse grained; chlorite after hblde; hypidiomorphic/ allotriomorphic; hblde appears in clots.

Contd/..

TABLE 13 Contd..

AREA 1		MODAL MINERALOGY								REMARKS
Sample No.	Rock Type	K-spars	Plag	Qtz	Hblde	Bt	Musc	Others	Accessory or Secondary	
4494	Qtz Diorite	5-10	50	20-25	-	5-10	3		Fe-oxides,Sph, Ep,Chl.	Slightly foliated dirty greenish biotite; medium to coarse grained
D04503	Foliated Granite	40	25	20	-	5-10			Zr,Sph.,Mgt,Ap	Qtz grains are slightly strained; textures are equigranular/hypidio-morphic medium to coarse grained. Contains twinne sphene crystals; biotite flakes are dirty greenis brown.
4515	Gneissic Granodiorite	5	50	25	-	4	1		Chl,Ep,Ap, Sericite,Fe-oxide.	Biotite flakes contain pleochloric haloes; Chl. is mostly after biotite which indicatestwo directions orientation.
4562	Granite	45-50	20	25-30	-	4	1		Zir,chl.,opaques	Pink, massive, medium to coarse grained; meta-micts present; pericline twinning; perthites are sometimes bent; allotrio morphic texture.
4572	Biotite Granite	45	25	20	-	5	1		Cal,Op,Ep,clay minerals	Microcline is predominan K-feldspar; calcite veinletsin K-spar crysta clay minerals are alteration products of microcline/orthoclase; mica flakes are sometime curved.

Contd/..

TABLE 13 Contd/..

AREA 1		MODAL MINERALOGY								REMARKS
Sample No.	Rock Type	K-spars	Plag	Qtz	Hblde	Bt	Musc	Others	Accessory or Secondary	
4644	Granite Gneiss	40-45	15-20	25	-	2	1		Zir,Mon,Op,Ap	Qtz. grains are elongated granoblastic; poly-deformation indicated by two directions of biotite flakes.
4661	Granodiorite	10-15	40-50	20-25	-	5	1		Ap,Ep,Zir, Chl, Sericite	Fine to medium grained; allotriomorphic.
4678	Granodiorite	5	60	20	-	10	1		Ap,Zir,Op,Ep,Chl.	Weak foliation is indicated by the preferred orientation of biotite flakes; fine to medium grained, equigranular texture.
4681	Gneissic Granite	45-50	20	15-20	-	-	-		Zir,Ep,Op	Leucocratic; allotriomorphic texture; myrmekitic and perthitic intergrowth not uncommon.
D04704	Qtz Diorite	5	50-60	5-10	-	4			Ap,Zir,Mon,carb,Ep, Op	Zircon crystals are mostly euhedral and may measure up to 3mm.
4714	Tronhedjemite Gneiss	1	60-65	20-25	-	5-10	-		Chl,Mgt,Ap,Sph.,Zir.	Quartz is mostly granulated; biotite is dirty green; medium to coarse grained.

Contd/..

TABLE 13 Contd/..

AREA 1		MODAL MINERALOGY							REMARKS
Sample No.	Rock Type	K-spars	Plag	Qtz	Hblde	Bt	Musc	Others	Accessory or Secondary	
4573	Tonalite	5	50	10-20	5-10	1			Mgt,Ap,carb,Zir	Massive; coarse grained plag. twin laminae slightly bent; hypidiomorphic texture.
4463	Quartz Diorite	10	50-60	20	10	1				Slight foliation observed microscopically; dirty green biotite relatively abundant; medium to coarse grained; allotriomorphic.
4592	Foliated Granite	40-45	20-25	10-15	1	1			Chl.,Mgt,Ep, clay minerals,Zir	Perthitic and myrmekitic intergrowths are relatively abundant, the preferred orientation of the quartz grains betrays the faint foliation.
D04601	Qtz Diorite Gneiss	10%	45-50	15-20	-	3			Zir,Chl.,Sph., Mgt,Ap,Ep,clay minerals	Pink; perthite intergrowths are very common; foliation is very faint.
4613	Gneissic Qtz Diorite	30-40	35	20	-	5	1		Mgt,Zir,Chl,Ap	Medium to coarse grained myrmekite intergrowth; perthites are abundant saussuritization and sericitization are present also but not common.
4621	Foliated Granite	40	25	25	-	4	1		Mgt,Chl,Ep,Zir, Sericite,Ap.	Medium to coarse grained; abundant perthite and myrmekite intergrowths allotriomorphic/hypidiomorphi
4632	Granite Gneiss	35-40	25-30	20	-	3			Op,chl,Zir,Ap	Appears mass macroscopically, but foliated under the microscope.

Contd/..

TABLE 13 Contd/..

AREA 11		MODAL MINERALOGY								REMARKS
Sample No.	Rock Type	K-spars	Plag	Qtz	Hblde	Bt	Musc	Others	Accessory or Secondary	
4661	Quartz Diorite	10-15	40-50	25	-	3	1		Ap,Mgt,Ep,Chl, Sericite	Mesocratic, coarse grained; dense.
4711	Quartz Diorite Gneiss	1	60-65	25	-	8	1		Chl,Ep,Zir,Mgt,Ap, Sph.	Biotite has been extensively chloritized; qtz shows undulatory extinction; antiperthit intergrowths are common.
4751	Granite(pink)	40-45	25-30	20-25	-	3	1		Chl,Ap,Mon,Ep, Zir,Op/Fe-oxides	Both types of feldspars are dusty, plag. more so. Medium to coarse grained; augens and phenocrysts of feldspars are not uncommon. Euhedral crystals of apatite and zircon are common; texture is allotriomorphic.
4753	Foliated Granite	35-40	25%	20-25	-	8	1		Ap,Chl,Ep,Zir, Mgt tour.	Perthitic and myrmekitic intergrowths are common; biotite crystals are dusty green. Some portions of section show crushed qtz grains in trains.
4765	Granodiorite	10-20	40-50	15-20	-	1-5	1		Zir,Fe-oxides, Ep,Ap	Two directions of slight foliation observed as defined by mica flakes and elongated qtz; medium to coarse grained. Epidiote makes up about 3% total volume.

Contd/..

TABLE 13 Contd/..

AREA 11		MODAL MINERALOGY								REMARKS
Sample No.	Rock Type	K-spars	Plag	Qtz	Hblde	Bt	Musc	Others	Accessory or Secondary	
4773	Quartz Monzonite Gneiss	35-40	30-40	25	-	5	1		Mgt,Chl.,Ep,Z ,Ser, Sph.	Foliation is marked by the elongation of qtz and feldspars along with micas, perthite and myrmekite intergrowths are abundant.
AREA 111										
4784	Quartz Diorite Gneiss	5	60%	30	-	-	1	Tour.		Tourmaline may be up to 3% or more. Bent twin lamellae of plagioclase observed; sericite has dendritic feature; medium to coarse grained, nemato-blastic texture.
4794	Pegmatite	5	50-60	25-30	-	5		Op		Quartz appears mainly as inclusion in the feldspars bent twin lamellae observe in plagioclase.
4803	Two-mica Granite Gneiss	40-50	10-15	20-25	1	10	2	Tour.		Both perthite and myrme-kitic structures are abundant; very coarse grained. Slightly foliated; a brownish hornblende.
4804	Gneissic Granite	60-65	5-10	20	-	2				Coarse grained; slightly weathered; myrmekite and perthite intergrowths are abundant.

Contd/..

TABLE 13 Contd/..

AREA III		MODAL MINERALOGY							REMARKS	
Sample No.	Rock Type	K-spars	Plag	Qtz	Hblde	Bt	Musc	Others	Accessory or Secondary	
4822	Pegmatite Granite	60-70	5	20	2	1			Mgt,chl. Ser.	String perthite not uncommon, plagioclase is zoned.
4823	Granite Gneiss	45-50	10	25	4	1			Mg,Ap,clay clay minerals	Fine to medium grained; allotriomorphic/granular.
4832	Pegmatite Gneiss	45-50	10	35	2	1			Ep,Sph,Zir,Mgt, Chl.	Biotite has been chloritized to some degree; like other samples, most epidote result from saussusitization of the plagioclase feldspars.
4843	Two-mica Granite/ Quartz Monzonite Gneiss	35-45	30-35	25	5	3			Ep,Sph.,Zir.	Two foliation directions are shown by the mica flakes; some of these flakes are also curved.
4845	Pegmatite Gneiss	40-45	30-35	25-30	8	1				Curved perthites are common.
4855	Granite	40	15	35	5			Tour.	Fe-oxides,Ap, Zir,Chl.,Ser.,Ep.	Slightly sheared; plagioclase crystals are poikilitic with epidote.
AREA IV										
4881	Quartz Diorite Gneiss	8	60	28				Ep.	Carb,Sph,Chl.,Fe-oxides	Quartz is strained and sometimes granulated; saussuritization is fairly extensive. Biotite is shredded with flow structure; nematoblastic.

Contd/..

TABLE 13 Contd/..

AREA IV		MODAL MINERALOGY								REMARKS
Sample No.	Rock Type	K-spars	Plag	Qtz	Hblde	Bt	Musc	Others	Accessory or Secondary	
4892	Diorite (Augen) Gneiss	8	45	15	8	8		Ep	Ap,Al,Fe-oxides,Sph.	Most of the K-feldspars appear as inclusions in the plagioclase;primary epidote.
4895	Quartz Diorite Gneiss	10	45	20	5	10		Ep.	Sph,Fe-oxides,Chl, Ap.	Fine to medium grained streaks of epidote (green) can be observed sometimes in hand specimen; biotite is heavily chloritized.
4921	Quartz Diorite Gneiss	2	45-50	30	15	5		Ep.,Sph.		Fine to medium grained granular.
4933	Quartz Diorite Gneiss	10	30	20	25	2		Ep.	Chl,Sph.	Strongly foliated; pockiloblastic; quartz crystals are strained; nematoblastic texture.
5001	Gneissic Quartz Diorite	10	30	25	15	15		Ep.	Sph., Ap,Mgt,Chl.	Medium to coarse grained pockiloblastic; foliation is indicated by the preferred orientation of micas/hornblende.
5012	Gneissic Quartz Monzonite	35	38	20	1	10		Ep.	Mgt,Ap.	Ribbon/mortar textures observed; cataclastic effects.
5034	Quartz Diorite Gneiss	15	45	20	5	10		Ep.,Sph.	Chl,Ap,Fe-oxides.	Sericitization and saussuritization are very slight; quartz crystals are elongated and exhibit undulatory extinction.

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TABLE 13 Contd/..

AREA IV		MODAL MINERALOGY								REMARKS
Sample No.	Rock Type	K-spars	Plag	Qtz	Hblde	Bt	Musc	Others	Accessory or Secondary	
5043	Quartz Monzonite Gneiss	28	30	20	5	10		Mgt,Ap	Ep.,Zir.	Quartz is commonly structured at the boundaries; two directions of foliation as indicated by mica flakes.
5052	Trondhjemite	1	60	25	10			Ap.,Mgt.	Zir,Ep.	Biotite flake is generally riddled with pleochloric halos; albite lamellae are curved.

Abbreviations used in Table 13:

Ep = epidote
Ap = apatite
Zir = zircon
Carb = carbonate (calcite)
Chl = chlorite
Sph = sphene
Fuch = fuchsite
Cord = cordierite
Mgt = magnetite
Op = opaque
Tour = tourmaline

CHAPTER 8

THE GEOCHEMICAL FEATURES OF THE AREAS STUDIED

8.1 INTRODUCTION

From the petrographic study (Chapter 7) it has been established that all of the suites of rocks under investigation are in general granitoids. However, because of local as well as regional petrographic and chemical differences observed, (however small they may be in some cases!), it is considered appropriate to discuss the geochemical features of each of the four areas individually. One objective of this chapter, then, is to provide a basis for a comparative study of the geochemistry of the granitic rocks of Liberia as a whole (Chapter 9.).

The analytical data for the samples are listed in a loose enclosure to the thesis, and are also tabulated on microfich in the back pocket. It should be noted that Ag, Mo, Cr and Cd were found to be below their detection limits in the majority of the samples, and may therefore no longer be considered in the subsequent discussions or, interpretations.

8.2 THE GEOCHEMISTRY OF THE NORTHWEST GRANITES AND ASSOCIATED GNEISSES (NWG)

8.2.1 Element Abundance

Table 14 presents the means, medians, standard deviations, minima,

TABLE 14 MEANS COMPOSITIONS OF THE NORTHWEST GRANITE AND ASSOCIATED GNEISSES AS COMPARED TO SIMILAR PRECAMBRIAN GRANITES AND TUREKIAN AND WEDEPOHL'S HIGH-Ca GRANITE

Major (%)	Mean	St. Dev.	Median	Min.	Max	1	2	3
Al	5.75	0.99	5.80	0.38	8.40	8.20	7.62	7.84
Ca	1.89	1.08	1.78	0.05	7.10	2.58	1.61	1.56
Fe	1.97	1.54	1.54	0.25	10.0	2.70	0.39	1.98
K	2.03	1.03	1.76	0.06	6.10	2.52	2.27	2.68
Mg	0.57	0.75	0.34	0.01	5.50	0.94	0.94	0.62
Mn	0.03	0.03	0.02	0.01	0.27	0.05	0.02	-
Na	3.18	0.60	3.30	0.08	4.30	2.84	3.17	3.53
P	0.05	0.04	0.04	0.01	0.23	0.09	0.04	-
Ti	0.20	0.16	0.16	0.01	0.30	0.34	0.15	-
Trace(ppm)								
Ag	1.70	0.70	1.50	1.10	2.90	0.05	-	-
Ba	1146	806	900	2	1940	420	795	880
Be	1.20	0.50	1.10	0.10	2.93	2.00	-	-
Cd	1.50	2.70	1.10	0.50	17.20	0.13	-	-
Co	11.0	11.0	8.0	1.0	94	7.0	-	7.0
Cr	14.0	40.0	6.0	1.0	330.0	0.05	-	9.0
Cd	21.0	36.0	8.0	1.0	230.0	30.0	-	-
La	27.0	22.0	23.0	5.0	164.0	45.0	-	63.0
Li	14.0	8.0	13.0	1.0	55.0	24.0	-	-
Mo	4.0	1.90	3.80	1.10	7.80	1.0	-	-
Ni	25.0	35.0	15.0	1.10	270.0	15.0	-	-
Pb	25.0	13.0	24.0	6.0	153.0	15.0	-	-
Rb	72.0	40.0	66.0	21.0	250.0	110.0	80.0	105.0
Sr	330.0	162.0	310.0	5.0	490.0	440.0	288.0	692.0
V	34.0	3	22	2.0	270.0	88.0	-	-
Zn	50.0	34.0	43.0	6.0	360.0	60.0	-	-

RATIOS	a	b
K_2O/Na_2O	.7	-
k/Rb	328	98
Rb/Sr	.45	58
Ba/Rb	20	0.5
Ca/Sr	61	1306
K/Ba	32	-

Note:
(1) Turekian and Wedepohl's (1961) mean for high-Ca granites.
(2) Goldich and Wooden's (1980) mean for the Precambrian -granodiorite gneiss.
(3) Condie and Hunter's (1976) average for Dalmin "type" granodiorite.
(a) Some binary ratios for this work.
(b) Some binary ratios from the Bobbejaankop Granite (Precambrian, Lenthall and Hunter,1977).

maxima and a few important binary ratios of the concentrations of the elements determined, along with corresponding data on granitic rocks from elsewhere in the world for a comparison.

The high standard deviations and wide ranges are probably a reflection of the heterogeneous nature of these rocks, as indicated by the microscopic study. However, on average, these rocks are comparable to the high-Ca granites of Turekian and Wedepohl (1961), with similar concentrations of Ca,K,Na,Co,Rb and Zn, but lower contents of Al,Fe,Mn,Ti,La,Li,Sr, and V. On the other hand, these granitoids are significantly higher in Ba,Pb, and Ni. Similar comparison with granites (sensu latu) from elsewhere (e.g. Condie and Hunter,1976; Goldich and Wooden, 1980; Marmo, 1956) reveal that the chemical compositions of these rocks are not very unusual. However, it should be remembered that generous margins should be allowed in such comparisons as the number of samples analysed in a particular study may often be small.

Figure 23a is the Kleiner-Hartigan "Trees" of the 185 samples from this suite. The template is shown in Figure 23b. Careful examination of the "Trees" indicates that some of the elements show high degrees of variation in concentration from sample to sample, despite the fact that very similar lithological units are shown by the geological map. For example, Ca is relatively more depleted in sample 4492 than in sample 4564. Such variation may be interpreted as a reflection

Fi .23a. The Kleiner-Hartigan "Trees" for the Northwest Granites and associated gneisses. Note that where the "Trees" were very close together and had similar element concentrations only representative ones are shown. Also arrows
arrows point in direction from where a "Tree" may have been drawn in.

Fig.23b. The template for the "Trees" of Fig.23a.

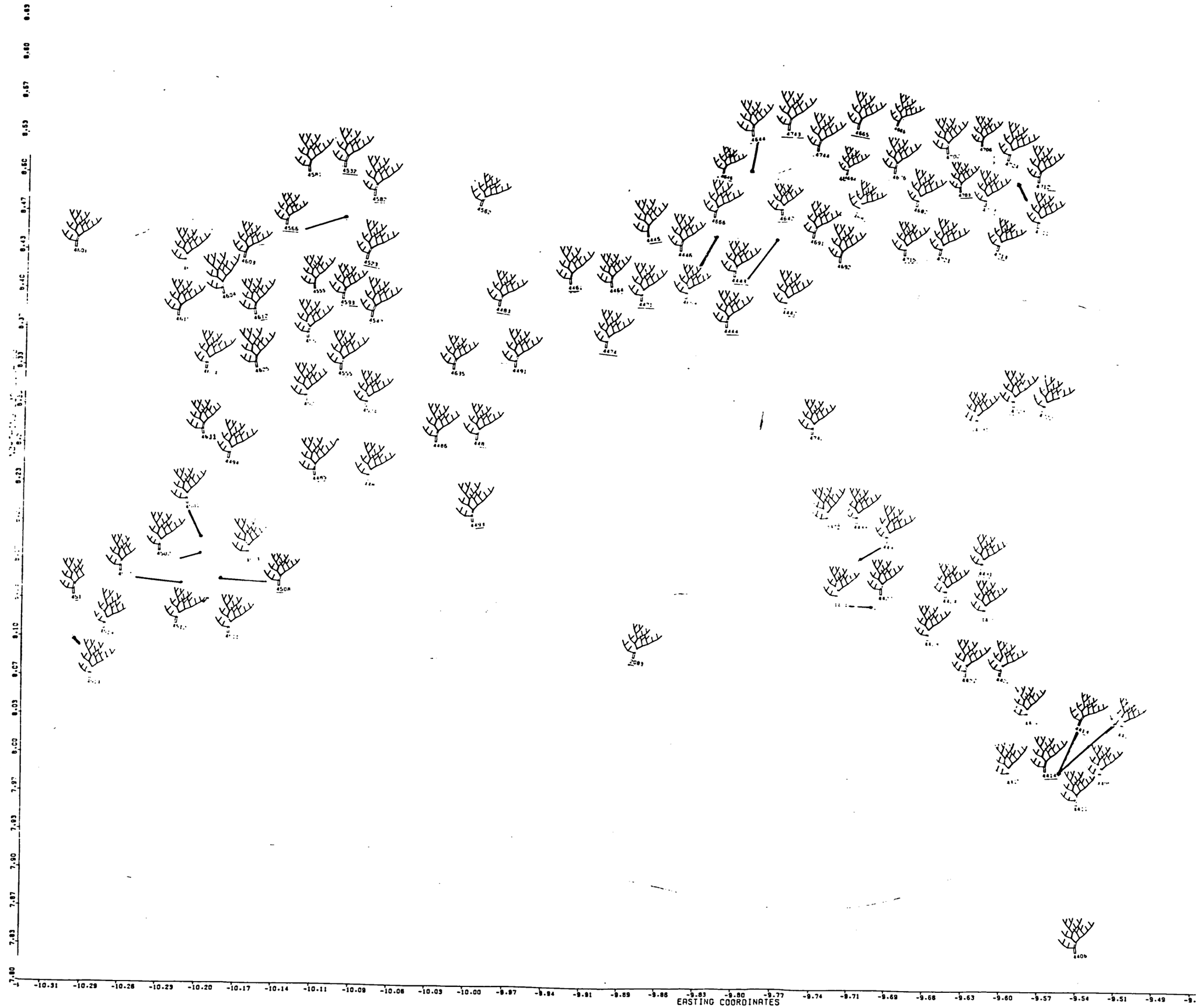


Fig. 23a.

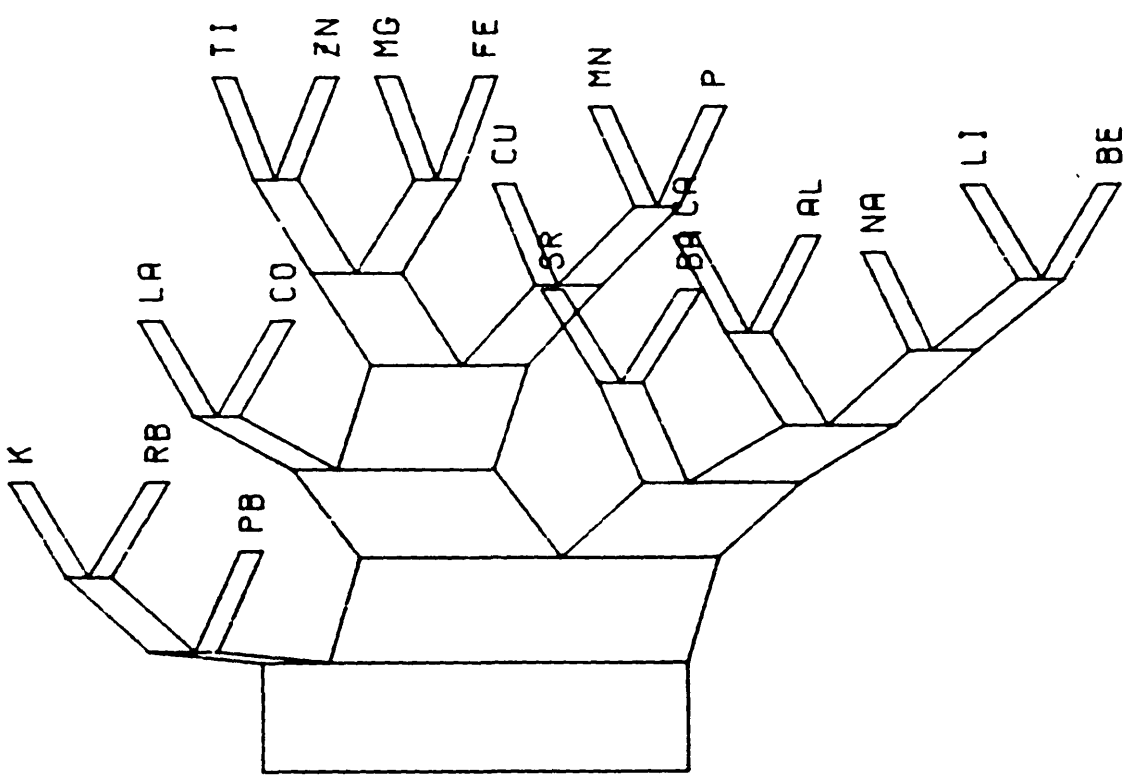


Fig.23b

of local lithological variability, which could not possibly be expected to be revealed by the reconnaissance-scale geological mapping previously carried out in the area.

8.2.2 The Frequency Distribution Patterns

In order to visualize the distribution patterns of the elements within this suite, histograms and normal probability plots were generated through the use of the Minitab package (Ryan et al., 1976). Visual inspection of the histograms and probability plots shows that most of the elements tend to display some degree of polymodal distribution, and among both the major and trace elements under consideration, only K, Ba, and Sr show normal or near-normal unimodal distributions (Fig.24), whilst the others are either positively or negatively skewed (Fig.25 for e.g.). These trends are generally consistent with trends observed for many granitic rocks elsewhere (Ahrens, 1963b, 1964; Condie, 1969; Hattori et al., 1960; Svesson, 1970; Rooke, 1969), and many workers including Howarth (1983) have attempted to explain such behaviour in terms of the concentrations of the elements in the particular rock types. For example, Svensson (1970) postulates that as the behaviour of an element is governed by the degree of its dispersion in a particular medium, an element most probably shows a normal distribution pattern when its mean is far from zero concentration whereas an element will tend to assume a log-normal

Fig. 24(a-c) Examples of approximately normal frequency distribution patterns of the elements (in ppm) determined in the Northwest Granites and associated gneisses.

K

EACH * REPRESENTS 2 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.	2	*
5000.	12	******
10000.	53	********************************** a
15000.	24	************
20000.	16	********
25000.	22	***********
30000.	30	***************
35000.	16	********
40000.	4	**
45000.	5	***
50000.	0	
55000.	0	
60000.	1	*

DA

EACH * REPRESENTS 2 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.	10	*****
500.	57	****************************** b
1000.	58	*******************************
1500.	27	**************
2000.	14	*******
2500.	11	******
3000.	1	*
3500.	3	**
4000.	4	**

SR

EACH * REPRESENTS 2 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.	4	**
100.	13	*******
200.	32	****************
300.	69	********************************** c
400.	41	*********************
500.	11	******
600.	3	**
700.	5	***
800.	3	**
900.	4	**

Fig.25(a-c) Examples of other types of frequency distribution patterns of elements (in ppm) in the Northwest Granites and associated gneisses.

AL
EACH * REPRESENTS 2 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.	1	*
10000.	1	*
20000.	0	
30000.	1	*
40000.	5	***
50000.	55	**********************************
60000.	90	**
70000.	24	************
80000.	8	****

a

NA
EACH * REPRESENTS 2 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.	2	*
5000.	0	
10000.	0	
15000.	3	**
20000.	4	**
25000.	26	**************
30000.	55	**********************************
35000.	66	**
40000.	27	***************
45000.	2	*

b

ZN
EACH * REPRESENTS 5 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.	26	******
40.	103	**********************
80.	45	*********
120.	7	**
160.	1	*
200.	2	*
240.	0	
280.	0	
320.	0	
360.	1	*

c

distribution when its mean is close to zero concentration and when it exhibits high dispersion. The trends of statistical behaviour shown by the chemical elements in these suite of rocks are therefore not unexpected, especially when one takes into account the observed high standard deviations. Butler (1964) and Rooke (quoted in Clifford and Gass, 1970) and Condie(1969) in particular have observed similar statistical distribution patterns of elements in Precambrian granites from West Africa and Wyoming.

8.2.3 Inter-element Relationships

In order to prevent data closure (Aitchinson, 1984) each element was ratioed to Fe and log-transformed before the Pearson correlation matrix (Table 15) was determined. Based on the correlation coefficients at the 98% confidence level, three main groups of elements exist. Be,Rb,K,Al,Na, and Pb all have strong positive correlations with one another, whereas Ba,Sr, and Ca form a second group with moderately strong positive correlation coefficients. For the third group, which is composed of Li,Mg, Co,Ni,Ti,La,Cu,Zn,V,Mn, and P correlations are generally weakly positive. The first two groups or associations of elements may be related to both alkali and plagioclase feldspars respectively, as the two groups show some degree of strong mutual inter-correlation. The third association may possibly be attributed to biotite (which is the main ferromagnesian mineral in these rocks) and

Table 15 The Pearson correlation matrix for the log-transformed ratio (x/Fe) data from the Northwest Granites and associated gneisses.

	LI	NA	K	RB	BE	MG	CA	SR	BA	AL	LA	TI	V	MN	CO	NI	CU	ZN	PB	P
NA	.458																			
K	.485	.772																		
RB	.527	.737	.942																	
BE	.541	.845	.776	.765																
MG	-.319	-.536	-.652	-.683	-.546															
CA	.180	.674	.274	.199	.507	.035														
SR	.225	.744	.562	.408	.596	-.178	.745													
BA	.216	.649	.803	.645	.544	-.330	.408	.796												
AL	.483	.947	.854	.839	.829	-.608	.596	.698												
LA	.334	.454	.588	.483	.463	-.389	.102	.350												
TI	-.023	-.054	-.245	-.356	-.189	.445	.150	.048												
V	-.337	-.517	-.587	-.591	-.443	.606	.011	-.160												
MN	-.038	-.196	-.137	-.091	-.021	.226	-.202	-.309												
CO	-.042	-.200	-.185	-.040	-.155	.415	.023	-.101												
NI	-.004	.051	.158	.189	.139	-.068	-.064	-.016												
CU	-.158	-.175	-.081	-.037	-.024	.162	.006	-.041												
ZN	.371	.398	.303	.287	.370	-.158	.151	.211												
PB	.503	.783	.893	.914	.798	-.721	.264	.460												
P	-.090	-.211	-.269	-.337	-.164	.417	.000	.021												

	BA	AL	LA	TI	V	MN	CO	NI	CU	ZN	PB	P
AL	.695											
LA	.485	.512										
TI	-.068	-.207	-.056									
V	-.310	-.565	-.375	.353								
MN	-.299	-.212	-.150	-.017	-.004							
CO	-.085	-.154	-.202	.291	.398	.108						
NI	.057	.126	.210	-.131	-.020	.163	.033					
CU	-.073	-.126	-.075	-.068	.205	.193	.267	-.022				
ZN	.198	.342	.291	.132	-.346	.089	-.039	-.025				
PB	.631	.854	.594	-.343	-.626	-.111	-.172	.194				
P	-.073	-.330	-.036	.362	.382	.008	.083	-.136				

	CU	ZN	PB	P
ZN	-.033			
PB	-.085	.440		
P	.133	.003	-.350	

also to such accessory minerals as apatite and sphene which have a high capacity to admit such elements in trace amounts into their lattices (Deer et al., 1982; Bradshaw, 1967 and Mittlefehldt and Miller, 1983).

To a certain extent, the observed grouping of the elements is repeated by the hierarchical clustering (Fig. 26) obtained through the application of the Kleiner-Hartigan graphic Trees technique to the untransformed data. According to this analysis the elements fall into three main groups, viz: (i)K,Rb, and Pb; (ii) La,Co,Ti, Zn,Mg,Fe,Cu,Mn, and P; (iii) Sr,Ba,Ca,Al,Na,Li, and Be. Here it is again likely that groups (i) and (iii) reflect associations of elements in the two types of feldspars, whilst the second association may be correlated with the mafic minerals and/or the accessory minerals. Note that within each group some elements are better associated with one another than with the rest of the group. For example, within the second group Mg and Fe have better relationship with each other than with Ti and Zn, whose association in turn is even stronger with Mg and Fe than with the rest of the group. It can also be observed that the group (i) elements (K, Rb, Pb) cluster at higher order as an entity, and therefore their association may be considered the strongest.

The $Al_2O_3/(K_2O+Na_2O+CaO)$ ratio has been used to determine whether the granitic rocks being studied are aluminous, sub-aluminous, meta-aluminous

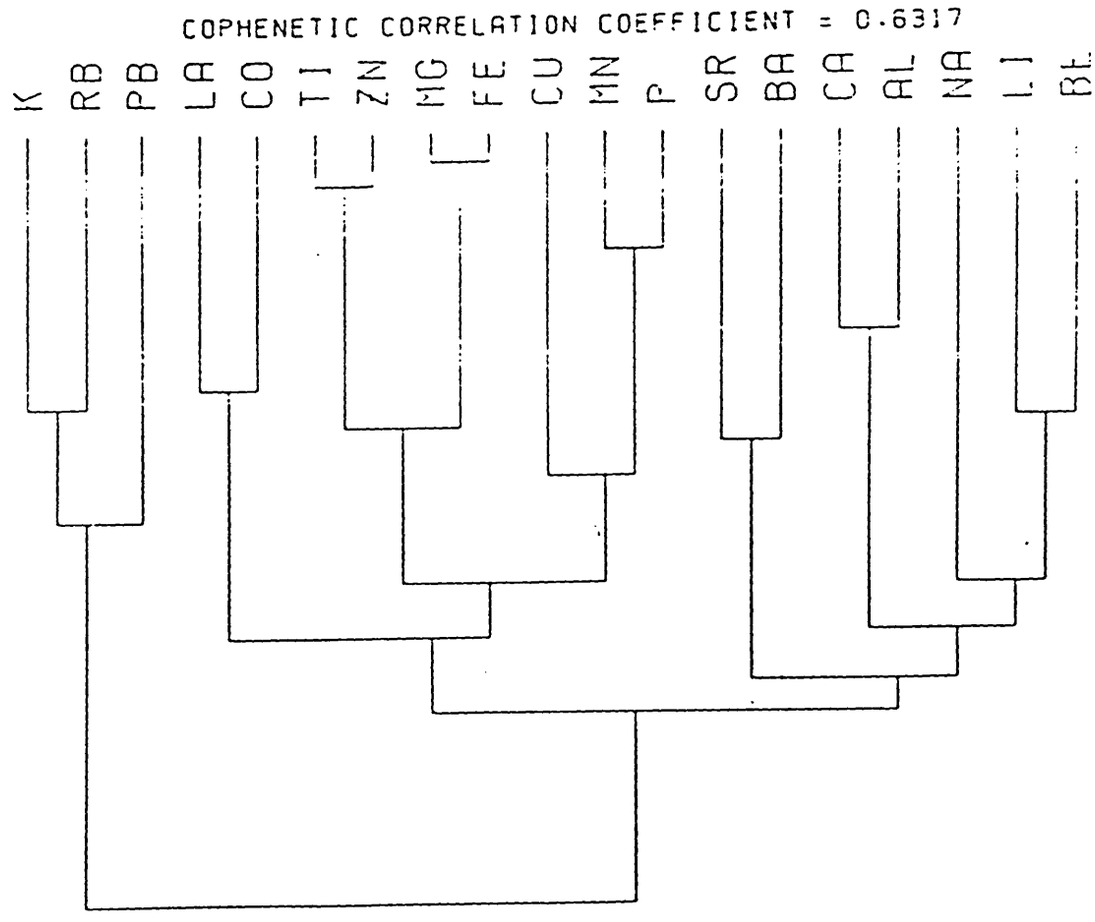


Fig.26. Hierarchical dendrogram of elements in the Northwest Granites and associated gneisses.

or peraluminous (Fig.27). The figure shows that the ratio lies between 0.53 and 1.00, suggesting that these rocks are sub-aluminous to meta-aluminous (Banerjee et al., 1983 and Martin and Bowden, 1981). This range of values should however be accepted with caution since the high Na and Ca contents rather than low Al content could possibly be responsible for this inference.

The fact that the K_2O/Na_2O ratio is generally less than one (Fig.28) suggests that the suite is relatively sodic. This is consistent with observation from other Precambrian granites in similar low to medium grade regional metamorphic terrain which are generally granodioritic rocks (Condie and Hunter, 1976; and Goldich and Peterman, 1980). Average values of other element ratios are shown in Table14. Comparison between these ratios (especially those of K/Rb, and Ba/Rb) and those from similar Precambrian granitic rocks (e.g. Lenthall and Hunter, 1977) indicate that the ratios are higher for the North West Granite and may therefore possibly suggest less differentiated fraction in general. This is again consistent with the petrographic study and the relatively lower concentrations of elements such as Rb and Pb.

8.2.4 Ridge Regression Analysis

For reasons given earlier in Chapter 6, the ridge regression technique has been applied to the present data in preference to using the classical

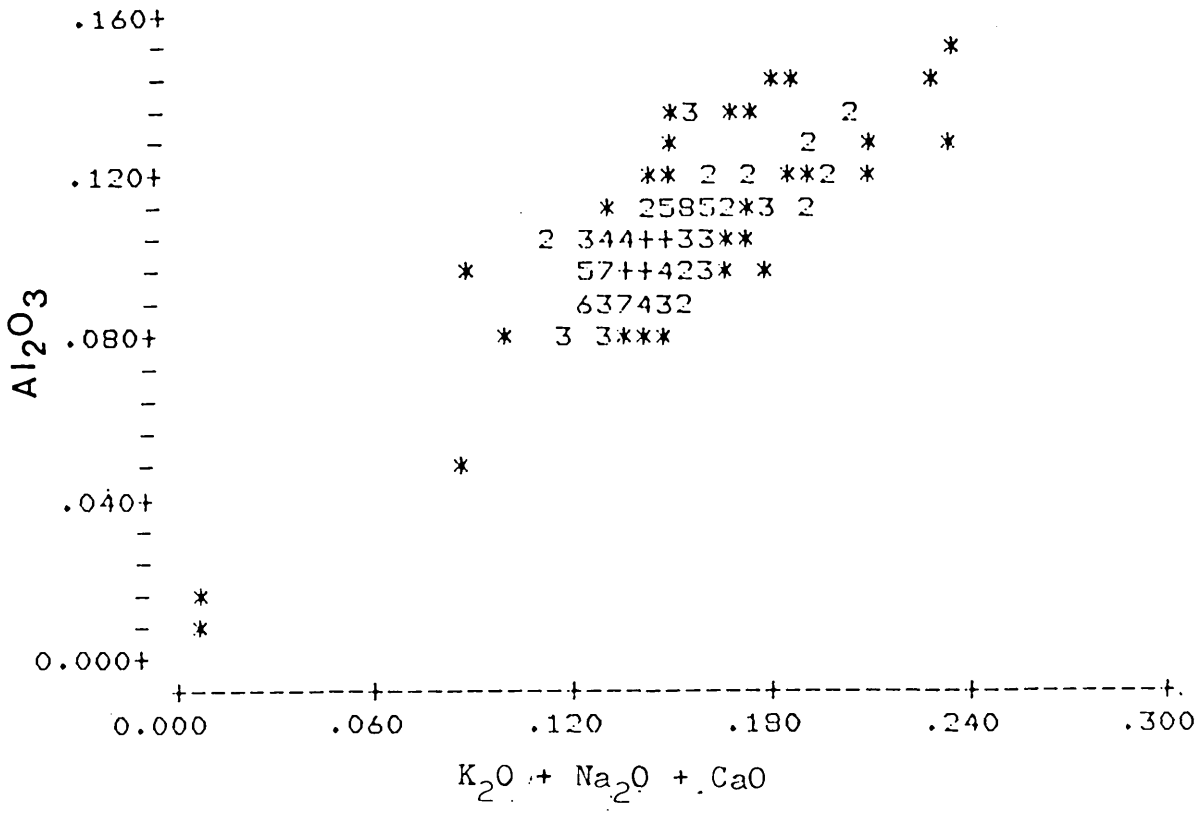
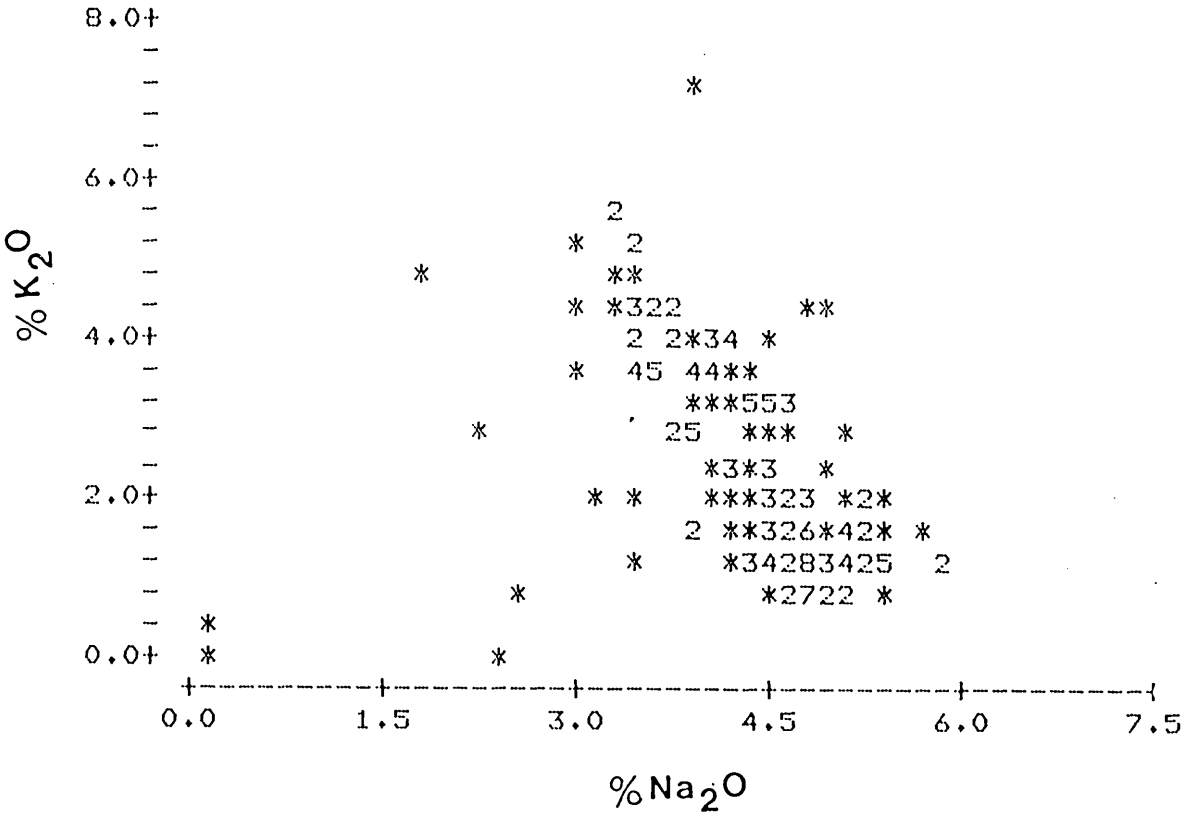


Fig.27. Plot of Al_2O_3 vs K_2O + Na_2O + CaO for the Northwest Granite and associated gneiss suite.

Fig.28. The K_2O vs Na_2O plot for the Northwest Granites and associated gneisses.



method of regression analysis, to determine which major elements were the best predictors for the trace elements. A ridge trace, the residuals and a residual normal probability plot were obtained for each of the trace elements, Li, Be,Rb, Sr, Ba, Cu, Ni, Zn and Pb. The results are summarized in Table 16.

For the purpose of illustration the ridge trace for Rb (Fig.19a) is discussed here. In the figure, it is apparent that of all the predictors used, K has the strongest influence on the behaviour of Rb. It is followed by Mg, whilst Ca, Ti and Fe are the best negative predictors for Rb. Na changes from being negative to being weakly positive, as the ridge constant increases, indicating that it is an unstable predictor (Howarth, 1984). The emergence of Mg as the second positive (though much weaker) predictor for Rb is geochemically uncharacteristic, and may be an artifact of the data.

The residual normal probability for Rb is shown in Fig.19b as an example of such plots for the present data. The linear relationship of the ordered residual values in this plot, (like those for the other elements with the exception of Sr) indicates that they are normally distributed or nearly so. No strong outliers are evident.

The Kleiner-Hartigan "Trees" were applied to the positive residuals in order to identify which trace element(s) had higher relative residual concentrations in any of the 185 samples in this

TABLE 16 RIDGE REGRESSION PARAMETERS AND RESULTS

	INITIAL			FINAL			IMPORTANT PREDICTORS**	LINEAR MODEL
	n	R^2	K	n*	R^2	K		
Li	185	0.27	0.2	183	0.28	0.2	Ti P Mn	ok
Rb	161	0.65	0.2	159	0.68	0.2	K Mg-Ca-Ti	ok
Be	185	0.48	0.2	184	0.43	0.2	Na P Mn K	ok
Sr	185	0.51	0.2	184	0.51	0.2	Na P Ca	ok
Ba	185	0.35	0.2	182	0.39	0.2	K P	ok
Cu	176	0.50	0.2	174	0.55	0.2	P Ca Fe Mn	ok
Zn	185	0.75	0.2	182	0.75	0.2	P Ti Fe Mn	ok
Pb	184	0.47	0.2	183	0.57	0.2	K - Ca	ok
Mo	77	0.24	0.2	77	0.28	0.2	Mg Ca-Al-Fe	ok

* Representing "background" relationship.

** Elements with standardized coefficients exceeding ± 0.1

n = No. of samples.

R^2 = Multiple correlation coefficient.

K = Ridge constant

data set. The result (Table 17) showed that none of the trace elements under investigation had higher relative residual concentration consistently throughout the area. Therefore results cannot be meaningfully interpreted.

8.2.5 The Geographical Distribution of the Chemical Elements

The geographical distribution of twenty-one elements determined in this suite has been examined, and the pattern is shown in Fig. 29(a-u). The concentration range of each element was divided into two or more class intervals for plotting mainly on the basis of sub-populations present. These maps indicate that the western part of the area is relatively enriched in all the elements except for Na, Rb, K, Be and Li which are uniformly distributed.

One important observation is that the elements which show no preferential enrichment generally occur in the felsic minerals including both kinds of feldspars, which in turn are the main constituents of granitoids. On the other hand, almost all of the elements showing enrichment in the west are more or less associated with the mafic minerals/rocks.

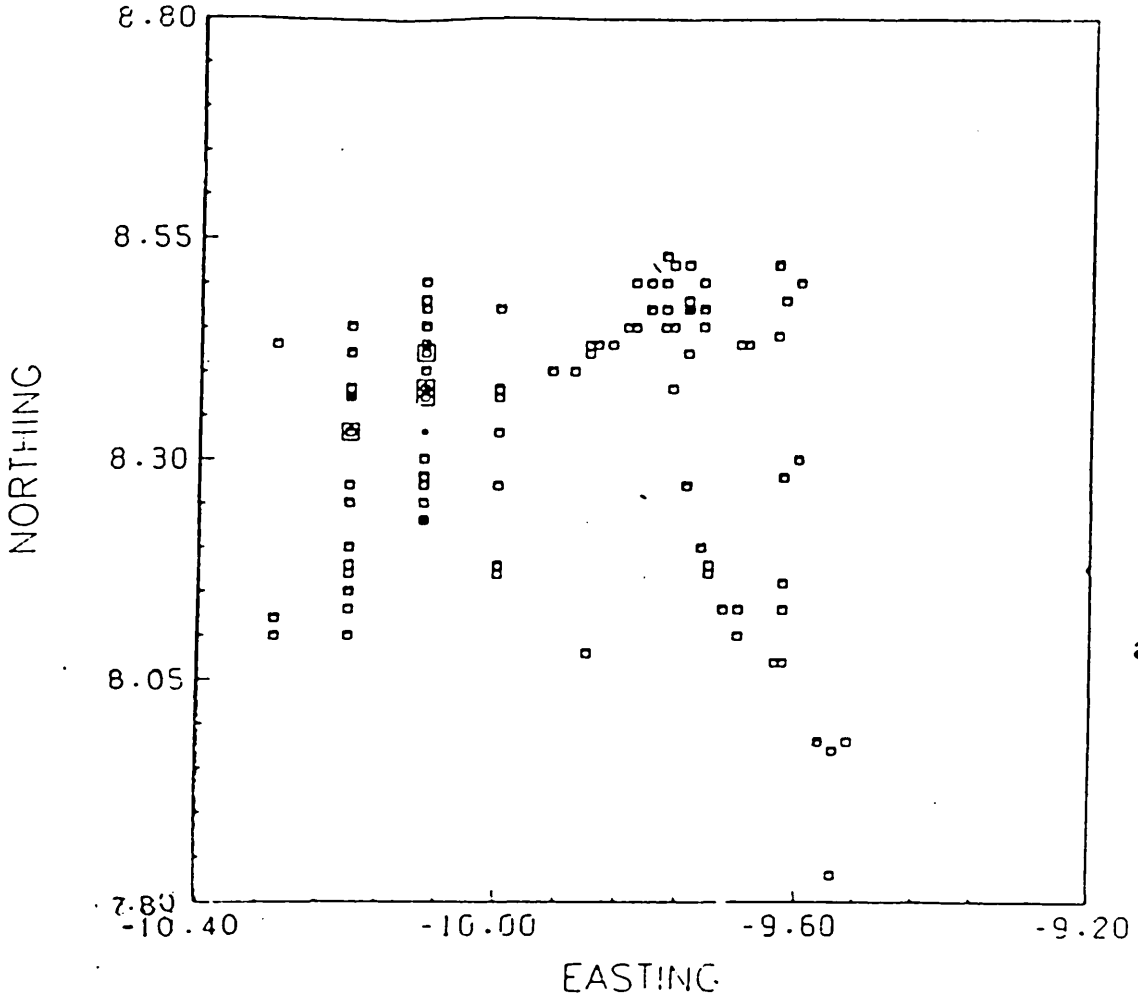
Table 17 Locations of samples (from the Northwest Granites and associated gneisses) having higher relative residual concentrations of certain elements.

SAMPLE NO.	ELEMENTS	CO-ORDINATES	
		N	W
4531	Cu, Ba, Sr	8° 22'	10° 12'
4646	Cu, Li, Rb	8° 30'	9° 48'
4563	Li, Rb, Be	8° 28'	10° 05'
2083	Li, Cu	8° 10'	9° 53'
4475	Li, Rb, Be	8° 22'	10° 08'
4433	Li, Rb, Cu	8° 10'	9° 43'
4415	Cu, Zn, Li, Rb	7° 59'	9° 33'
4651	Li, Rb, Cu	8° 30'	9° 47'
4613	Cu	8° 33'	10° 12'
4463	Li, Rb, Be, Cu	8° 25'	9° 53'
4561	Li, Rb, Be, Ba, Sr	8° 28'	10° 05'
4573	Mo, Li, Rb, Be, Pb, Zn	8° 23'	10° 11'
4666	Mo, Li, Rb, Pb, Zn	8° 28'	9° 48'
4644	Zn, Pb	8° 29'	9° 48'
4464	Li, Rb	8° 24'	9° 56'
4488	Cu, Zn	8° 16'	10° 05'
4507	Ba, Sr, Cu	8° 08'	10° 17'
4715	Ba, Sr, Cu	8° 26'	9° 41'
4471	Li	8° 23'	10° 00'
4722	Li	8° 26'	9° 40'
4745	Li	8° 11'	9° 43'
4492	Ba, Sr, Cu	8° 14'	10° 09'
4643	Mo, Li, Rb, Cu, Pb, Zn	8° 28'	9° 48'
4522	Li, Be	8° 16'	9° 07'
4473	Li, Cu, Be	8° 23'	10° 01'
4481	Li, Rb, Pb, Zn	8° 28'	10° 04'
4692	Cu	8° 27'	9° 44'
4492	Ba, Sr, Cu	8° 16'	10° 09'
4521	Ba, Zn	8° 07'	10° 20'
4562	Li, Rb, Zn, Be	8° 28'	10° 05'
4494	Li, Be	8° 12'	10° 13'
4533	Ba, Sr	8° 23'	10° 12'
4484	Ba, Sr, Cu	8° 16'	10° 05'
4507	Ba, Sr, Cu	8° 08'	10° 17'
4581	Cu	8° 25'	10° 09'
4446	Cu, Pb, Zn	8° 26'	9° 51'
4445	Cu, Zn	8° 27'	9° 47'

Contd/.....

SAMPLE NO.	ELEMENTS	CO-ORDINATES	
		N	W
4493	Ba, Sr, Cu	8° 14'	10° 10'
45C6	Cu	8° 09'	10° 17'
4514	Cu	8° 06'	10° 23'
4624	Mo, Li	8° 20'	10° 12'
4542	Mo, Li	8° 22'	10° 12'
4542	Mo	8° 25'	10° 11'

Fig.29(a-u). The geographical distribution patterns of twenty-one of the elements determined in the suite of samples from the Northwest Granites and associated gneisses. A simplified geology overlay for the area is found in the rear pocket of the thesis.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8.30
8.05
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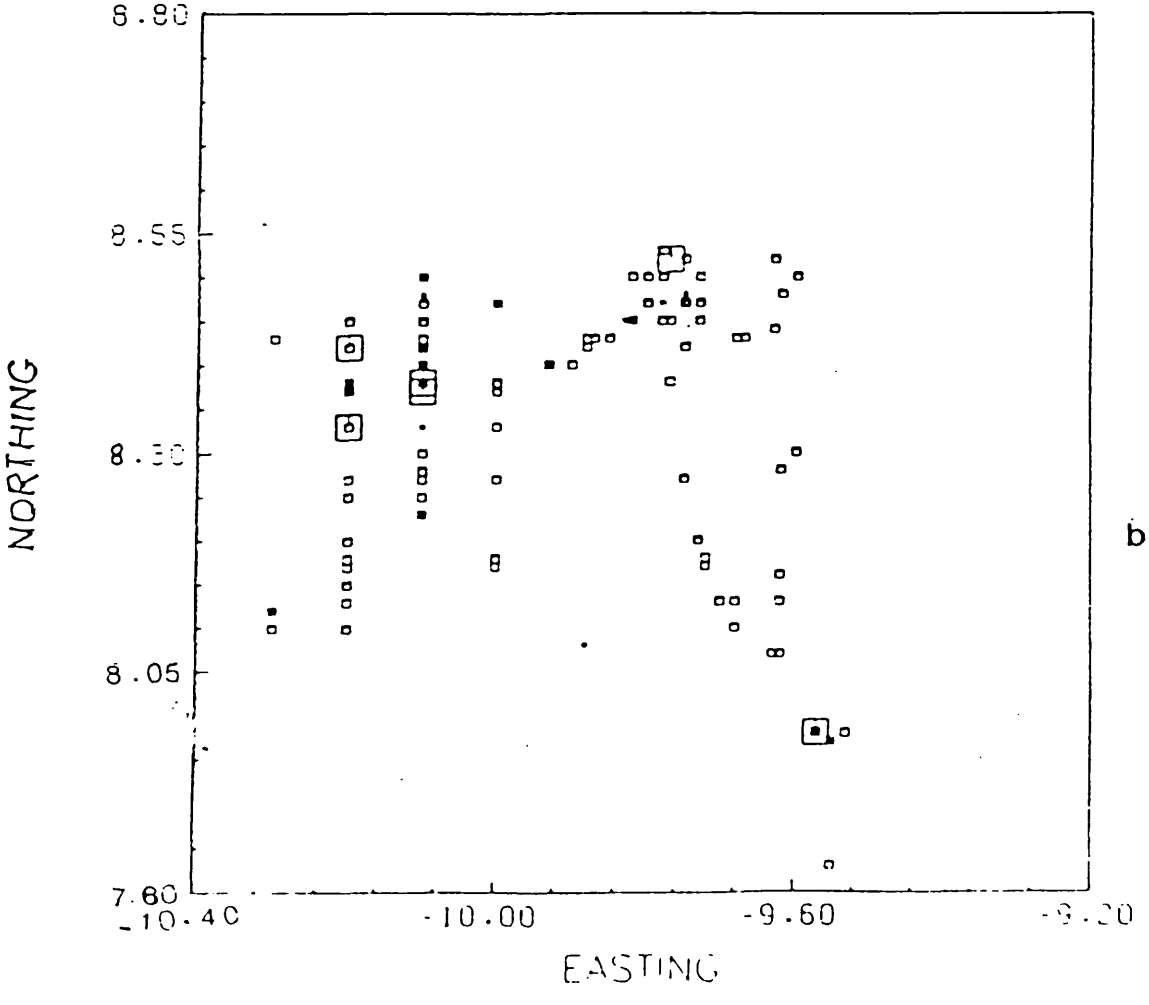
▫ ≧ 4
⊡ ≧ 8
%Al

a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EASTING
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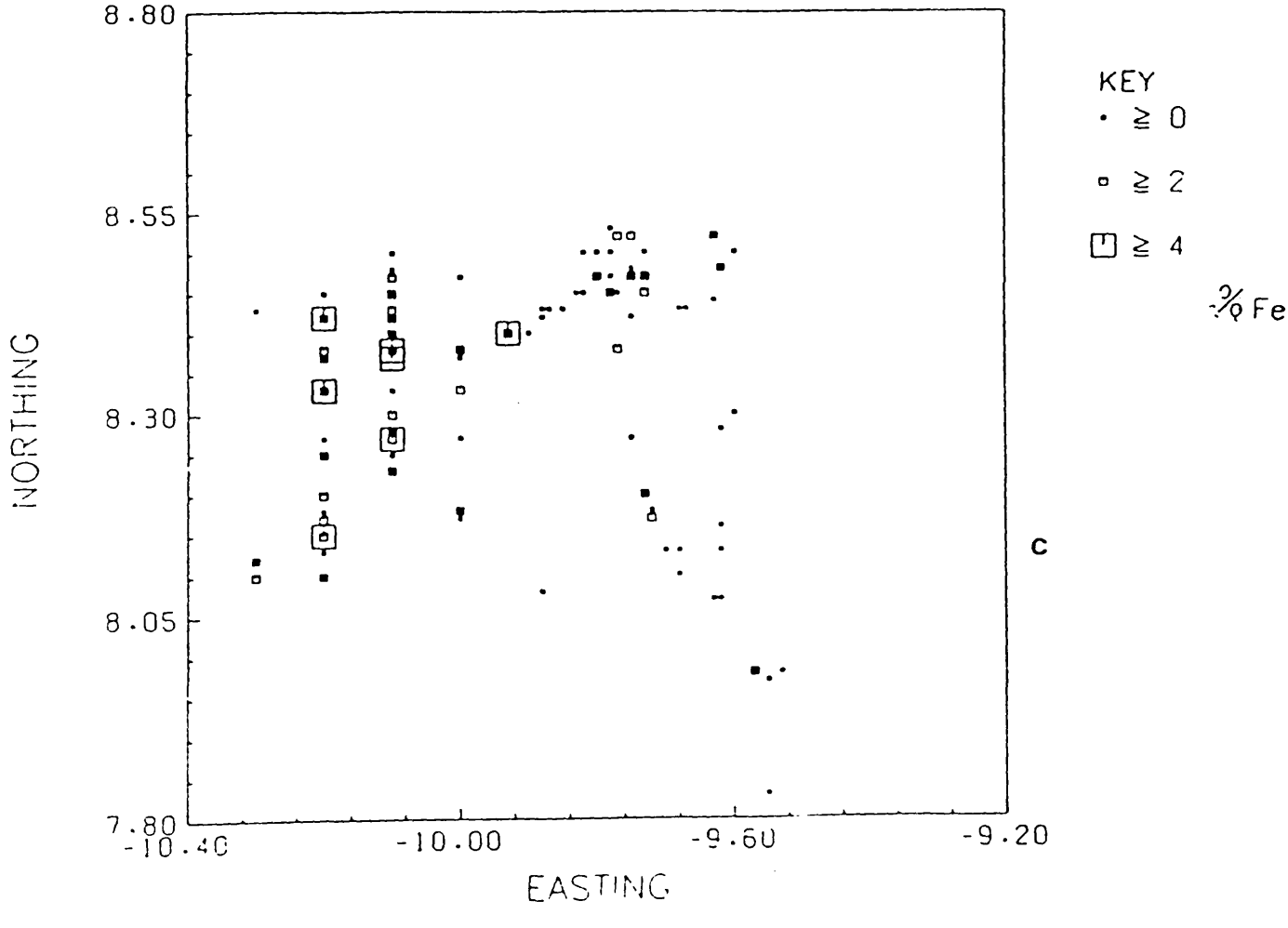
⊡ ≧ 4
%Co

b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-10.40
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NORTHING
EASTING
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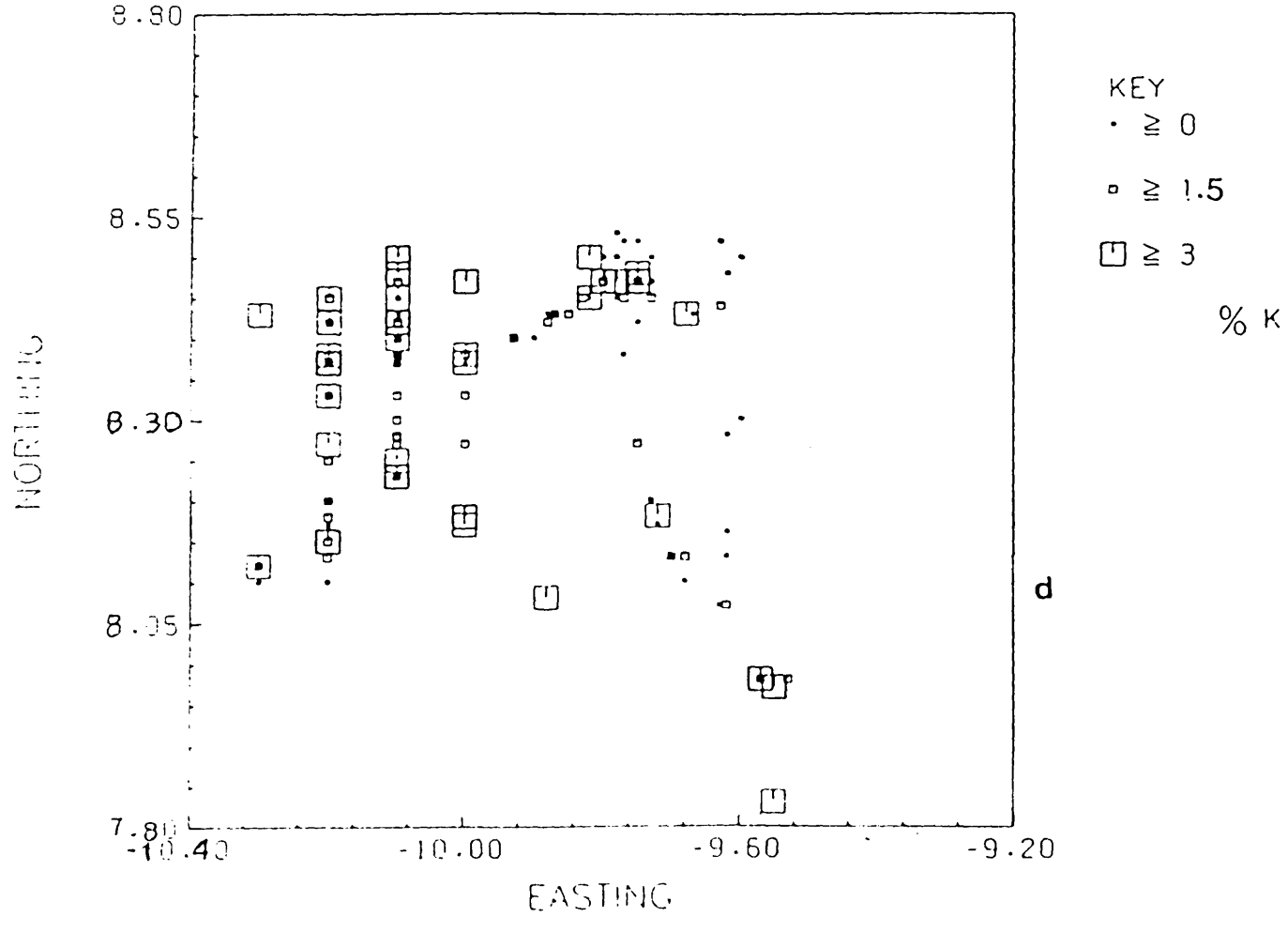
⊡ ≧ 4
% Fe
c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EASTING
KEY
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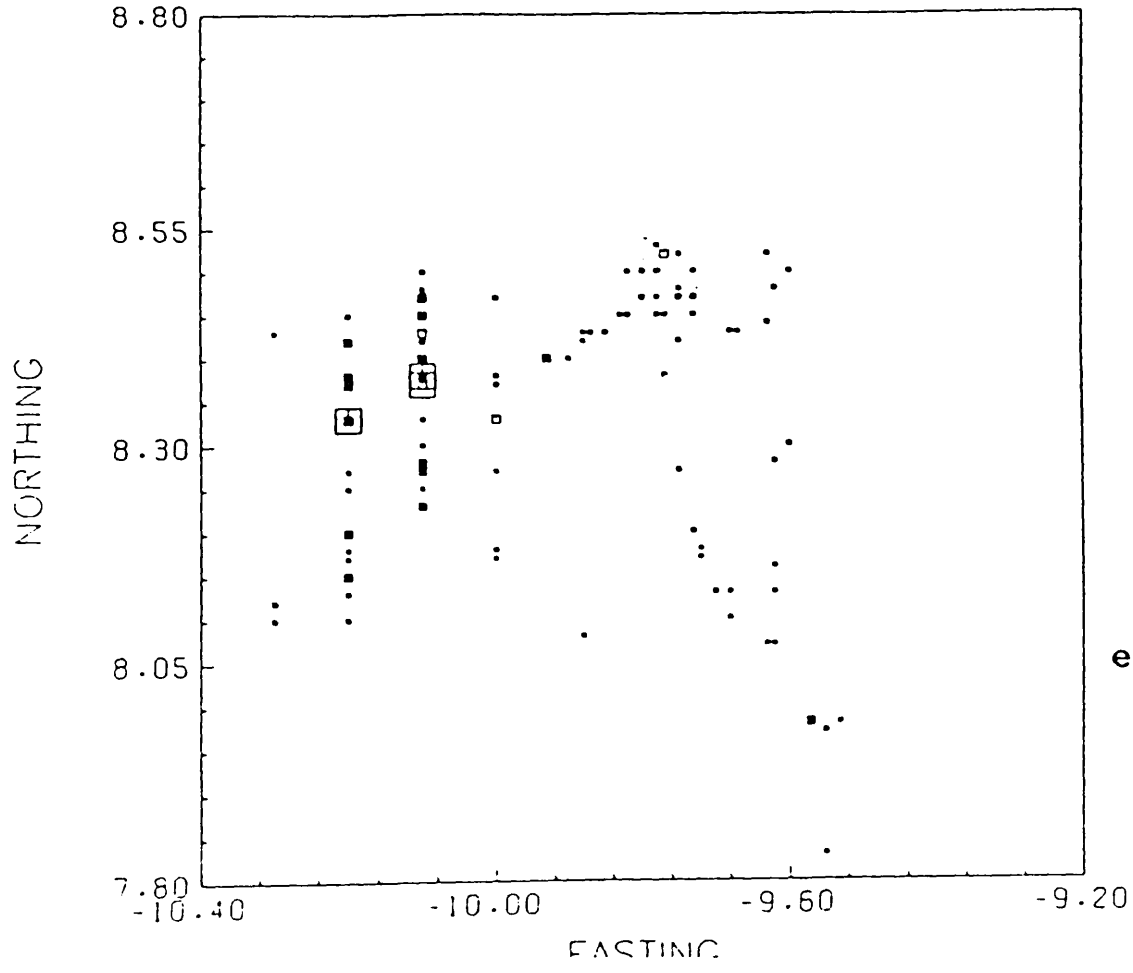
▫ ≧ 1.5
⊡ ≧ 3
% K
d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8.30
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NORTHING
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-9.60
-9.20
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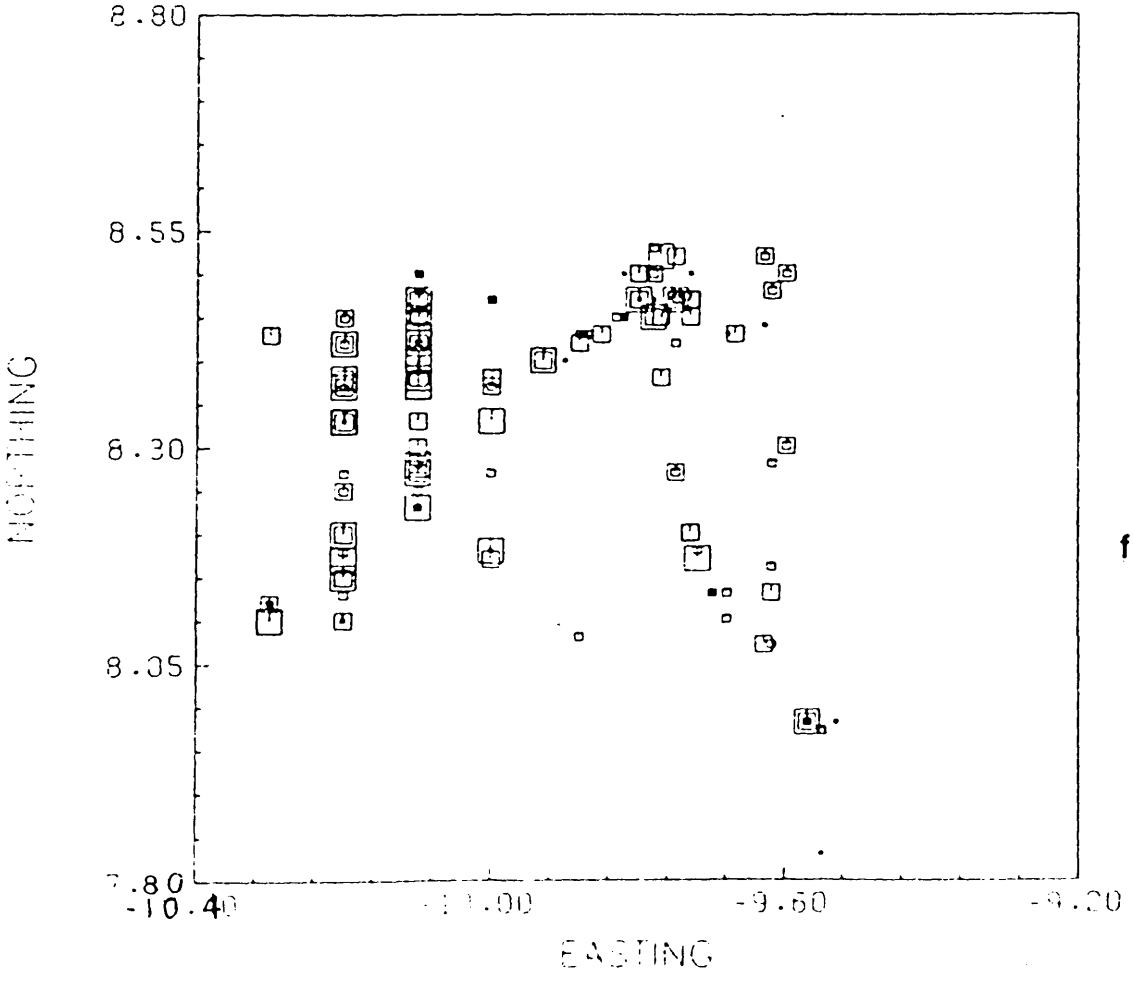
≥ 1
≥ 3
% Mg

e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-9.60
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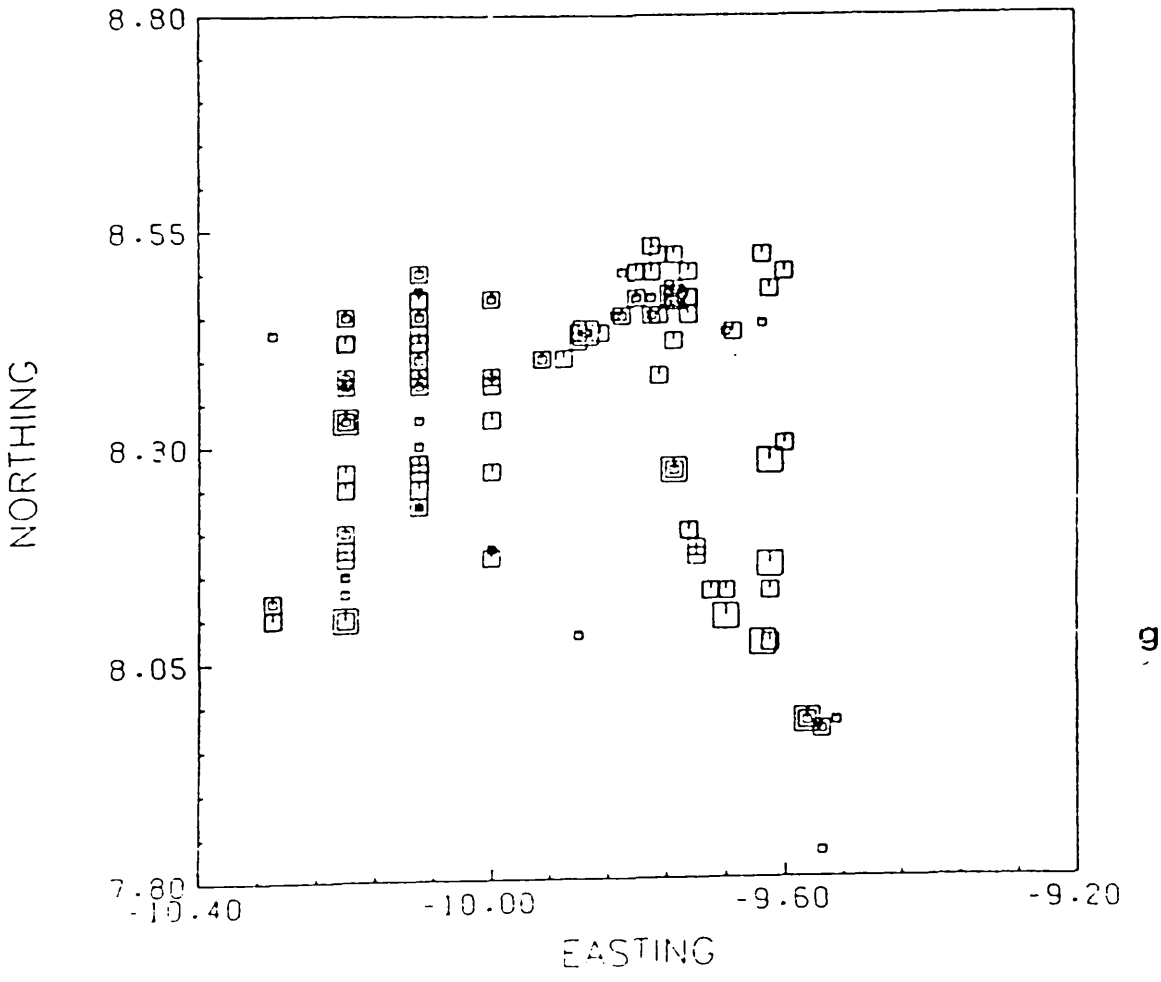
≥ 100.00
≥ 200.00
≥ 400.00
ppm Mn

f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8.30
8.05
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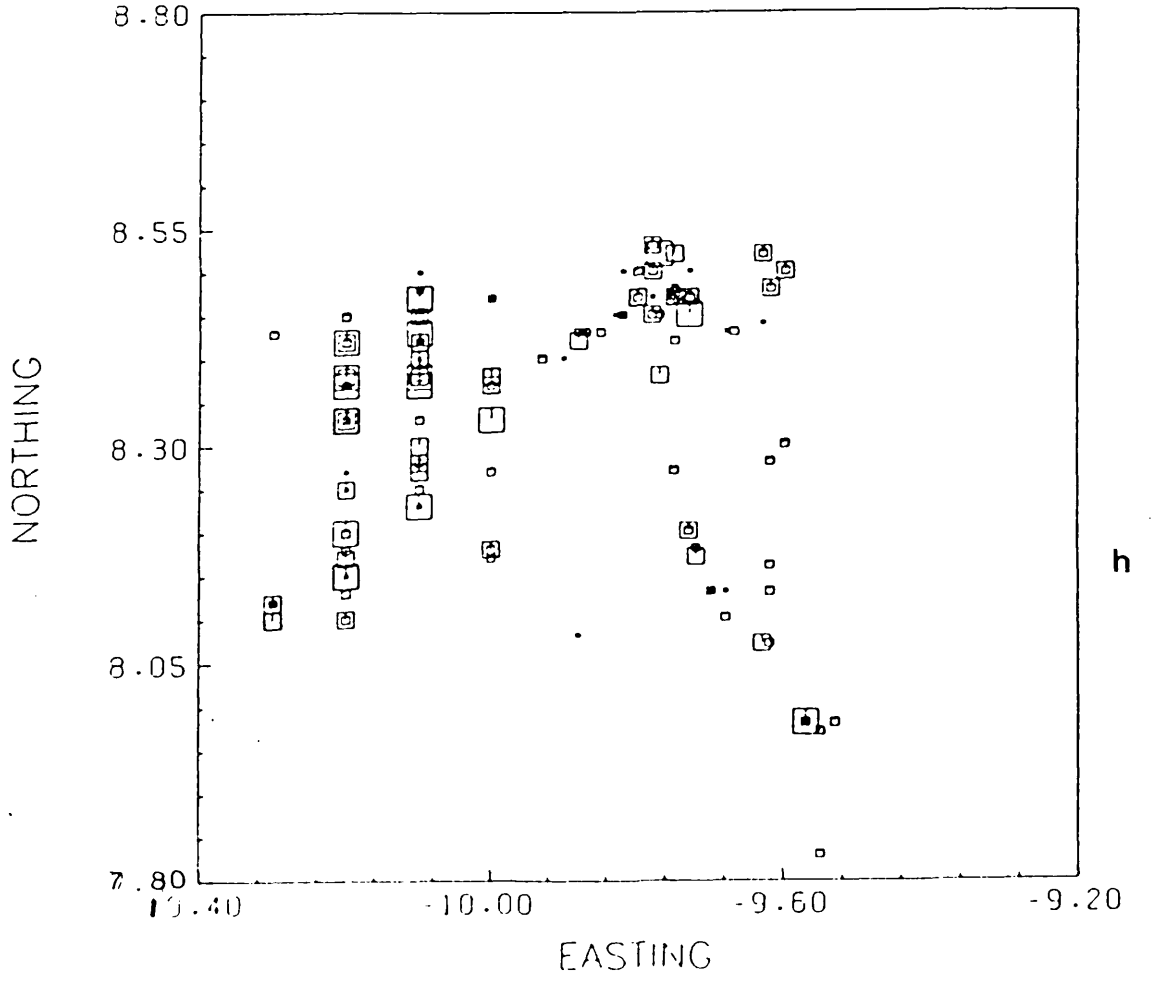
≥ 1
≥ 3
≥ 4
%Na

g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8.30
8.05
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NORTHING
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-9.20
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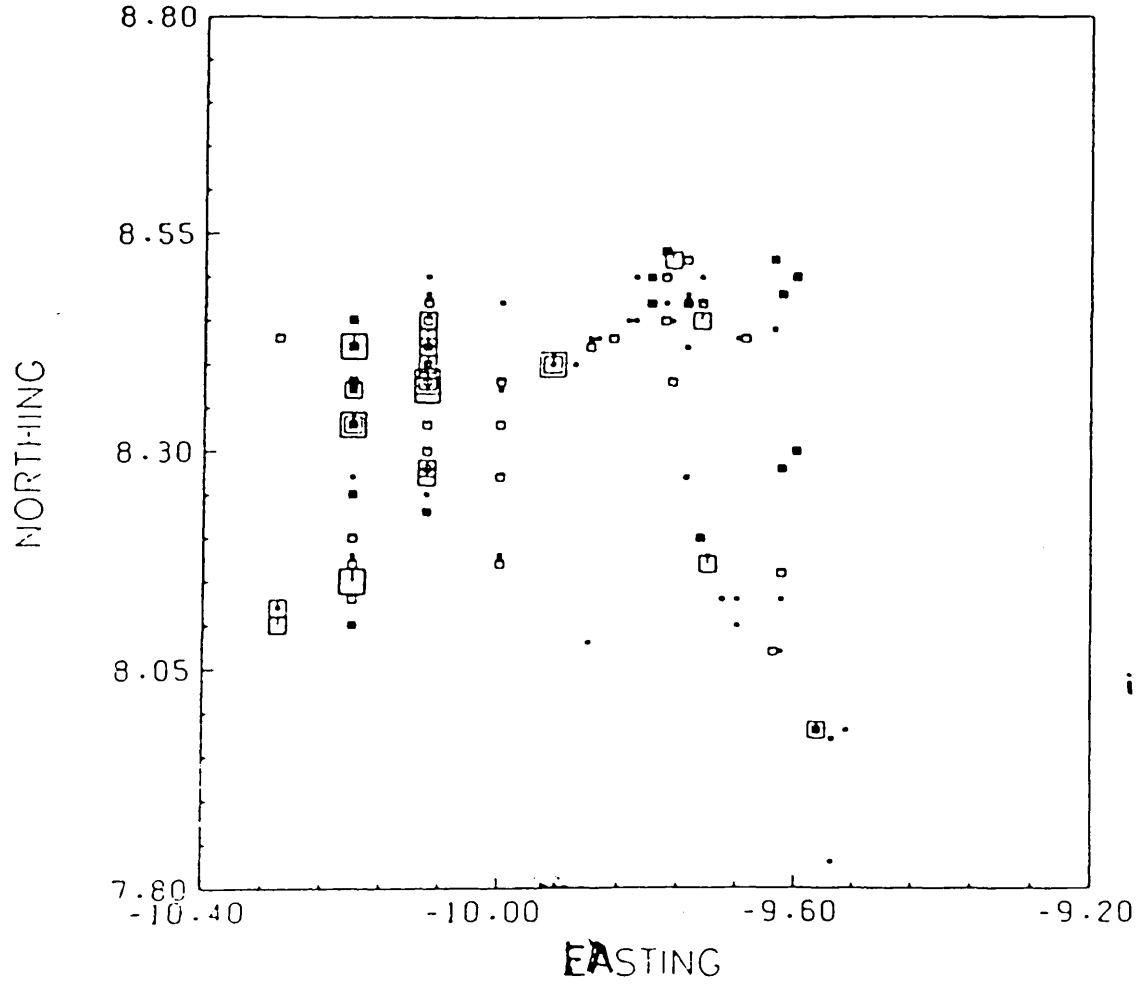
≥ 100.00
≥ 500.00
≥ 1000.00
ppm P

h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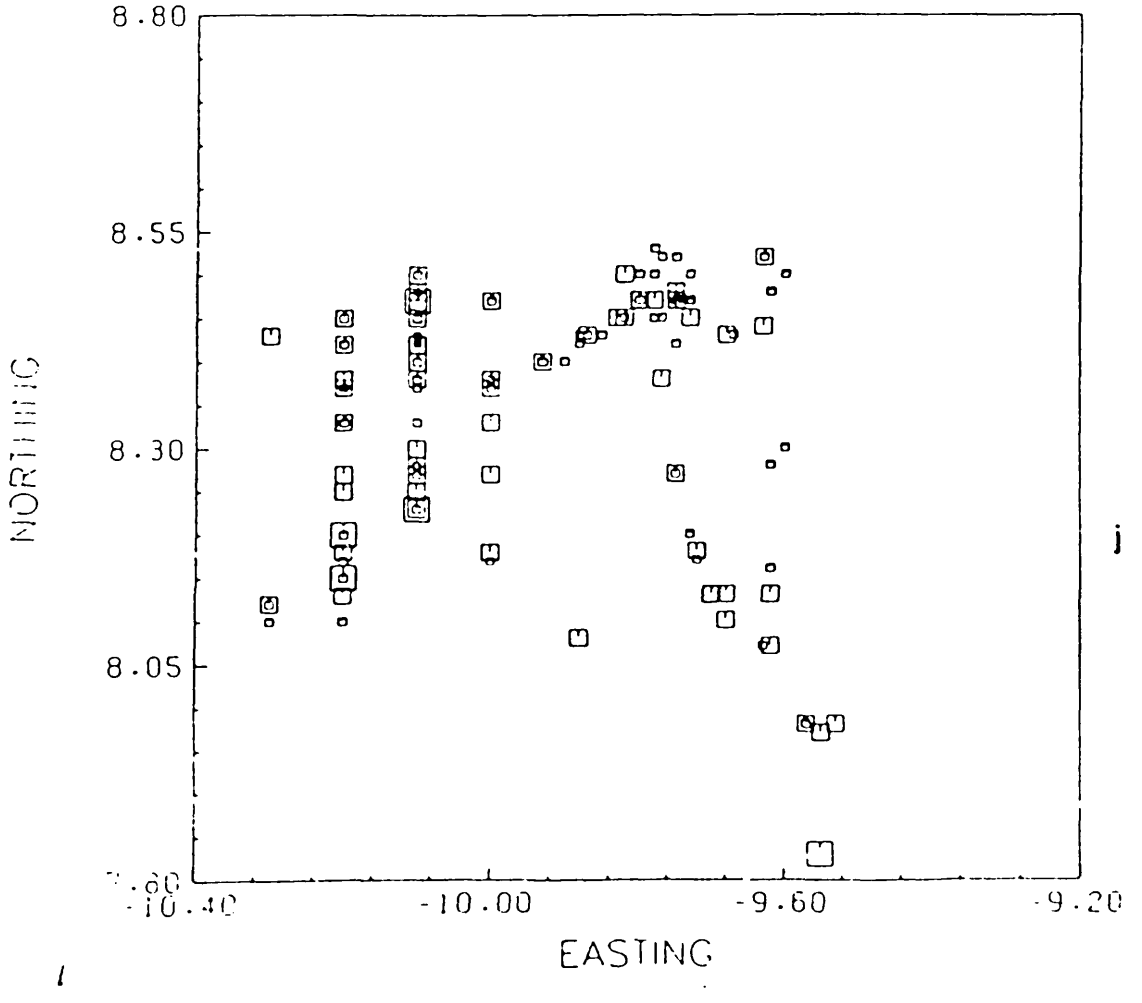
≧ 3000.00
≧ 5000.00
ppm Ti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≧ 3000.00
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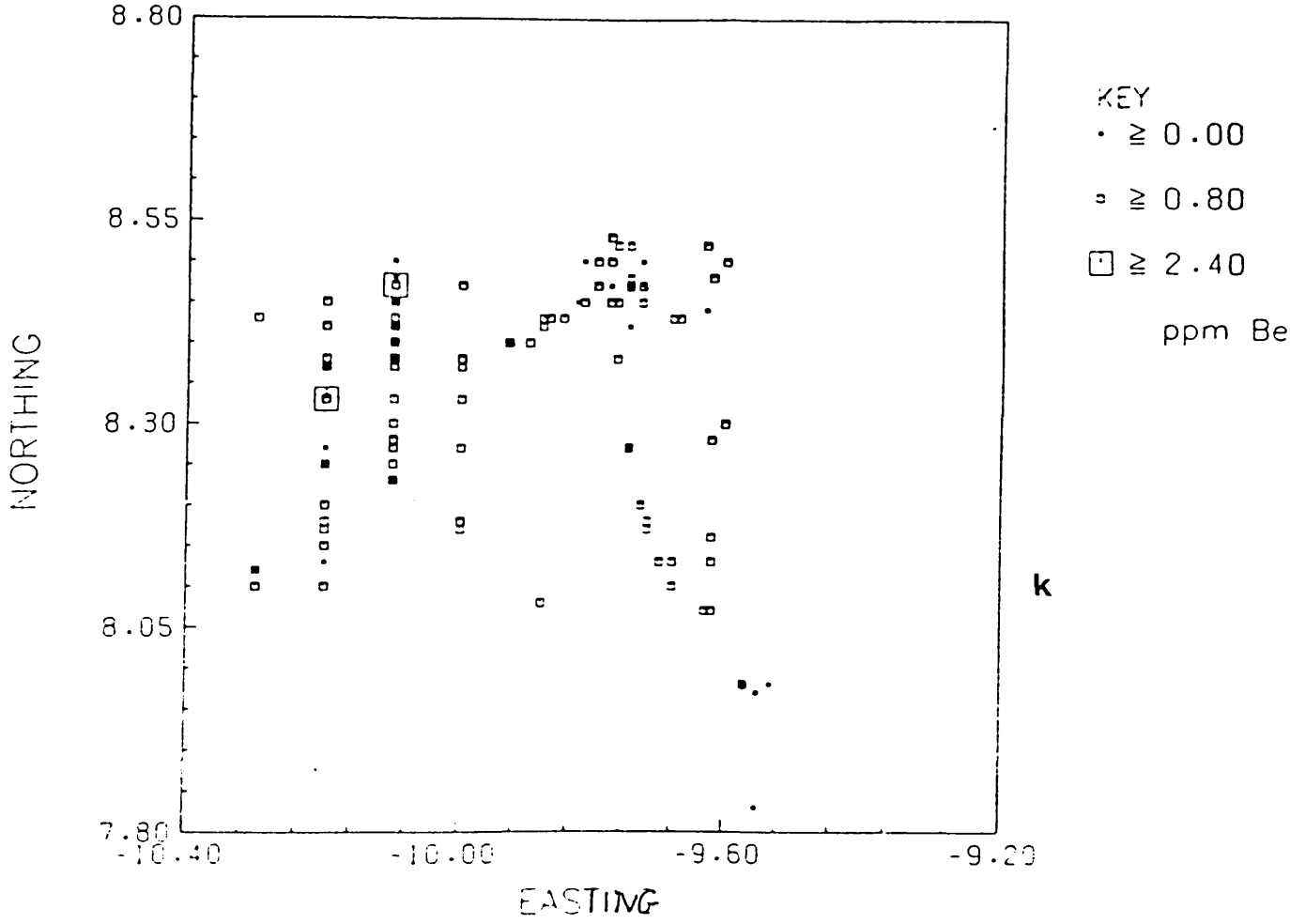
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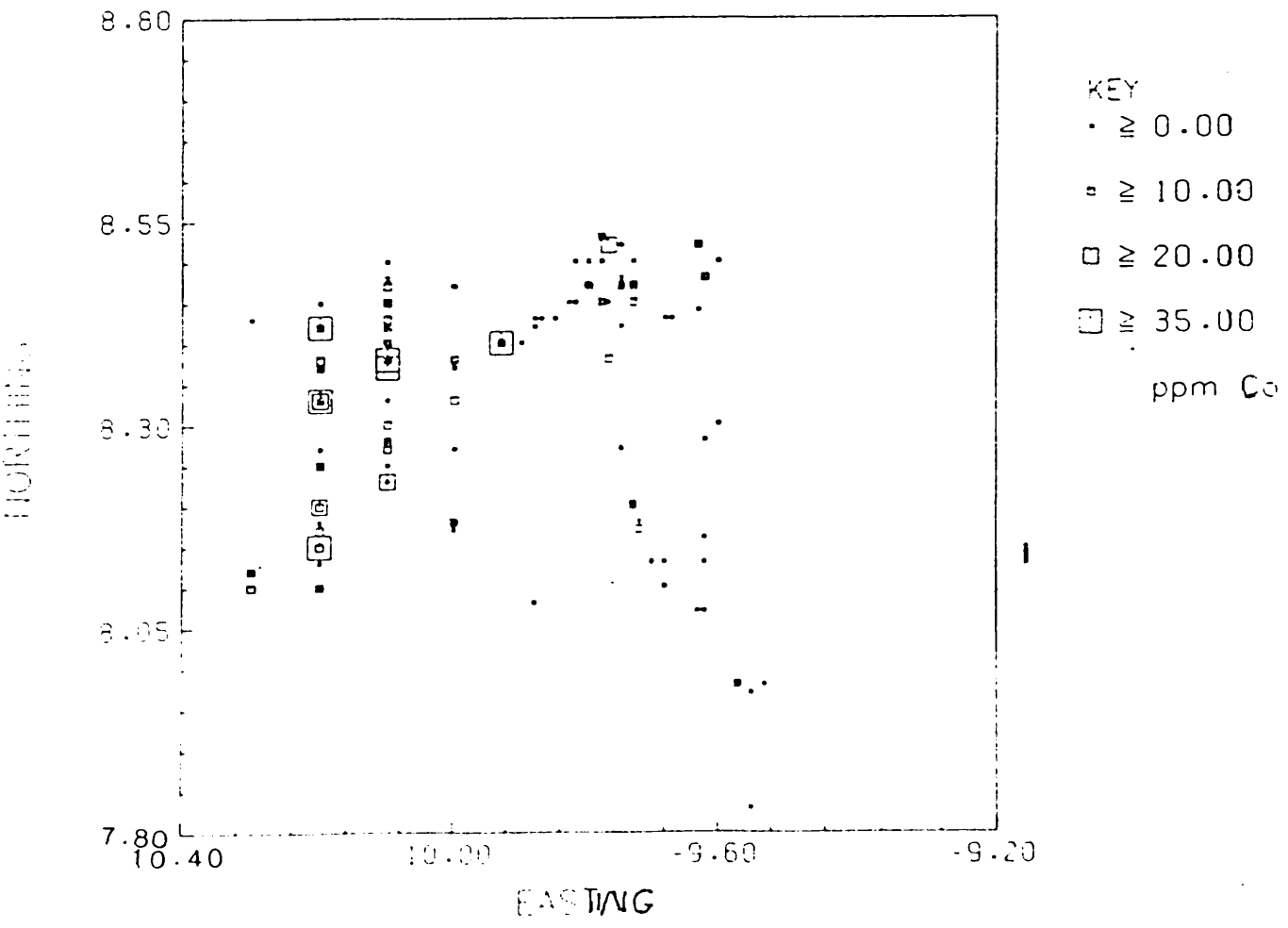
k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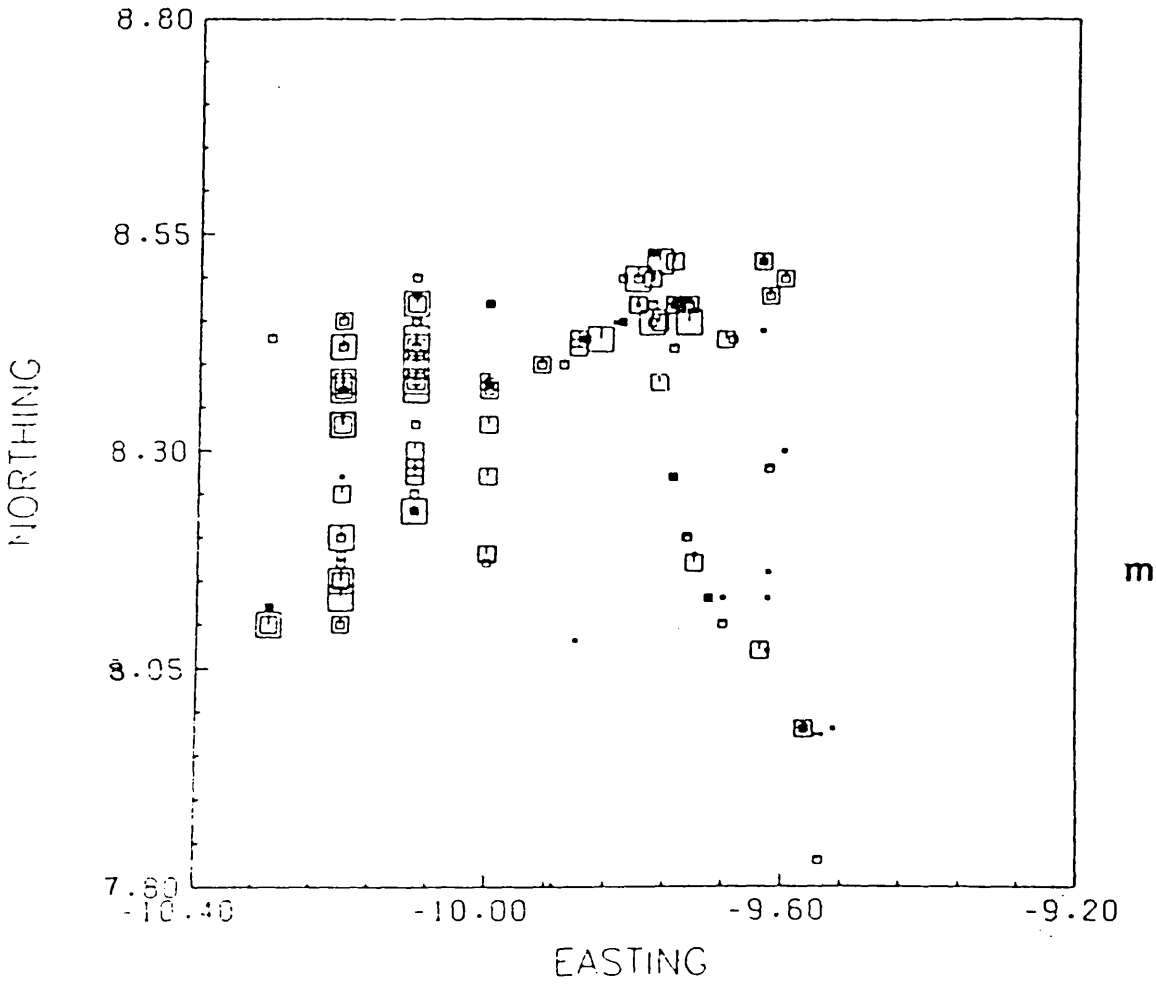
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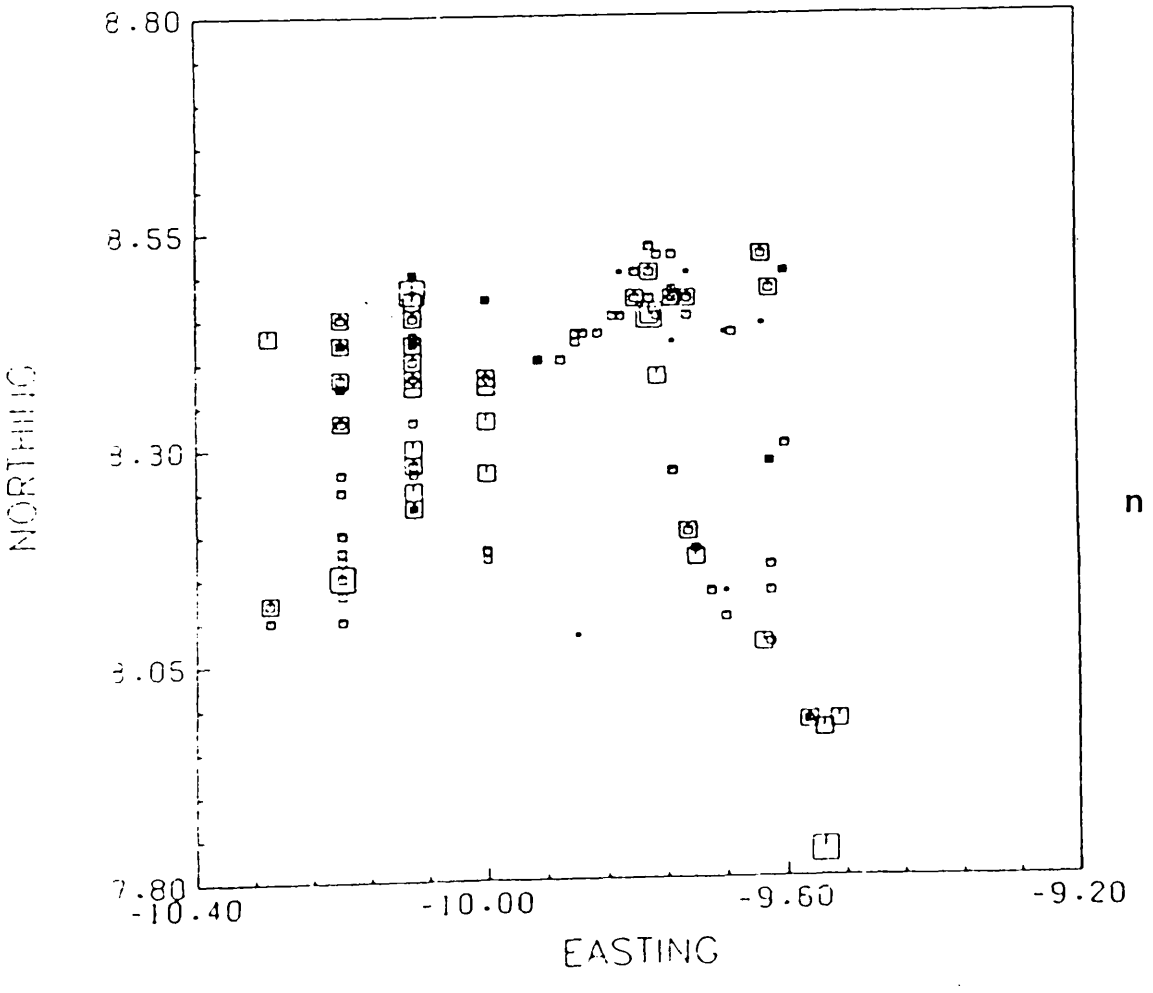
ppm Cu

m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EASTING
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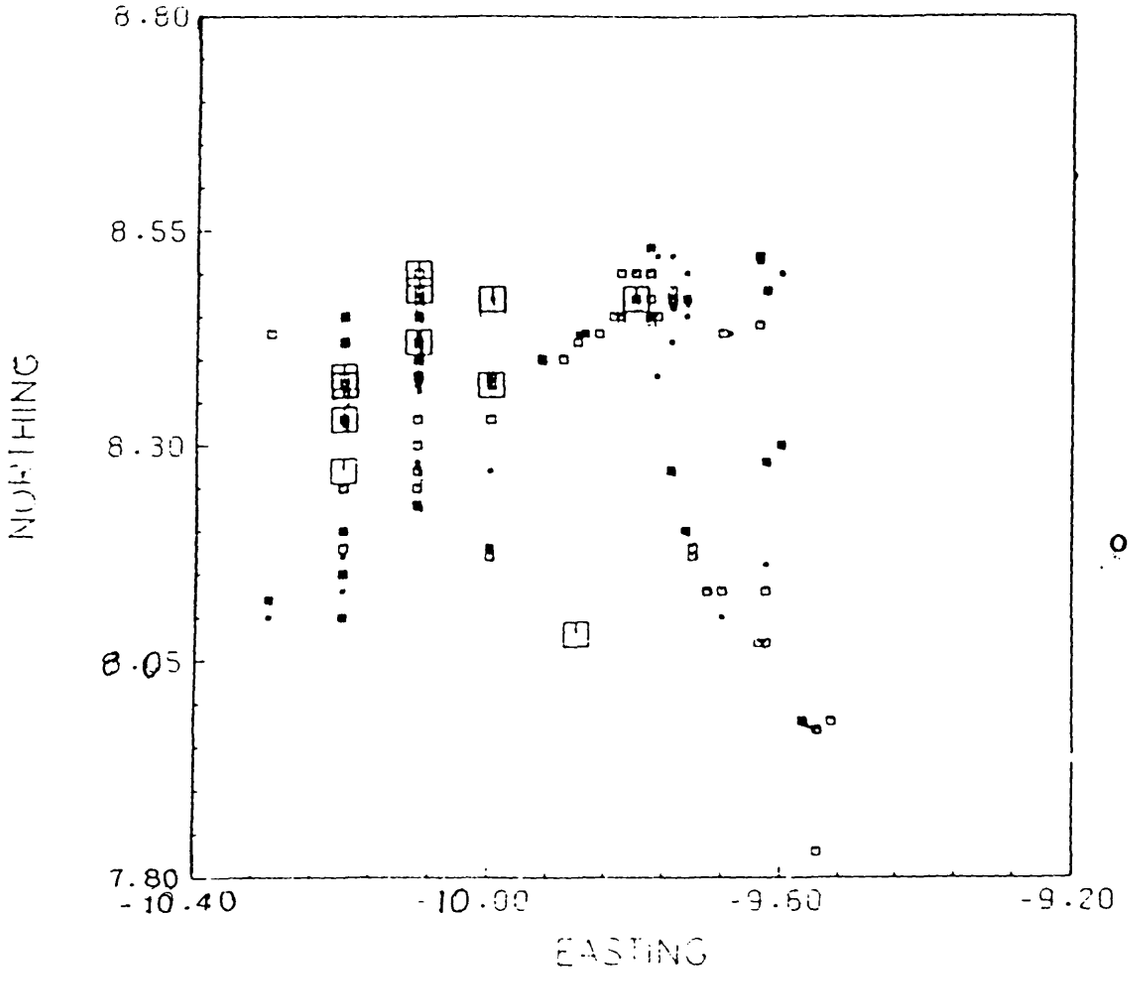
ppm La

n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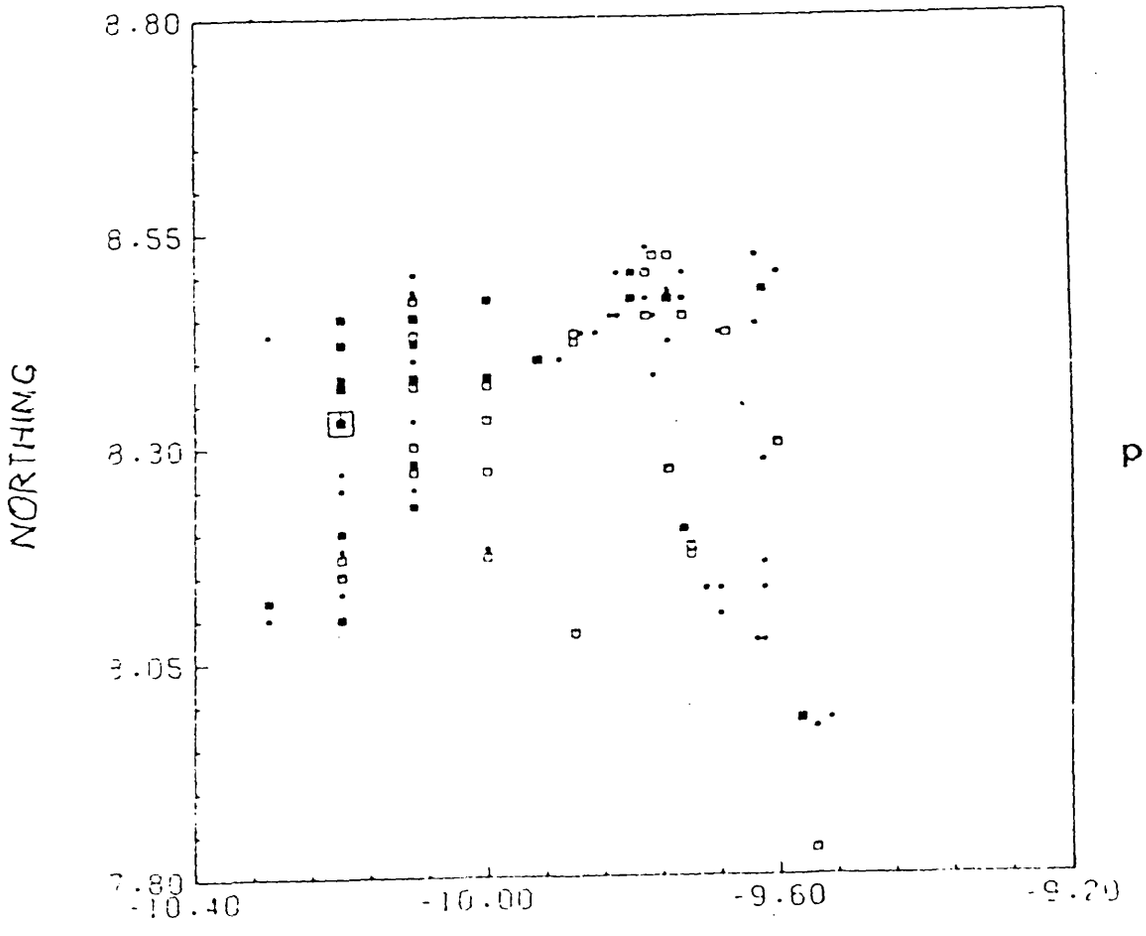
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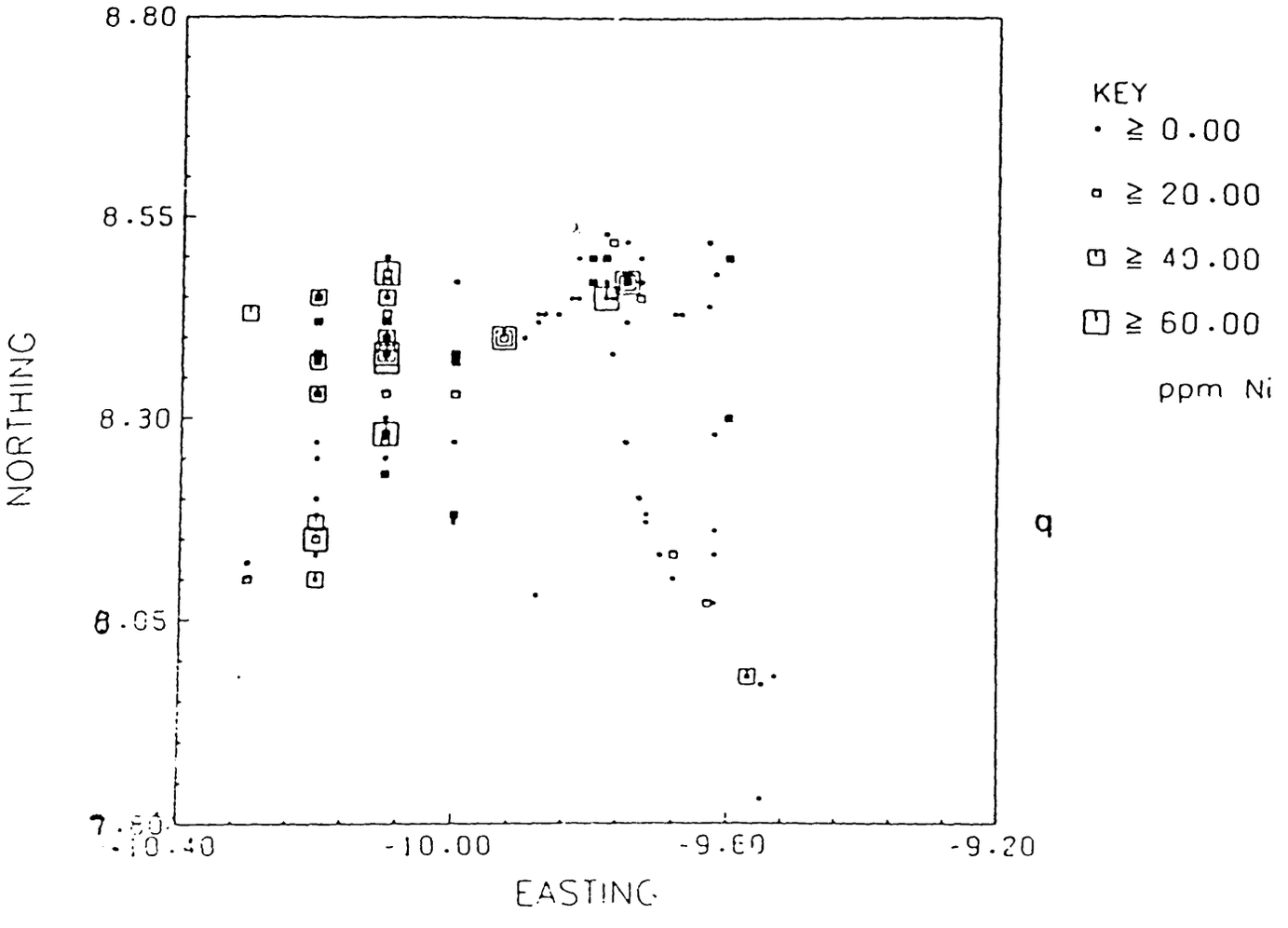
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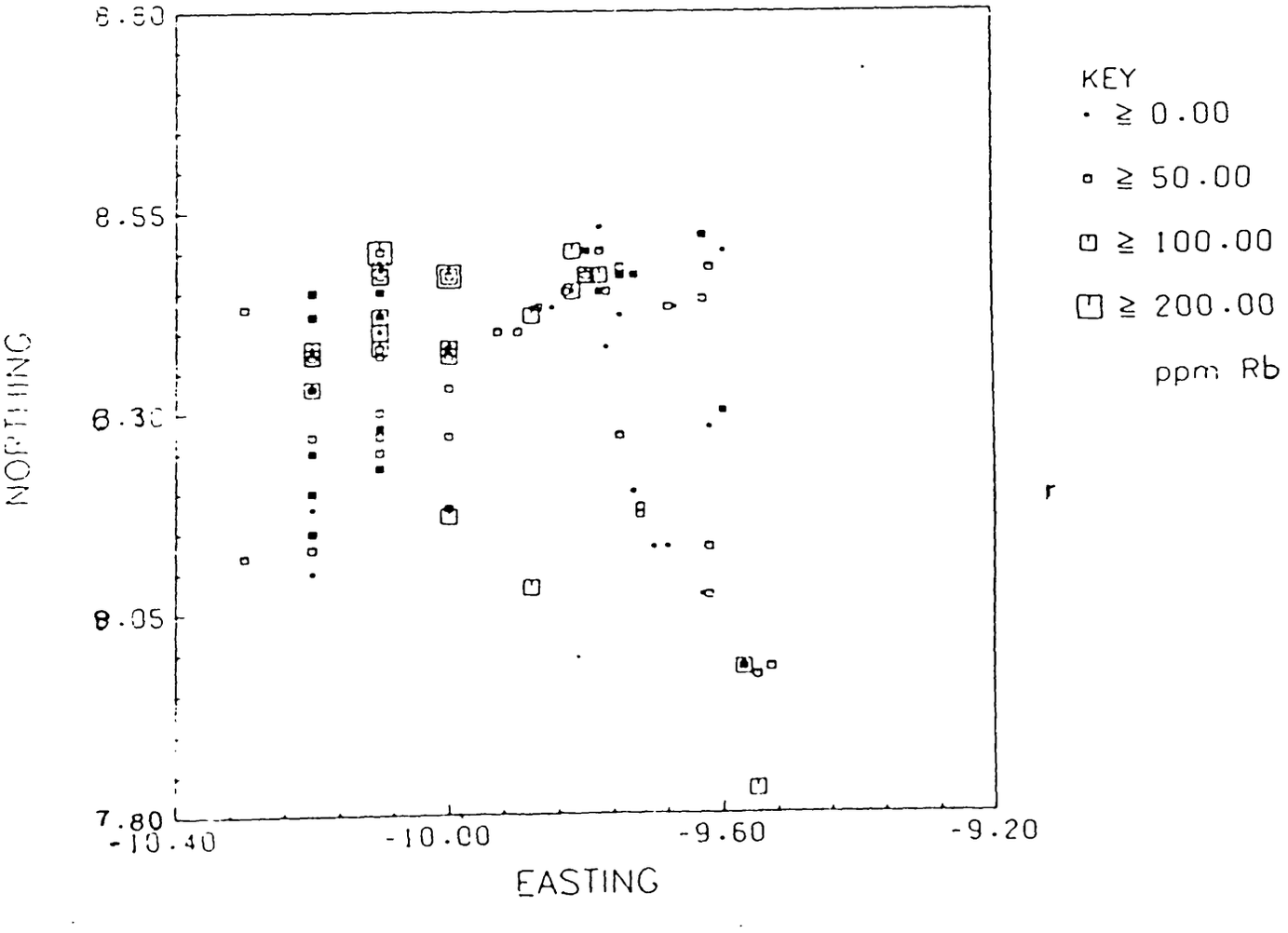
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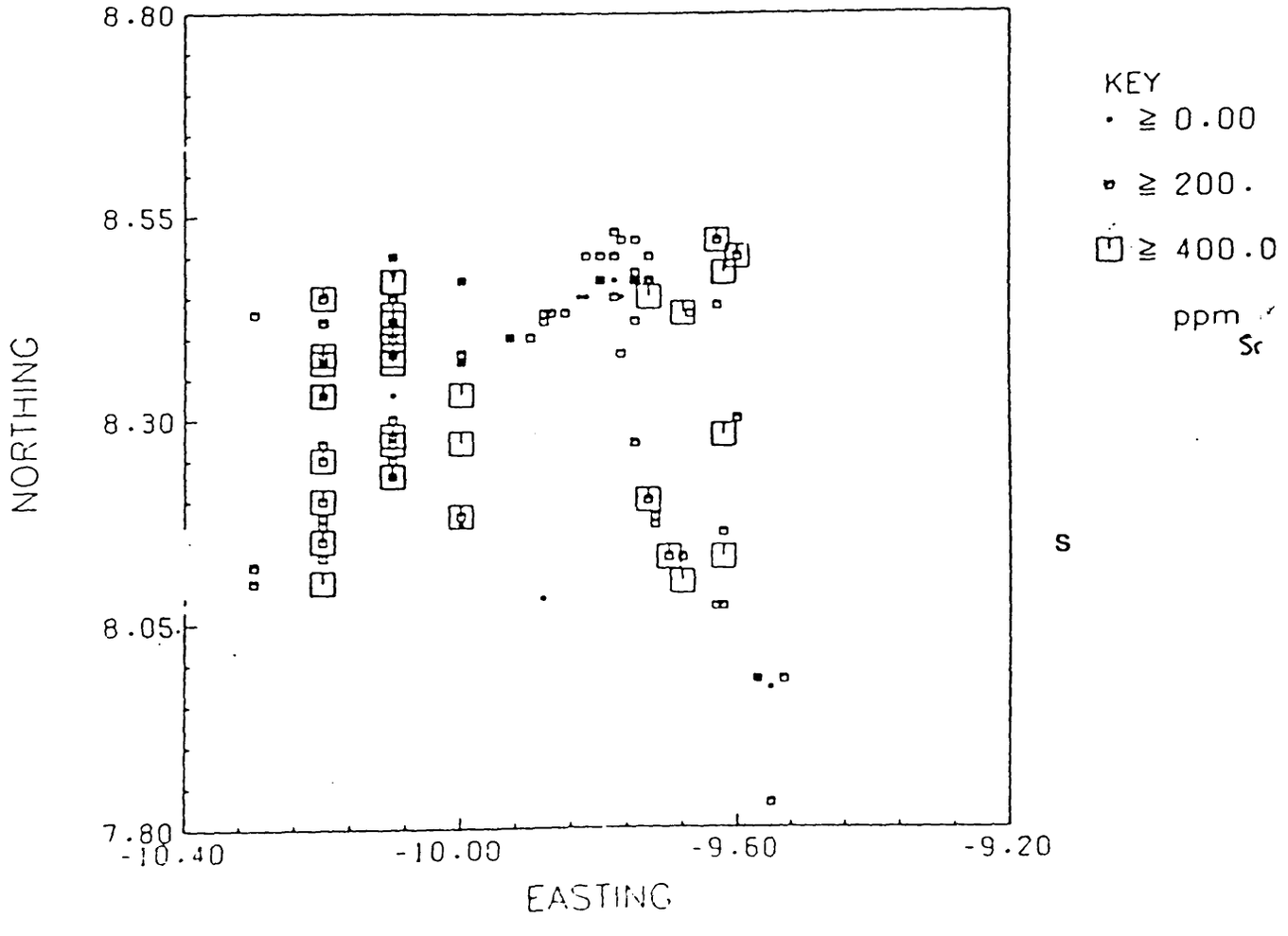
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7.80
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-9.20
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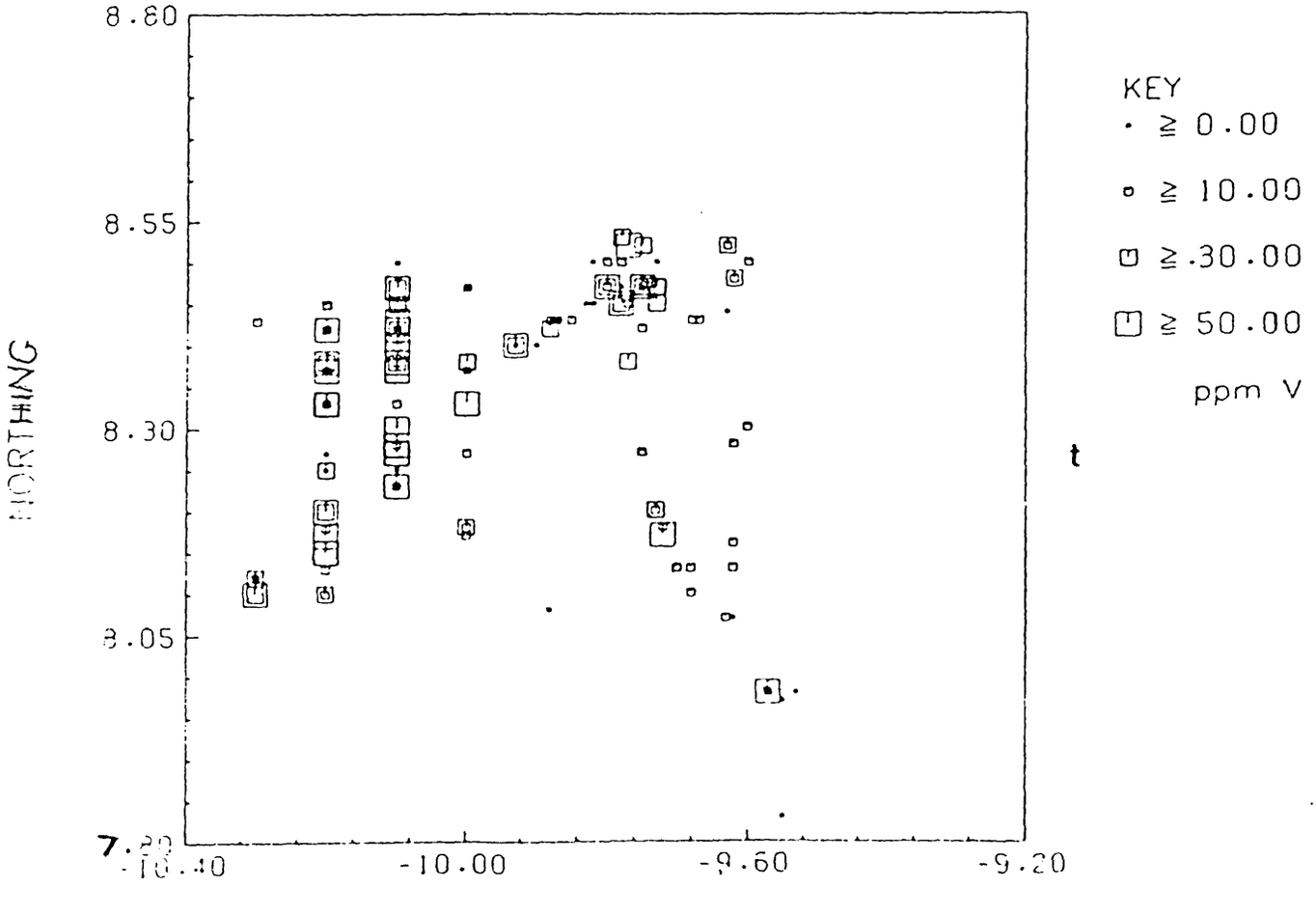
≧ 400.0
ppm Sr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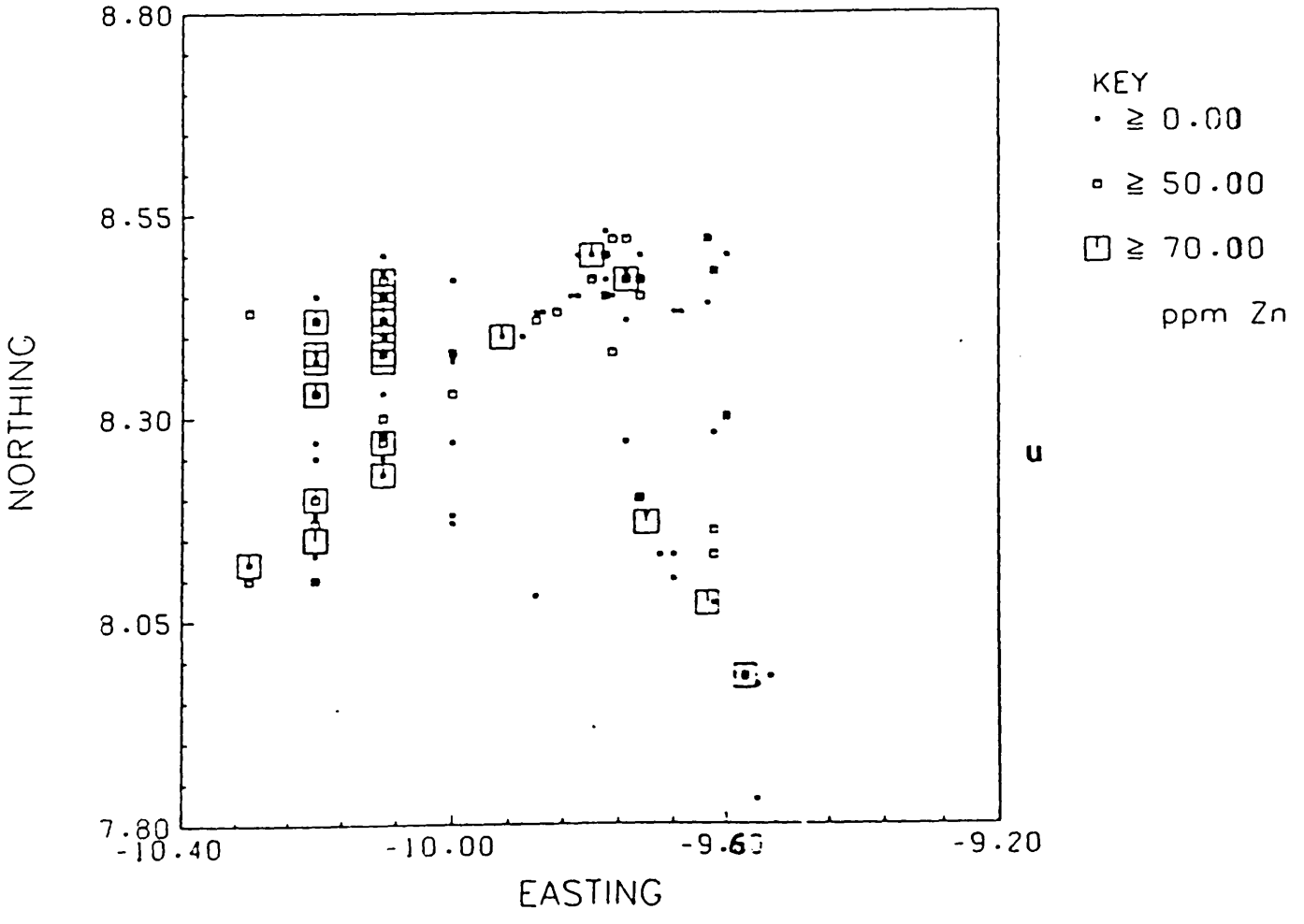
7.80
NORTHING
-10.40
-10.00
-9.60
-9.20
KEY
≧ 0.00
≧ 10.00
≧ 30.00
≧ 50.00
ppm V


8.80
8.55
8.30
8.05
7.80
NORTHING
-10.40
-10.00
-9.60
-9.20
EASTING
KEY
≧ 0.00
≧ 50.00
≧ 70.00
ppm Zn

Using the available chemical data as the main supporting evidence, it may therefore be reasonable to propose here that it is more likely that the original magma which gave rise to these Northwest Granites was chemically uniform or nearly so. But during its emplacement it might possibly have become contaminated with more mafic material (or country rocks) in the western section, hence the increased level of most of the mafic elements.

Additional support for this hypothesis comes from the petrography. For the granitic rocks to the west of Kolahun ($8^{o}16'N$, $10^{o}06'W$) appear to be more melanocratic or richer in mafic minerals. Microscopic study has shown that biotite is the main mafic constituent. Behrendt and Wotorson (1974) also noted the possible occurrence of greater amounts of mafic components in these granitic rocks when they interpreted a magnetic survey data of this area.

8.2.6 Summary and Conclusions

The granitic rocks from this area of the country show a high degree of variation in their chemical composition, which is in agreement with the lithological heterogeneity observed in the field. The western section shows more enrichment in the mafic elements, but on the average these rocks fall in the class of high-Ca granites of Turekian and Wedephol (1961). Element abundance ratios such as K/Rb and Ba/Sr in these rocks indicate that they only achieved early stage of evolution in

general. Hence their mineralization potential may be considered low on the basis of the available chemical data.

8.3 THE GEOCHEMICAL FEATURES OF THE GRANITOIDS ALONG NORTH-CENTRAL CORRIDOR

8.3.1 Element Abundance

The chemical composition of the granitic rocks along this corridor (traverse) is summarized in Table 18 together with data from the literature for comparison.

Using available data from Precambrian granitic gneisses elsewhere, for comparison between the Litchfield Granite Gneiss of the Chinamora Batholith, Zimbabwe (Snowden and Snowden, 1981), and the granitic gneiss of the North-central corridor indicates that the latter is significantly lower in all the elements except Ca, K, and Rb, whereas its chemical composition is very similar to that of the granodiorite gneiss of the Monton area, S W Minesota (Goldich and Wooden, 1980). Comparison with the Ilesha Granite Gneiss of the Basement Complex of southwestern Nigeria (Elueze, 1982) shows that the North Central suite is higher in Ca, Mg, Na, P, Ti and Sr, but lower in Al, K, Ba, Cr, Ni and Rb.

The high standard deviations observed for most of the chemical elements in the suite are a reflection of the wide variations in concentration. This trend of high element variance is also apparent from the Kleiner-Hartigan Trees (Fig. 30a),

TABLE 18 AVERAGE CHEMICAL COMPOSITION OF THE NORTHWEST CENTRAL CORRIDOR ROCKS IN RELATION TO OTHER PRECAMBRIAN GRANITIC ROCKS

Major(%)	Mean	St. Deviation	Median	Min	Max	1	2	3
Al	5.88	1.43	6.10	0.20	8.6	7.95	7.56	7.44
Ca	2.13	2.26	1.39	0.12	12.30	2.38	1.83	0.62
Fe	1.99	1.97	1.35	0.09	11.20	2.48	4.08	1.11
K	2.21	1.30	1.93	0.26	5.40	2.06	1.99	4.47
Mg	0.59	0.84	1.29	0.01	4.80	0.81	1.91	0.11
Mn	0.03	0.03	0.02	0.01	0.16	0.06	0.06	0.02
Na	2.77	0.91	2.90	0.03	4.50	3.10	3.15	1.67
P	0.04	0.04	0.03	0.01	0.21	0.07	0.06	0.02
Ti	0.22	0.32	0.13	0.01	2.10	0.24	0.53	0.07
Trace (ppm)								
Ag	1.20	0.10	1.10	1.10	1.30			
Ba	280	956	930	25	3500	540	592	1060
Be	1.30	0.60	1.10	0.50	3.40			
Cd	1.0	0.40	0.80	0.50	2.80			
Co	11	14	7	1	74		39	
Cr	28	89	4	1	530		32	185
Cu	20	70	4	1	430		26	
La	35	21	34	2	94		58	
Li	19	12	15	2	51			
Mo	4.5	4.3	3.4	1.1	20			
Ni	26	48	11	2	290		30	36
Pb	29	13	25	11	70			
Rb	83	34	80	29	220	86	101	315
Sr	248	105	270	40	440	342	588	115
V	35	69	16	1	420			
Zn	48	24	42	12	131		57	

(1) Granodiorite Gneiss (Precambrian) from S W Minesota (Goldich and Wooden, 1980).
(2) Gneissic Granite (Precambrian) from the Chinamora Batholith, Zimbabwe (Snowden and Snowden, 1981).
(3) Granitic Gneiss (Precambrian) from Southwestern Nigeria (Elueze, 1982).

with template as shown in Fig. 30b . It can be seen, for example, that the Al content of sample 4388 is much lower than that of sample 4393; while Ba is obviously more enriched in sample 4371 than in sample 4391.

8.3.2 Frequency Distributions

Histograms and normal probability plots were generated through the use of the Minitab package for most of the elements determined in the suite. Most of the elements have multi-modal distributions, with Al, V, Ba, Ni, P, Pb, Li, Mg, and La approaching lognormal distribution, whilst K, Rb, Be, and Sr are nearly normally distributed. The rest of the elements have neither lognormal nor normal distributions. Examples of the various types of frequency distribution patterns are shown in Figs.31 (a-d).

The polymodal distribution patterns of the elements observed are not entirely unexpected, as they are possibly a reflection of the effects of metamorphism on the rock chemistry. Condie (1969) reported similar erratic distribution patterns from the metamorphic aureole around the Laramie Batholith in Wyoming.

8.3.3 Inter-element Relationships

Table 19 shows the correlation matrix for the log-transformed ratio data (log(x/Fe)) for the 41 samples analysed. The table shows two main groups at the 95 confidence limit. Li, Na, K, Rb, Be, Pb, Ba, Al, P, Zn and La form one group, while Mg, Ni,

Fig.30a. The Kleiner-Hartigan "Trees" for the North Central Corridor data subset.

Fig.30b. The template for the "Trees" of the North Central Corridor data subset.

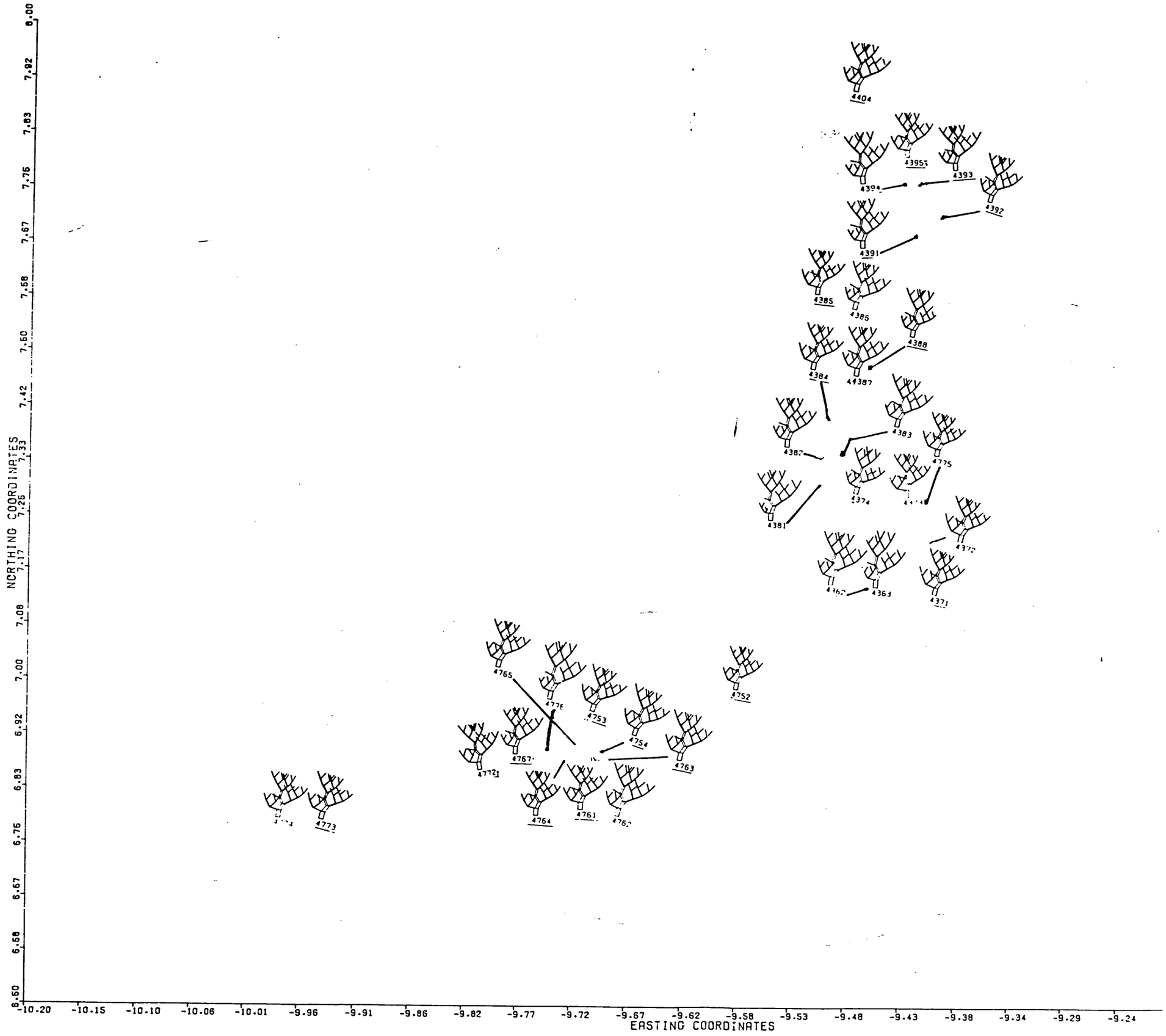

NORTHING COORDINATES
7.26
7.33
7.42
7.50
7.58
7.67
7.75
7.83
7.92
8.00
7.17
7.08
7.00
6.92
6.83
6.75
6.67
6.58
6.50
-10.20
-10.15
-10.10
-10.06
-10.01
-9.96
-9.91
-9.86
-9.82
-9.77
-9.72
-9.67
-9.62
-9.58
-9.53
-9.48
-9.43
-9.38
-9.34
-9.29
-9.24
EASTING COORDINATES
4404
4395
4393
4394
4392
4391
4385
4386
4388
4384
4387
4383
4382
4775
4374
4381
4372
4363
4371
4765
4776
4753
4754
4752
4767
4763
4764
4761
4773

Fig. 30a.

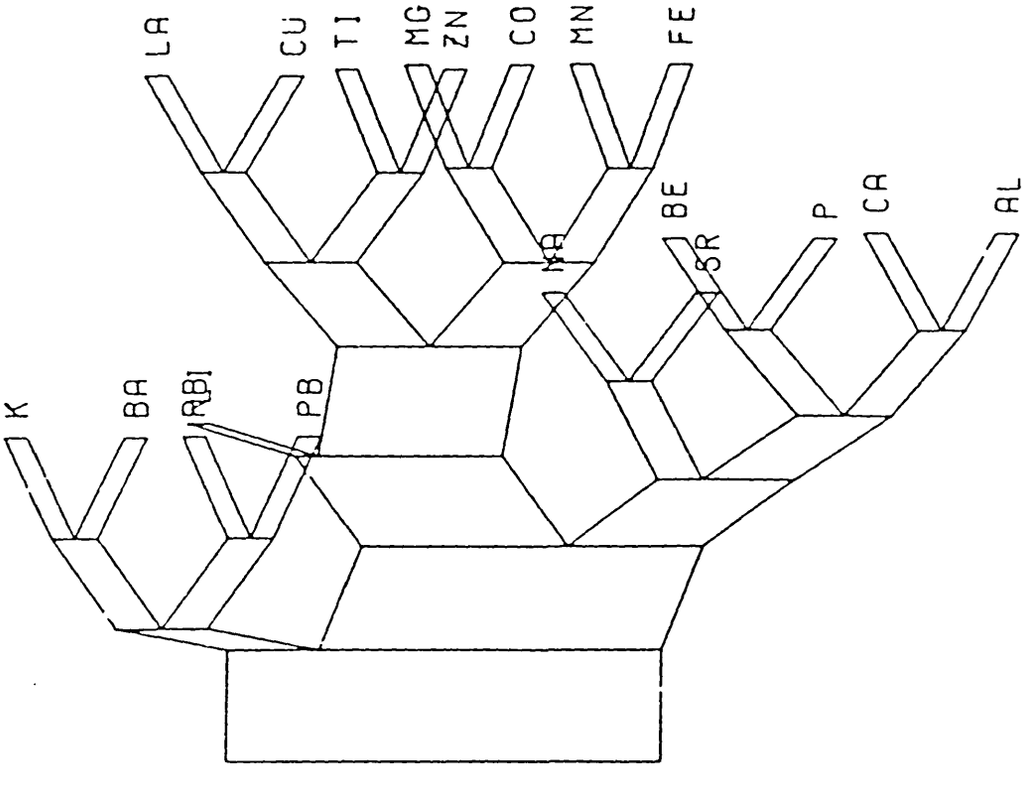


Fig.30b.

Fig.31(a-d) Examples of the frequency distribution patterns of the elements (in ppm) determined in the North Central corridor data subset.

Log Ni

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
.2	3	***
.4	2	**
.6	5	*****
.8	8	********
1.0	5	*****
1.2	3	***
1.4	5	*****
1.6	5	*****
1.8	2	**
2.0	1	*
2.2	0	
2.4	1	*

a

Log V

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
.2	1	*
.4	1	*
.6	2	**
.8	3	***
1.0	8	********
1.2	10	**********
1.4	6	******
1.6	5	*****
1.8	2	**
2.0	0	
2.2	1	*
2.4	0	
2.6	1	*

b

K

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
5000.	3	***
10000.	8	********
15000.	5	*****
20000.	8	********
25000.	5	*****
30000.	5	*****
35000.	2	**
40000.	2	**
45000.	0	
50000.	2	**
55000.	1	*

c

SR

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
50.	3	***
100.	3	***
150.	4	****
200.	5	*****
250.	8	********
300.	9	*********
350.	4	****
400.	4	****
450.	1	*

d

	LI	NA	K	RB	BE	MG	CA	SR
NA	.631							
K	.576	.759						
RB	.554	.654	.932					
BE	.522	.794	.534	.682				
MG	-.313	-.350	-.417	-.344	-.323			
CA	.047	.518	.081	.014	.428	.267		
SR	.368	.763	.667	.577	.644	-.194	.394	
BA	.356	.567	.864	.767	.326	-.326	-.033	.763
AL	.420	.906	.722	.640	.733	-.261	.597	.643
LA	.408	.606	.622	.510	.395	-.376	.283	.653
TI	-.279	-.228	-.223	-.290	-.465	.253	-.118	.144
V	-.435	-.336	-.516	-.617	-.397	.620	.360	-.058
CR	-.497	-.409	-.381	-.280	-.328	.862	.367	-.325
MO	.276	.623	.641	.666	.613	-.063	.271	.616
MN	-.111	-.342	-.526	-.407	-.255	.523	.216	-.490
CO	-.001	.115	-.119	-.387	.245	.385	.361	.058
NI	-.202	-.006	-.125	-.020	-.016	.573	.480	-.032
CU	-.161	-.142	.004	-.116	-.224	.224	-.159	-.167
AG	.888	.977	-.247	.757	.868	.524	.989	1.000
ZN	.569	.643	.424	.370	.534	-.244	.207	.636
CD	.418	.717	.816	.825	.646	-.375	.483	.820
PB	.534	.806	.933	.925	.754	-.510	.280	.712
P	.292	.393	.300	.046	.346	-.203	.076	.411

	BA	AL	LA	TI	V	CR	MO	MN
AL	.495							
LA	.654	.492						
TI	.137	-.339	.140					
V	-.297	-.363	-.177	.624				
CR	-.379	-.148	-.583	-.242	.577			
MO	.646	.607	.250	.109	-.255	-.051		
MN	-.643	-.265	-.253	-.004	.371	.476	-.423	
CO	-.178	.077	-.198	-.179	.552	.470	.163	-.019
NI	-.158	.103	-.185	.026	.352	.656	.052	.508
CU	-.010	-.095	-.136	.116	.311	.112	.195	.108
AG	-.993	.995	-.851	.113	.319	.690	1.000	.856
ZN	.507	.383	.665	.370	-.098	-.553	.292	-.104
CD	.790	.600	.558	-.156	-.477	-.324	.831	-.445
PB	.738	.760	.587	-.385	-.586	-.421	.683	-.535
P	.345	.177	.349	.113	.004	-.399	.086	-.429

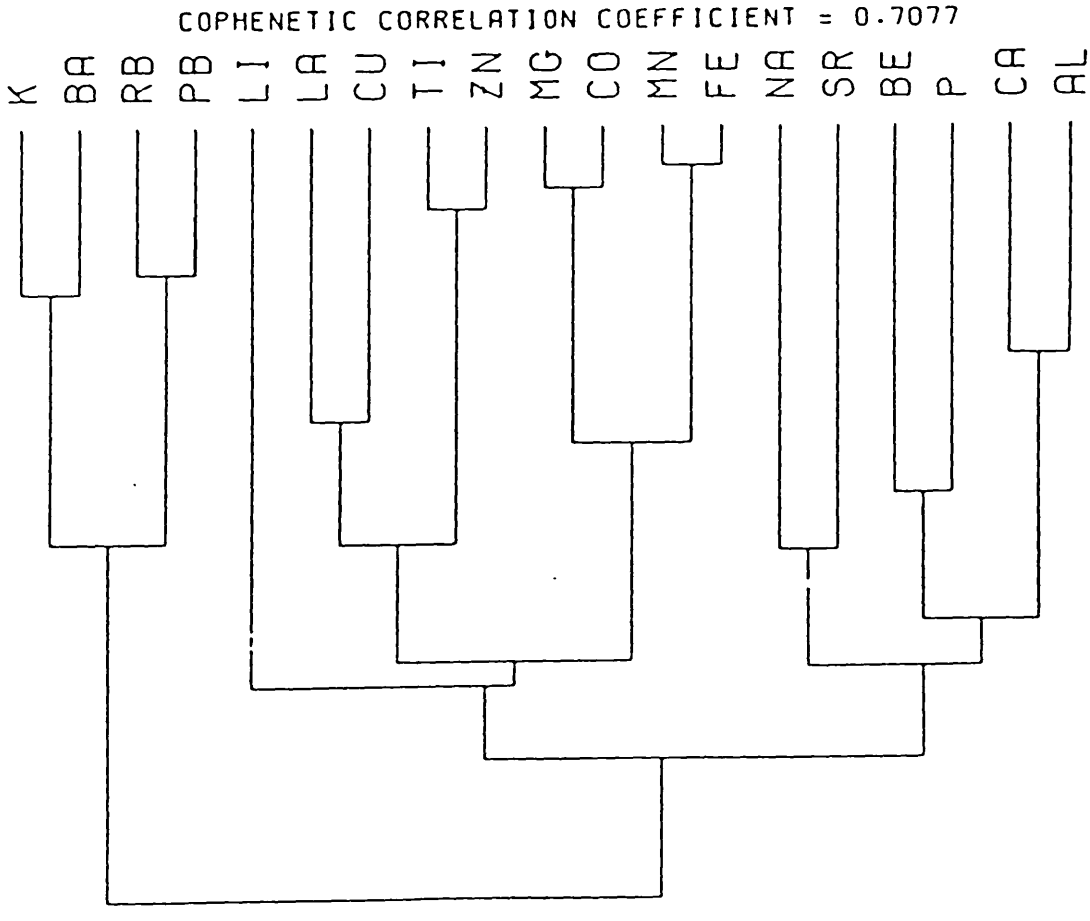
	CO	NI	CU	AG	ZN	CD	PB
NI	.121						
CU	.238	.186					
AG	-.758	.979	.870				
ZN	-.278	-.083	-.207	.817			
CD	-.318	.203	-.153	.968	.494		
PB	-.026	-.115	-.177	.919	.458	.913	
P	.231	-.207	.143	.316	.309	-.403	.264

Table 19 The Pearson correlation matrix for the log-transformed ratio (x/Fe) data from the North Central Corridor suite of samples.

Mn, Ca, V and Ti constitute the second group (with positive correlation coefficients ranging from 0.5 upwards). Cu and Co only have negative to weak positive correlation coefficients with most of the other elements. The first association may possibly be correlated with the feldspars, although the presence of Zn, P and Li and the absence of Ca are uncharacteristic. Campiglio and Darling (1975) attributed such irregularities in part of the Bourlamaque Batholith to metamorphism. The second group may be tentatively correlated with sphene which, besides containing Ca and Ti as its main cations, is capable of accommodating Mg, V, Mn and possibly Ni in its lattices (Deer et al., 1982). The isolation of Cu and Co is very strange, and it is possible that perhaps these elements exist in mineral components which are only occurring in trace amounts in these rocks.

A hierarchical cluster analysis based on the dendrogram (Fig.32) resulting from the application of the Kleiner-Hartigan method to the data reveals three main associations or groups among the elements: (1) K, Ba, Rb, Pb; (2) Li, La, Ca, Ti, Zn, Mg, Mn, Fe and (3) Na, Sr, Be, P, Ca, Al. This grouping is, however, more relevant to the spatial relationships among the elements in the individual "Trees" of Fig . 29a . Elements with more correlated distributions are clustered at higher levels. On the basis of superficial mineralogical consideration Groups 1 and 3 may be related to the felsic minerals (mainly the feldspars) whilst Group 2 may be

Fig.32. Hierarchical dendrogram of elements association in the North Central Corridor suite.



associated with the mafic minerals.

8.3.4 Ridge Regression Analysis

The ridge traces, residual normal probability plots and the residuals for certain trace elements were again produced for this data subset. The results for the ridge traces with the parameters used are summarized in Table 20, and the ridge trace for Be (Fig.20a) is presented as an illustration. In this figure it is seen that Al (A) and K (D) are respectively the strongest positive and negative predictor elements for Be. It is also observed that although Mn and Ti start off as negative predictors, they become weak positive predictors with increase in the k. Howarth (1984) has interpreted such a behaviour as indicating that the predictor element(s) is unstable.

Fig. 20b presents the residual normal probability plot for Be also as an illustration. Here two samples (4372 and 4767) with positive anomalous values and three samples (4387, 43852, 4385) with probable negative anomalous values are identifiable. It is also apparent that the plot shows a poly-modal distribution. The residuals for the other selected trace elements were normally distributed.

Kleiner-Hartigan Trees were also applied to the positive residuals of the trace elements to ascertain which one(s) had higher relative concentration in any particular sample(s). Locations of the samples with elements having higher relative residual concentrations are shown in Table 21. However, the

TABLE 20

RIDGE REGRESSION PARAMETERS AND RESULTS

Element	Initial			Final		Important Predictors**	Linear Model
	n	R^2	K	n*	R^2		
Li	41	0.41	0.2	39	0.34	Mn-P-Ca	ok
Rb	39	0.59	0.2	34	0.74	K - Na	ok
Be	41	0.47	0.2	37	0.65	Al Ca P Na-K	ok
Sr	41	0.24	0.2	40	0.40	Na Ca Ti P-Mn	ok
Ba	41	0.52	0.2	40	0.60	K P Mg Na - Mn	ok
Cu	38	0.58	0.2	37	0.65	Mn P Mg Ti Fe-Al	ok
Zn	40	0.75	0.2	39	0.77	P Mn Fe-K	ok
Pb	40	0.74	0.2	39	0.75	K Ti Na-Mn	ok

* Representing "background" relationship.

** Elements with standardized coefficients exceeding $\pm$ 0.1.

n = No. of samples.

R^2 = Multiple correlation coefficient.

K = Ridge constant.

TABLE 21 LOCATIONS OF SAMPLES OF GRANITIC ROCKS FROM THE NORTH CENTRAL CORRIDOR HAVING HIGHER RELATIVE RESIDUAL CONCENTRATIONS OF CERTAIN ELEMENTS

Sample No.	Elements	Co-ordinates N	W
BMC1	Be	10° 09'	60° 18'
476G	Rb, Be	6° 52'	9° 46'
476C	Li, Zn, Rb, Be	6° 53'	9° 43'
439B	Li	7° 42'	9° 25'
438F	Li, Mo	7° 37'	9° 29'
438C	Ba, Sr, Mo	7° 20'	9° 30'
439A	Li	7° 40'	9° 25'
475A	Li, Ba, Sr	6° 58'	9° 35'
476B	Rb, Be, Mo	6° 53'	9° 43'
476A	Ba, Sr, Be	6° 53'	9° 43'

sporadic distribution pattern of such higher relative concentration values does not permit any meaningful geochemical interpretation of the results.

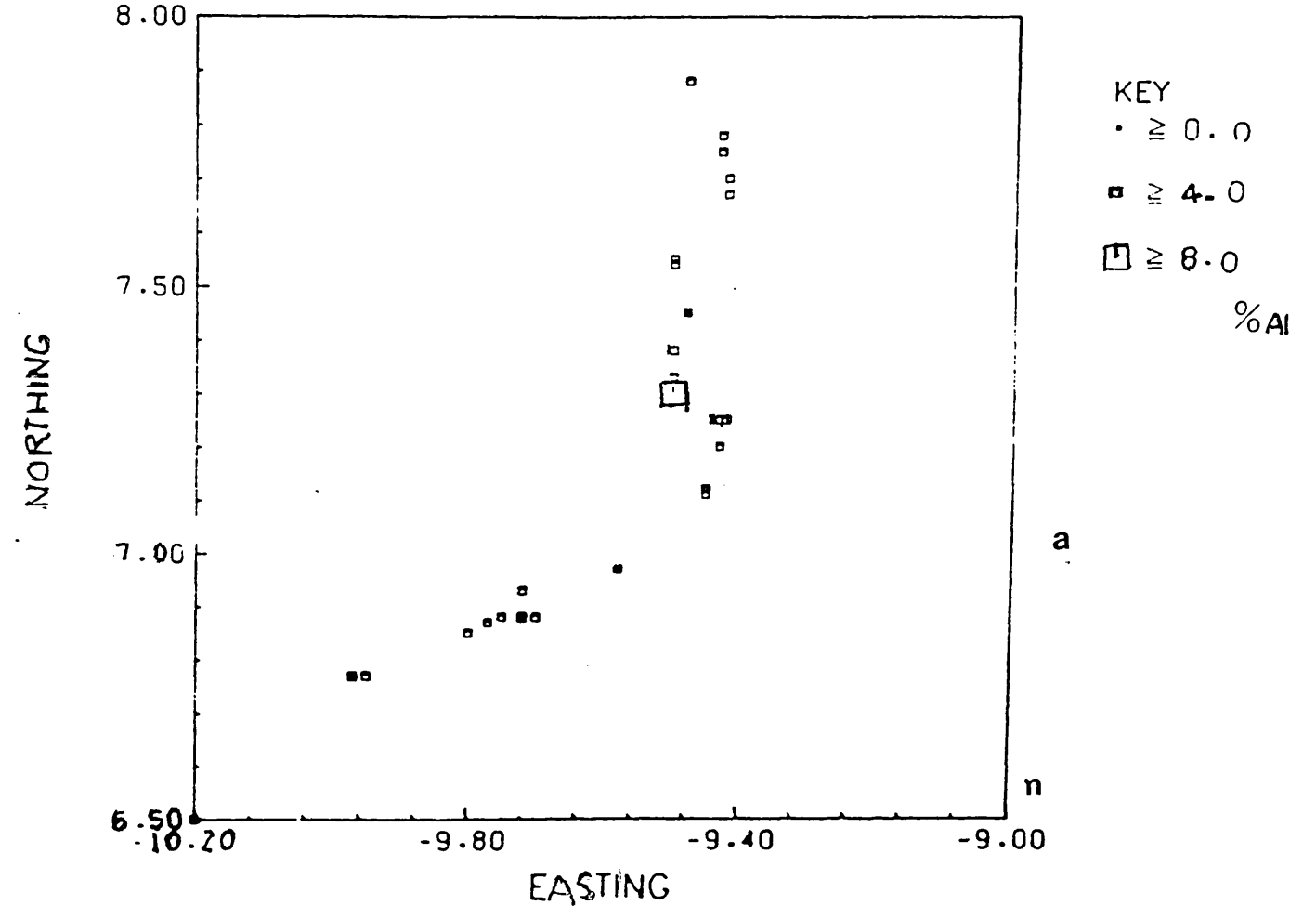
8.3.5 The Spatial Distribution of the Chemical Elements

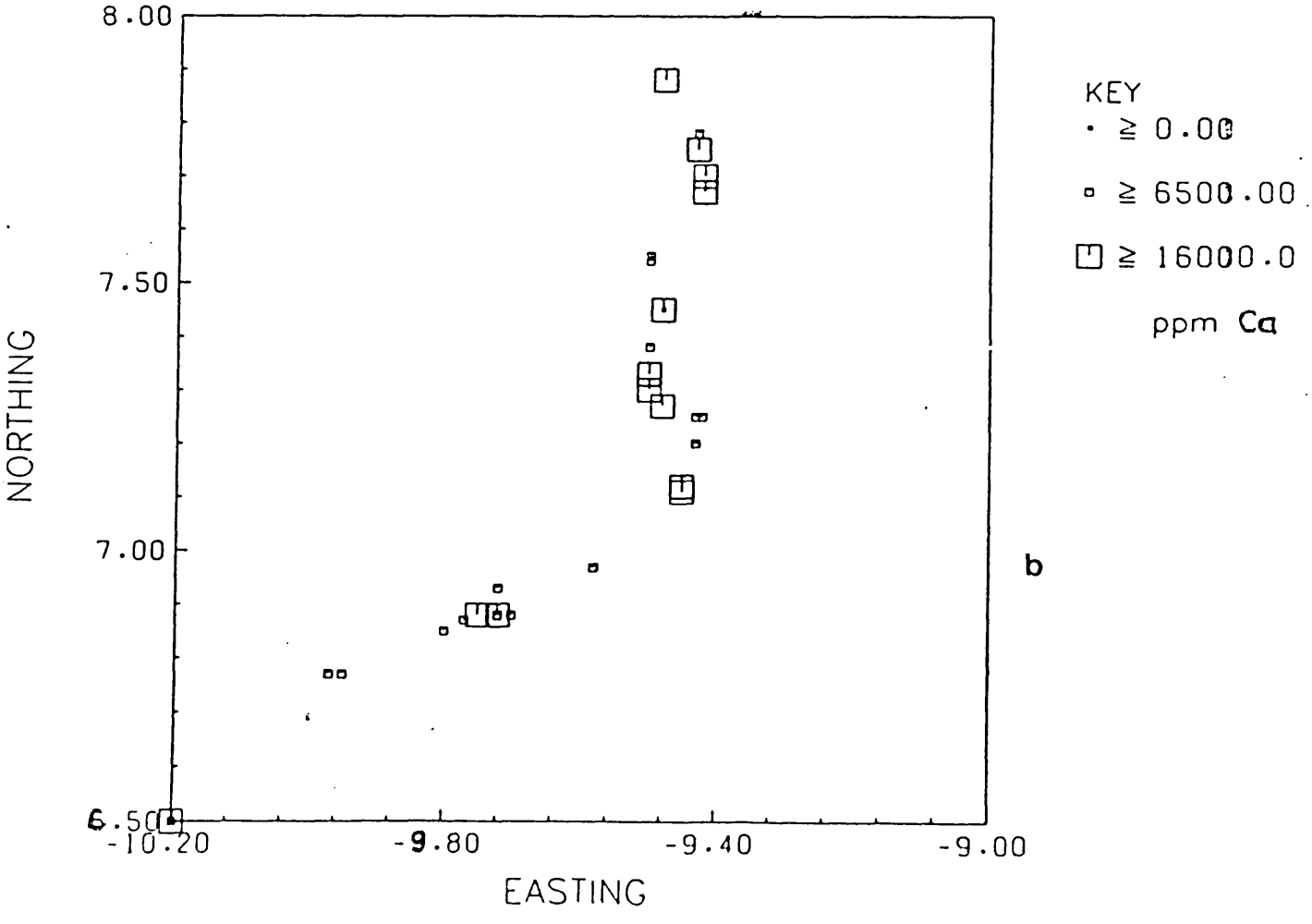
Figure 33(a-u)show the geographical distributions of the chemical elements, where each element has been subdivided into two or more classes or intervals. From inspection of the distribution trends, it appears that no element or group of element has a systematic variation along the traverse. It is interesting to note, however, that sample 4381 from around the centre consistently shows higher concentrations of most of the elements determined. But the enhancements are too local for meaningful interpretation.

8.3.6 Summary and Conclusions

From the foregoing discussions, it is apparent that most of the elements tend to behave erratically. Such behaviour may be related to the high variances of the elements as shown by the high standard deviations. This in turn could be the result of the low density of samples collected. However, on a broad basis the chemical compositions of the rocks are similar to those of other Precambrian granitic rocks.

Fig.33(a-u). The geographical distribution patterns of twenty-one of the elements determined in the North Central Corridor suite. Note that a simplified geology overlay is located in the rear pocket of the thesis.


8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.80
-9.40
-9.00
EASTING
KEY
• ≧ 0.0
▫ ≧ 4.0
⊡ ≧ 8.0
%Al
a
n


8.00
7.50
7.00
6.50
NORTHING
-10.20
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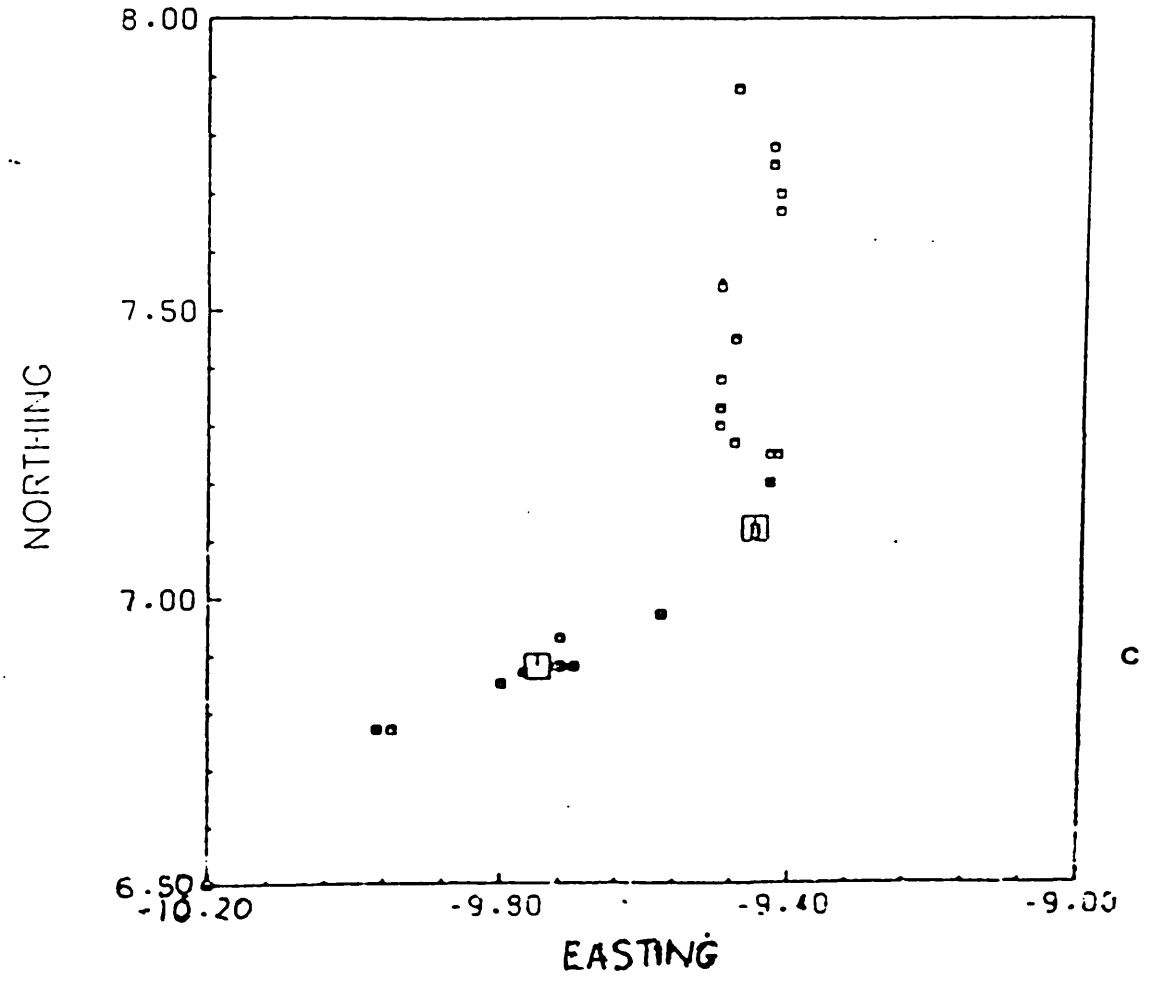
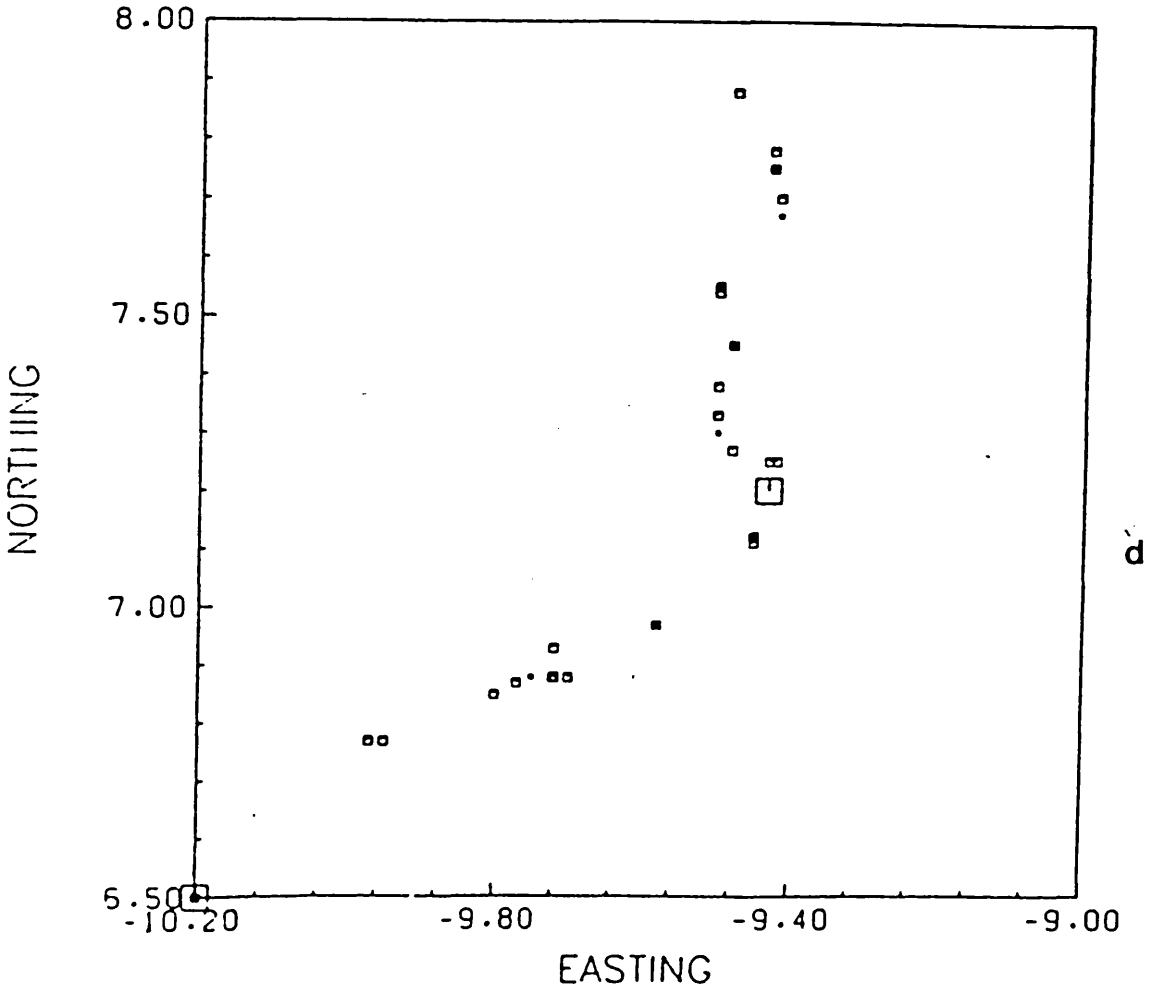
-9.00
EASTING
KEY
• ≧ 0.00
▫ ≧ 6500.00
⊡ ≧ 16000.0
ppm Ca
b


8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.80
-9.40
-9.00
EASTING
KEY
• ≧ 0.0
▫ ≧ 0.8
⊡ ≧ 6.0
%Fe
c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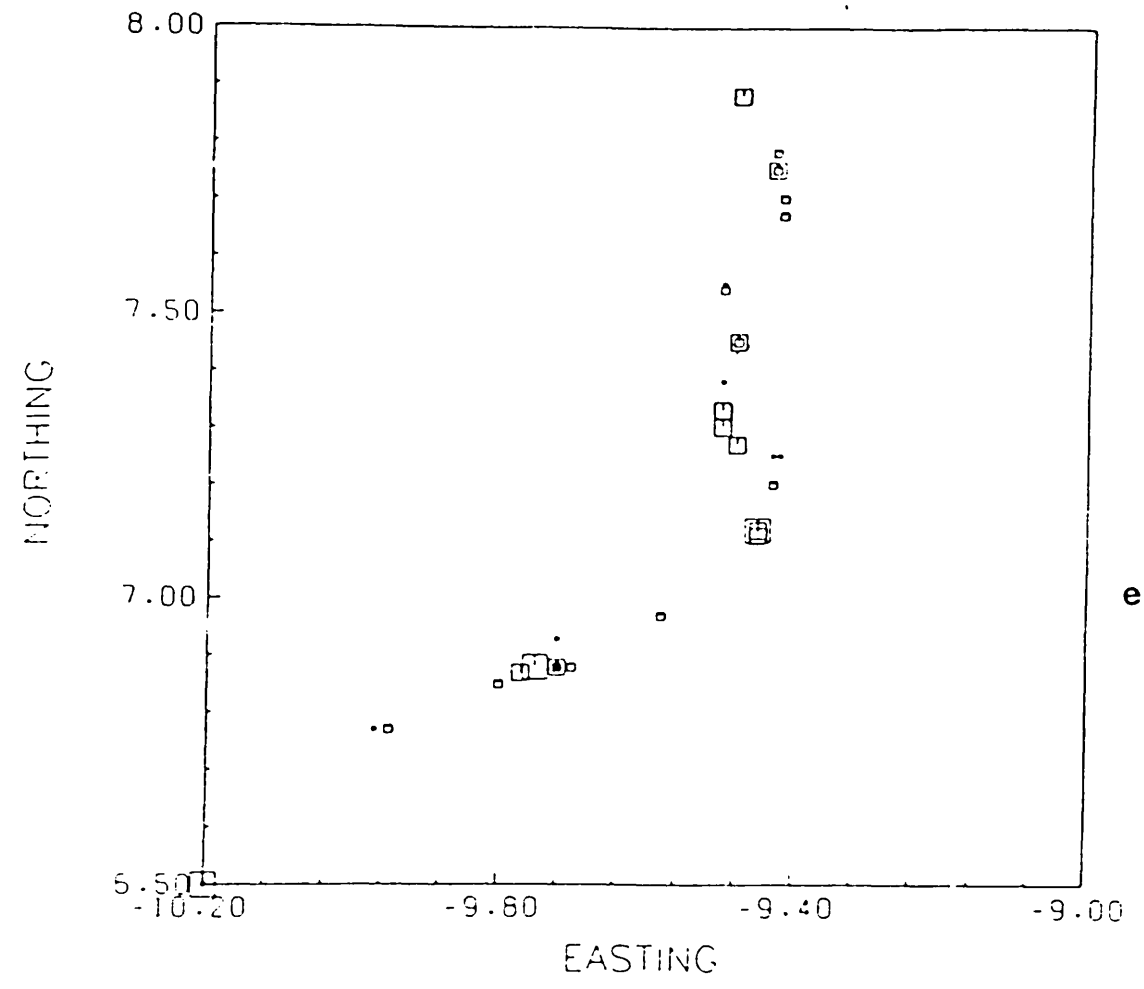
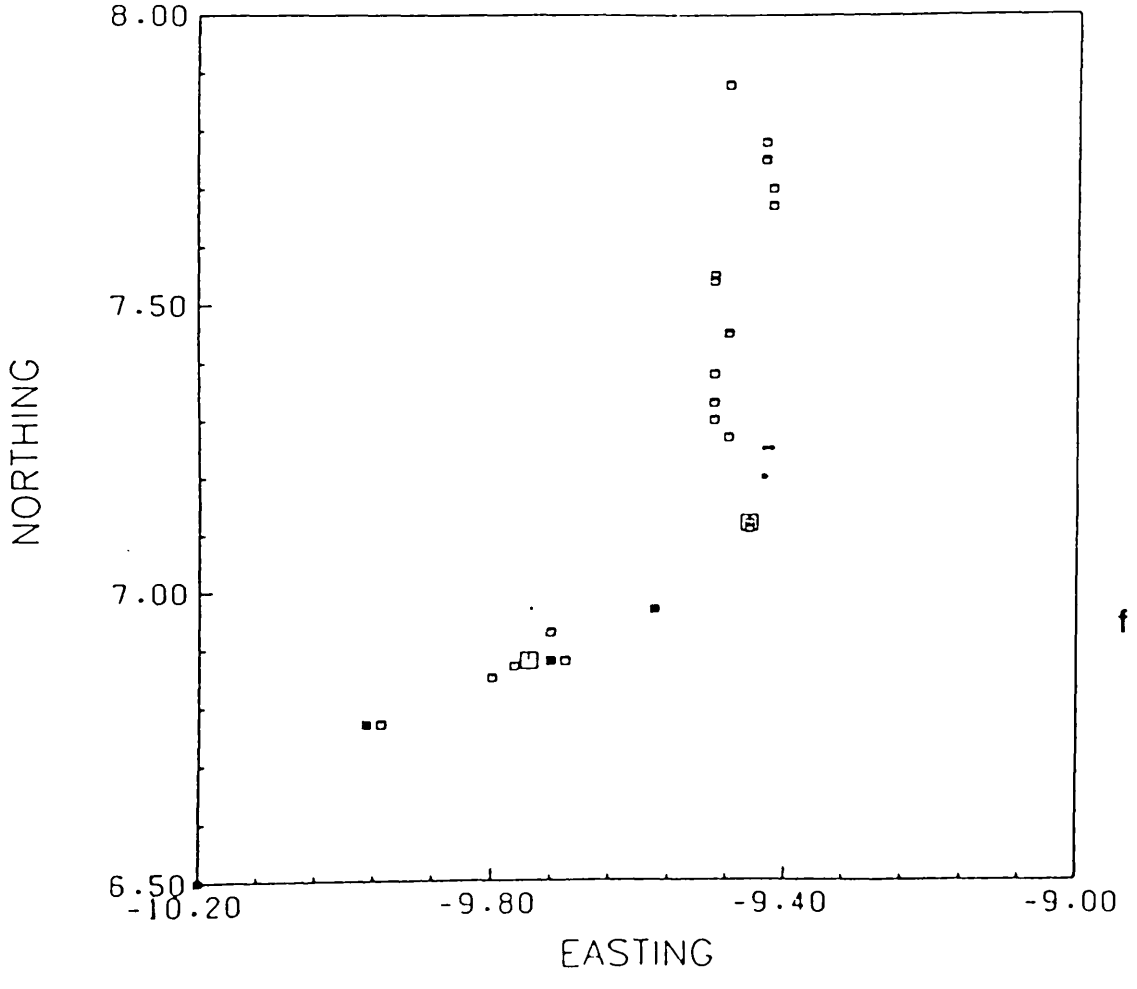
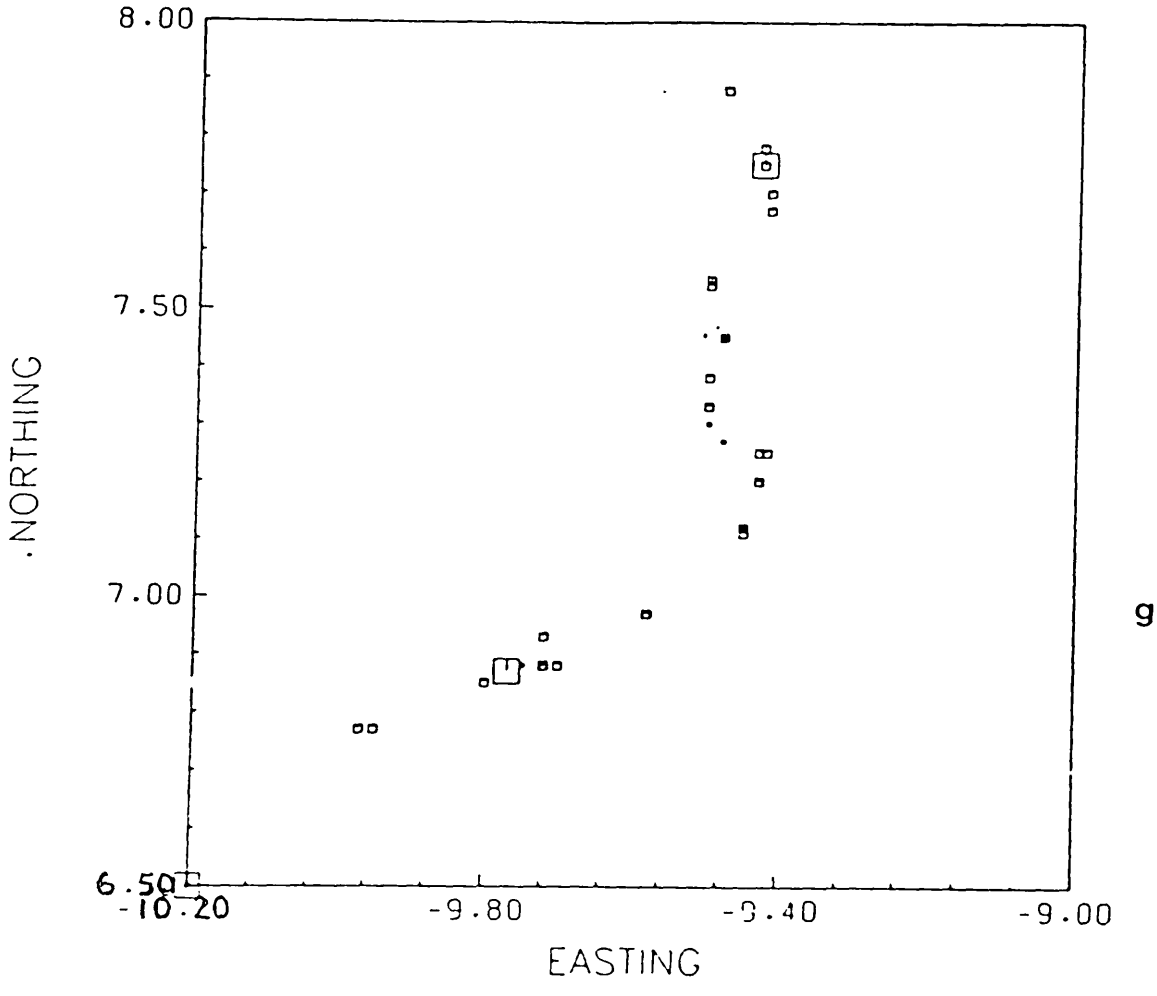
7.50
7.00
6.50
NORTHING
-10.20
-9.80
-9.40
-9.00
EASTING
KEY
• ≧ 0.0
▫ ≧ 1.0
⊡ ≧ 4.5
%K
d


8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.80
-9.40
-9.00
EASTING
KEY
≥ 0.0
≥ 0.2
≥ 0.4
≥ 1.6
% Mg

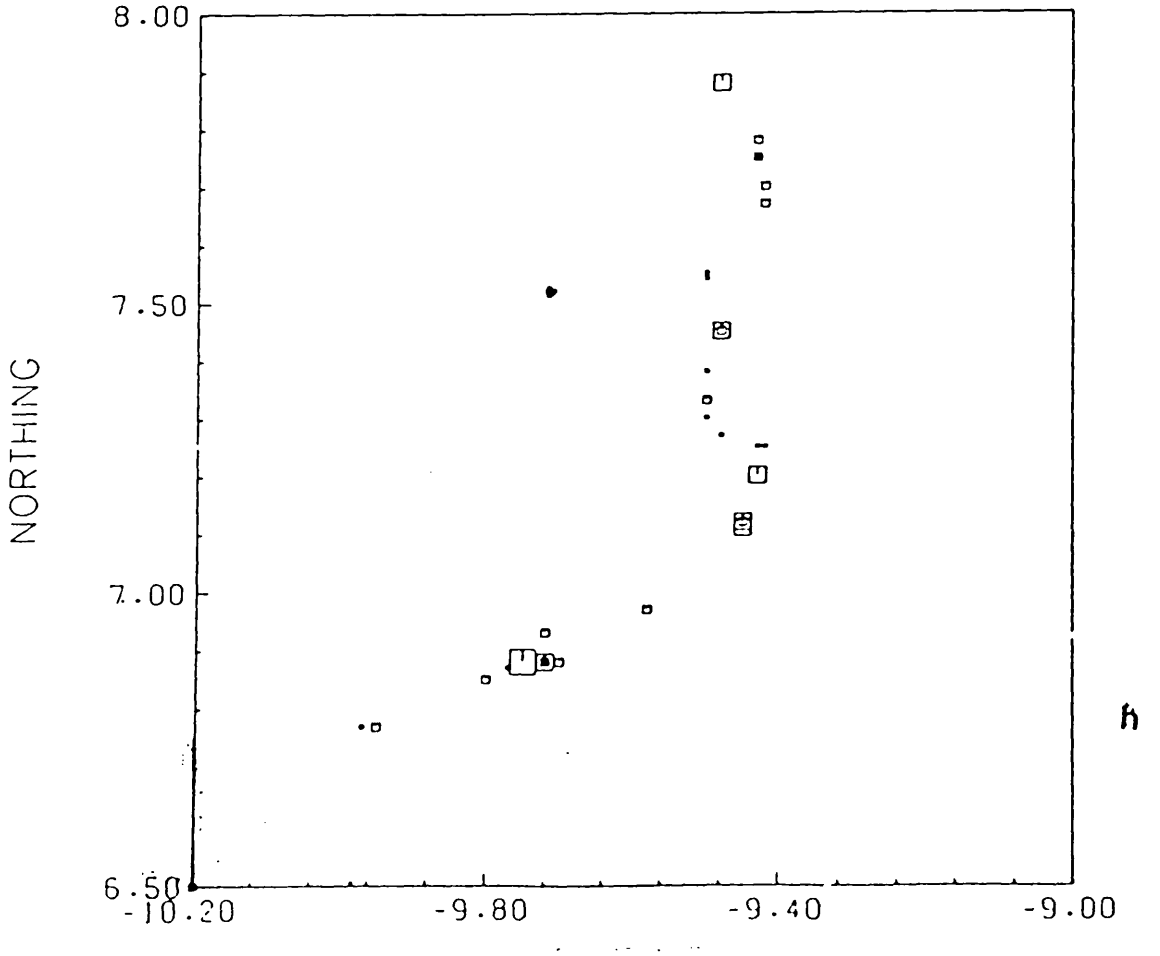
e


8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.80
-9.40
-9.00
EASTING
KEY
≥ 0.00
≥ 100.00
≥ 1000.00
ppm Mn

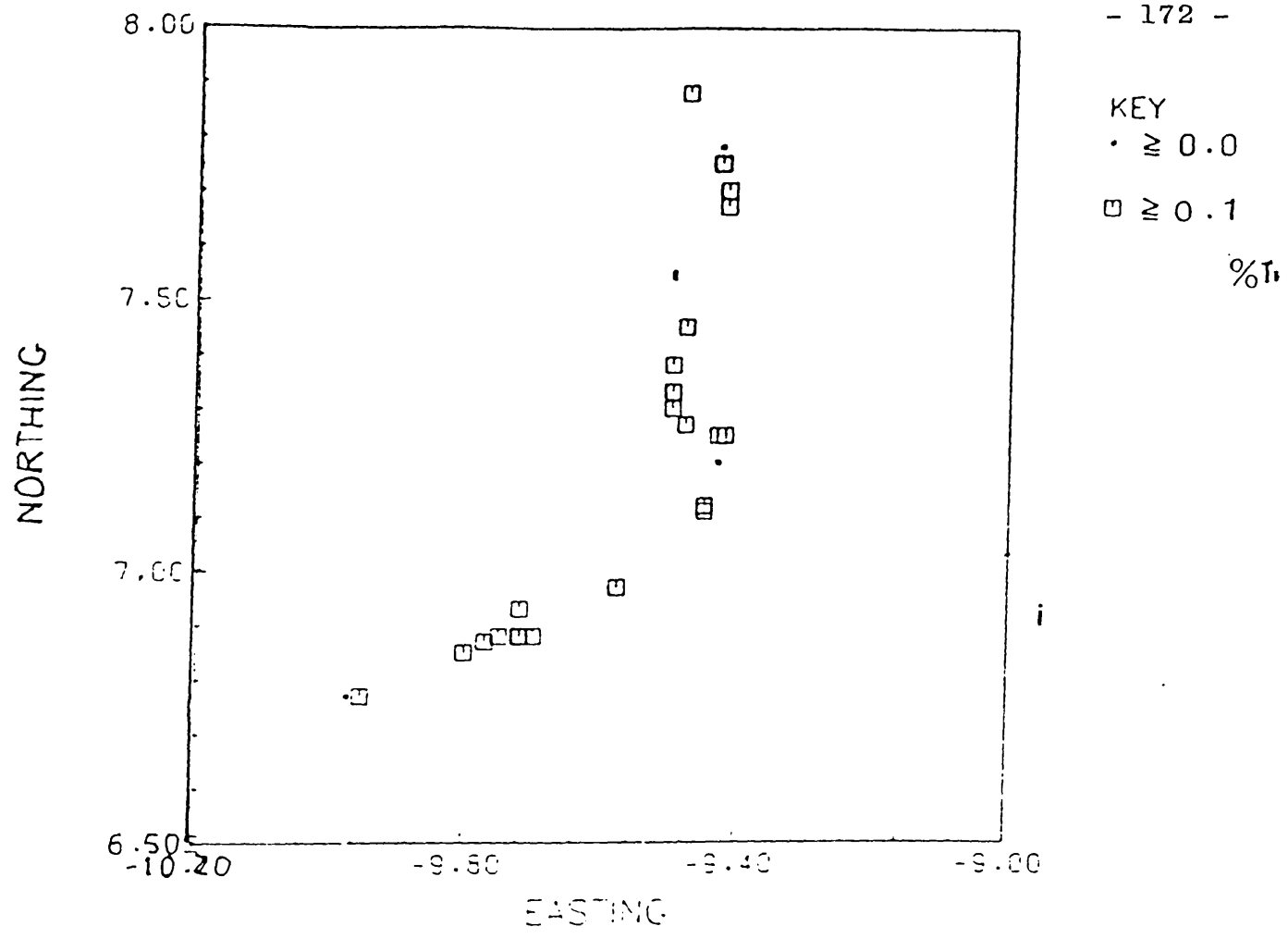
f

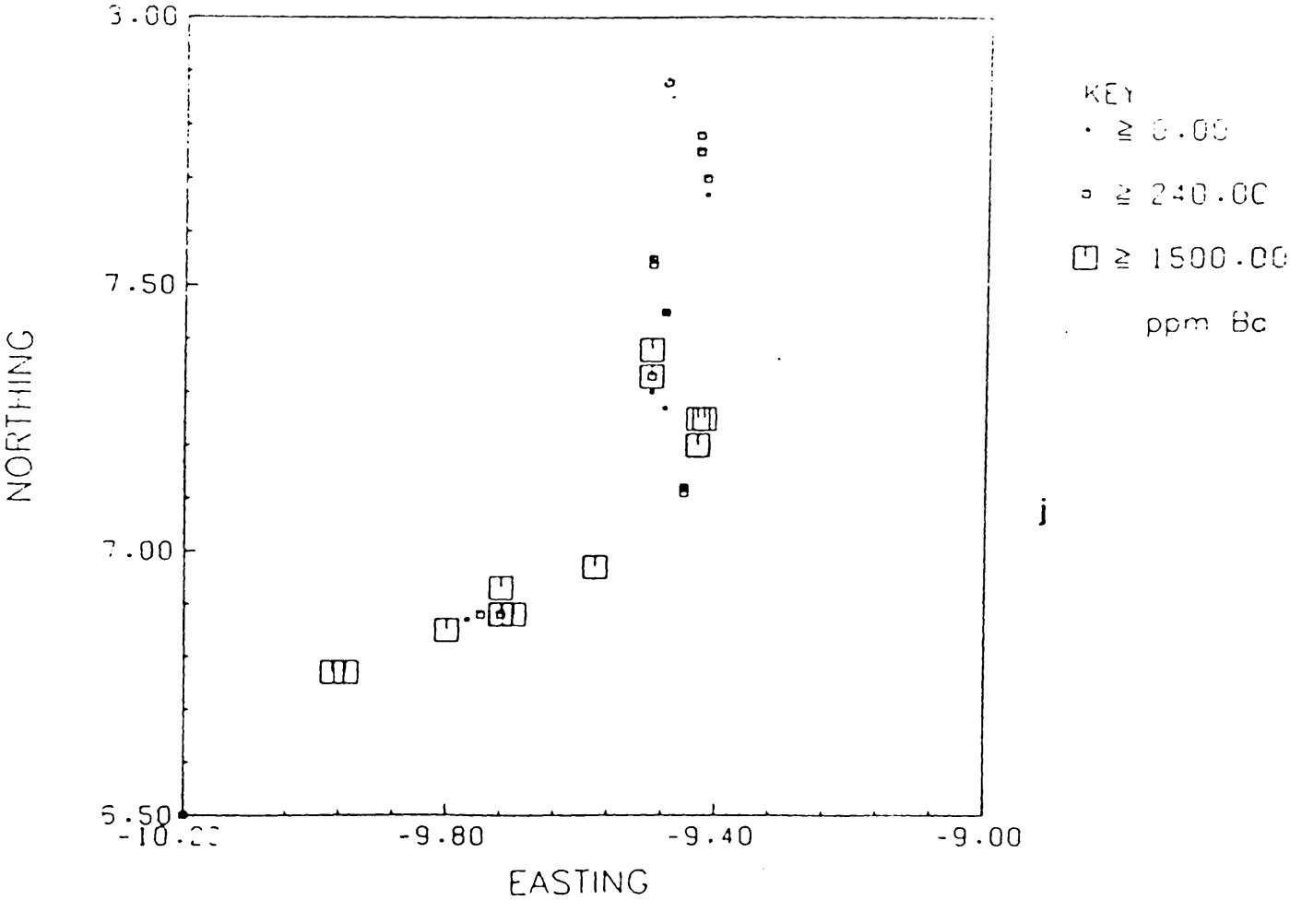

8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.80
-9.40
-9.00
EASTING
KEY
≥ 0
≥ 2
≥ 4
%Na

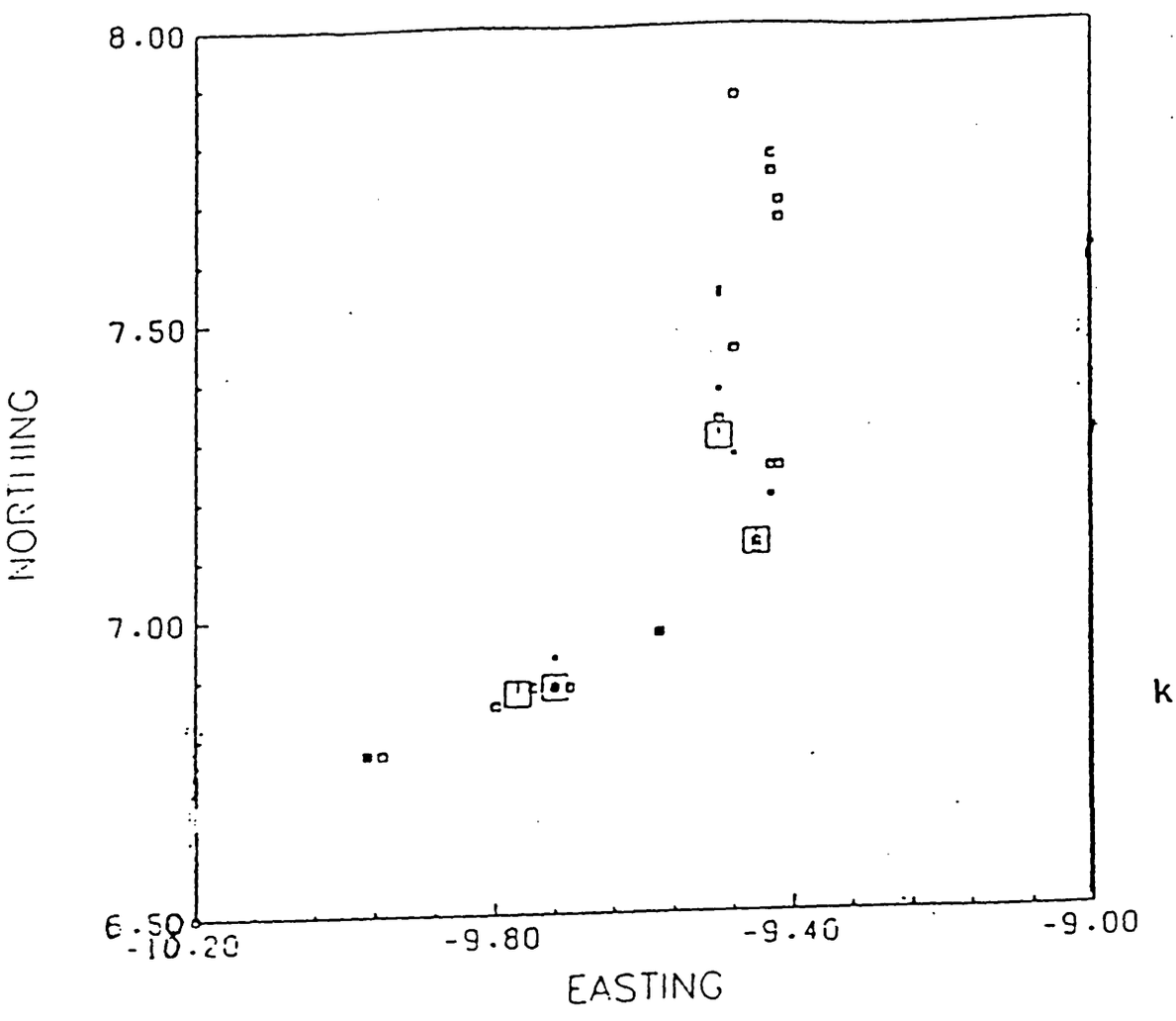
g


8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.80
-9.40
-9.00
KEY
≥ 0.00
≥ 200.00
≥ 700.00
≥ 1500.00
ppm P

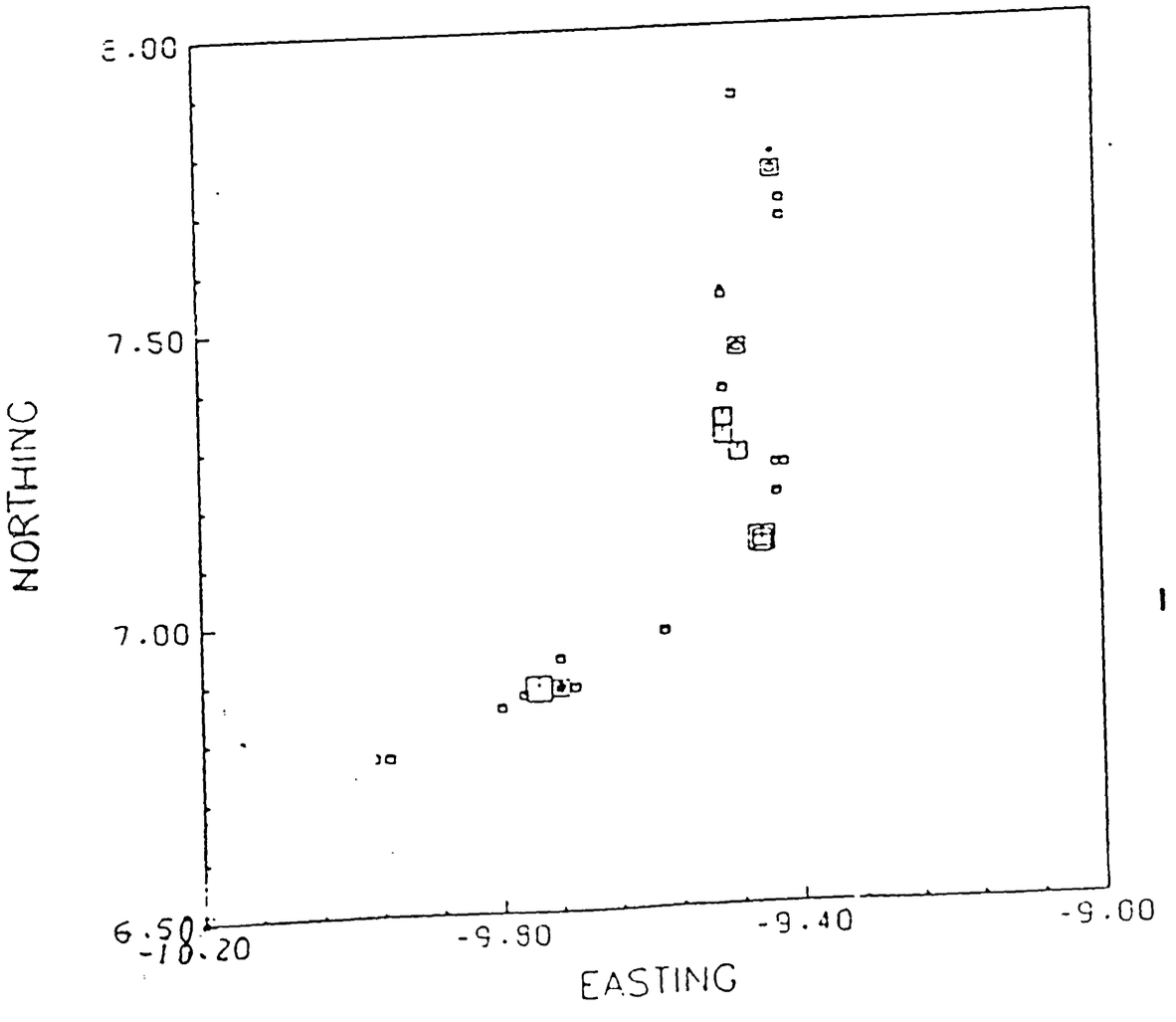
h


8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.60
-9.40
-9.00
EASTING
KEY
• ≥ 0.0
□ ≥ 0.1
%Ti

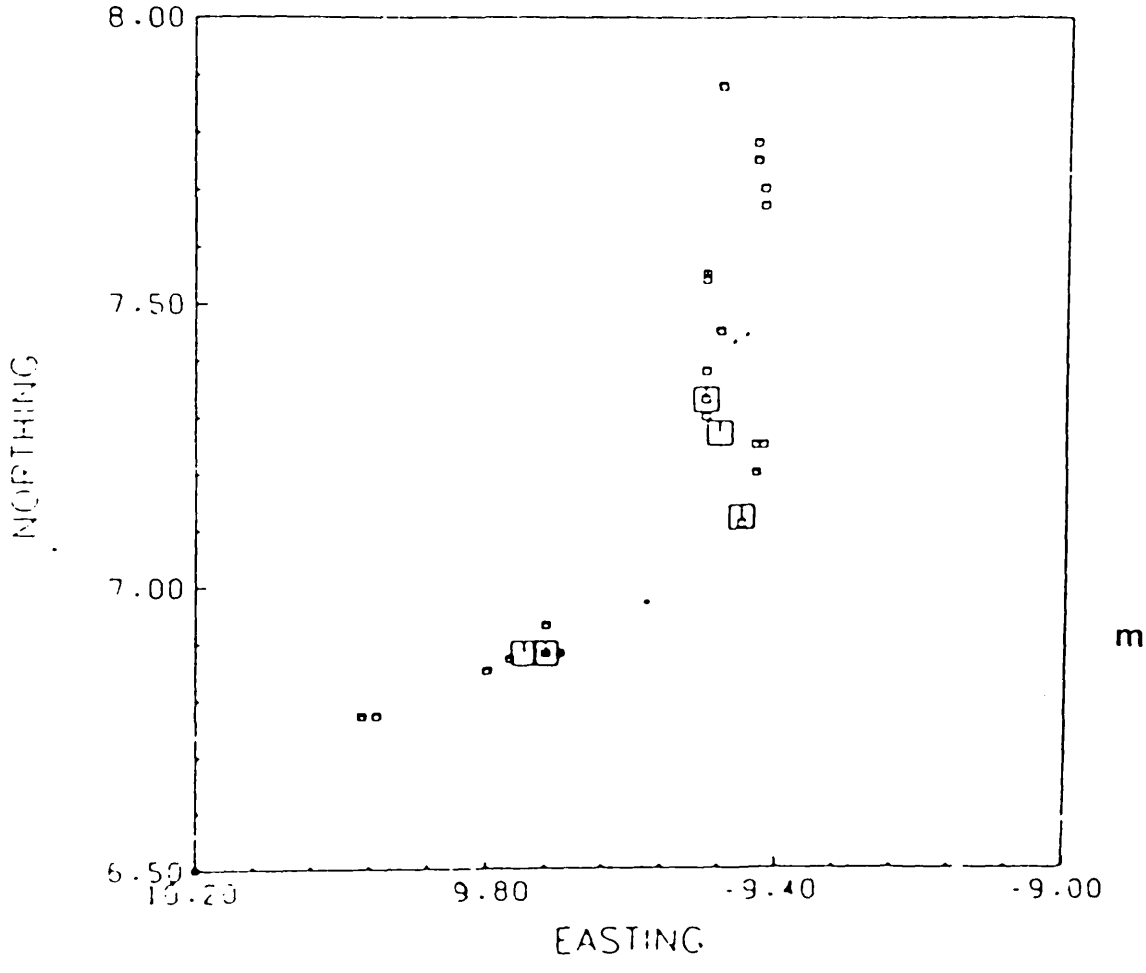

8.00
7.50
7.00
6.50
NORTHING
-10.00
-9.80
-9.40
-9.00
EASTING
KEY
• ≥ 0.00
▫ ≥ 240.00
□ ≥ 1500.00
ppm Ba


8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.80
-9.40
-9.00
EASTING
KEY
• ≧ 0.00
▫ ≧ 0.96
⊡ ≧ 2.40
ppm Be

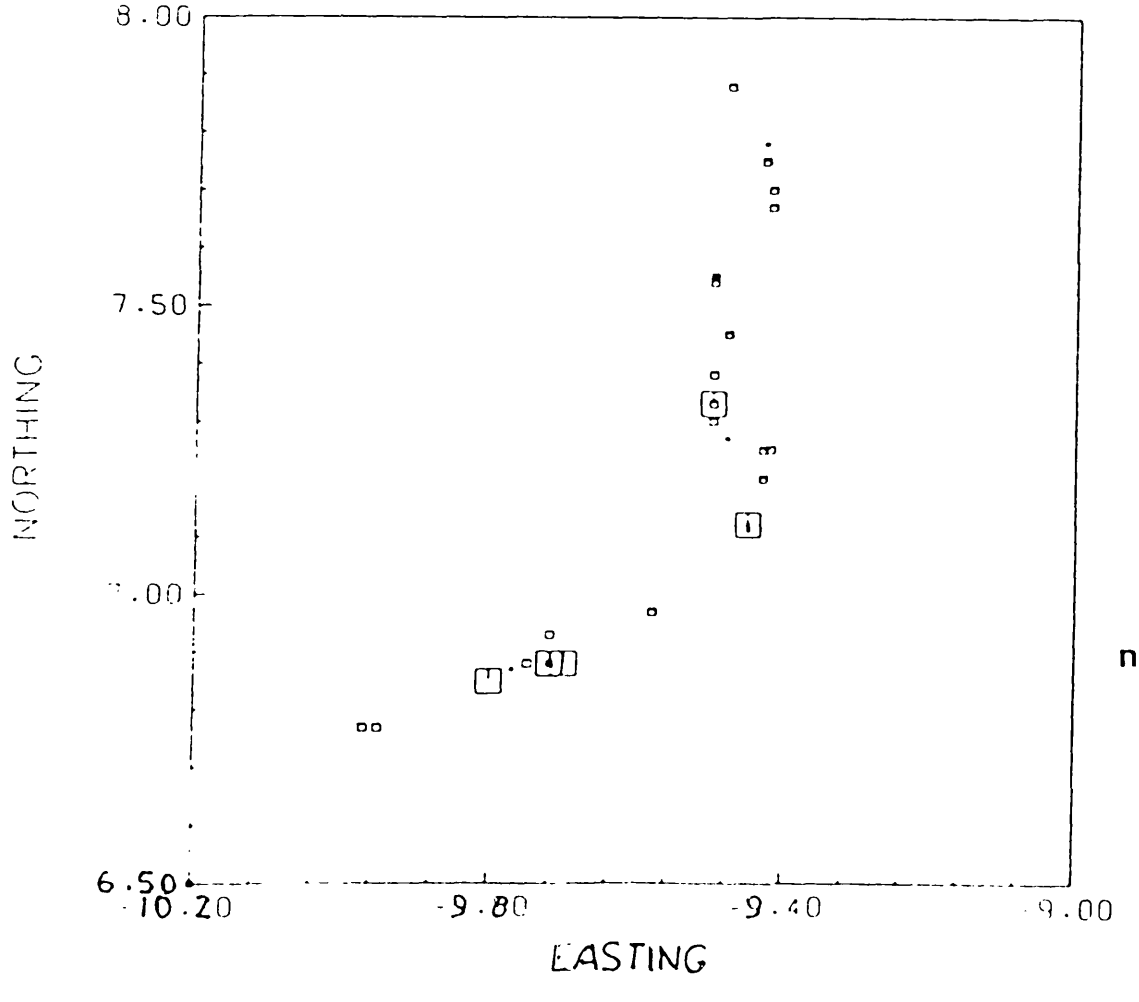
k


8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.90
-9.40
-9.00
EASTING
KEY
• ≧ 0.00
▫ ≧ 3.00
⊡ ≧ 10.00
⊡ ≧ 30.00
ppm Co

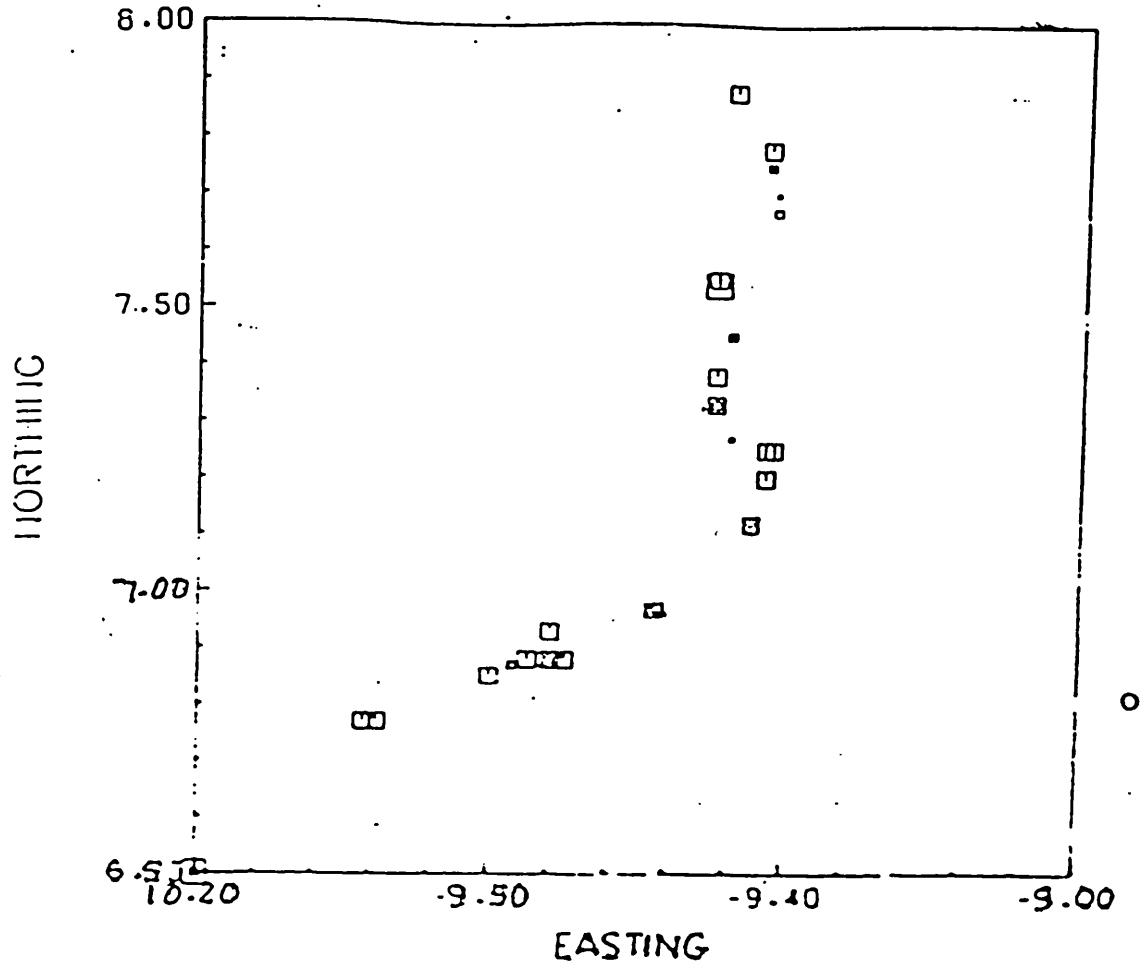
l

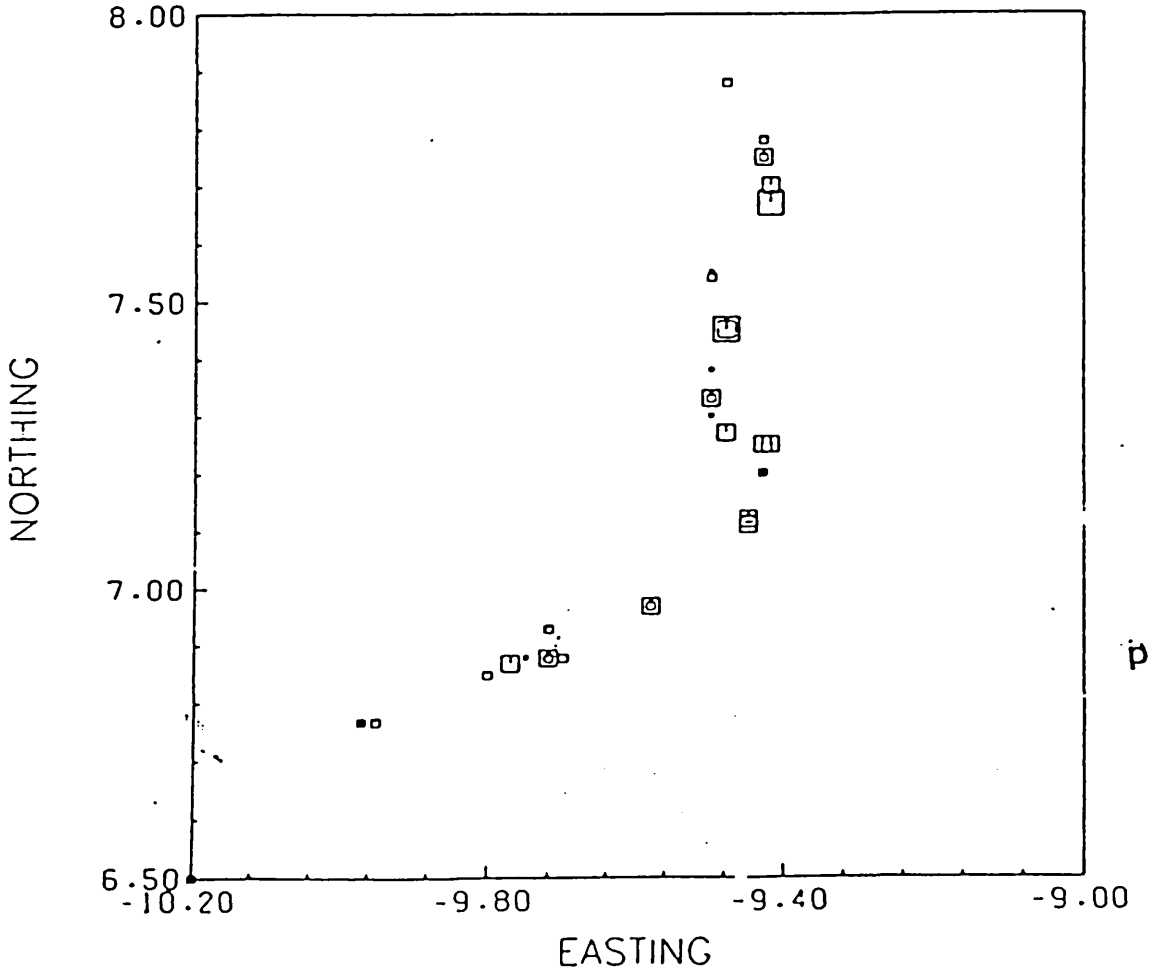

8.00
7.50
7.00
6.50
NORTHING
10.20
9.80
9.40
9.00
EASTING
KEY
≥ 0.00
≥ 1.00
≥ 9.00
ppm Cu

m


8.00
7.50
7.00
6.50
NORTHING
10.20
9.80
9.40
9.00
EASTING
KEY
≥ 0.00
≥ 20.00
≥ 50.00
ppm La

n


8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.50
-9.40
-9.00
EASTING
KEY
≧ 0.00
≧ 15.00
≧ 25.00
≧ 50.00
ppm Pb


8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.80
-9.40
-9.00
EASTING
KEY
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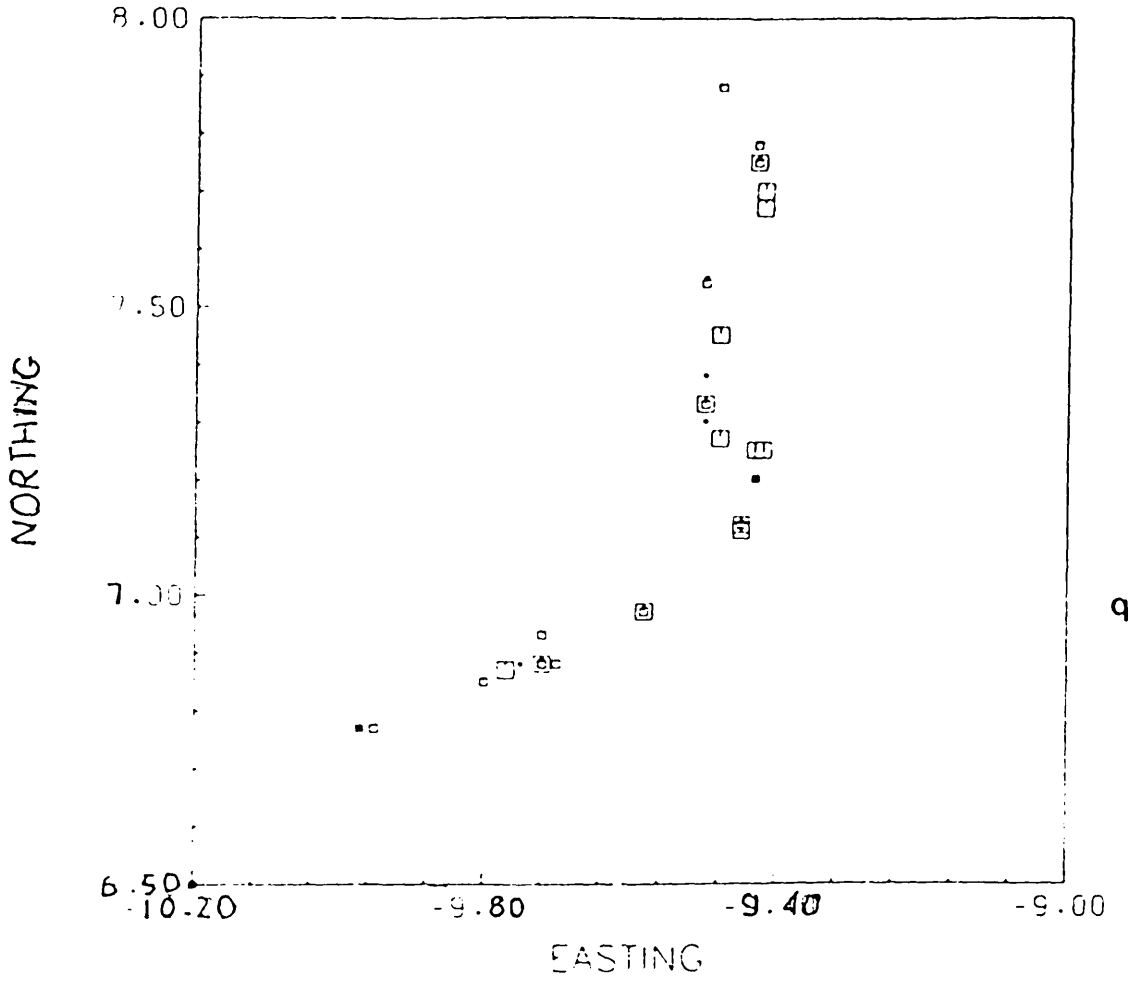
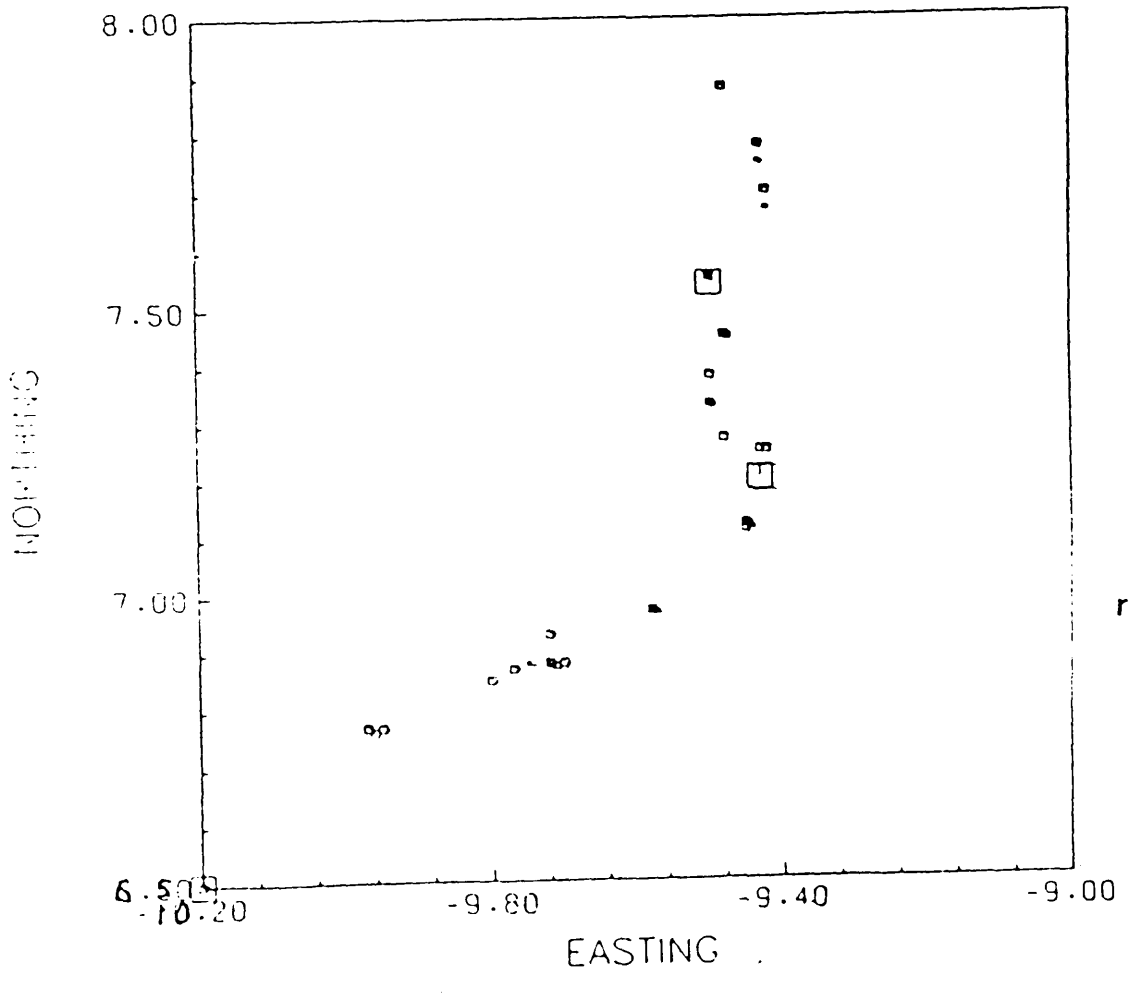
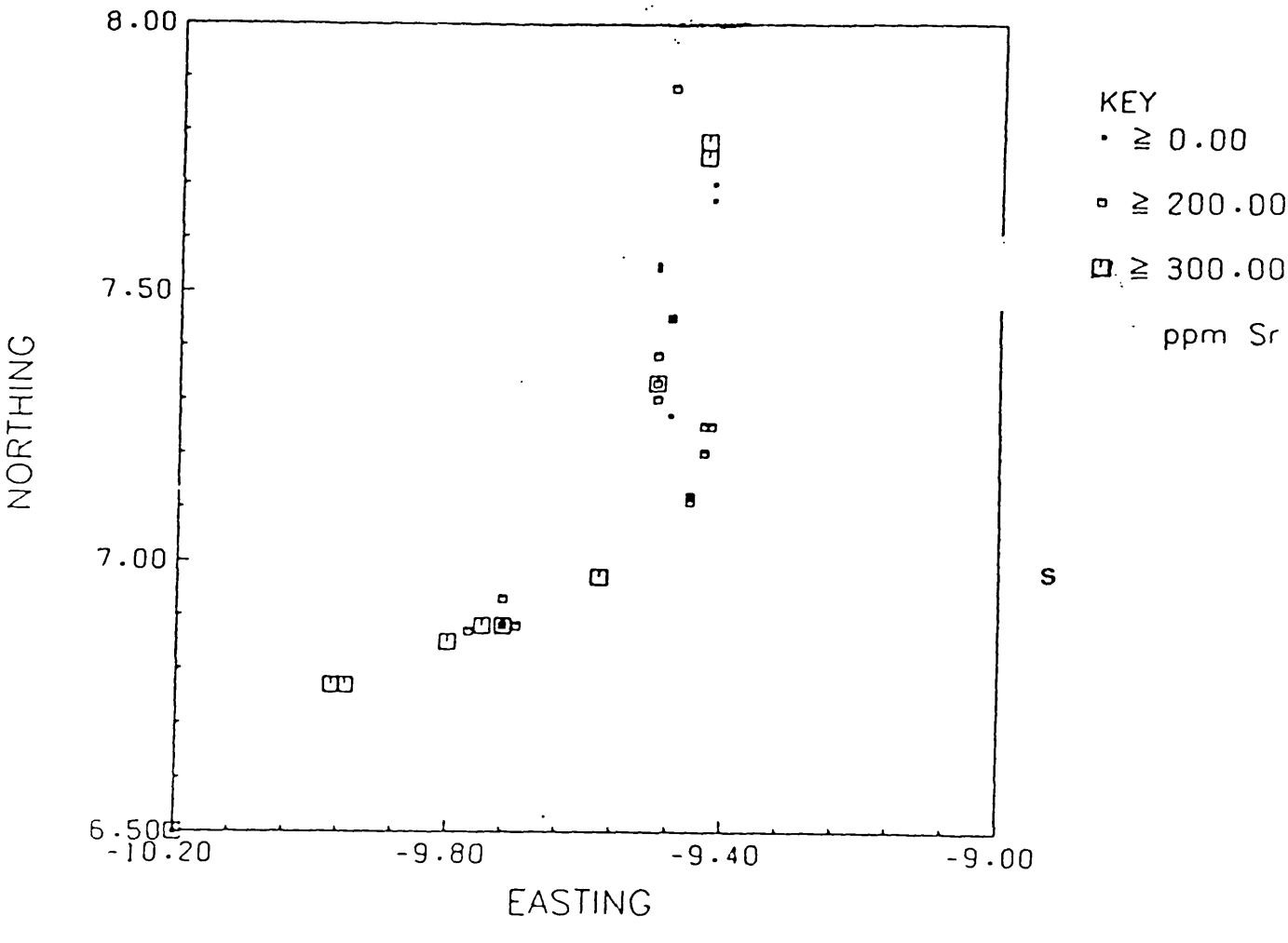
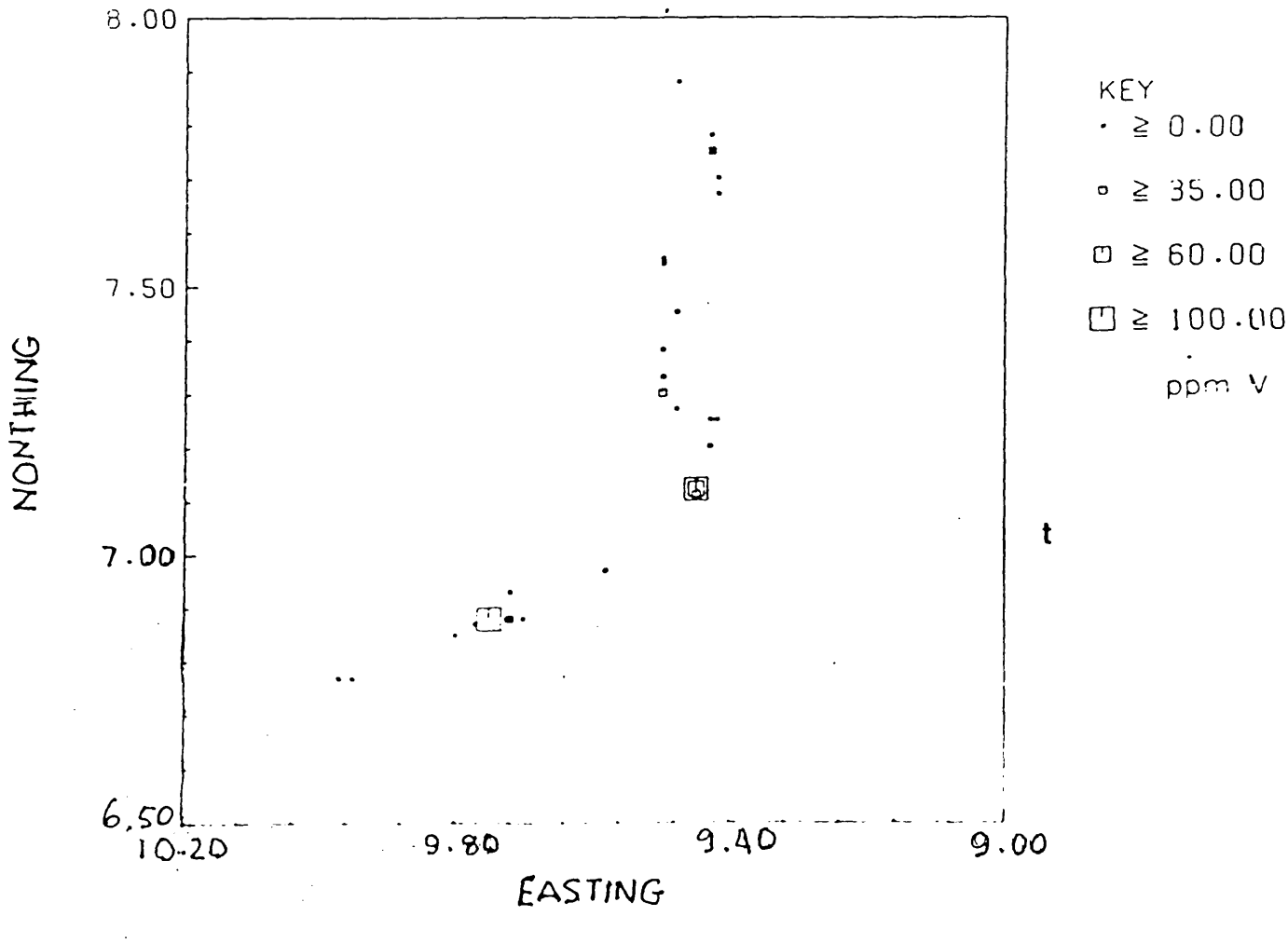
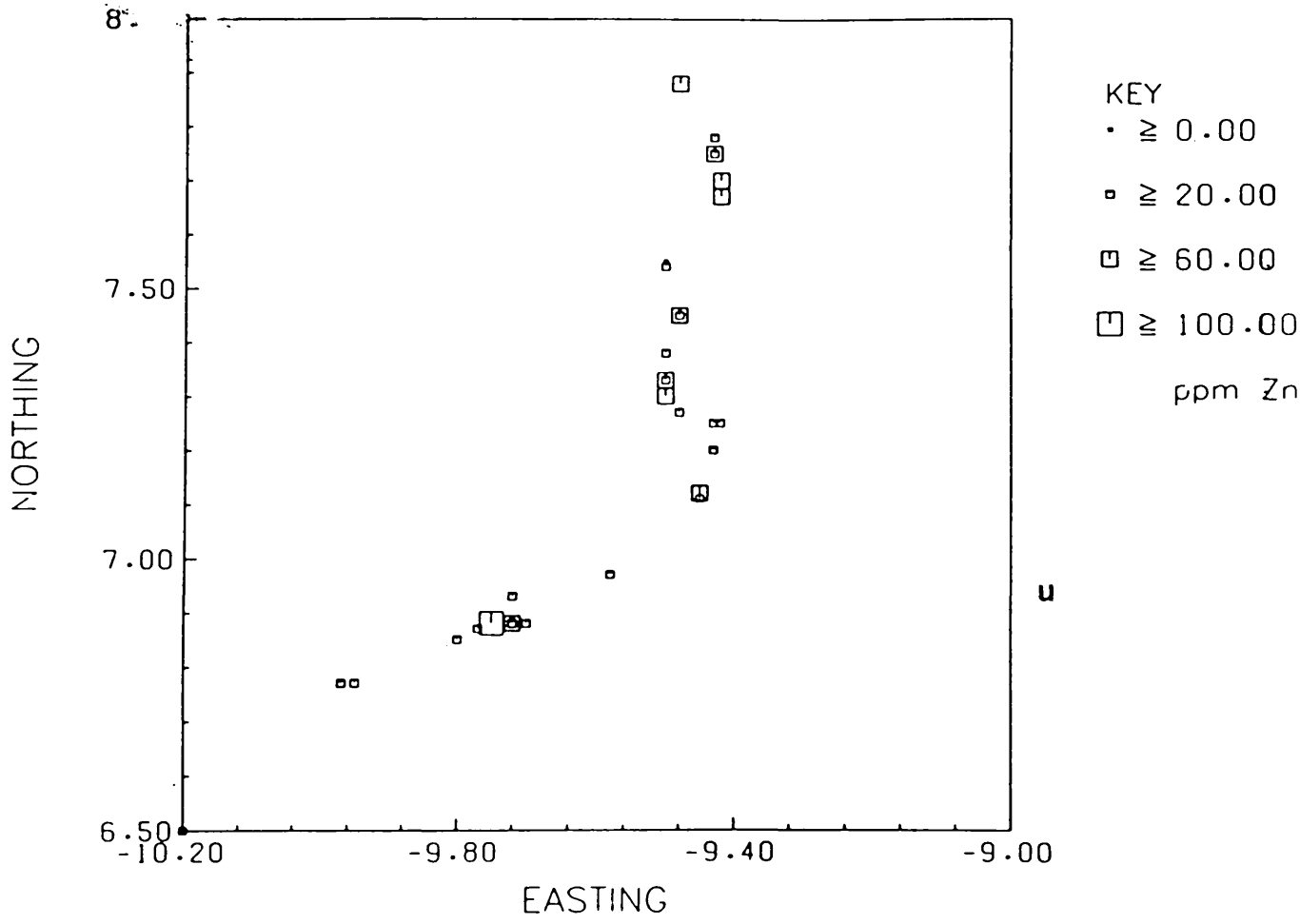
≧ 10.00
≧ 20.00
≧ 50.00
ppm Li


8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.80
-9.40
-9.00
EASTING
KEY
≧ 0.00
≧ 10.00
≧ 20.00
≧ 60.00
ppm Ni
q


8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.80
-9.40
-9.00
EASTING
KEY
≧ 0.00
≧ 60.00
≧ 120.00
PPM Rb
r


8.00
7.50
7.00
6.50
NORTHING
-10.20
-9.80
-9.40
-9.00
EASTING
KEY
≧ 0.00
≧ 200.00
≧ 300.00
ppm Sr
s


8.00
7.50
7.00
6.50
NONTHING
10-20
9.80
9.40
9.00
EASTING
KEY
≧ 0.00
≧ 35.00
≧ 60.00
≧ 100.00
ppm V
t


8.
7.50
7.00
6.50
NORTHING
-10.20
-9.80
-9.40
-9.00
EASTING
KEY
≧ 0.00
≧ 20.00
≧ 60.00
≧ 100.00
ppm Zn

8.4 GEOCHEMICAL FEATURES OF THE GREBO TOWN AREA PEGMATITE LENSES AND OTHER ASSOCIATED GRANITOIDS

8.4.1 Introduction

The importance of these granitic rocks stems mainly from the retrieval by several previous workers (Offerberg and Tremaine, 1961; Rosenblum, 1969 and UN geologists, 1972) of cassiterite crystals from panned stream sediments and soil heavy mineral concentrates in this area. The area also forms part of an extensive fault zone (the St John Fault Zone), which could possibly be a locale of various styles of mineralization.

8.4.2 Element Abundance

The compositions of the 47 representative rock samples from this area are summarized in Table 22, together with chemical data on granitoids of similar age (Precambrian), from (1) an unmineralized pegmatite granite body in the Black Hills, South Dakota; (2) Sn-mineralized (and productive) Esmeralda Granite, Queensland; and (3) Cullen Granite, Queensland for comparison. Comparisons between the mean compositions of the pegmatite granite from the Black Hills and the Grebo Town Area suite indicate that the latter is distinctly higher in Ca, Fe, K, Mg, Ti, Li, Ba and Pb but lower in Al, Mn, Na and P. When compared with the stanniferous Cullen Granite, the Liberian suite has similar concentrations of Al, Ca, Fe (total).

TABLE 22 AVERAGE COMPOSITION OF THE GREBO TOWN AREA PEGMATITE LENSES AND OTHER ASSOCIATED GRANITOIDS (n = 47) IN RELATION TO OTHER SIMILAR GRANITOIDS

Majors (%)	Mean	St Deviation	Median	Min	Max	1	2	3
Al	5.92	1.38	5.90	0.40	8.30	8.42	7.05	7.17
Ca	0.96	1.06	0.63	0.01	5.90	0.25	0.99	1.08
Fe	1.54	2.12	0.91	0.05	11.80	0.92	1.86	2.93
K	3.50	2.11	3.60	0.11	9.30	1.81	4.17	4.17
Mg	0.43	1.01	0.12	0.01	6.10	0.03	0.17	0.35
Mn	0.03	0.05	0.01	0.01	0.20	0.06	0.04	0.31
Na	2.24	0.73	2.30	0.03	3.80	3.88	1.92	2.35
P	0.03	0.02	0.03	0.03	0.09	0.15	0.06	0.04
Ti	0.11	0.12	0.06	0.01	0.47	0.01	0.19	0.16
Trace (ppm)								
Ag	1.3	0.10	1.20	1.20	1.30			
Ba	1052	920	910	25	4300			549
Be	1.3	1	1	0.2	6.20	15	4.4	4
Cd	1	0.5	1	0.5	1.4			
Co	8	12	4	1.1	65			7
Cr	56	182	3	1	960		4	
Cu	9	18	4	1	108		7	5
La	26	30	16	2	133			69
Li	20	29	11	2	177	60	39	26
Mo	3.9	2.7	2.7	1.1	8.5			
Ni	28	62	8	1	380		3	5
Pb	38	19	38	9	110		51	29
Rb	152	104	132	24	580	15	291	124
Sr	107	81	113	1	290	7	78	151
V	21	39	7	1	200			36
Zn	44	85	21	1	550		79	28

Some Element Ratios

	a	b	c
Mg/Li	168	44	-
Rb/Sr	1.9	3.7	2.0
K/Rb	247	143	289
K/Pb	871	820	
Sr/Ba	0.2		0.28
Ba/Rb	8.9		

(1) Unmineralized pegmatite, Black Hills, South Dakota (Pε) (Orville, P.M.,1960).
(2) Sn-producing Esmaralda Granite, Queensland (Pε) (Sheraton, J.W. and Black, L.P. 1973).
(3) Staniferous Cullen Granite (Northern Territory, Queensland (Pε) (Ewers, G.R. and Scott, P.A., 1977).
(a) Ratios from present work.
(b) Ratios from Esmaralda Granite.
(c) Ratios from Pegmatite of the Chakradharpur Granite-Gneiss Complex (Pε) of India (Sengputa, 1983).

Na, Ti, Co, Li, Pb, Rb, and Sr, higher concentrations of Mg, Ba, Cu, and Ni but lower concentrations of K, Mn, P, Be, La, V, and Zn. On the other hand a comparison with Sn-mineralized (and producing) Esmeralda Granite, Queensland, shows that the Grebo Town pegmatite lenses and granites have similar concentrations of Al, Ca, Fe, Cu, but are lower in K, Mg, Mn, P, Ti, Be, Li, Rb, Pb, and Zn, higher in Na, Ni, and Sr.

It is evident from these comparisons that the mean chemical compositions of the Grebo Town suite are relatively quite variable. However, on the average, it appears to be less fractionated than the Cullen and Esmeralda granites.

Kleiner-Hartigan trees have been used to show the compositions of these samples (Fig. 34a and 34b). A careful inspection of Fig. 34a reveals that although only one lithological type has been previously mapped, significant differences exist in the concentrations of some elements from sample to sample. For example, samples 4782 and 4813 have similar concentrations of all the elements except Cu, Na, and Sr in which sample 4813 is relatively more enriched. Similarly, when compared with the rest of the samples, sample 4793 is severely depleted in all the elements. These and other such features can also be recognised from the raw chemical data (rear pocket). In the present situation such observations may only be interpreted as a reflection of sporadic local variability of the geology or

Fig.34a. The Kleiner-Hartigan "Trees" for the Grebo Town area suite. Arrows point to the direction or position from which a "Tree" may have been drawn in.

Fig.34b. The template for the Grebo Town area "Trees".

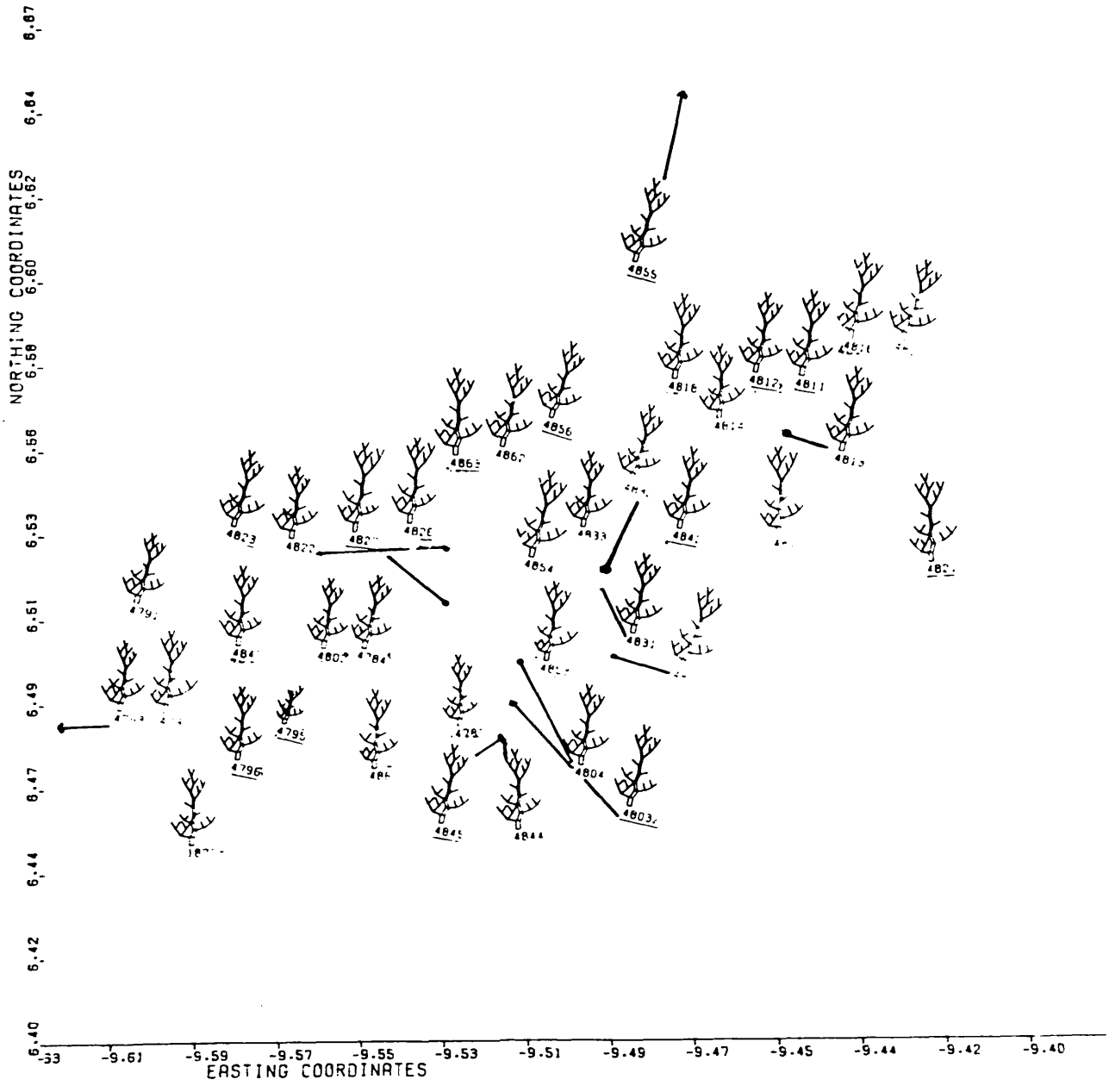

NORTHING COORDINATES
6.67
6.64
6.62
6.60
6.58
6.56
6.53
6.51
6.49
6.47
6.44
6.42
6.40
-9.61
-9.59
-9.57
-9.55
-9.53
-9.51
-9.49
-9.47
-9.45
-9.44
-9.42
-9.40
EASTING COORDINATES

Fig. 34a.

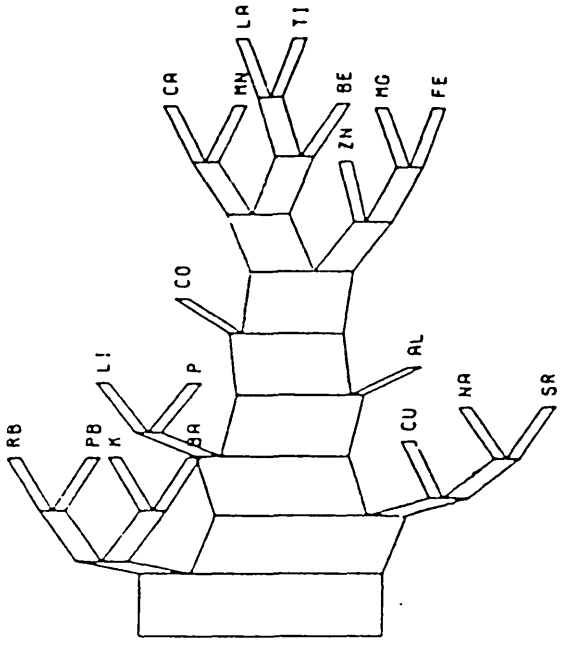


Fig. 34b.

the high degree of variance of element distribution in these rocks.

8.4.3 Frequency Distribution of Elements

The histograms and normal probability plots suggest that despite the apparent overall similarity, the majority of the elements display high degrees of variance. Among the major elements only K is approximately normally distributed whilst Na is distinctly negatively skewed (Figs. 35a and 35b). Among the trace elements only Sr approaches a normal distribution (Fig. 35c). Li, Rb, Mg, Be, La, V, Mn, Fe, Co, Ni, Cu, Zn, and P have moderate to large positive skewness and approach lognormal distribution. The rest of the elements (Ba, Ca, and Al) have distribution patterns that can only be described as uncertain (Ahrens, 1963).

These various types of frequency distribution patterns are not unique to the Grebo Town granitic suite; for they are in general agreement with those reported for similar granitic rocks by several investigators (e.g. Condie, 1969; Ahrens, 1963a, 1963b, 1966; Svenson, 1970; Aubrey, 1955; Horatori et al, 1960).

These patterns are in general again a reflection of local random variations of the chemical elements in these rocks. It is possible, though, that some of these patterns may be related to the yet equivocally proven cassiterite mineralization associated with these granitic rocks. For erratic variation, hence high coefficients of variation, of

Fig.35(a-c) Examples of the frequency distribution patterns of the elements (in ppm) determined in the Grebo Town suite.

K

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.	4	****
10000.	6	******
20000.	7	*******
30000.	4	****
40000.	12	************
50000.	7	*******
60000.	3	***
70000.	2	**
80000.	0	
90000.	2	**

a

NSCORES C4 C28

NA

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.	1	*
5000.	1	*
10000.	3	***
15000.	3	***
20000.	13	*************
25000.	15	***************
30000.	10	**********
35000.	0	
40000.	1	*

b

SR

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.	3	***
40.	10	**********
80.	8	********
120.	13	*************
160.	8	********
200.	4	****
240.	0	
280.	1	*

c

Fig.35(a-c). Examples of the frequency distribution patterns of the elements determined in the Grebo Town suite.

trace element concentrations in granitoids has been considered as one of the indications of possible mineralization by some workers (Moseley, 1981 and Govett, 1983). But the present data cannot be adequately used to confirm or disprove this hypothesis. The high variance for both the major and trace elements is also evident from the high standard deviations obtained for most elements (Table 22).

8.4.4 Inter-element Relationships

The correlation matrix for the log ratio transformed data (log(x/Fe))for the 47 analysed samples is shown in Table 23 (following Aitchison's (1984) suggested method to overcome closure). An analysis of this matrix suggests that three main associations of elements exist. The first group comprises K, Na, Be, Pb, Rb, Sr, Al, and Ba, all of which have strong mutual positive correlation coefficients. A second group, composed of Li, Ca, Co, P, and Cu shows some degree of weak to moderate affinity with most members of the first group; Mg and Ti form the third association. V, Mn, Ni and Zn, all show no correlation with any other elements at the 95% confidence level.

The first element association may be correlated with feldspars whereas the second and third groups are difficult to relate to any one mineral or a group of minerals. These correlation trends are in a large measure a reflection of the element abundance levels. According to several workers (Beach and

	LI	NA	K	RB	BE	MG	CA	SR
NA	.323							
K	.421	.752						
RB	.595	.782	.984					
BE	.482	.777	.647	.694				
MG	.088	-.599	-.438	-.483	-.259			
CA	-.127	.615	.151	.167	.437	-.333		
SR	.161	.800	.647	.651	.649	-.451	.663	
BA	.290	.653	.862	.791	.550	-.388	.307	.826
AL	.540	.901	.857	.913	.802	-.445	.327	.729
LA	.185	.513	.487	.436	.329	-.521	.354	.645
TI	-.290	-.247	-.127	-.358	-.286	.085	.198	.122
V	.019	-.258	-.140	-.156	-.050	.443	.125	.151
MN	-.069	-.123	-.299	-.229	.284	.336	.017	-.222
CO	.346	.284	.355	.367	.500	.269	.221	.234
NI	.260	.094	.204	.304	.319	-.044	-.081	.193
CU	.137	.498	.302	.262	.425	-.152	.408	.554
ZN	.145	.145	.457	.383	.098	.006	-.236	-.086
PB	.523	.894	.892	.917	.733	-.553	.270	.730
P	.546	.602	.464	.587	.537	-.142	.096	.307

	BA	AL	LA	TI	V	MN	CO	NI
AL	.716							
LA	.643	.437						
TI	.185	-.367	.396					
V	.110	-.166	.041	.435				
MN	-.334	-.158	-.340	-.331	.014			
CO	.255	.404	-.157	-.266	.428	.260		
NI	.228	.261	.010	-.164	.035	.136	.102	
CU	.390	.507	.311	-.094	.220	-.123	.215	.174
ZN	.228	.210	.020	-.110	-.257	-.113	.296	-.104
PB	.765	.946	.558	-.267	-.188	-.204	.302	.196
P	.244	.691	.233	-.526	-.161	.085	.323	.036

	CU	ZN	PB
ZN	-.194		
PB	.472	.279	
P	.320	.153	.653

Table 23 The Pearson correlation matrix for the log-transformed ratio (x/Fe) data from the Grebo Town area.

Tarney, 1978; Vriend et al., 1985; Howarth, 1983; and Chapman, 1976), correlation coefficients can be adversely affected if the distributions of the variables are highly skewed, multimodal, or if they contain outliers. Thus, in the present data, though logtransformed, some elements (especially those approaching detection limits) are likely to show uncertain or doubtful associations. The behaviour of Mg and Ti is strange since they are the only two majors to show weak positive correlations with the other major elements. Their high variance , as indicated by high standard deviations, may partly be responsible for their poor correlations, however. Similarly, the behaviours of V, Zn, Mn, and Ni as independent "lone" elements may probably be due to the high variance of the mafic minerals (mainly biotite) with which these elements can easily be correlated. The paucity of mafic minerals, hence their high variance, in this suite has been shown by the result of the petrographic study (Chapter 7).

The hierarchical dendrogram (Fig. 36) for the raw data on which the Kleiner-Hartigan Trees were based indicates four main groupings: (1) Rb, Pb, K and Ba; (2) Li and P; (3) Co, Mn, La, Ti, Zn, Mg, Be, Fe, and Al; and (4) Cu, Na, and Sr. The mineralogical implications of these associations are not clear, although on a broad basis Groups 1, 2 and 4 may be related to the felsic minerals whereas Group 3 may possibly be associated with the mafic minerals.

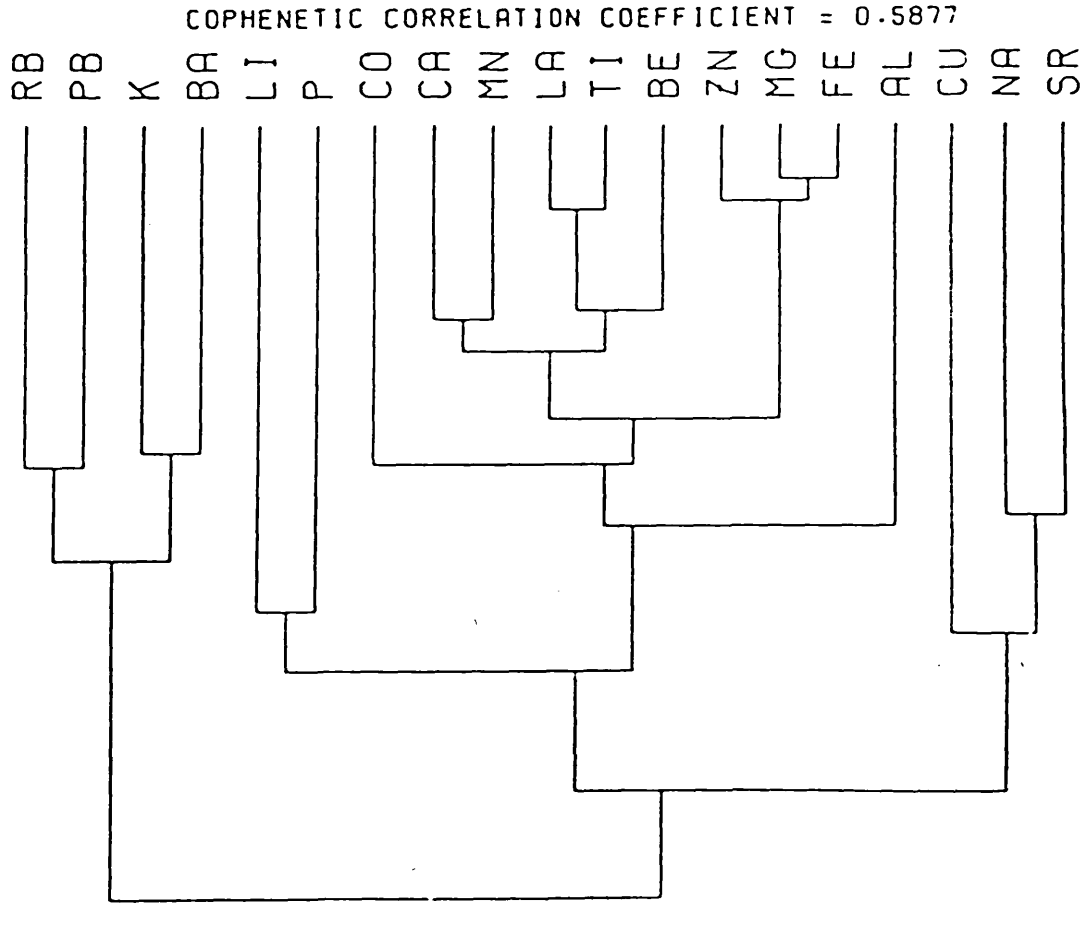


Fig.36. Hierarchical dendrogram showing element associations in the Grebo Town area suite.

8.4.5 Element Ratios

Element abundance ratios for certain selected element pairs have been used to speculate on other chemical properties of these granitic rocks.

The $Al_2O_3/(K_2O+Na_2O+CaO)$ ratio (Fig. 37) shows that these rocks are, on the average, sub-aluminous to meta-aluminous. The K/Rb, Rb/Sr, Sr/Ba, Ba/Rb, Mg/Li and K/Pb ratios were determined (Table 22), as these have been used by various workers to assess the degree of fractionation (and hence mineralization potential) of granitic rocks (Imeokparia, 1980). The values for K/Rb and Ba/Rb are close to those given by Turekian and Wedepohl (242) (1961) and Vinogradov (1962) (8.2) respectively for the average and also by Sengputa (1983) for an unmineralized pegmatite granite from India. The Mg/Li value is very much higher than that given by Sheraton and Black (1973) for the tin-bearing Esmeralda Granite. The exact degree of fractionation attained by these rocks is not quite clear on the basis of these ratios, but it is likely to be later than an early stage of evolution. After removing three extremely high values (6.5, 7.9, and 17.56) the K_2O/Na_2O ratio lies between 0.3 and 4.0, with a mean of about 1.44, suggesting that these granitoids range from granodiorite to alkali granite (Balasubrahmanyan, 1978; Sengputa et al., 1983) (Fig. 38). This is in agreement with the petrographic study of the area.

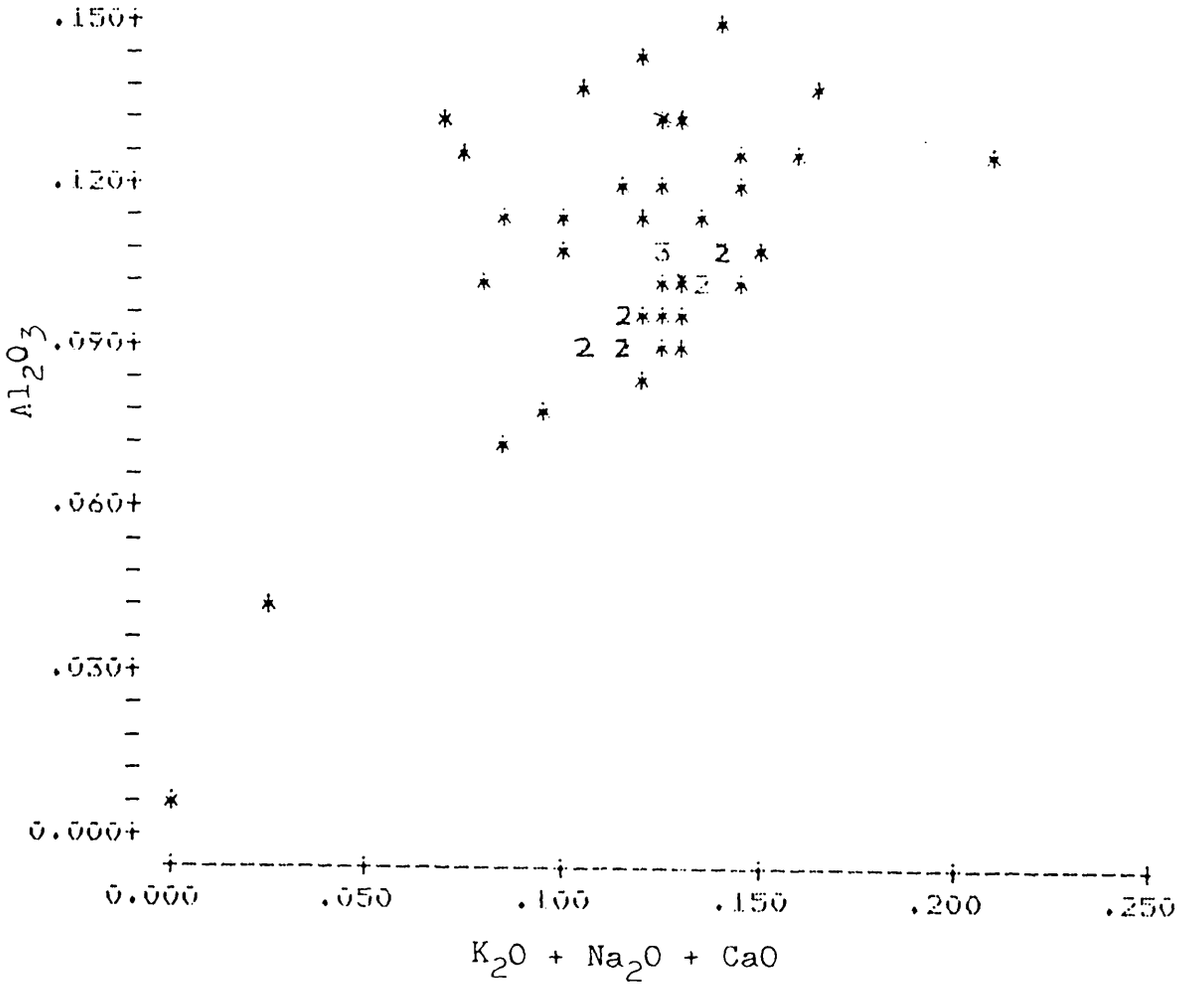


Fig.37. Plot of Al_2O_3 vs K_2O + Na_2O +CaO, Grebo Town area suite.

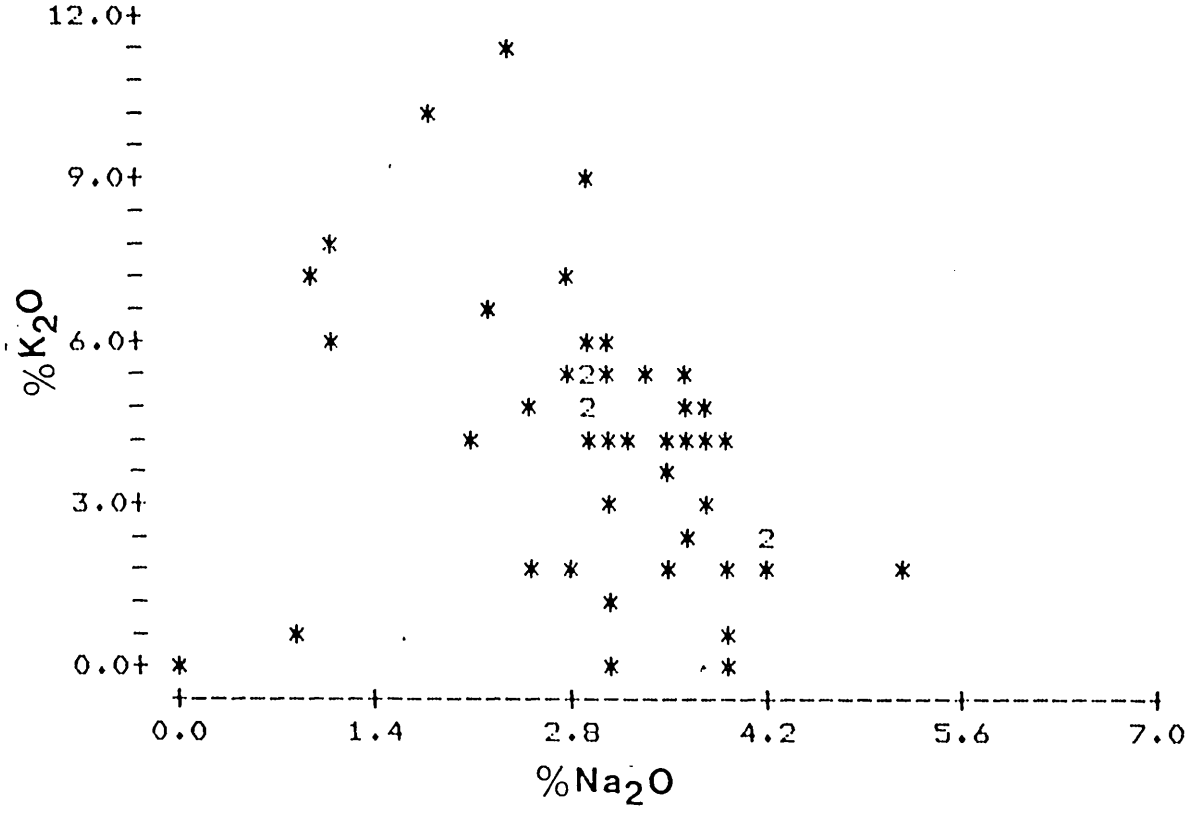


Fig.38. The K_2O vs Na_2O plot for the Grebo Town area suite.

8.4.6 Ridge Regression Analysis

A number of trace elements were regressed on the majors. The basis for this technique was given in Chapter 6. The parameters used, and the results are shown in Table 24.

Residual probability plots were also obtained for each of the dependent variables to check if they had normal distributions and to identify outliers. All of the plots, with the exception of Sr, had linear trends, indicating approximate normal distributions.

Kleiner-Hartigan Trees were applied to the (positive) residuals obtained from the ridge regression analysis in order to identify any dependent elements showing higher relative residual concentrations in any of the samples. The results are shown in Table 25 . It is apparent from this that of all the elements concerned Ba and Sr have higher relative residual concentrations in the majority of the samples More significant, however, is the observation that all the elements showing higher relative residual concentrations are granitophiles, with the exceptions of Zn and Cu, which probably underscores the granitic nature of the suite of rocks being studied. This may also lend support to a conclusion reached earlier that this suite appears to be the most fractionated among the granitic rocks of this study.

8.4.7 Spatial Distribution of the Elements

The geographical distribution pattern for 21 elements determined in this suite is shown in Fig 39(a-u). It is obvious from these figures

TABLE 24 RESULTS AND PARAMETERS FOR THE RIDGE ANALYSIS

	Initial			Final		Important Predictors**	Linear Model
	n	R^2	K	n*	R^2		
Li	45	0.44	0.2	39	0.72	Al, Ti, Mg-Ca	ok
Rb	43	0.84	0.2	41	0.86	K, Al, Ti-Ca	ok
Be	45	0.52	0.2	43	0.62	Mn, Na, Ti, Fe-K	ok
Sr	45	0.45	0.2	40	0.69	Al, Ca-Mg	ok
Ba	45	0.67	0.2	44	0.66	K, Ti-Mn-P	ok
Cu	44	0.44	0.2	40	0.59	Ca, Ti-Mg	ok
Zn	45	0.74	0.2	43	0.78	Ti, Fe, Na-Ca	ok
Pb	45	0.68	0.2	40	0.83	K, Al, P-Mg	ok

* Representing "background" relationship.

** Elements with standardized coefficients exceeding $\pm$ 0.1.

n = No. of samples.

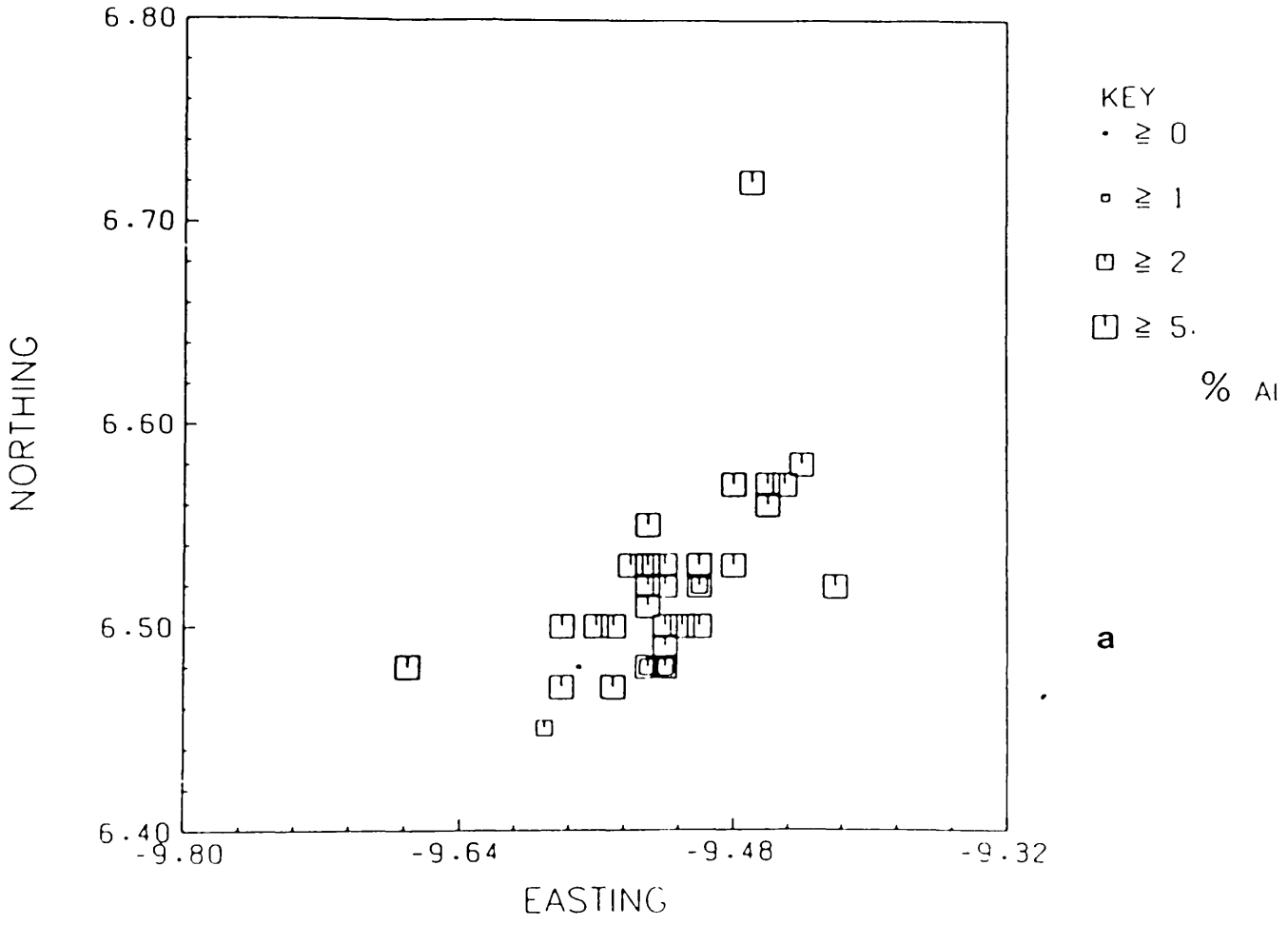
R^2 = Multiple correlation coefficient.

K = Ridge constant.

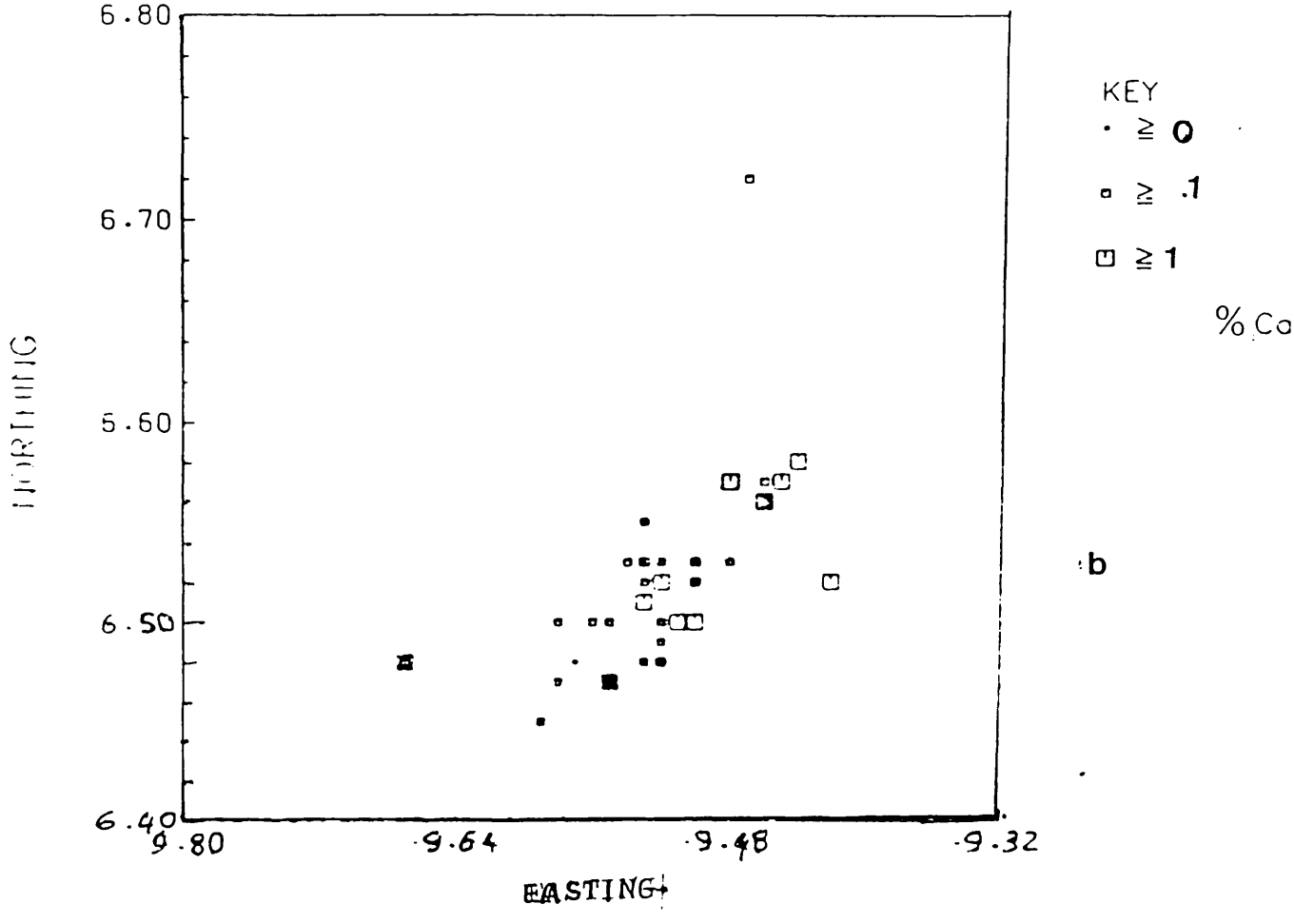
TABLE 25 LOCATIONS OF SAMPLES (FROM THE GREBO TOWN AREA) HAVING HIGHER RELATIVE RESIDUAL CONCENTRATIONS OF CERTAIN ELEMENTS

SAMPLE NO.	ELEMENTS	CO-ORDINATES N	W
4784	Be	6° 30'	9° 33'
4871	Cu, Li, Be	6° 10'	9° 08'
4804	Cu	6° 29'	9° 31'
4847	Li, Rb	6° 30'	9° 31'
4845	Li, Rb	6° 30'	9° 31'
4803	Zn, Li, Rb	6° 29'	9° 31'
4792	Li, Ba, Sr	6° 29'	9° 34'
4846	Ba, Li	6° 29'	9° 31'
4834	Ba, Sr	6° 41'	9° 30'
4816	Ba, Sr	6° 34'	9° 37'
4824	Ba, Sr	6° 31'	9° 31'
4783	Be, Cu, Pb	6° 29'	9° 32'

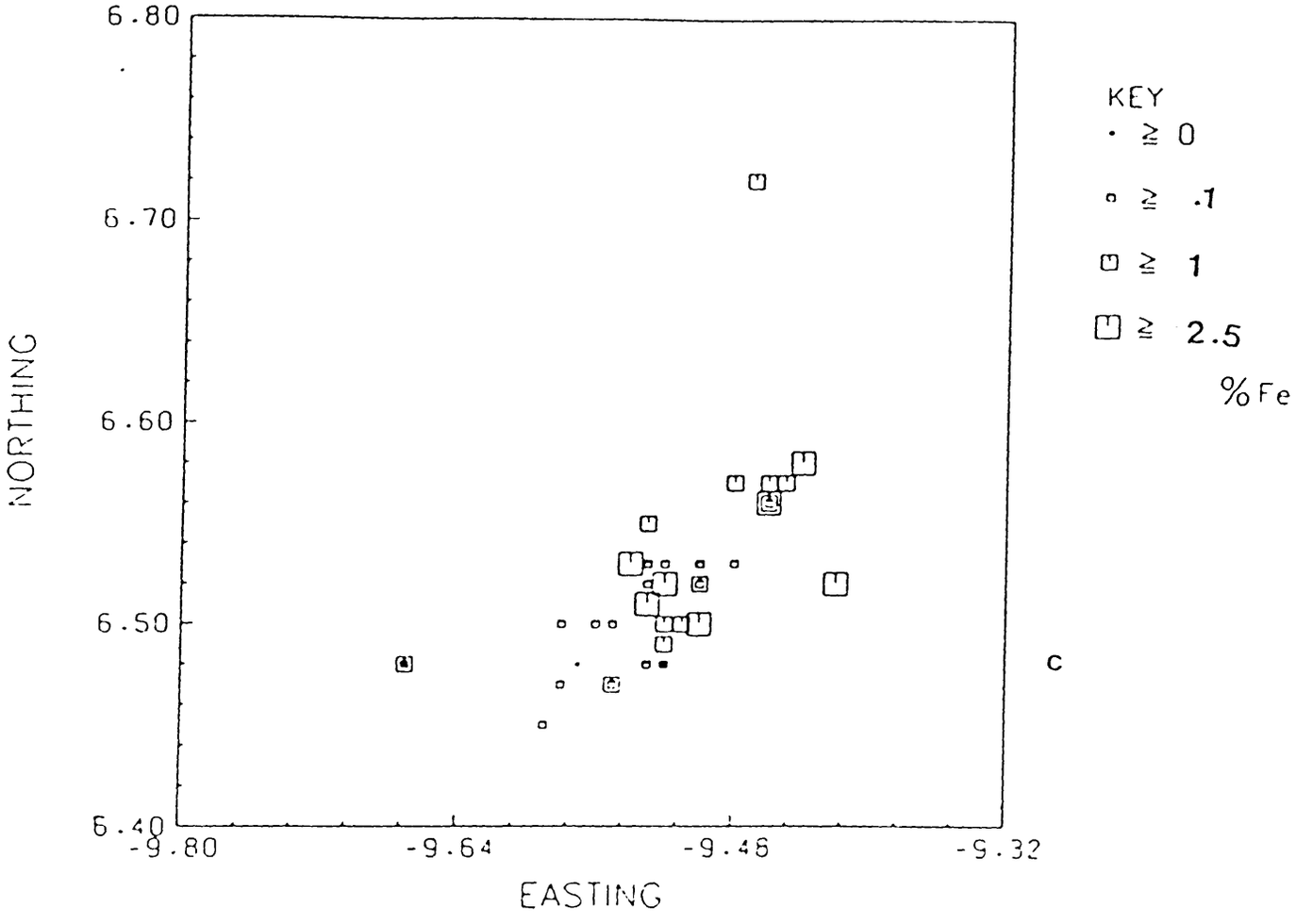
Fig.39(a-u). The geographical distribution patterns of twenty-one of the elements determined in the Grebo Town area suite. Simplified geology overlay can be found in the rear pocket of the thesis.

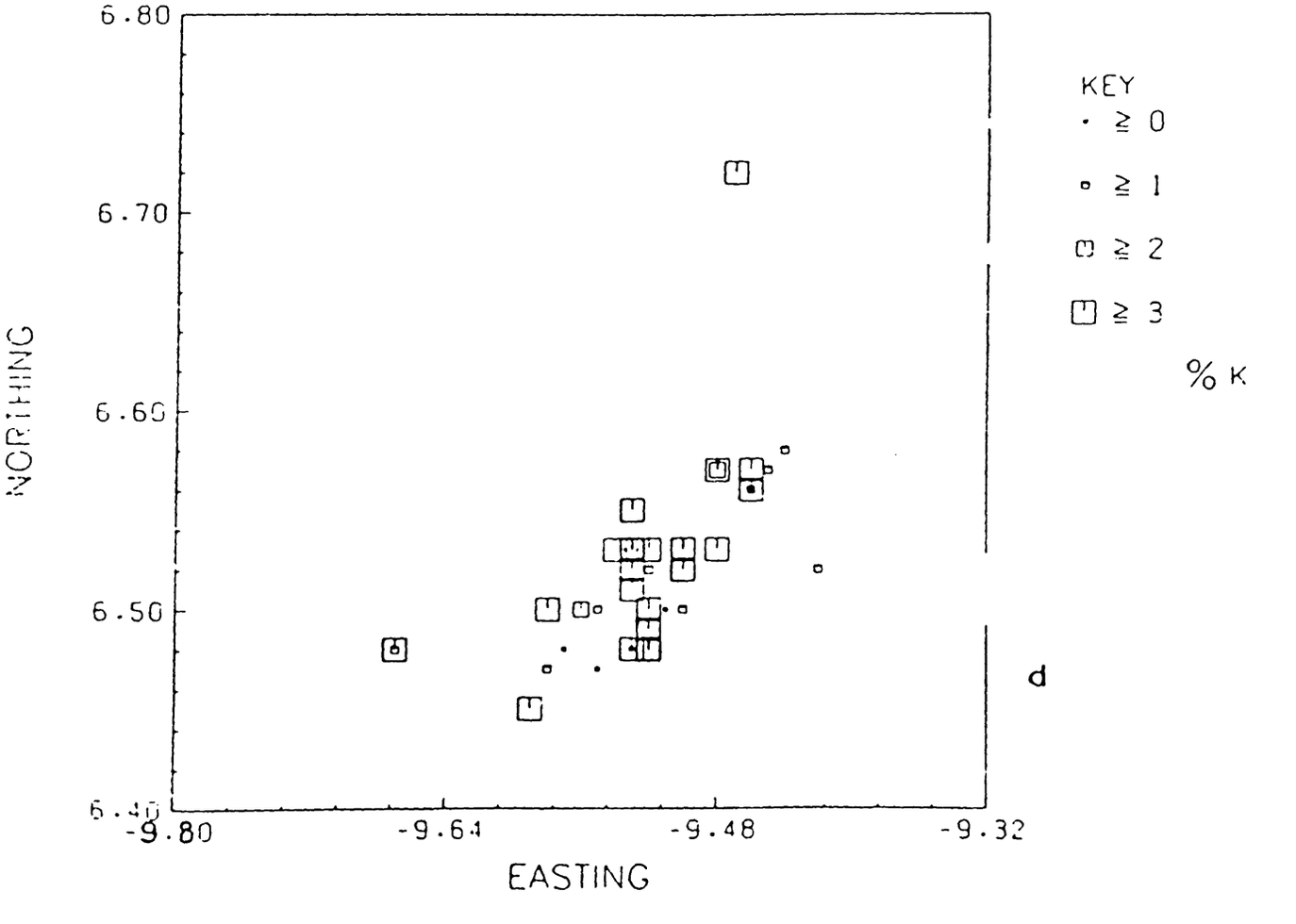

6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
≧ 0
≧ 1
≧ 2
≧ 5.
% Al

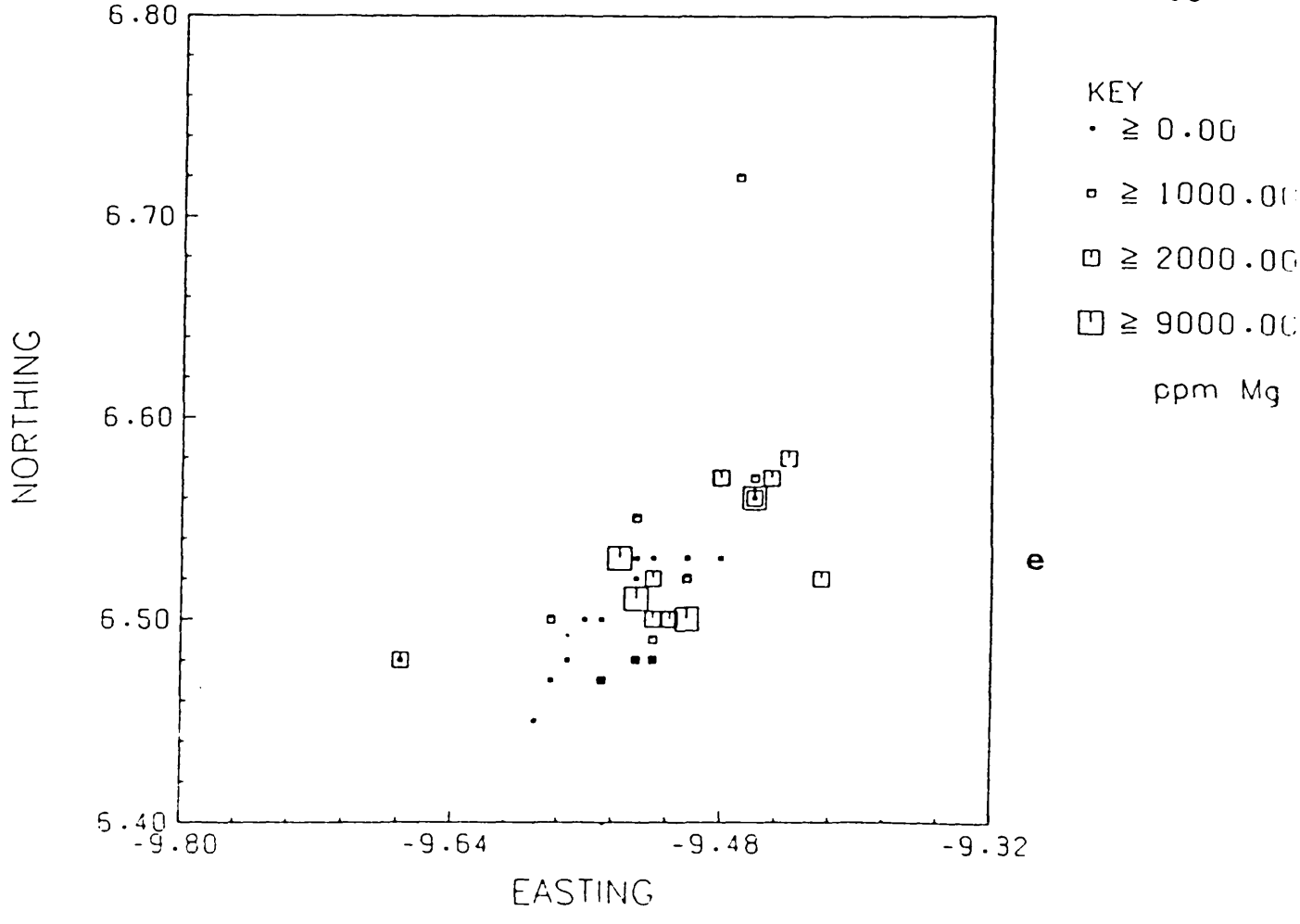
a

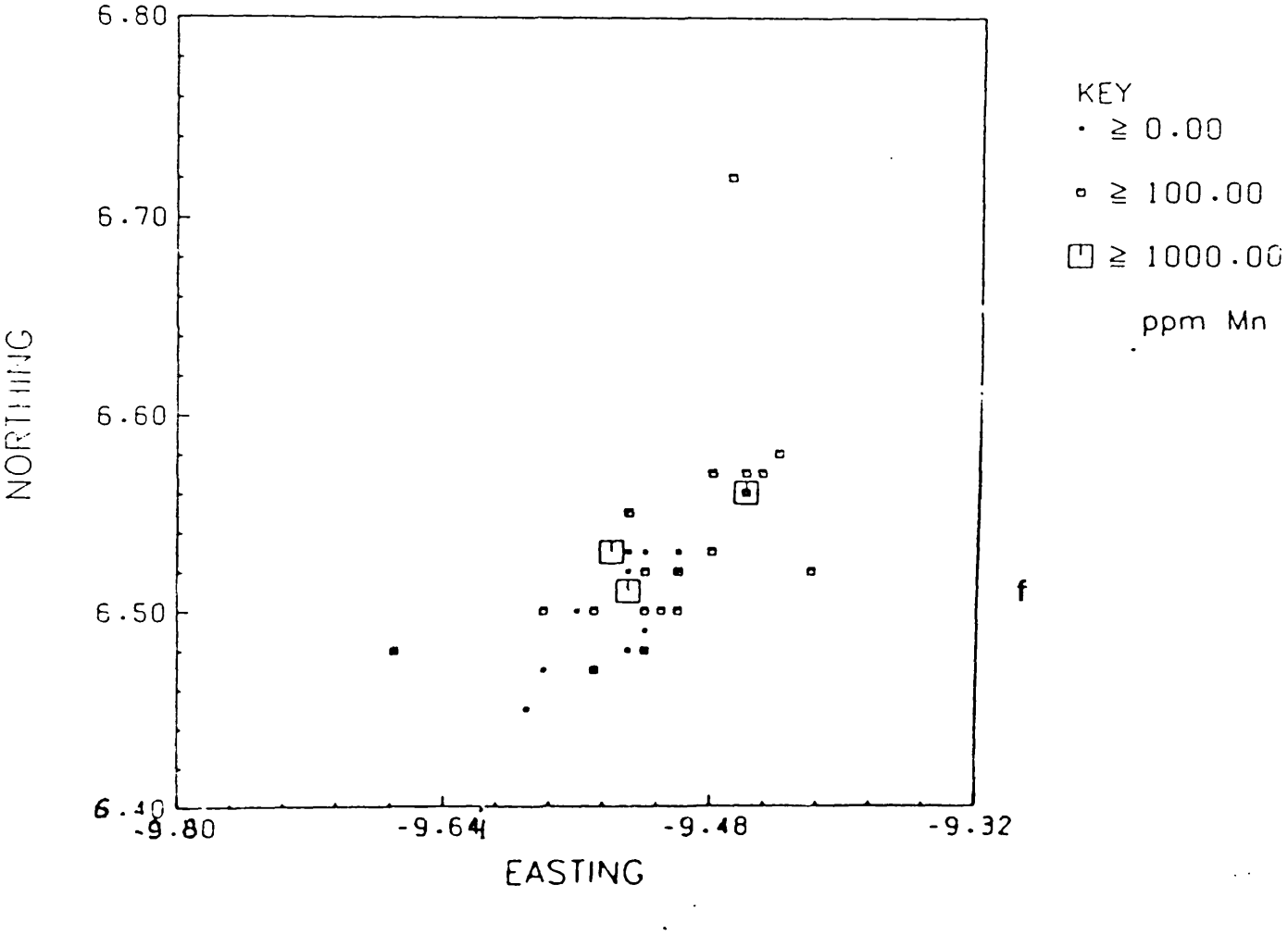

6.80
6.70
6.60
6.50
6.40
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
≧ 0
≧ .1
≧ 1
% Co

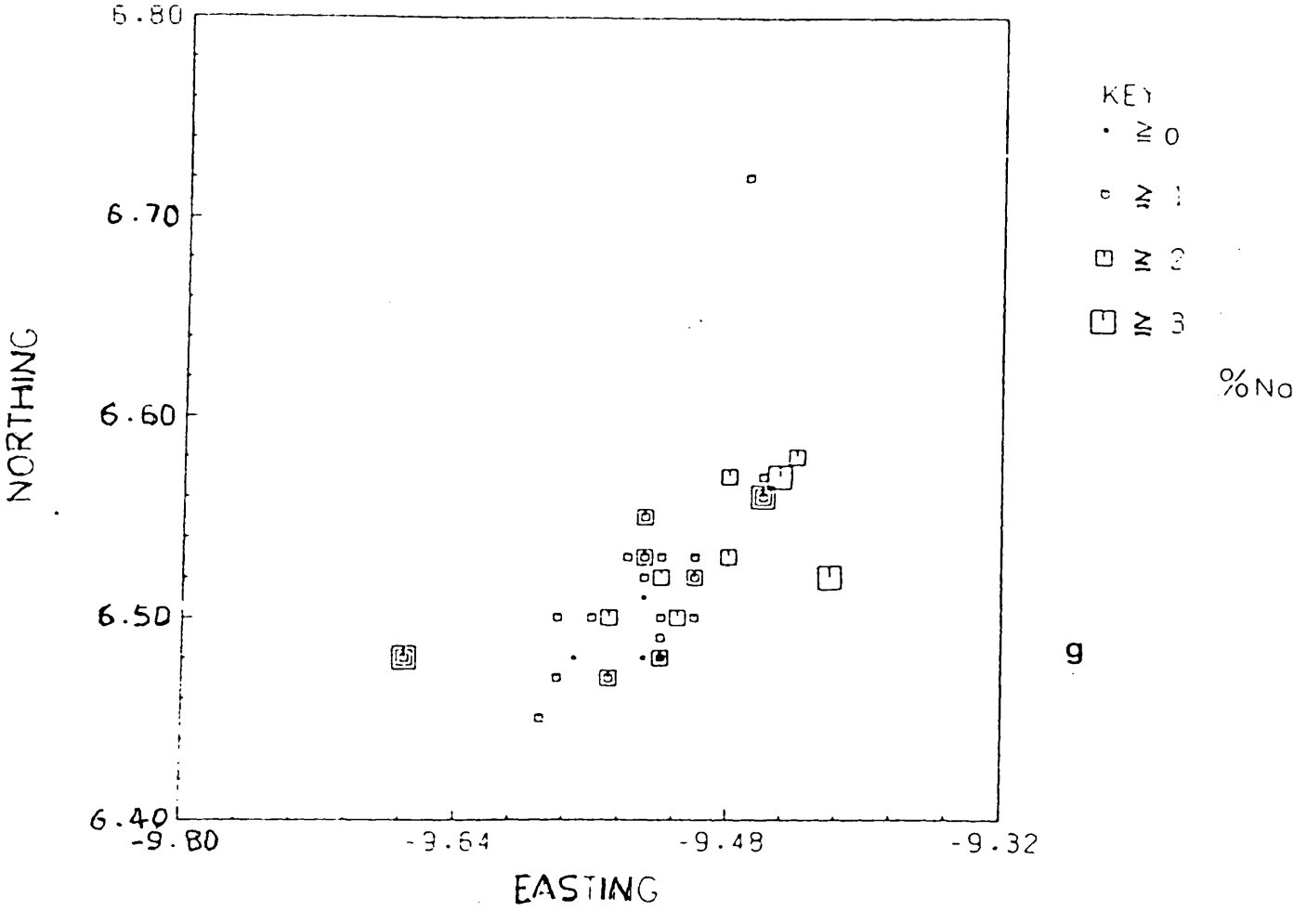
b


6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
• ≥ 0
▫ ≥ .1
□ ≥ 1
▣ ≥ 2.5
% Fe
c

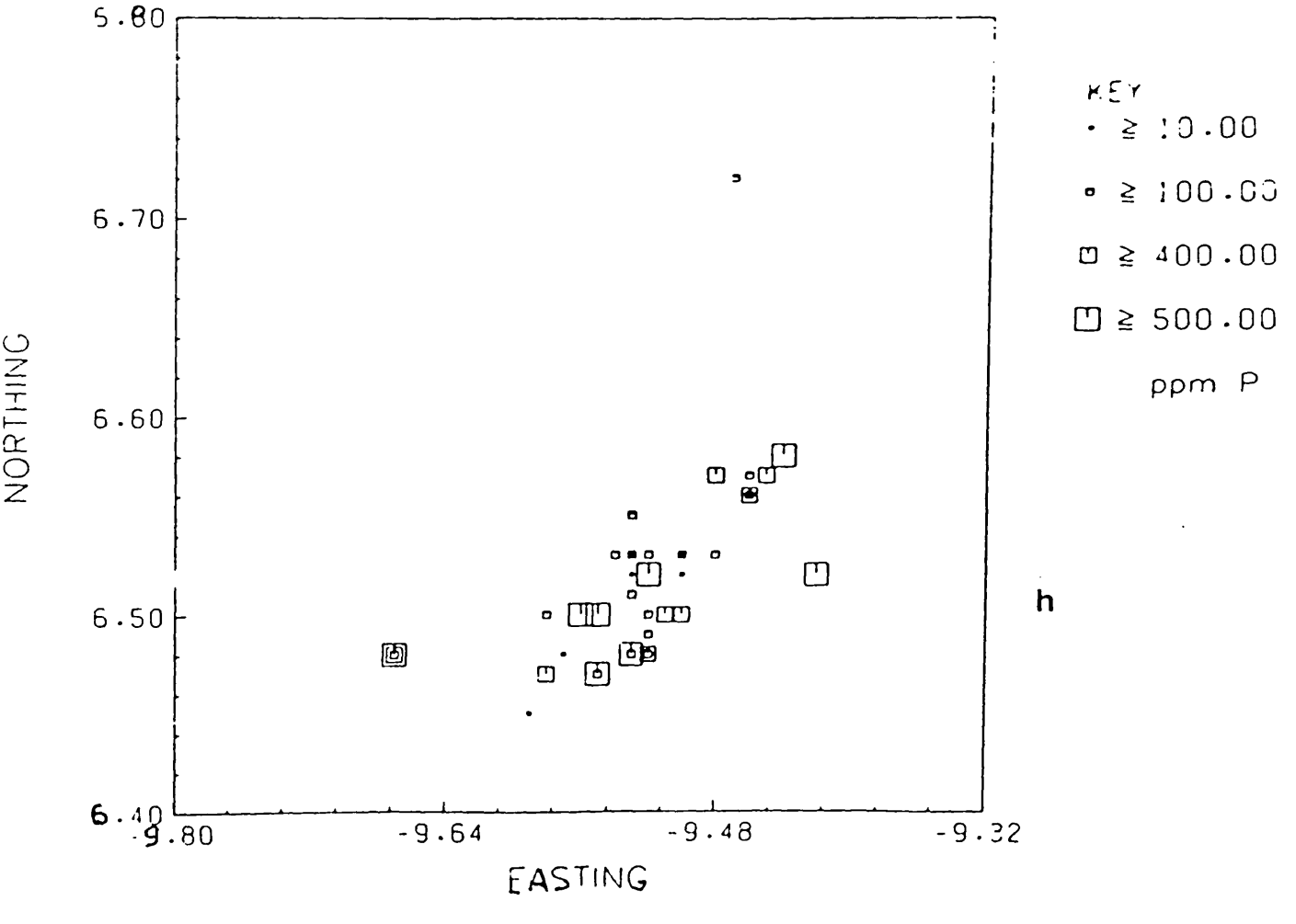

6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
• ≥ 0
▫ ≥ 1
□ ≥ 2
▣ ≥ 3
% K
d


6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
• ≧ 0.00
▫ ≧ 1000.00
⊡ ≧ 2000.00
⊞ ≧ 9000.00
ppm Mg
e

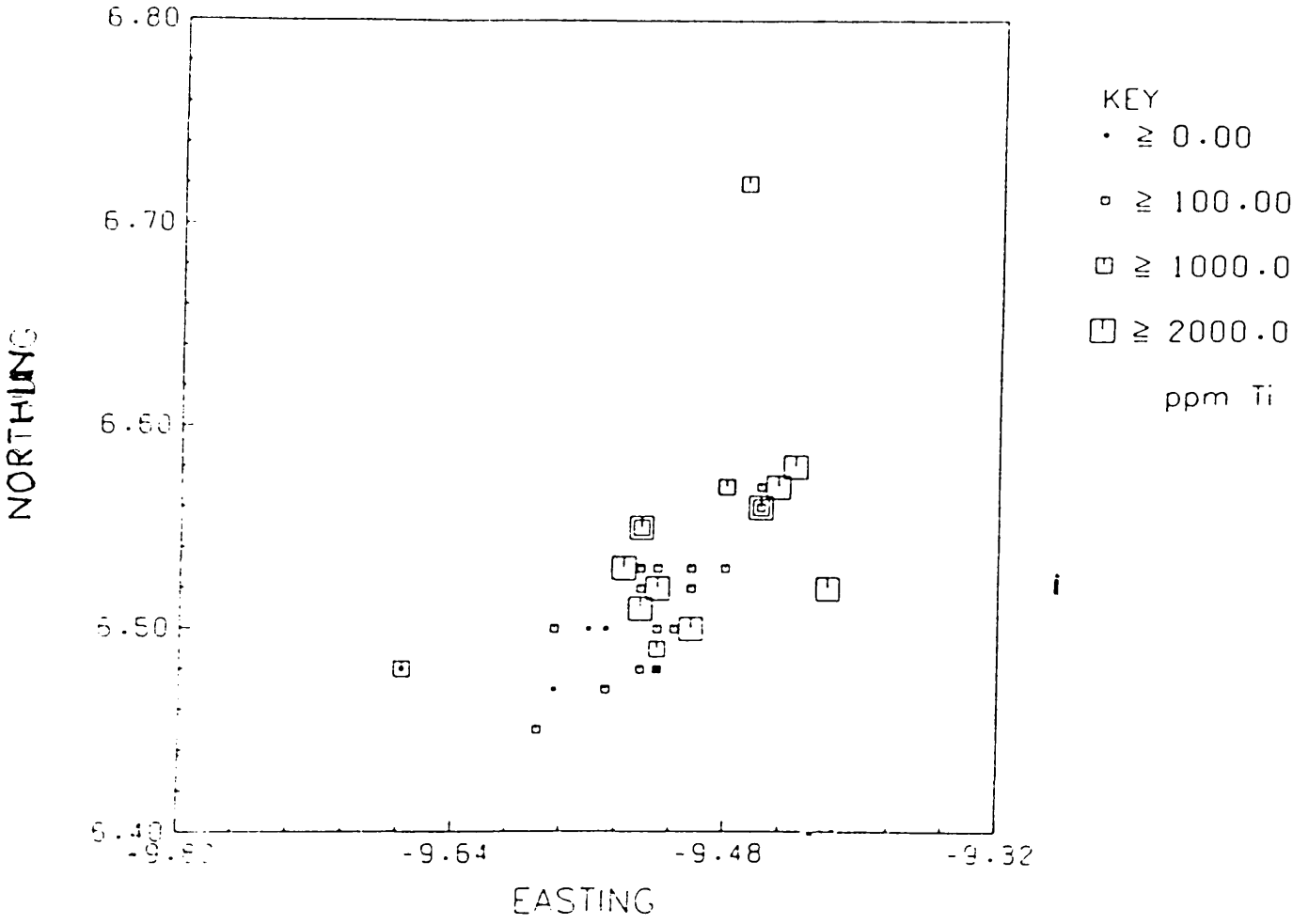

6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
• ≧ 0.00
▫ ≧ 100.00
⊞ ≧ 1000.00
ppm Mn
f


6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
≧ 0
≧ 1
≧ 2
≧ 3
%No

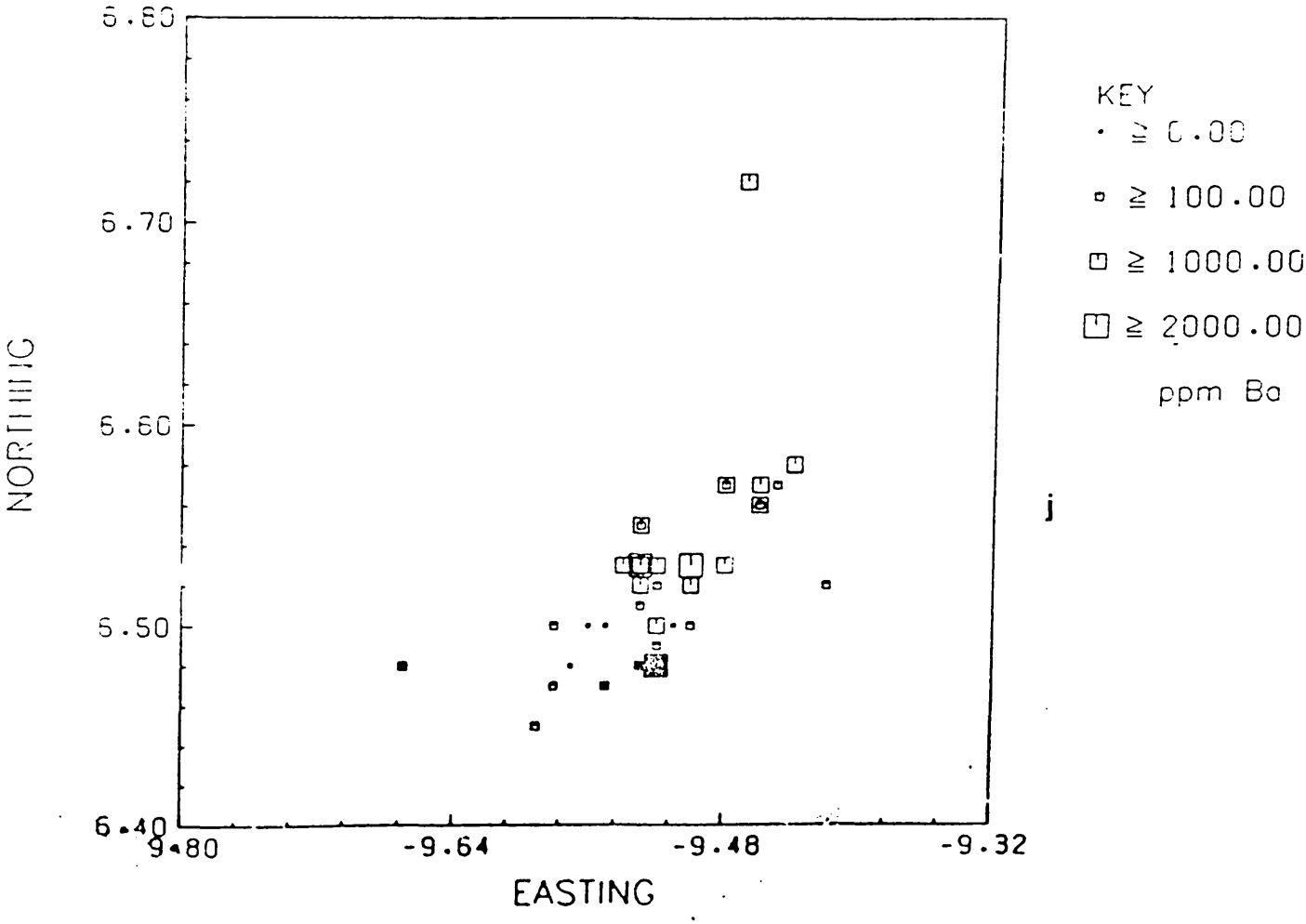
g


6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
≧ 10.00
≧ 100.00
≧ 400.00
≧ 500.00
ppm P

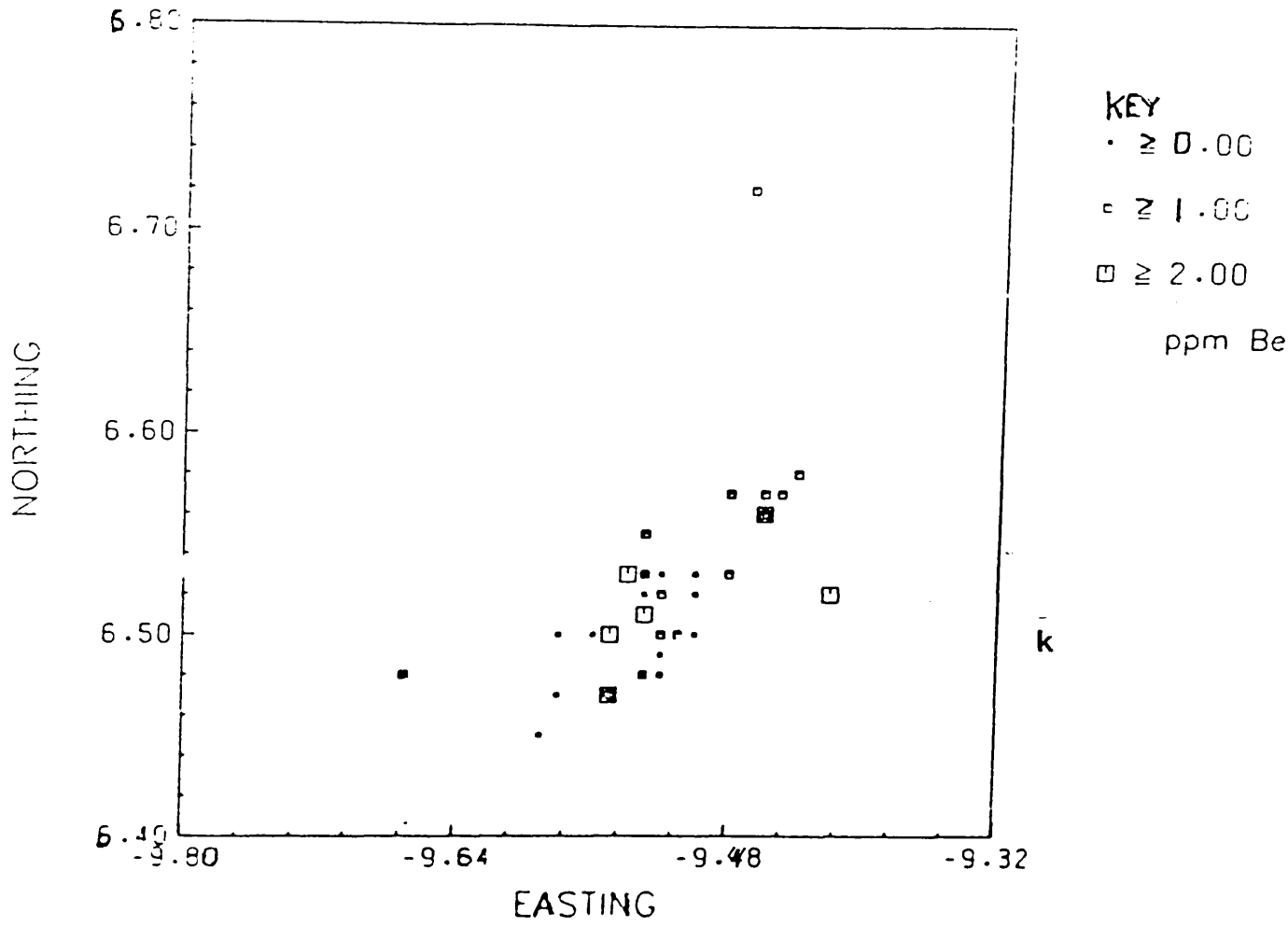
h

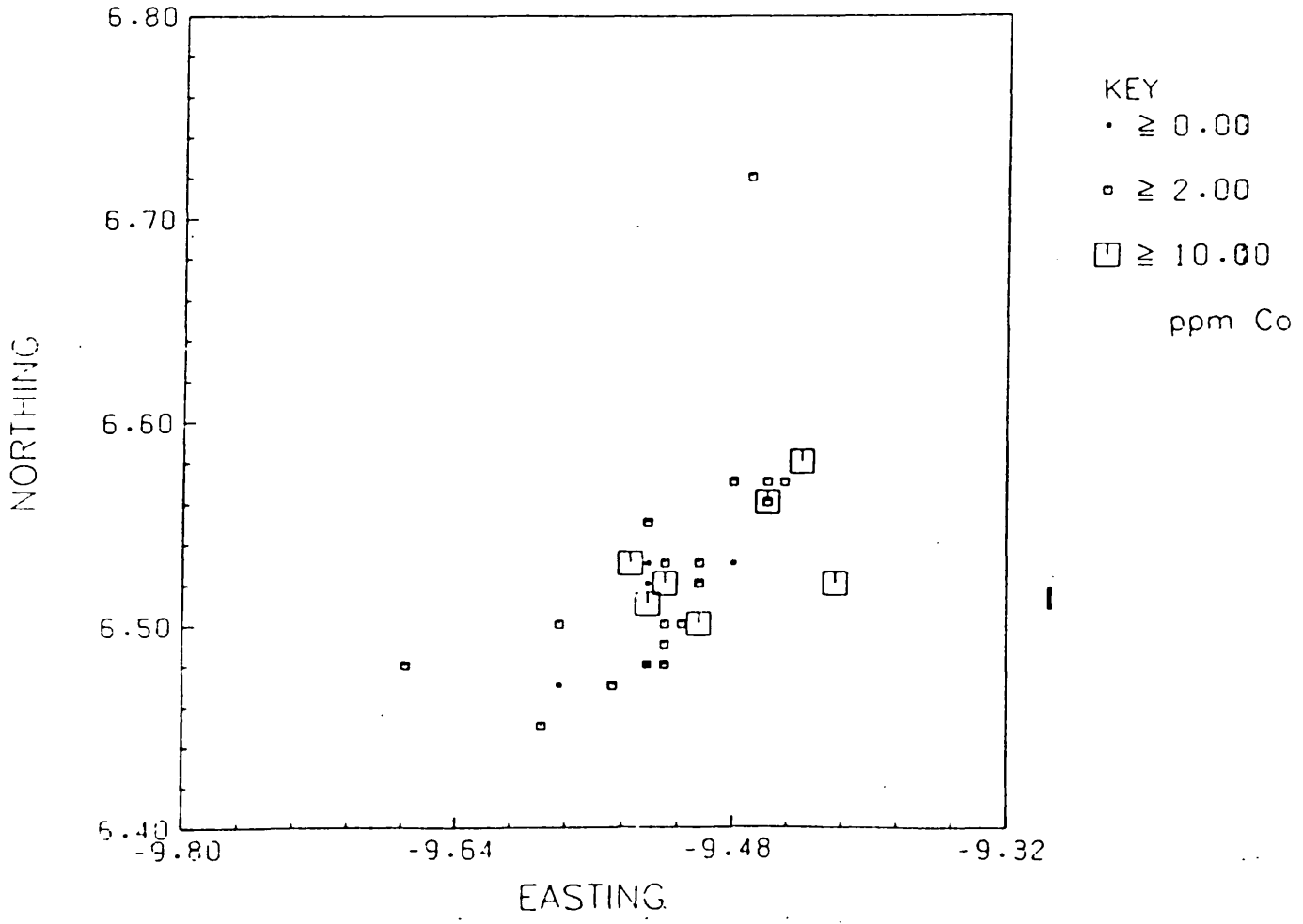

6.80
6.70
6.60
6.50
6.40
NORTHING
-9.64
-9.48
-9.32
EASTING
KEY
≥ 0.00
≥ 100.00
≥ 1000.00
≥ 2000.00
ppm Ti

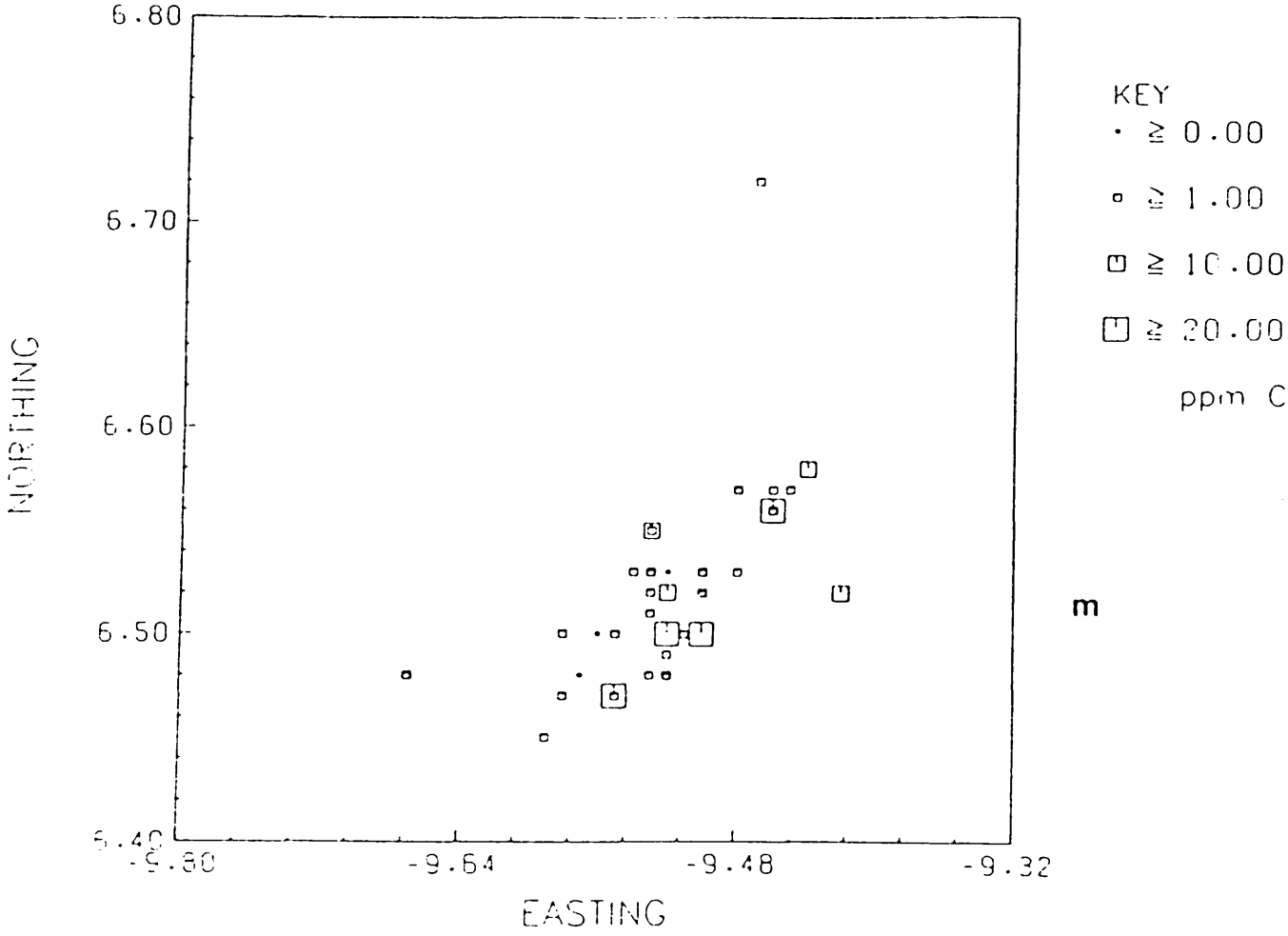
i


6.80
6.70
6.60
6.50
6.40
NORTHING
9.80
-9.64
-9.48
-9.32
EASTING
KEY
≥ 0.00
≥ 100.00
≥ 1000.00
≥ 2000.00
ppm Ba

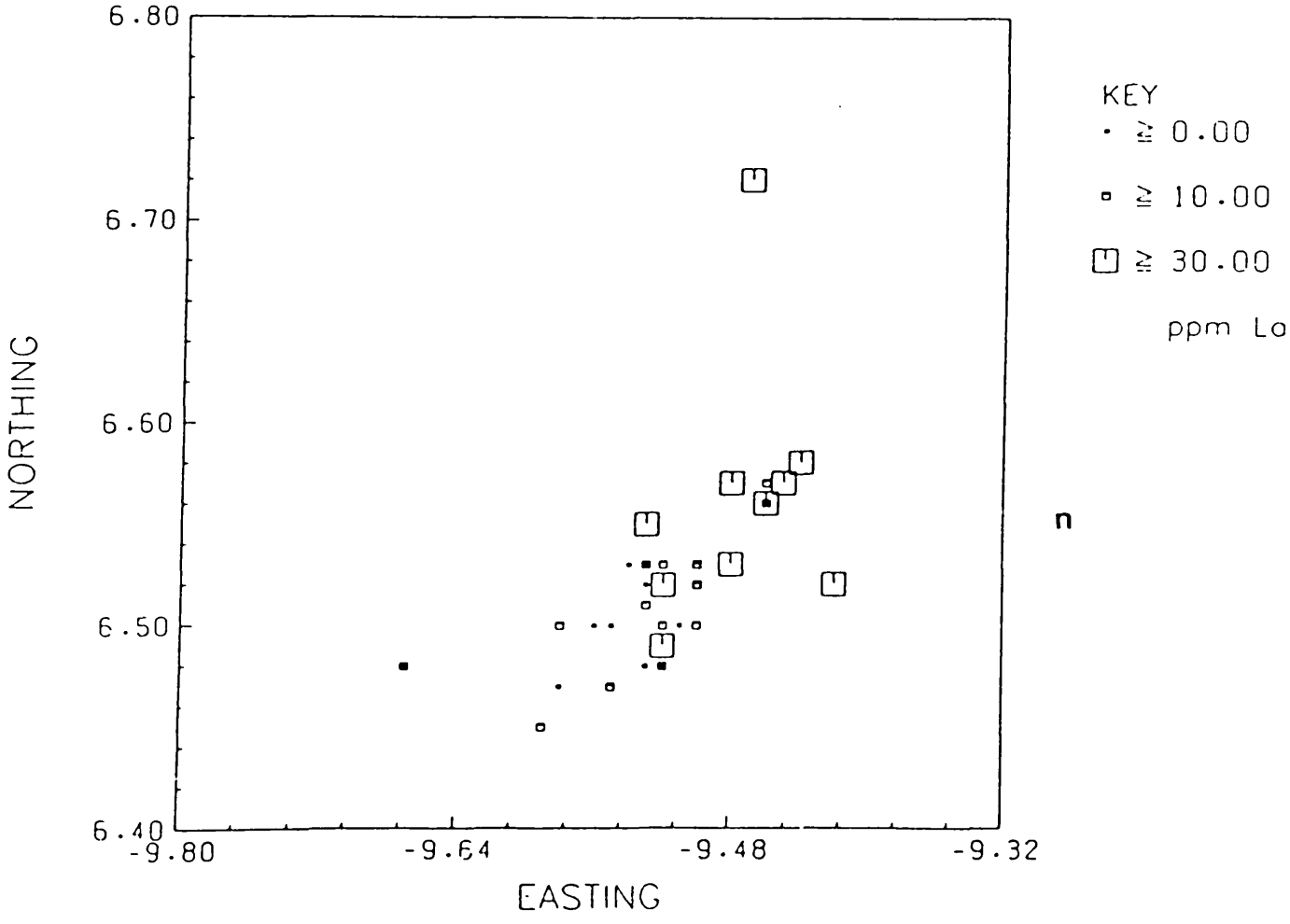
j


KEY
• ≧ 0.00
▫ ≧ 1.00
□ ≧ 2.00
ppm Be
NORTHING
6.70
6.60
6.50
-9.80
-9.64
-9.48
-9.32
EASTING

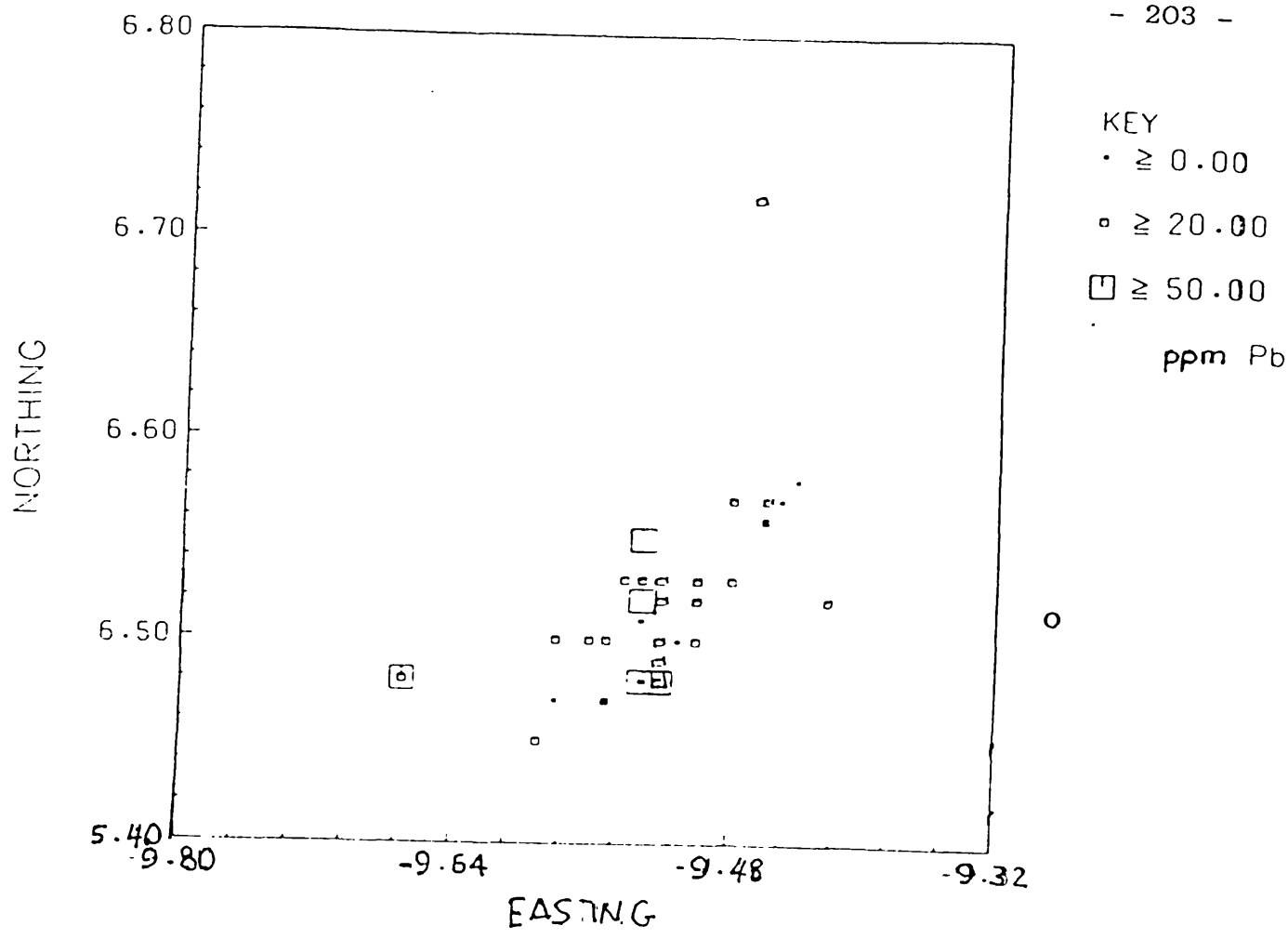

KEY
• ≧ 0.00
▫ ≧ 2.00
□ ≧ 10.00
ppm Co
NORTHING
6.80
6.70
6.60
6.50
-9.80
-9.64
-9.48
-9.32
EASTING

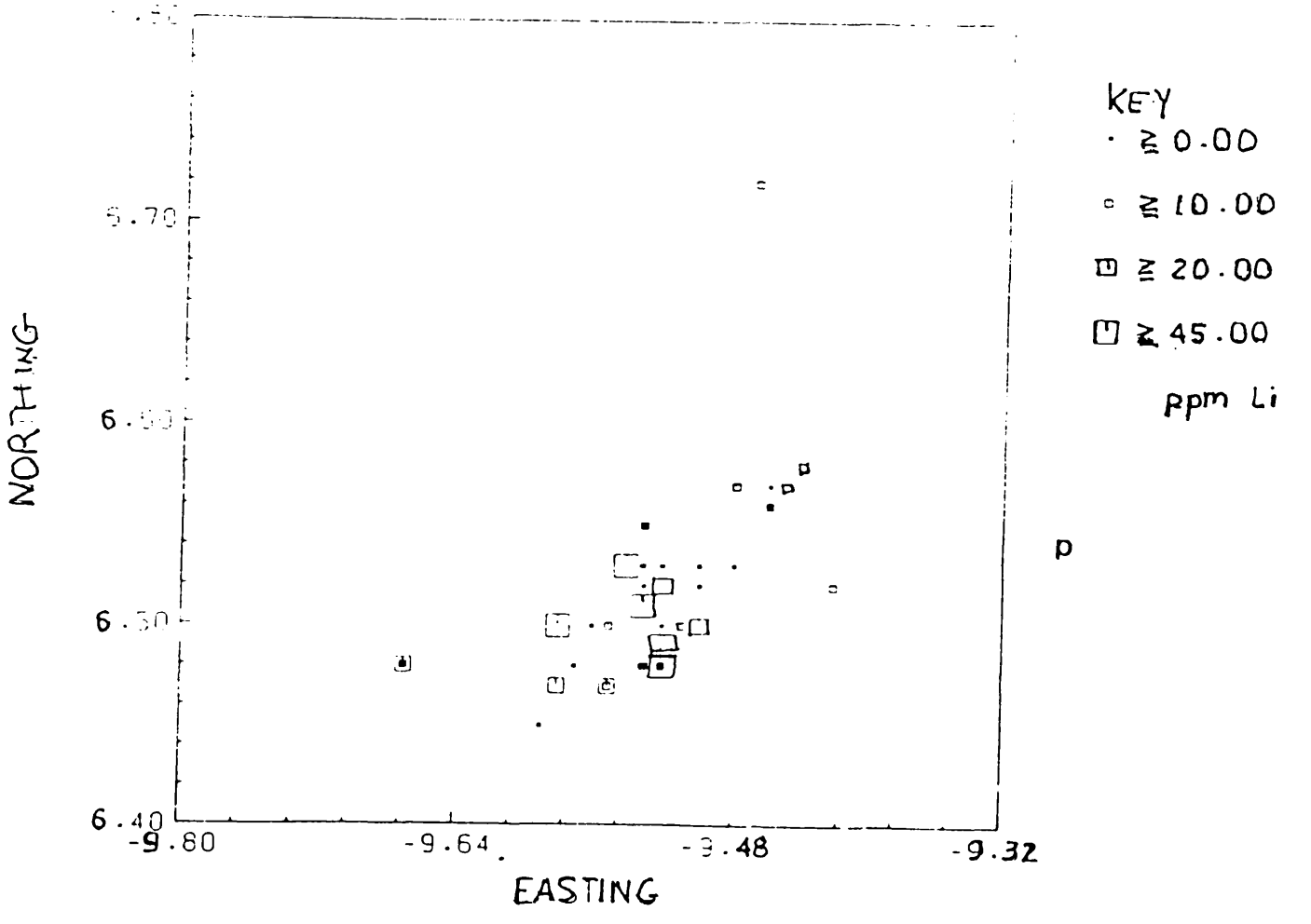

6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
≥ 0.00
≥ 1.00
≥ 10.00
≥ 20.00
ppm Cu

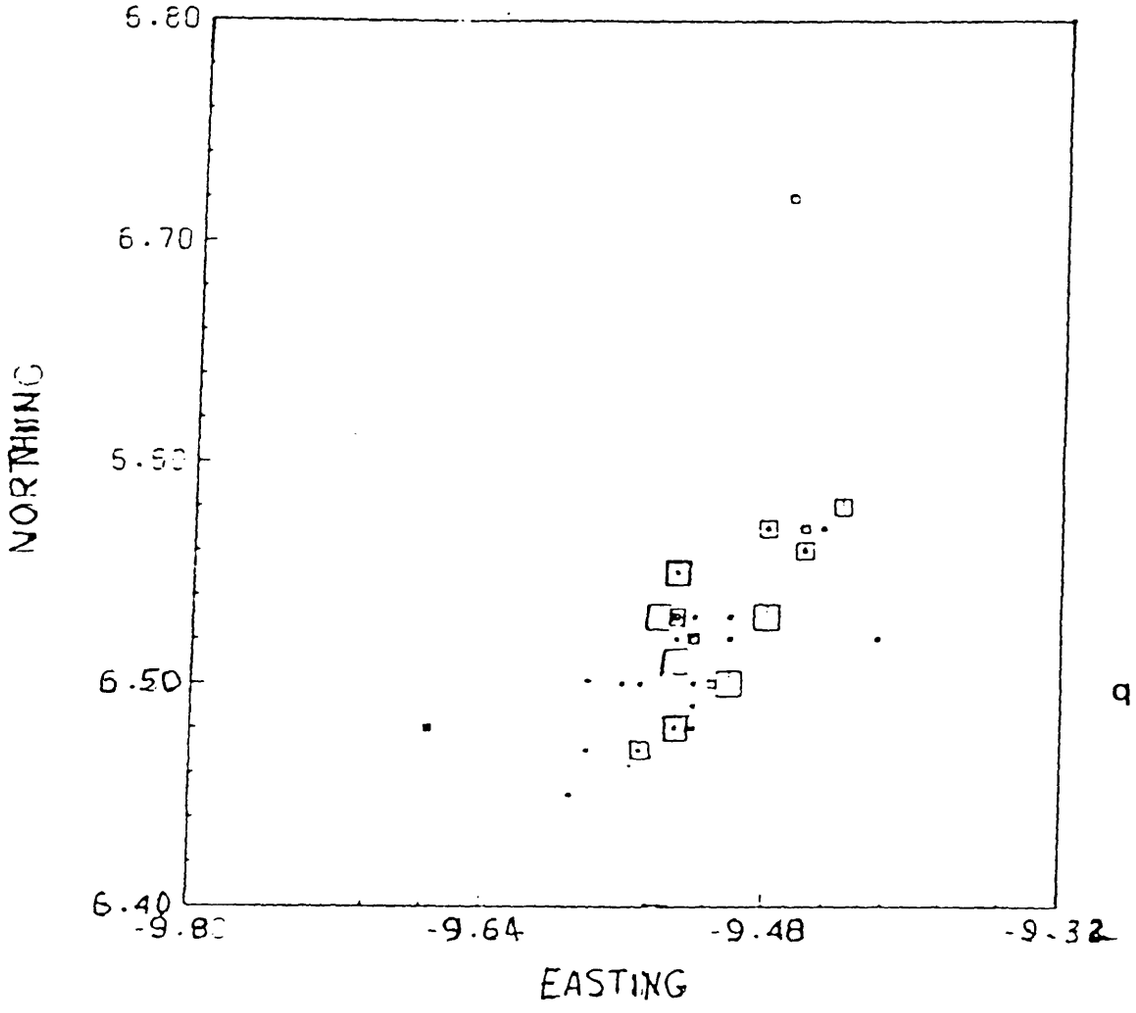
m

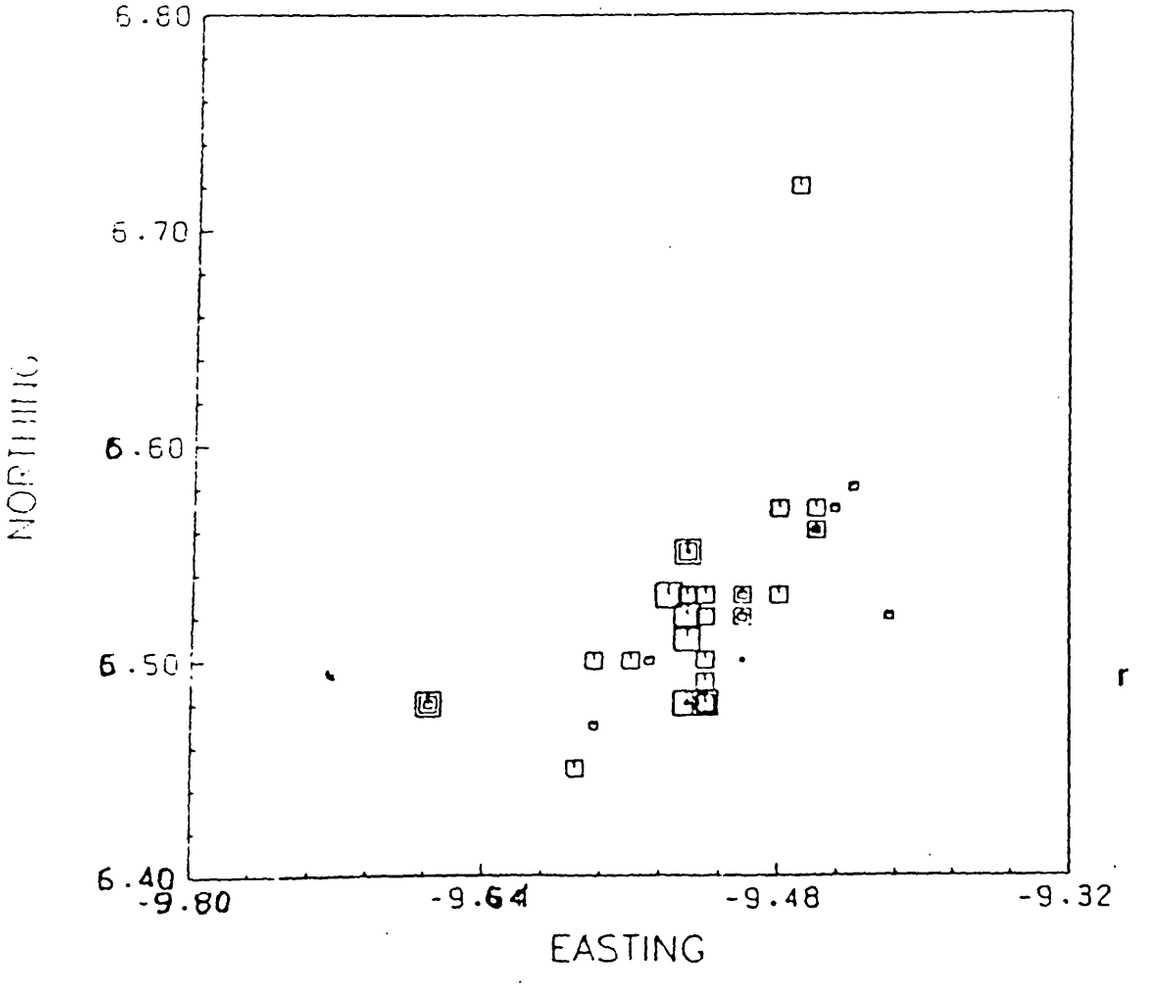

6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
≥ 0.00
≥ 10.00
≥ 30.00
ppm La

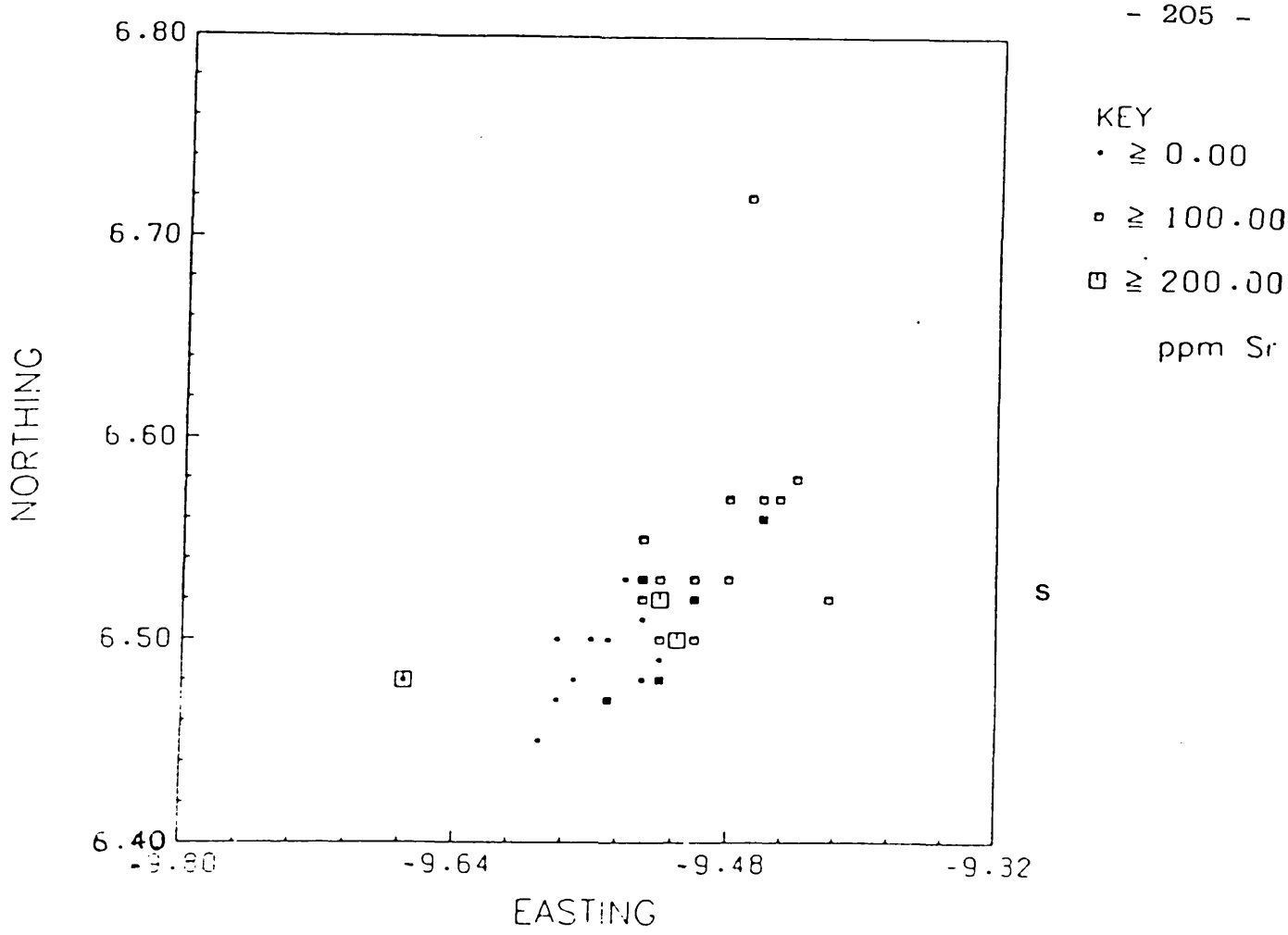
n

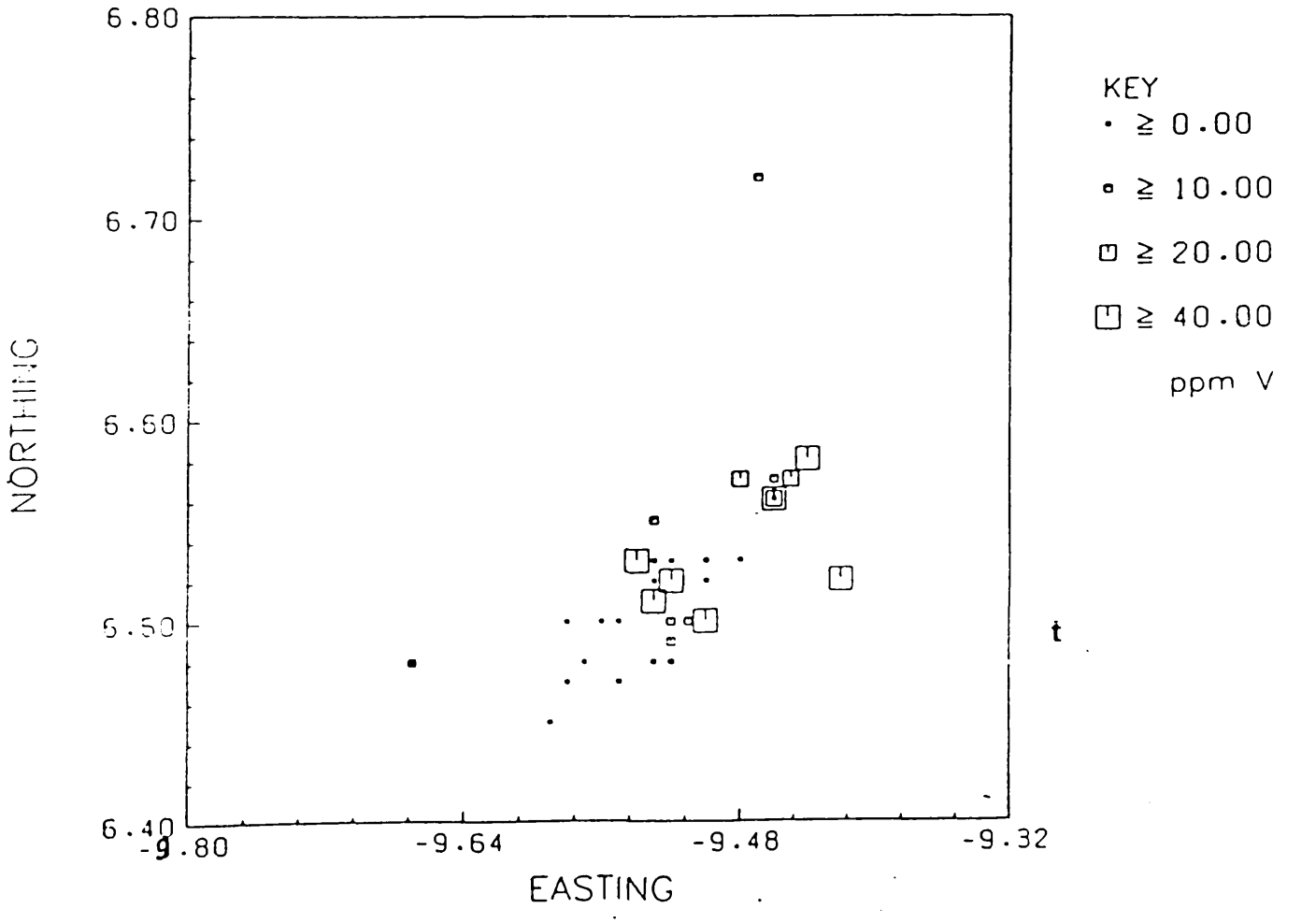

6.80
6.70
6.60
6.50
5.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
≧ 0.00
≧ 20.00
≧ 50.00
ppm Pb

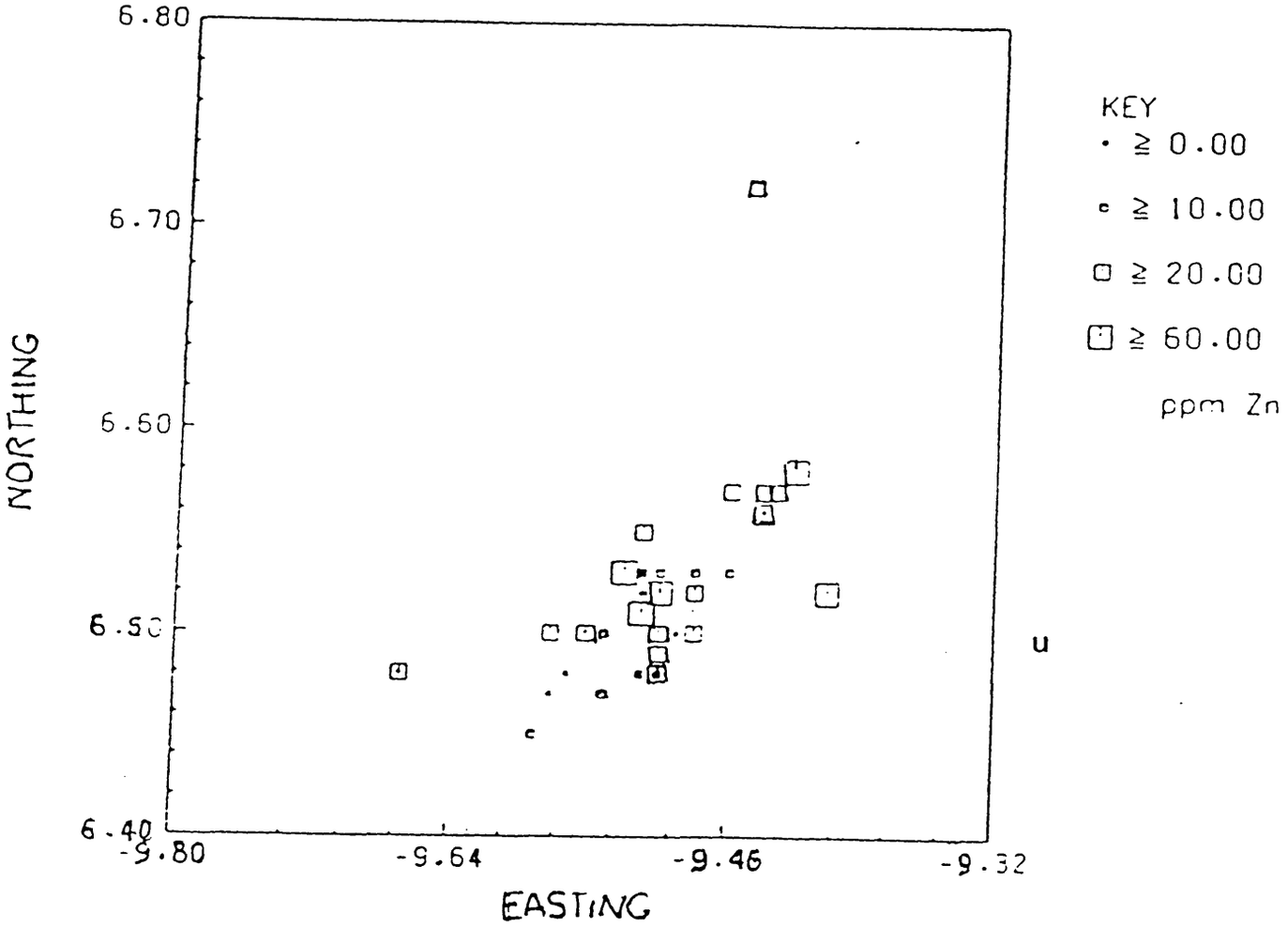

6.70
6.50
6.30
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
≧ 0.00
≧ 10.00
≧ 20.00
≧ 45.00
ppm Li


6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
≥ 0.00
≥ 10.00
≥ 20.00
≥ 40.00
ppm Ni


6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
≥ 0.00
≥ 50.00
≥ 100.00
≥ 200.00
ppm Rb


6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
• ≧ 0.00
▫ ≧ 100.00
⊡ ≧ 200.00
ppm Sr
S


6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.48
-9.32
EASTING
KEY
• ≧ 0.00
▫ ≧ 10.00
⊡ ≧ 20.00
⊞ ≧ 40.00
ppm V
t


6.80
6.70
6.60
6.50
6.40
NORTHING
-9.80
-9.64
-9.46
-9.32
EASTING
KEY
• ≧ 0.00
◦ ≧ 10.00
□ ≧ 20.00
⊡ ≧ 60.00
ppm Zn

that most of the elements appear to have higher concentration in the central part of and at the eastern extreme of the sampled area. This observed trend of element geographical distribution may possibly be the result of the mobility of some of these elements, as aided or induced by the large-scale metamorphism which has affected the region as a whole. On the other hand, this could possibly be a phenomenon of some kind of natural random grouping of elements where favourable geochemical environments exist. But too small an area has been covered to provide data to firmly establish or reject such theories in the present investigation.

8.4.8 Summary and Conclusion

The available chemical data on the suite of rocks from the Grebo Town area suggest that the major elements display moderate variance whereas the trace elements show very wide ranges of concentrations. Ahrens (1964); Govett, (1983) and other workers have related such behaviour of elements to their levels of concentration in certain rock types. The mafic elements (which are especially low in these rocks) show the highest degree of variability. The chemical and petrographic characteristics of this suite may also be considered in relation to the "alleged" cassiterite (and columbite) mineralization in this area. The deficiency of these granitic rocks in elements such as Ca, Mg, Fe, V, and Sr and their enrichment in the granitophiles K, Rb and Li is significant as such opposing trends

are possibly indicative of relatively high degree of fractionation and, hence the possibility of mineralization, especially if there has been water-rock interaction (Simpson et al., 1977). The high standard deviation of trace element concentrations in these rocks may similarly be taken into consideration in this connection as it is considered as one of the characteristics of mineralization potential of granitoids (Plant et al., 1980; Govett, 1983).

The findings of the petrographic study are consistent with the relative enhancement of the granitophiles over the mafic elements for they indicate that the rocks from this area are pegmatitic. A number of other petrographic features including the indication of water-rock interaction (e.g. replacement of biotite by muscovite, the presence of tourmaline), sericitization and/or kaolinization of feldspar and chloritization and/or epidotization of ferromagnesian minerals have also been observed in these rocks. Such (hydrothermal) petrographic characteristics have been interpreted by Plant et al., (1980) as indicative of mineralization potential of granitoids.

8.5 THE GENERAL GEOCHEMISTRY OF THE CESTOS BATHOLITH AREA

8.5.1 Element Abundance

The means, medians, standard deviations, minima, maxima and abundance ratios for the various elements determined are given in Table 26. Relevant analytical data from elsewhere are also provided in this table for comparison.

The present suite of granitic rocks is significantly enriched in almost all of the mafic elements determined, compared with the average granite of Taylor (1964), but is moderately depleted in the granotophile elements K, Na, Be, Li and Rb. A similar comparison with Wedepohl's (1969) average quartz diorite shows that the Cestos Batholith area granitic rocks are slightly higher in K and low in Al, but have comparable contents of Ca, Fe, Mg, Mn and P. On a broad regional basis, the Cestos Batholith rocks are higher in Ca, Fe, K, Mg, Mn, P and Ti but distinctly lower in Na compared with the River Tobenko quartz diorite of Sierra Leone (Marmo, 1971). These comparisons should be accepted with caution however, as factors such as the numbers of samples and standard deviations are not known for the literature data used for comparison.

8.5.2 The Frequency Distribution of the Chemical Elements

Histograms and normal probability (Q-Q) plots were obtained for the twenty- one elements , using the Minitab package. Visual inspection indicated

TABLE 26 COMPOSITION OF THE CESTOS BATHOLITH AREA SUITE IN RELATION TO OTHER SUCH ROCKS

Majors(%)	Means	St. Deviation	Median	Min	Max	1	2	3	4
Al	6.73	1.24	6.90	0.54	8.90	7.46	8.25	8.20	7.8
CaCa	3.28	1.50	3.30	1.38	9.80	1.24	3.30	3.07	1.42
Fe	3.80	1.24	3.90	0.28	11.8	0.77	3.58	3.40	2.52
K	2.32	0.70	2.50	0.11	4.10	0.60	1.18	1.27	3.43
Mg	1.49	0.86	1.45	0.09	5.60	0.07	1.16	1.55	0.33
Mn	0.07	0.03	0.07	0.04	0.27	0.01	0.06	-	0.04
Na	2.62	0.66	2.70	0.05	4.0	4.39	2.80	3.50	2.62
P	0.09	0.03	0.09	0.01	0.15	0.03	0.09	-	0.07
Ti	0.30	0.09	0.32	0.05	0.54	0.01	0.39	0.31	0.144
Trace (ppm)									
Ag	0.10	0.10	0.10	0.10	0.10	-	-	450.0	600.0
Ba	744.0	249.0	790.0	20.0	1130.0	-	-	-	4.0
Be	1.50	0.4	1.60	0.10	2.30	-	-	-	-
Cd	0.90	0.60	1.10	0.10	1.60	-	-	-	-
Co	20.0	8.0	20.0	3.0	94.0	-	-	21.0	2.0
Cr	40.0	40.0	32.0	0.10	220.0	-	-	46.0	-
Cu	47.0	35.0	40.0	1.00	430.0	-	-	-	-
La	27.0	11.0	26.0	2.0	78.0	-	-	19.0	10.0
Li	21.0	6.0	22.0	3.0	34.0	-	-	-	0.34
Mo	3.20	3.40	4.30	0.10	20.0	-	-	-	2.0
Ni	38.0	42.0	23.0	2.0	380.0	-	-	-	4.0
Pb	20.0	7.0	21.0	1.0	56.0	-	-	-	30.0
Rb	86.0	32.0	89.0	1.0	173.0	-	-	59.0	145.0
Sr	577.0	204.0	650.0	30.0	840.0	-	-	552.0	285.0
V	112.0	39.0	118.0	4.0	182.0	-	-	-	40.0
Zn	60.0	18.0	63.0	9.0	121.0	-	-	-	-

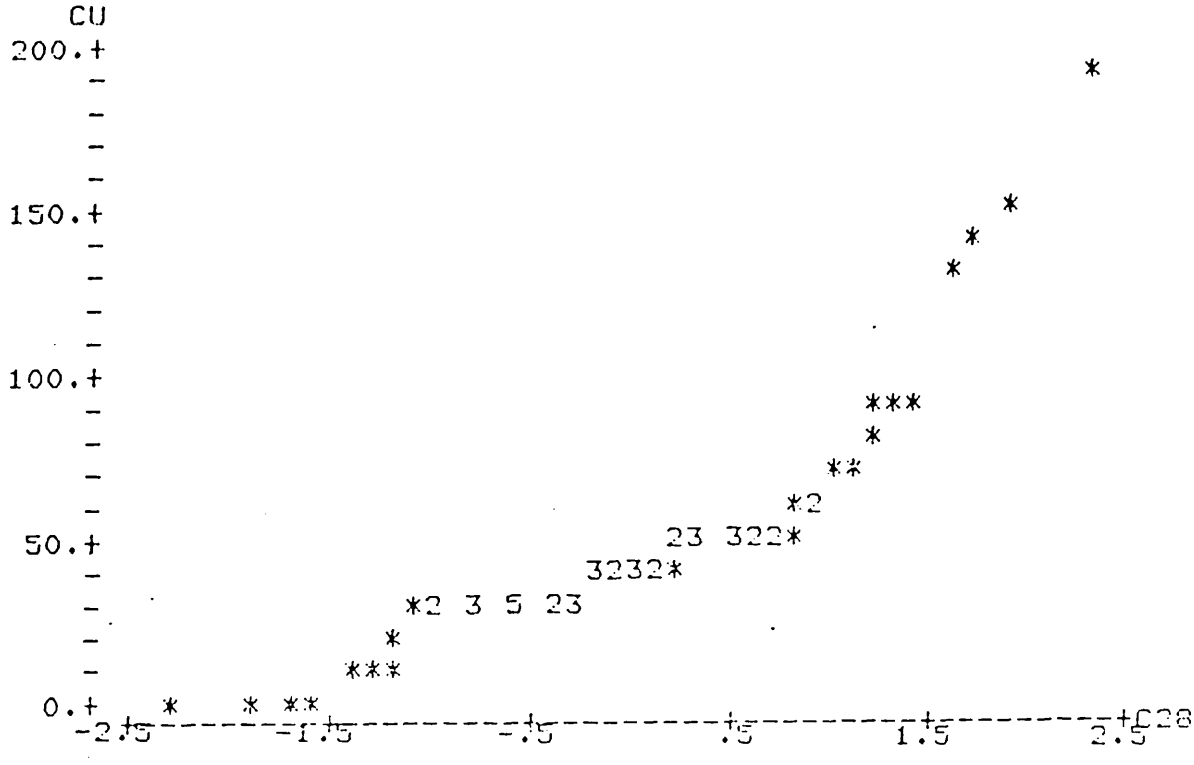
Ratios	a	b
K/Rb	272	219
Rb/Sr	0.14	0.11
Ba/Sr	1.22	0.82

(1) Quartz diorite (n = 1) (Precambrian) from River Tobenko area, Sierra Leone (Marmo, 1971).
(2) Average quartz diorite according to Wedepohl (1969).
(3) Quartz diorite (Precambrian) from South Africa (Condie and Hunter, 1975).
(4) Average granite of Taylor (1964).
(a) = Ratios from this work.
(b) = Ratios from Condie and Hunter (1975).

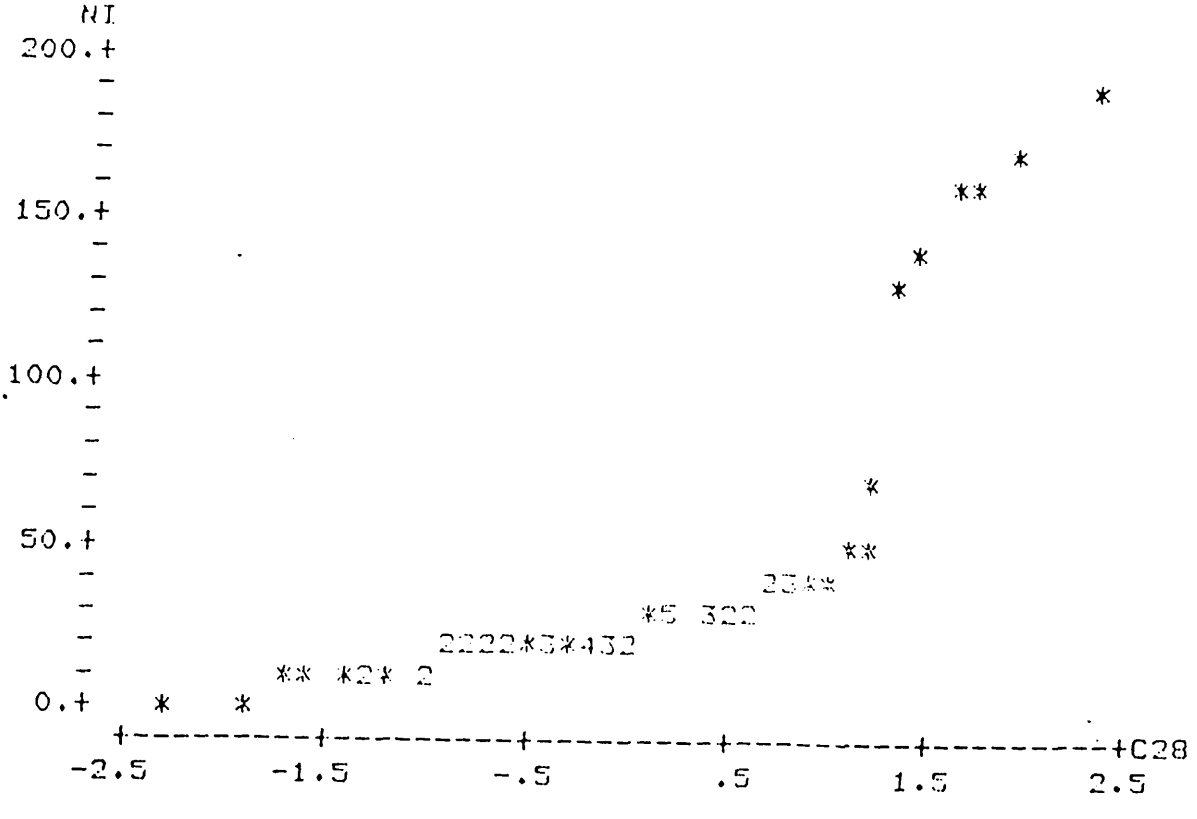
that many of the elements showed two or more populations (Fig.40a, b, c) which may suggest that these rocks show some degree of variation in their chemical composition. The histograms and Q-Q plots indicate that Ca, Al, V, Sr, K, Rb, Zn, and Na are in general negatively skewed, and are neither lognormally nor normally distributed. On the other hand, Mn, and Ti are approximately normally distributed, whereas as Co is the only element nearly lognormally distributed (Cu and Ni are positively skewed but do not fit either the normal or lognormal distribution closely). In general the standard deviations are low for all the elements (Table 26).

The frequency distribution patterns observed, particularly for the trace or minor elements, may appear to be in contrast with those found in most granitic rocks (Ahrens, 1963, 1964; Haratori et al., 1960; Condie, 1969). However, according to Aubrey (1955) such a situation would obtain when the trace elements are mainly associated with the contents of the host minerals. But, in the absence of information on the phase chemistry of the major or host minerals, it is almost impossible to unequivocally attribute the apparent anomalous behaviour of some of these elements under consideration to such a phenomenon. It is possible to suggest that metamorphism,which is the main postmagmatic event known to have taken place in the area, may have contributed to the overall pattern.

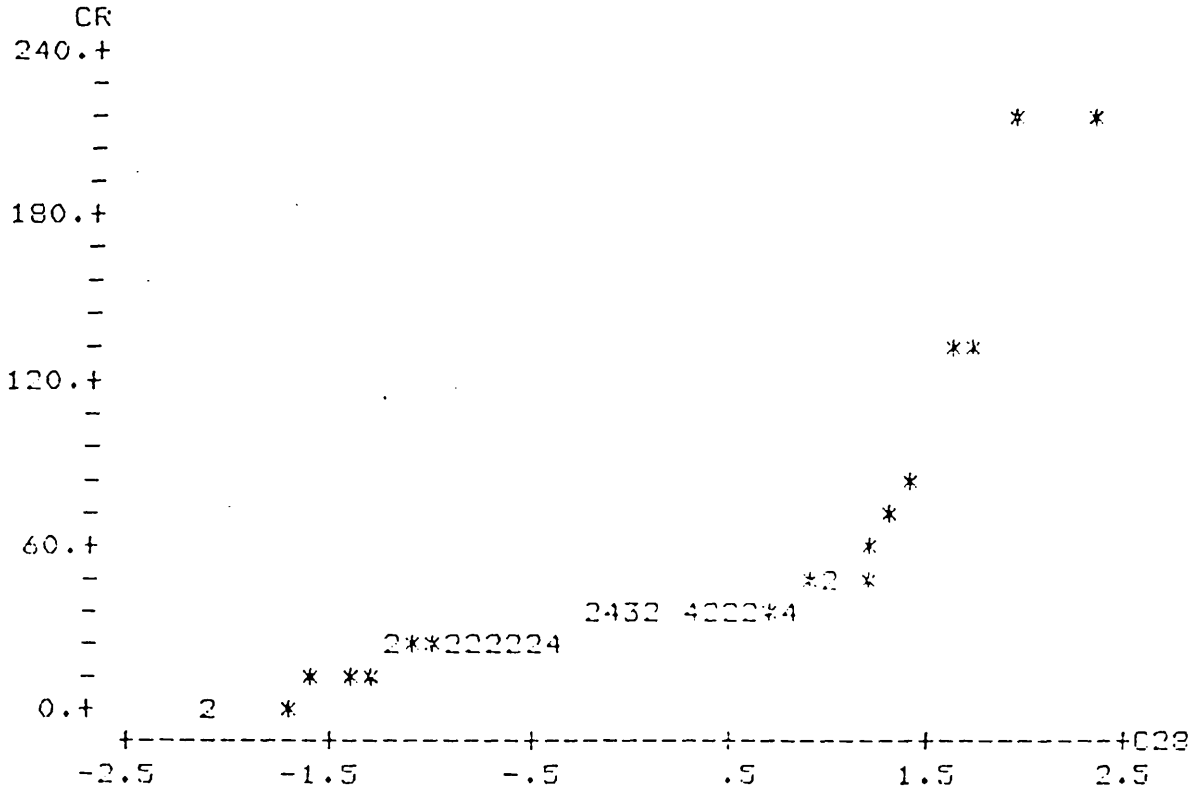
Fig.40(a-c) The Q-Q plots for the elements Cu, Ni, and Cr (in ppm), showing their distribution patterns in the Cestos Batholith area.


CU
200.+
150.+
100.+
50.+
0.+
-2.5
-1.5
-.5
.5
1.5
2.5
C28

a


NI
200.+
150.+
100.+
50.+
0.+
-2.5
-1.5
-.5
.5
1.5
2.5
C28

b


CR
240.+
180.+
120.+
60.+
0.+
-2.5
-1.5
-.5
.5
1.5
2.5
C

In this study, only one known lithological type is being investigated, and the variations in the element concentrations from one sample to the next may be conveniently shown using the Kleiner-Hartigan "Trees)(Fig.41a) based on the template shown in Fig. 41b for the individual sample samples. While there is a general broad similarity in composition, samples 4923 and 4981 are clearly depleted in almost all the elements except Ca and Mg respectively. This can be verified by an examination of the raw analytical data (rear pocket).

8.5.3 Inter-element Relationships

In order to overcome the effect of data closure (Aitchinson, 1984) the ratio of each element to Fe ($x_{/Fe}$) was log-transformed before the correlation matrix (Table 27) was determined. On the basis of the strength of correlation at the 95 % level, three main groups or associations of elements can be recognized. Thus, Li, Na, K, Rb, Be, Sr, Ba, Al, La, Pb, Zn, Ti, and P generally have strong positive correlations in one group, whereas Mg, Ca, Co, Mn and V form the second group Cu and Ni do not have strong correlations with any group.

The element associations observed here may superficially be correlated with certain minerals or groups of minerals. Thus the first group may be correlated with the felsic minerals (mainly the feldspars) whereas the second group may be

Fig.41(a). The Kleiner-Hartigan "Trees" from the Cestos Batholith area. Note that where the "Trees" were very close together with similar concentration levels of the elements only representative "Trees" are shown. Also arrows indicate that the "Trees" concerned are not in their actual positions.

Fig.41(b). The template for the "Trees" from the Cestos Batholith area.

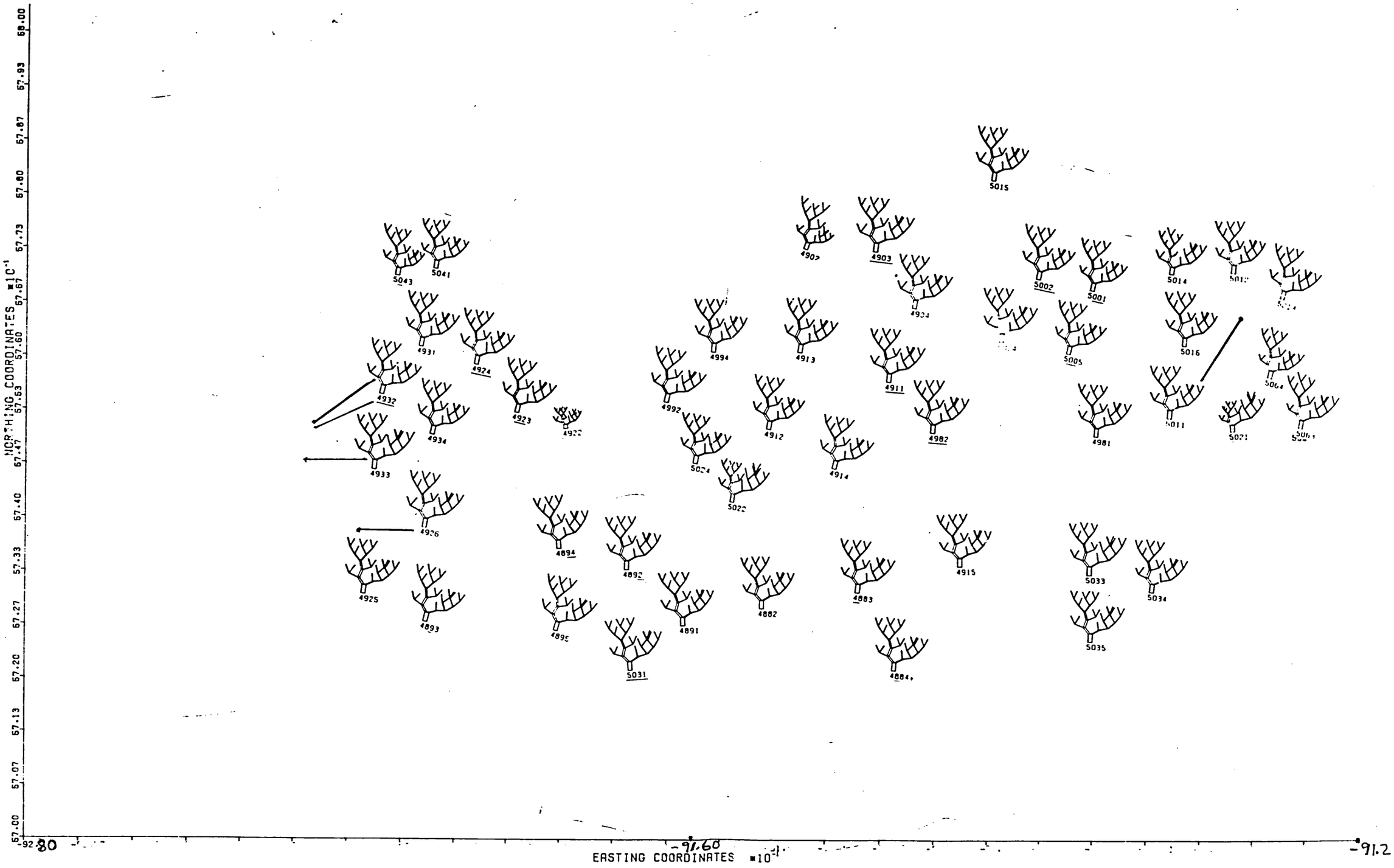
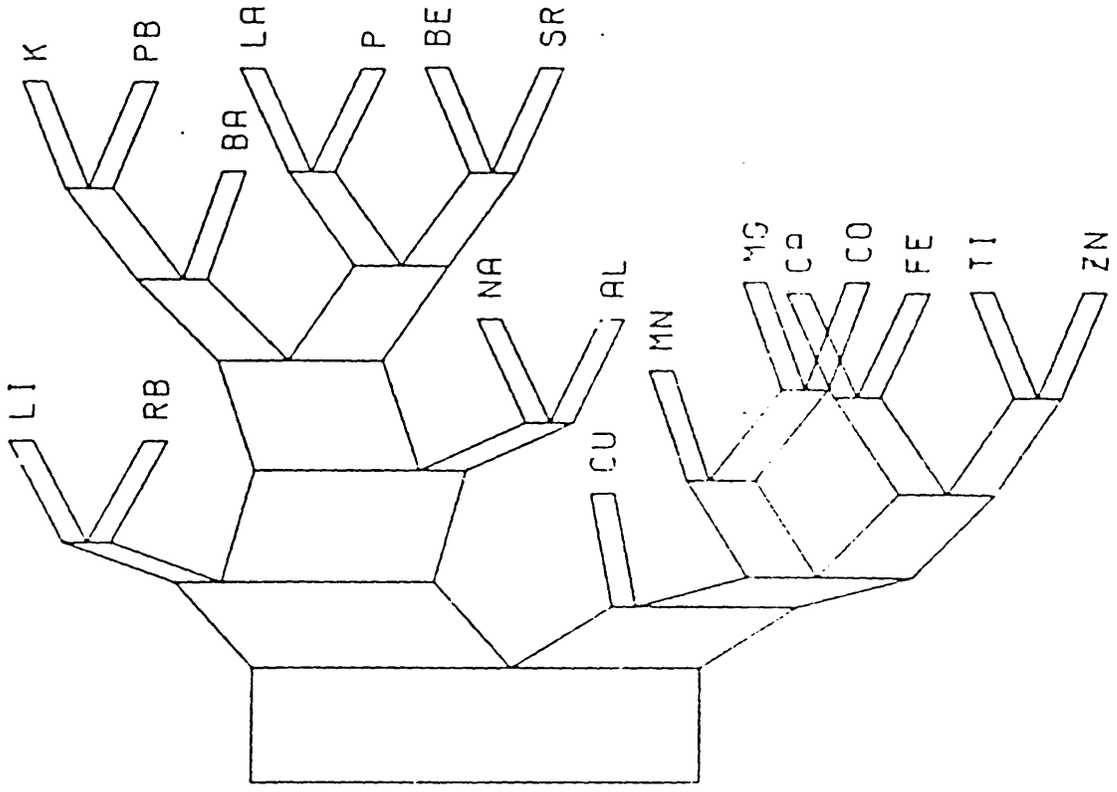

NORTHING COORDINATES ×10⁻¹
67.47
67.53
67.60
67.67
67.73
67.80
67.87
67.93
68.00
67.40
67.33
67.27
67.20
67.13
67.07
67.00
-92.80
-91.60
-91.2
EASTING COORDINATES ×10⁻¹
4933
4932
4934
4931
4924
4923
4922
5043
5041
4926
4925
4893
4894
4892
4895
5031
4891
4882
4884
4914
4912
4992
4994
4913
5024
5022
4902
4903
4904
4911
4982
4981
5015
5002
5001
5005
5014
5016
5011
5021
5064
5033
5034
5035
4915
4883

Fig. 41a.



b

	LI	NA	K	RB	BE	MG	CA	SR
NA	.435							
K	.804	.656						
RB	.792	.437	.832					
BE	.680	.817	.921	.642				
MG	-.619	-.545	-.751	-.455	-.709			
CA	-.195	.180	-.146	.087	-.024	.534		
SR	.490	.671	.740	.431	.811	-.310	.258	
BA	.680	.803	.902	.660	.888	-.418	.072	.809
AL	.524	.848	.600	.633	.698	-.556	.279	.476
LA	.633	.472	.756	.563	.717	-.646	-.098	.512
TI	.526	.361	.527	.280	.527	-.259	.020	.562
V	-.281	-.295	-.309	-.394	-.307	.575	.048	.114
MN	-.179	-.208	-.254	-.013	-.279	.689	.806	.073
CO	-.342	-.316	-.546	-.473	-.523	.501	.165	-.410
NI	-.285	-.072	-.274	-.162	-.180	.110	.048	-.171
CU	-.248	-.184	-.156	-.303	-.199	.046	-.123	-.249
ZN	.621	.335	.482	.521	.452	-.256	.209	.385
PB	.715	.730	.886	.821	.842	-.721	.046	.451
P	.468	.348	.715	.155	.724	-.449	-.139	.735

	BA	AL	LA	TI	V	MN	CO	NI
AL	.675							
LA	.734	.519						
TI	.597	.218	.599					
V	-.234	-.569	-.463	.110				
MN	-.107	-.122	-.237	-.005	.245			
CO	-.506	-.243	-.563	-.133	.293	.243		
NI	-.258	.024	-.136	-.173	.012	-.060	.166	
CU	-.218	-.279	-.298	-.406	.230	.061	.022	-.143
ZN	.512	.434	.635	.716	-.385	.187	-.109	-.162
PB	.764	.868	.690	.263	-.623	-.249	-.531	-.035
P	.653	.106	.636	.709	.063	-.165	-.505	-.212

	CU	ZN	PB
ZN	-.561		
PB	-.259	.513	
P	-.157	.403	.211

Table 27 The Pearson correlation matrix for the log-transformed ratio (x/Fe) data from the Cestos Batholith area.

possibly related to the mafic components. The third and fourth groups consist of elements which generally have low levels of concentrations in these rocks and therefore may be highly dispersed in the accessory minerals.

Fig.42 is a hierarchical dendrogram also obtained from these data. It suggests four main clusters or groups of elements, viz: (1) Li, Rb; (2) K, Pb, Ba, La, P, Be, Sr; (3) Na, Al; (4) Mn, Mg, Co, Ca, Fe, Ti and Zn. Cu does not show definite association with any of the groups. On a superficial basis the associations may be correlated with certain minerals or groups of minerals. Thus, Groups 1, 2 and 3 may be correlated with the felsic minerals and Group 4 may be associated with the mafic mineral constituents. However, the observed grouping or clustering is more related to the spatial relationships among the elements in each tree or sample (Fig.20a).

8.5.4 Element Abundance Ratios

The element abundance ratios K/Rb, Rb/Sr, and Ba/Sr were determined in order to speculate on the degree of fractionation of the magma which formed the granitic rocks under investigation. The values of these ratios are shown in Table 26. Compared to similar ratios from corresponding rock-types elsewhere (Condie and Hunter, 1975; Campiglio and Darling, 1975) these are typical of early fractionated suites. This inference is consistent with the petrographic classification of the suite (see

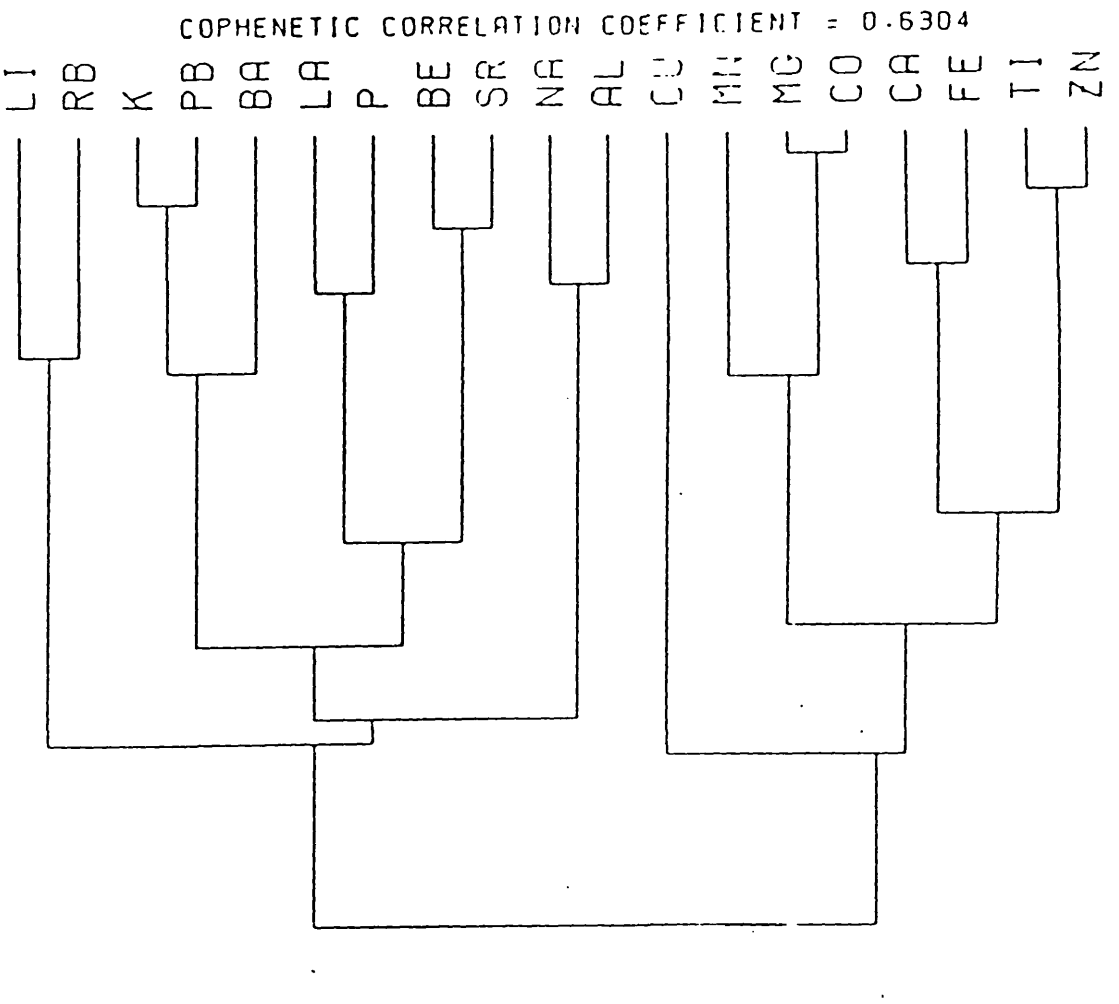


Fig.42. The hierarchical dendrogram showing the element association in the 61 samples from the Cestos Batholith area.

Chapter 7).

Other abundance ratios were also determined to ascertain other chemical properties of the suite. The $Al_2O_3/(Na_2O+K_2O+CaO)$ (moles) ratio (Fig.43) for example, indicates, according to Martin and Bowden (1981), a sub-aluminous character. However, the high Na and Ca contents of the Cestos Batholith rocks have possibly masked the relative importance of Al as these are relatively high.

8.5.5 Ridge Regression

The ridge regression (see section 6.2.5) has been applied to this data subset to get ridge traces, residual normal probability plots and residuals of the selected trace elements, and Table 28 shows the parameters used for, and the results of, the ridge traces.

The ridge trace for Be is shown for the purpose of illustration in Fig. 21a . In this figure Na is seen to be the best positive predictor whilst Ca is the best (though weak) negative predictor for Be in this suite of rocks. With the exception of Ca and Mg, each of the major elements concerned seems to have some positive predictor power over Be, although with different degrees of stability. The behaviour of Ti is especially interesting in this regard. It appears to be a negative predictor when $\underline{k}$ (the ridge constant) is close to zero, i.e. the classical least-squares solution, but becomes a (weak) positive predictor with increase in $\underline{k}$. This may probably be

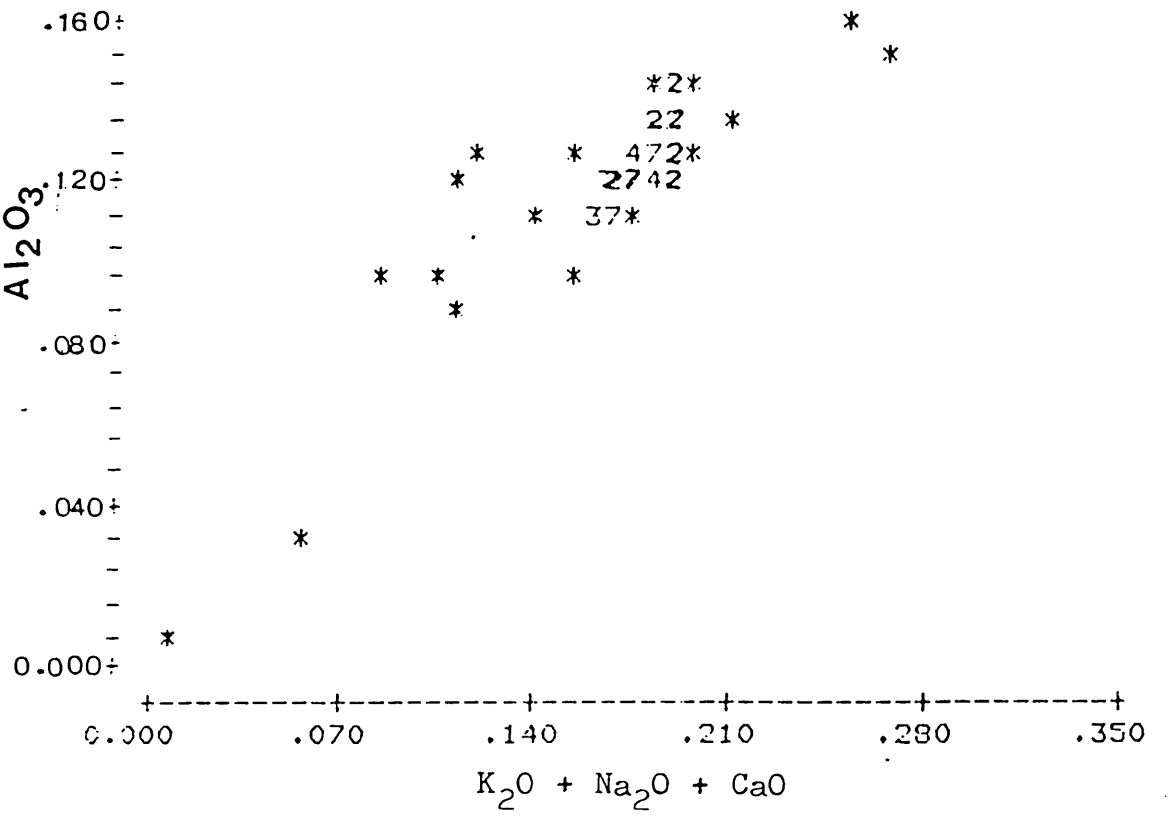


Fig.43. The Al_2O_3 vs $K_2O + Na_2O + CaO$ plot for the Cestos Batholith area.

TABLE 28

RIDGE REGRESSION PARAMETERS AND RESULTS

	n	Initial R^2	K	Final No. of Samples*	Final R^2	Important Predictors**	Linear Model
Li	61	0.92	0.2	56	0.92	K, Al, Na	ok
Rb	61	0.73	0.2	57	0.71	K, Mg, Ti, Al-P	ok
Be	61	0.91	0.2	57	0.90	Na, K, K, P, Ti-Mg	ok
Sr	61	0.82	0.2	58	0.93	Na, P, Al, K - Mg	ok
Ba	45	0.67	0.2	44	0.66	K, Ti-Mn-P	ok
Cu	61	0.55	0.2	55	0.91	Ti, Mn, P, K, Fe, Ca	ok
Zn	61	0.69	0.2	51	0.51	K, Al-Ca-Na	ok
Pb	61	0.69	0.2	51	0.51	K, Al-Ca-Na	ok

* Representing "background" relationship.

** Elements with standardized coefficients exceeding ± 0.1.

n = No. of samples.

R^2 = Multiple correlation coefficient.

K = Ridge constant.

related to its close relationship with Be in minerals like the micas and hornblende (Ahrens et al., 1965) in which both of them can co-exist with ease. The residual probability plot for Be in this data set is also shown in Fig. 21b, with linear feature, indicating normal distribution.

The ridge technique was used in combination with the Kleiner-Hartigan Trees to identify samples having higher relative residual concentration of some of the selected trace elements. Table 29 presents the results. It is evident that less than 30% of the samples have higher relative residual concentrati of few of the trace elements. The small number of samples, however, coupled with their random distribution, tends to mask any significance of the incidence of such higher relative residual concentrations.

8.5.6 The Spatial Distribution of Elements

The geographical distribution of the elements in the Cestos Batholith area is shown in Fig 44(a-u). It is obvious from the figure that there are no consistent patterns of important depletion or enhancement for any one element, or a group of elements, in a particular sub-area of the batholith and the associated granitic gneiss.

This observed pattern of distribution of the elements may possibly be the result of random variations of the elements in these rocks.

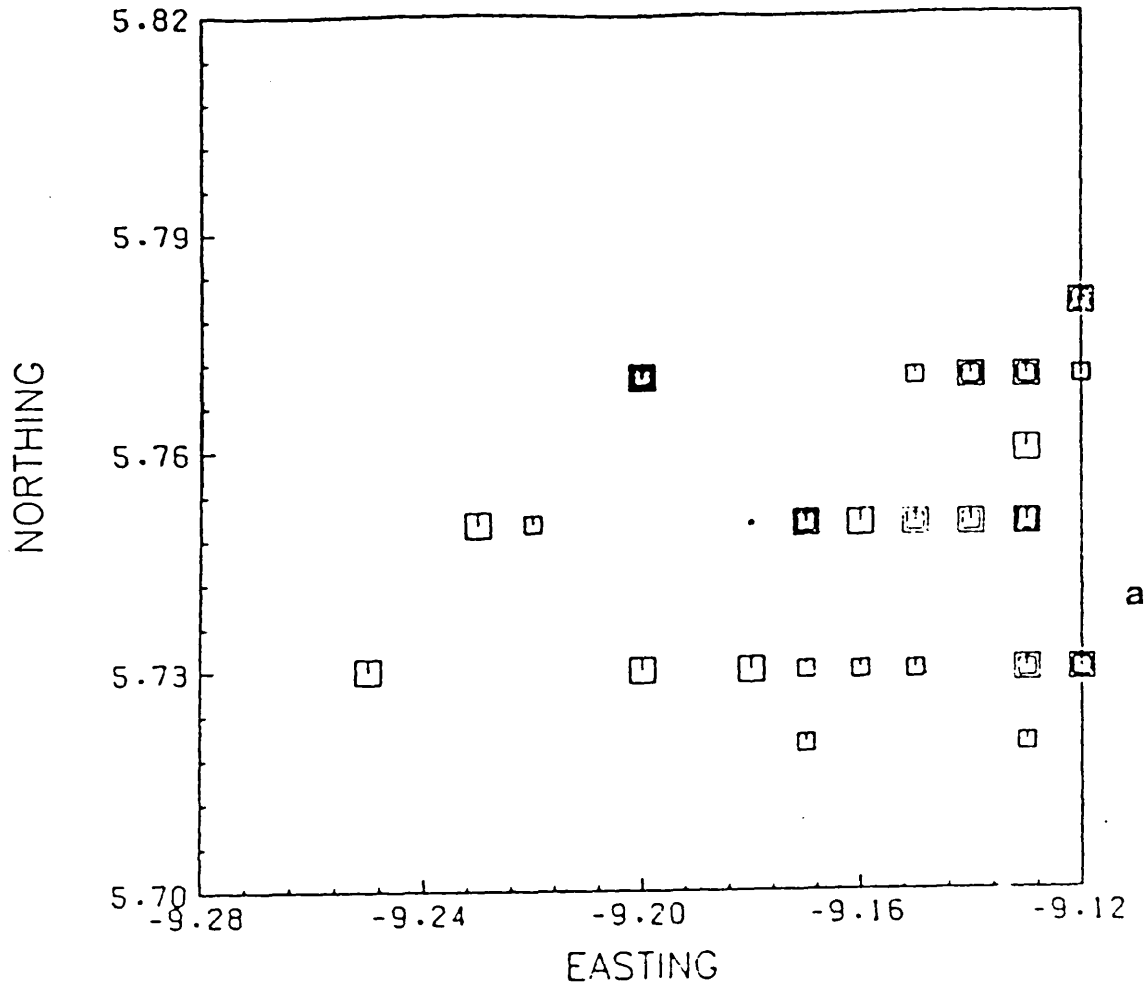
8.5.7 Summary

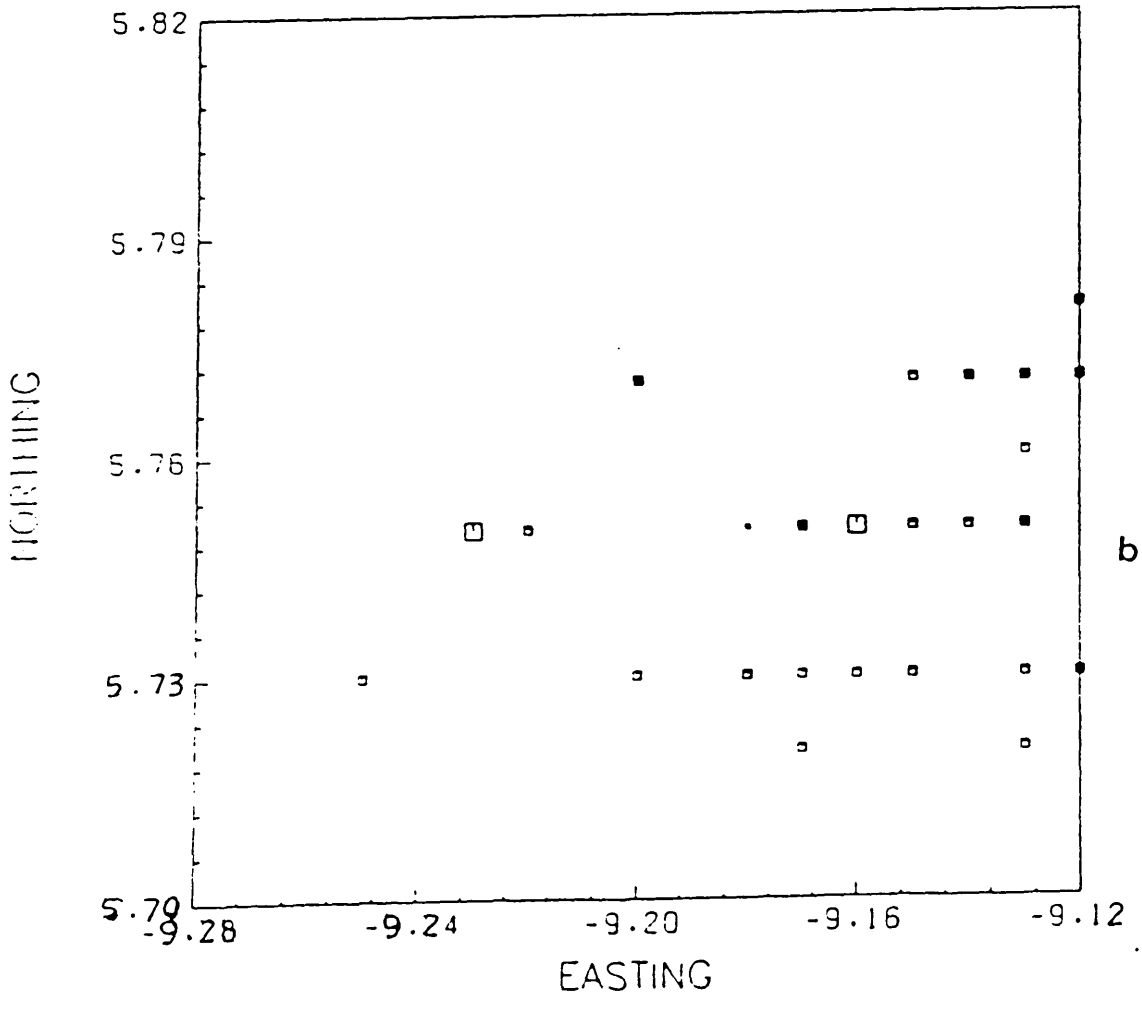
The available chemical data indicates that these granitic rocks are not unusual in any significant way. They appear to be just like many other typical unmineralized granitoids of Precambrian age.

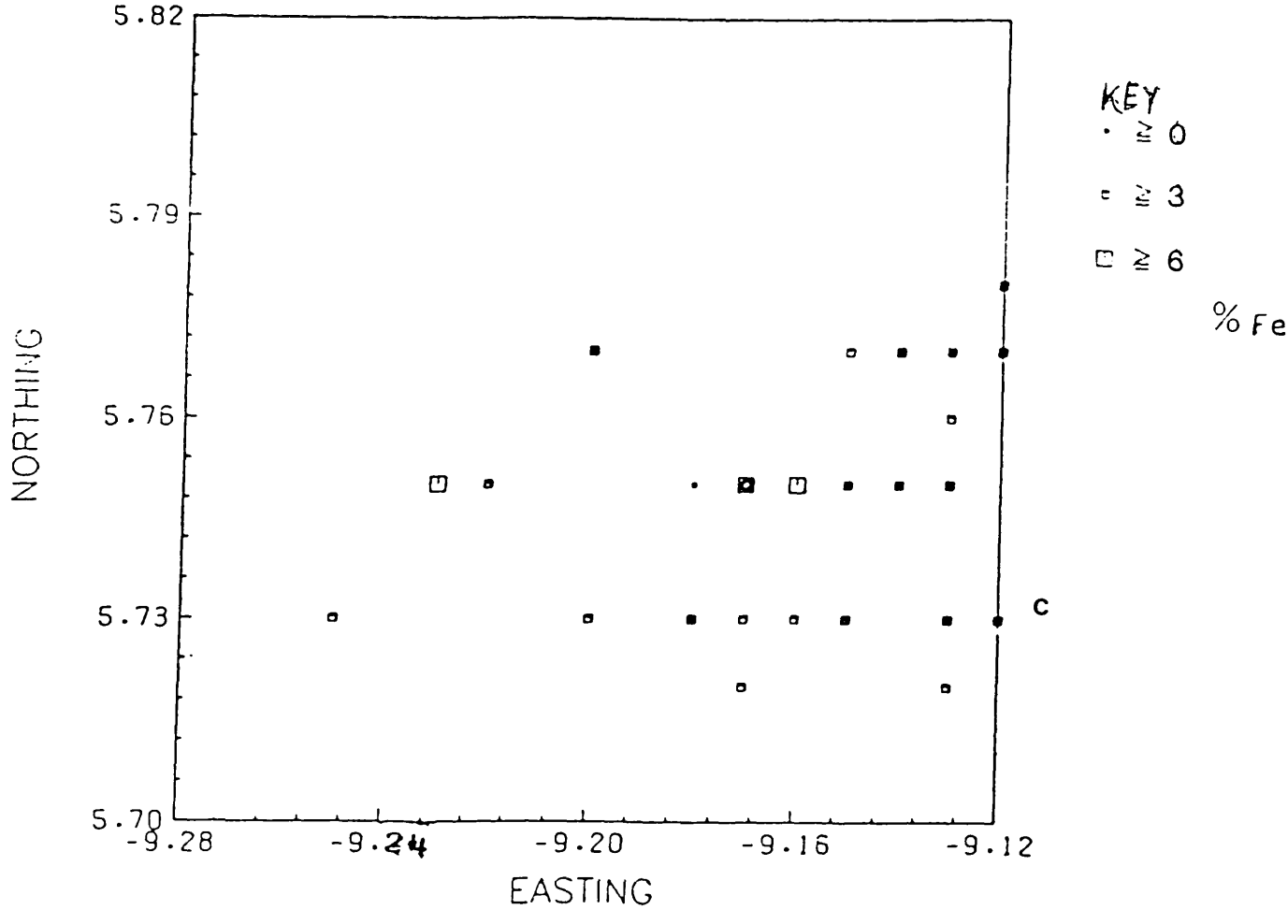
TABLE 29 LOCATIONS OF SAMPLES (FROM THE CESTOS BATHOLITH AREA) SHOWING HIGHER RELATIVE RESIDUAL CONCENTRATIONS OF CERTAIN ELEMENTS RELATIVE TO OTHER SAMPLES

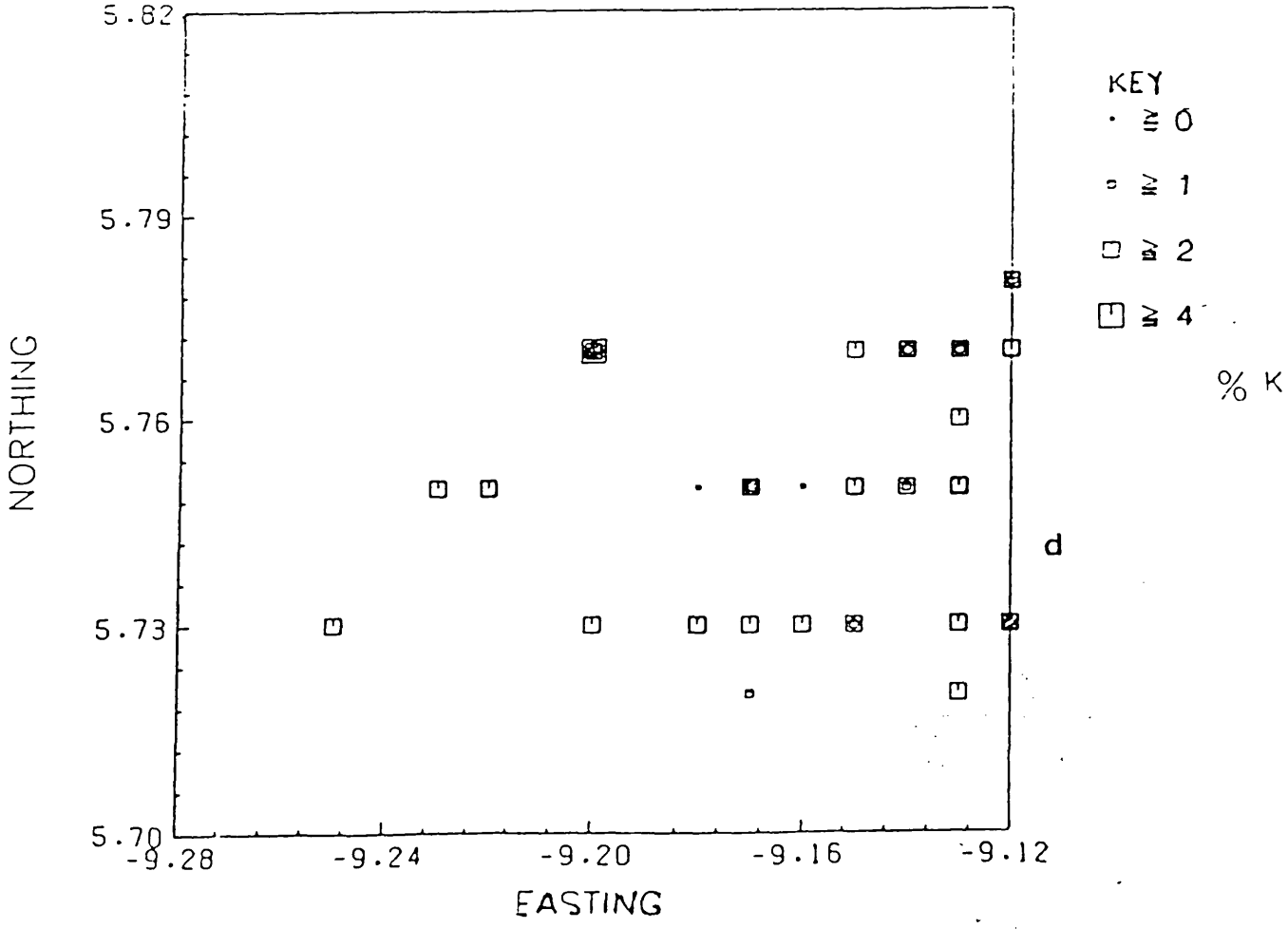
SAMPLE NO.	ELEMENTS	CO-ORDINATES	
		N	W
4992	Mo	5° 45'	9° 08'
5002	Mo	5° 46'	9° 08'
5016	Mo	5° 46'	9° 07'
4934	Mo, Li	5° 45'	9° 09'
5004	Mo	5° 46'	9° 07'
4991	Mo	5° 45'	9° 08'
4932	Mo	5° 45'	9° 09'
4891	Mo	5° 46'	9° 09'
4903	Mo, Pb, Rb	5° 45'	9° 10'
4981	Mo	5° 45'	9° 06'
4992	Mo	5° 45'	9° 08'
4904	Mo	5° 46'	9° 09'
4914	Mo, Li	5° 44'	9° 10'
5011	Mo	5° 46'	9° 07'
4994	Mo, Cu	5° 45'	9° 08'
5014	Mo	5° 46'	9° 07'
4922	Mo, Li, Cu	5° 45'	9° 11'
5031	Cu	5° 45'	9° 10'
4884	Cu	5° 43'	9° 08'
5024	Li, Mo, Cu	5° 45'	9° 10'
5024	Cu	5° 44'	9° 09'
4926	Mo, Pb, Rb	5° 44'	9° 10'
5023	Mo	5° 45'	9° 10'

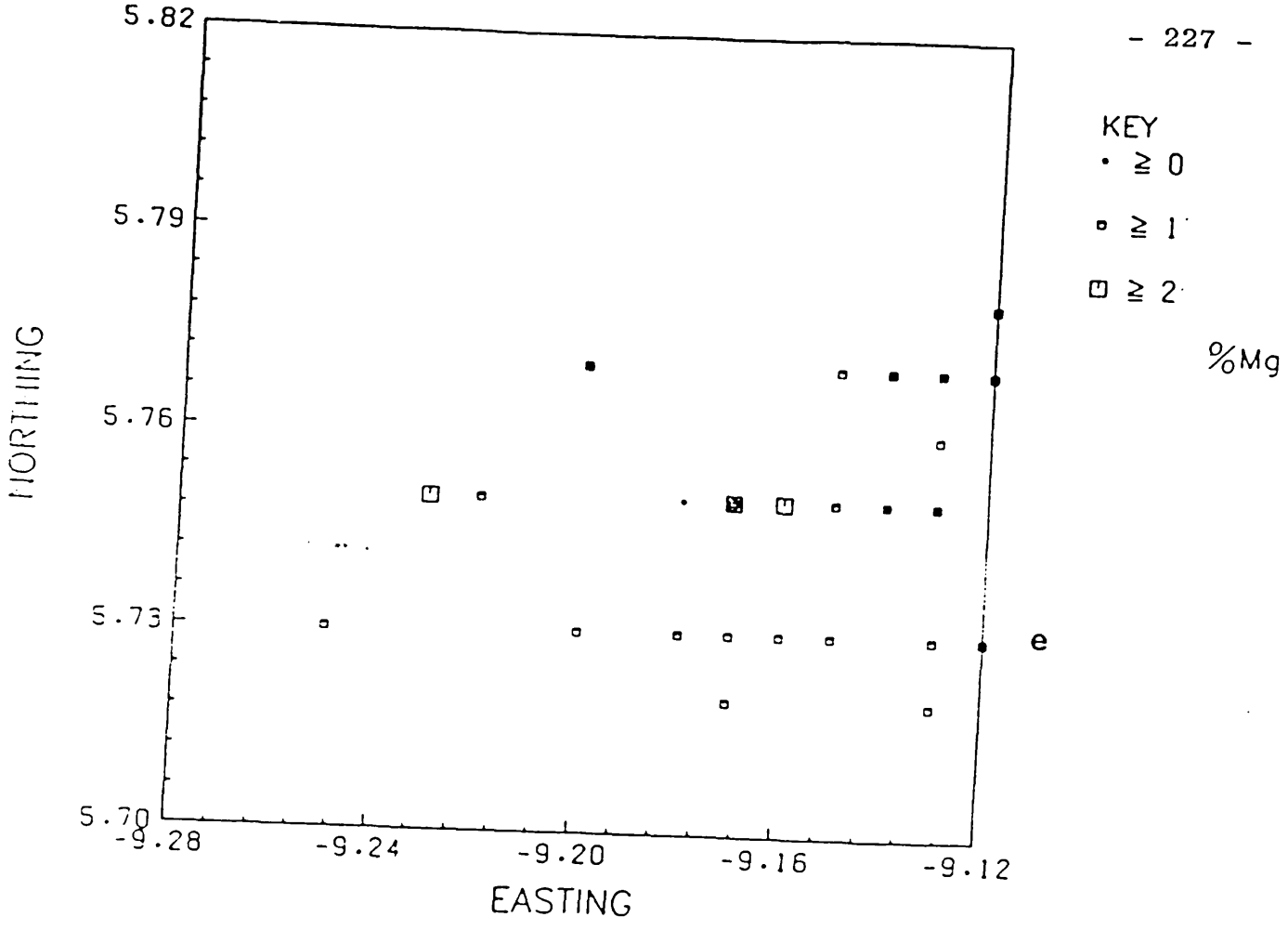
Fig.44(a-u). The geographical distribution patterns for twenty-one of the elements determined in the Cestos Batholith area suite. The simplified geology overlay is located in the rear pocked of the thesis.

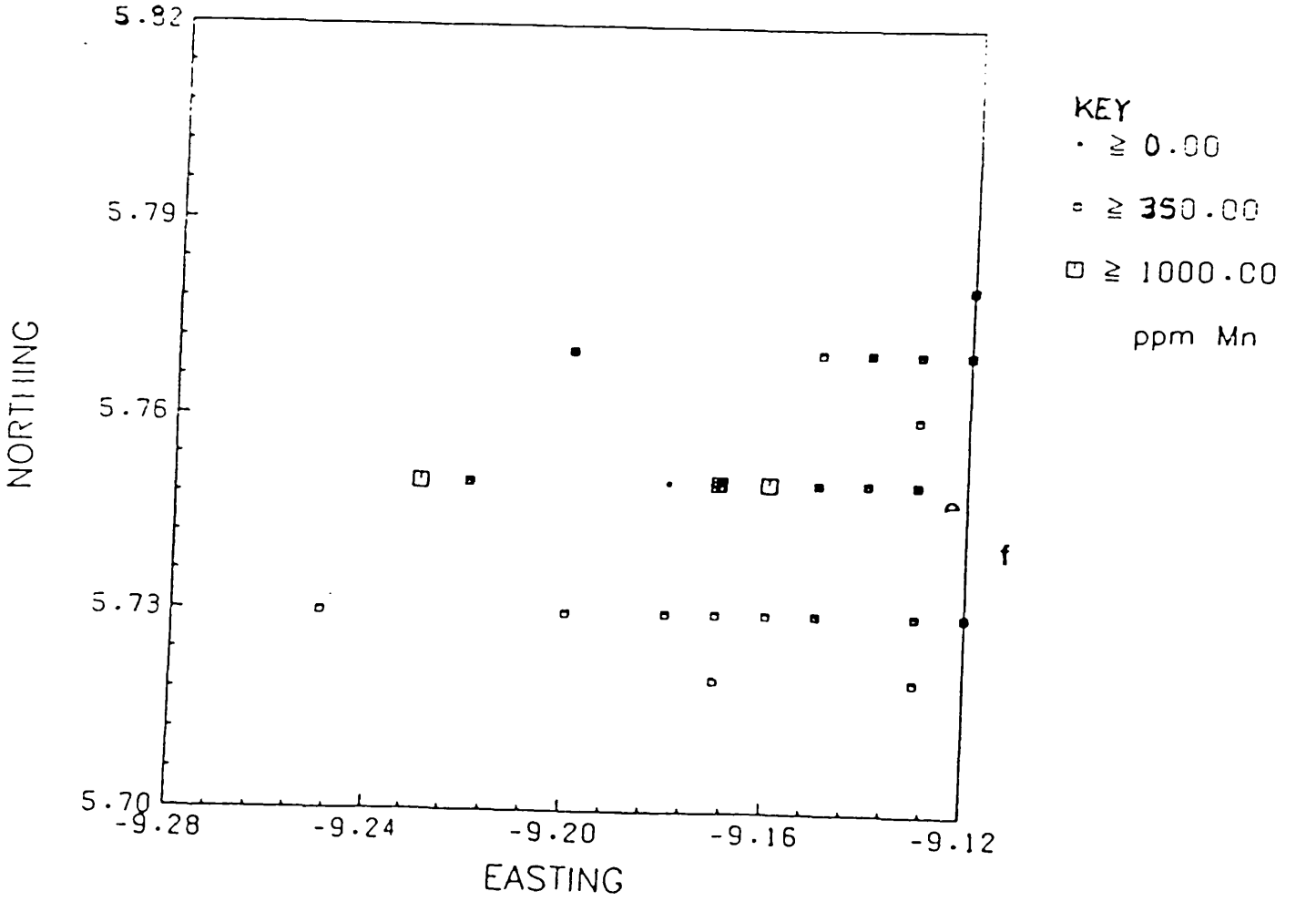

5.82
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
KEY
≥ 0
≥ 2
≥ 4
≥ 7
% A
a


5.82
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
KEY
≥ 0
≥ 2
≥ 5
% Ca
b


5.82
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
KEY
≧ 0
≧ 3
≧ 6
% Fe
c


5.82
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
KEY
≧ 0
≧ 1
≧ 2
≧ 4
% K
d


5.82
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
KEY
• ≧ 0
▫ ≧ 1
⊡ ≧ 2
%Mg
e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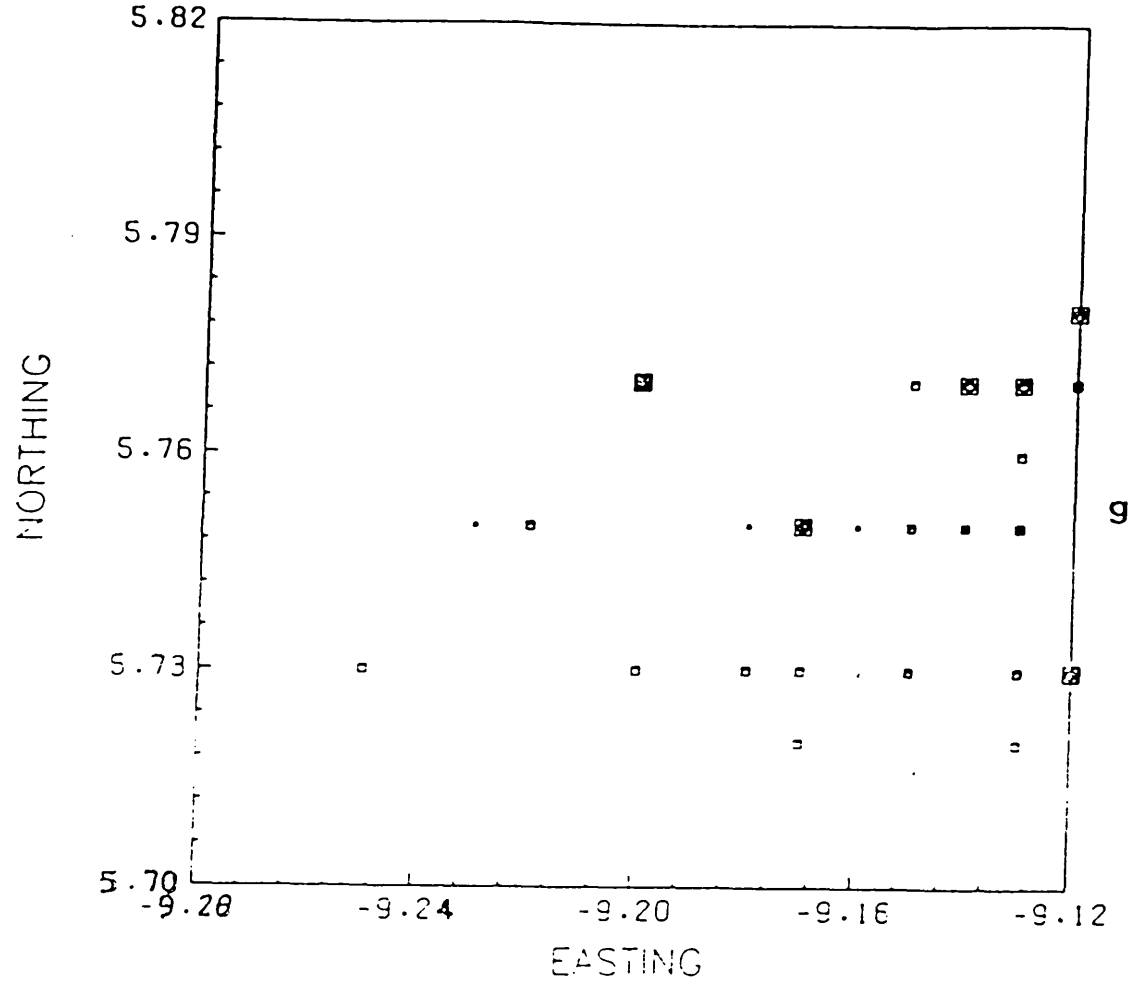
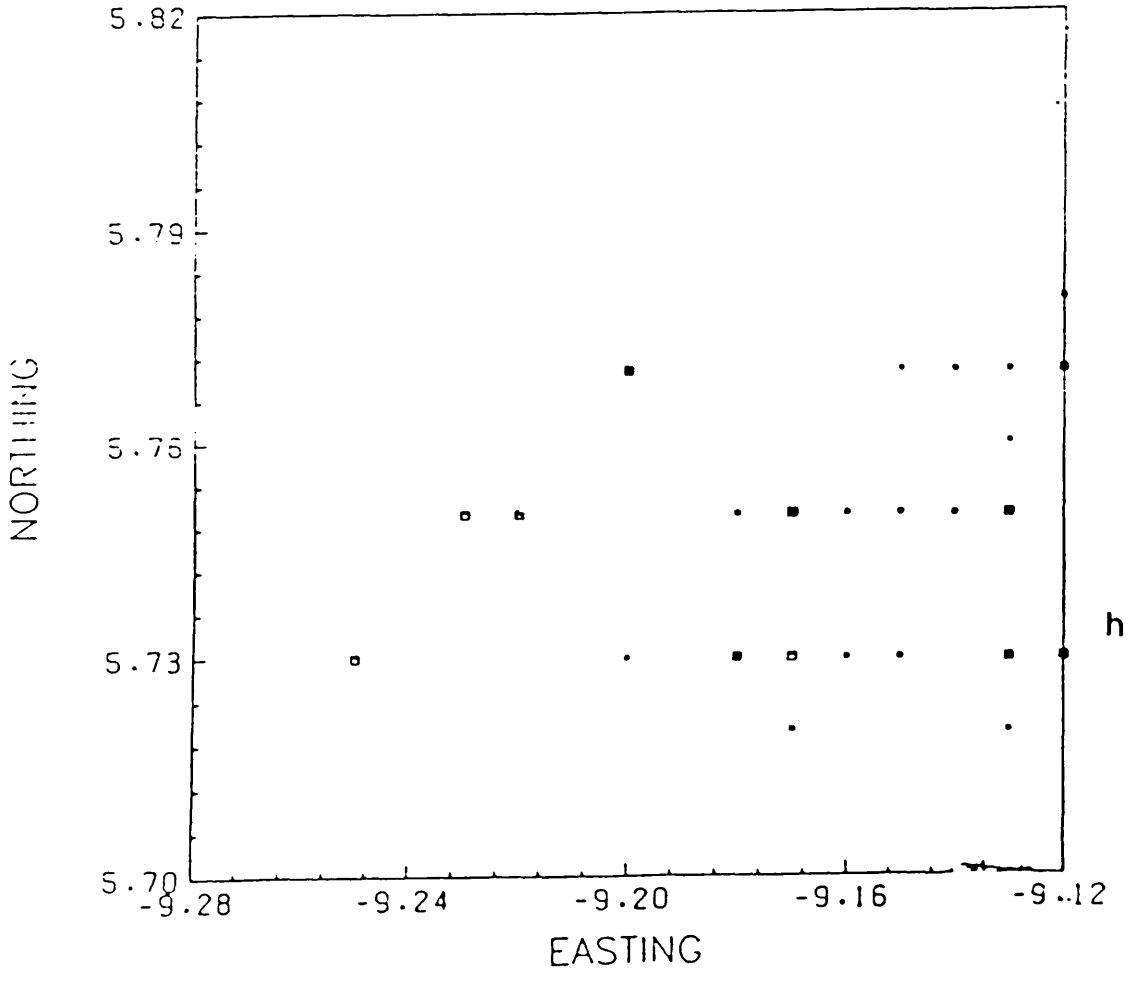
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
KEY
• ≧ 0.00
▫ ≧ 350.00
⊡ ≧ 1000.00
ppm Mn
f


5.82
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
KEY
• ≥ 0
▫ ≥ 2
□ ≥ 3
% Na
g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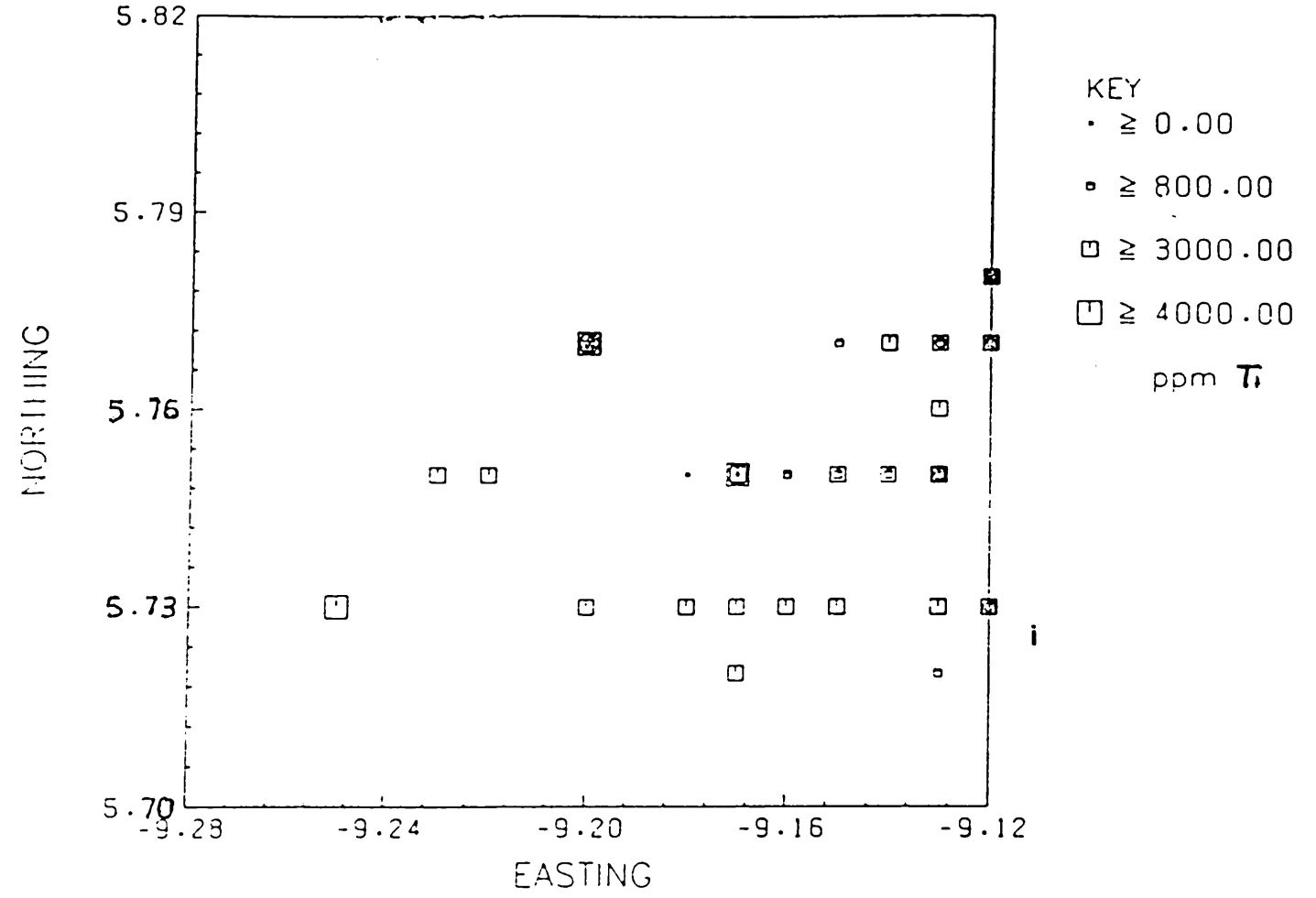
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
KEY
• ≥ 0.00
▫ ≥ 1000.00
□ ≥ 1600.00
ppm P
h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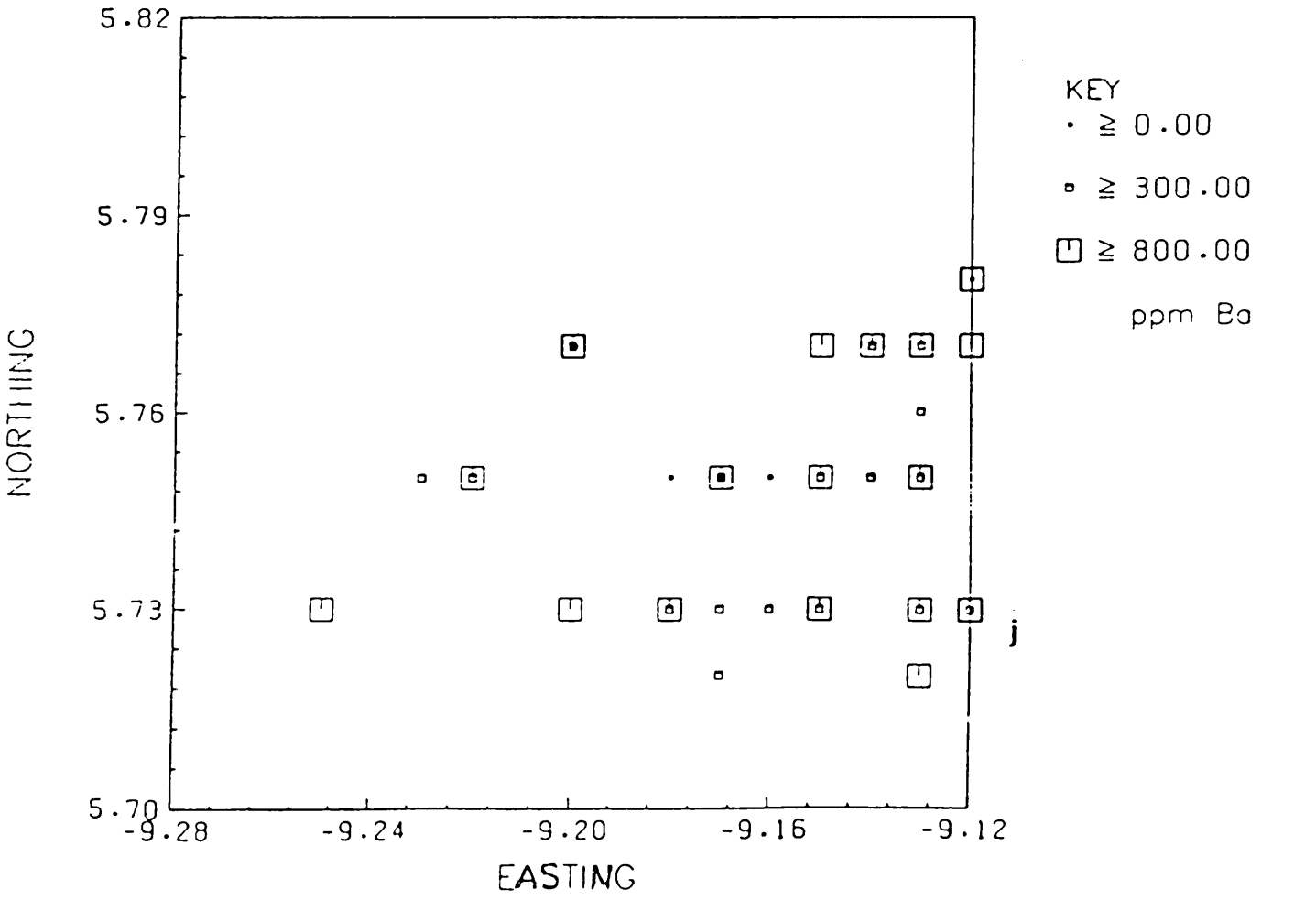
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
i
KEY
• ≥ 0.00
▫ ≥ 800.00
□ ≥ 3000.00
□ ≥ 4000.00
ppm Ti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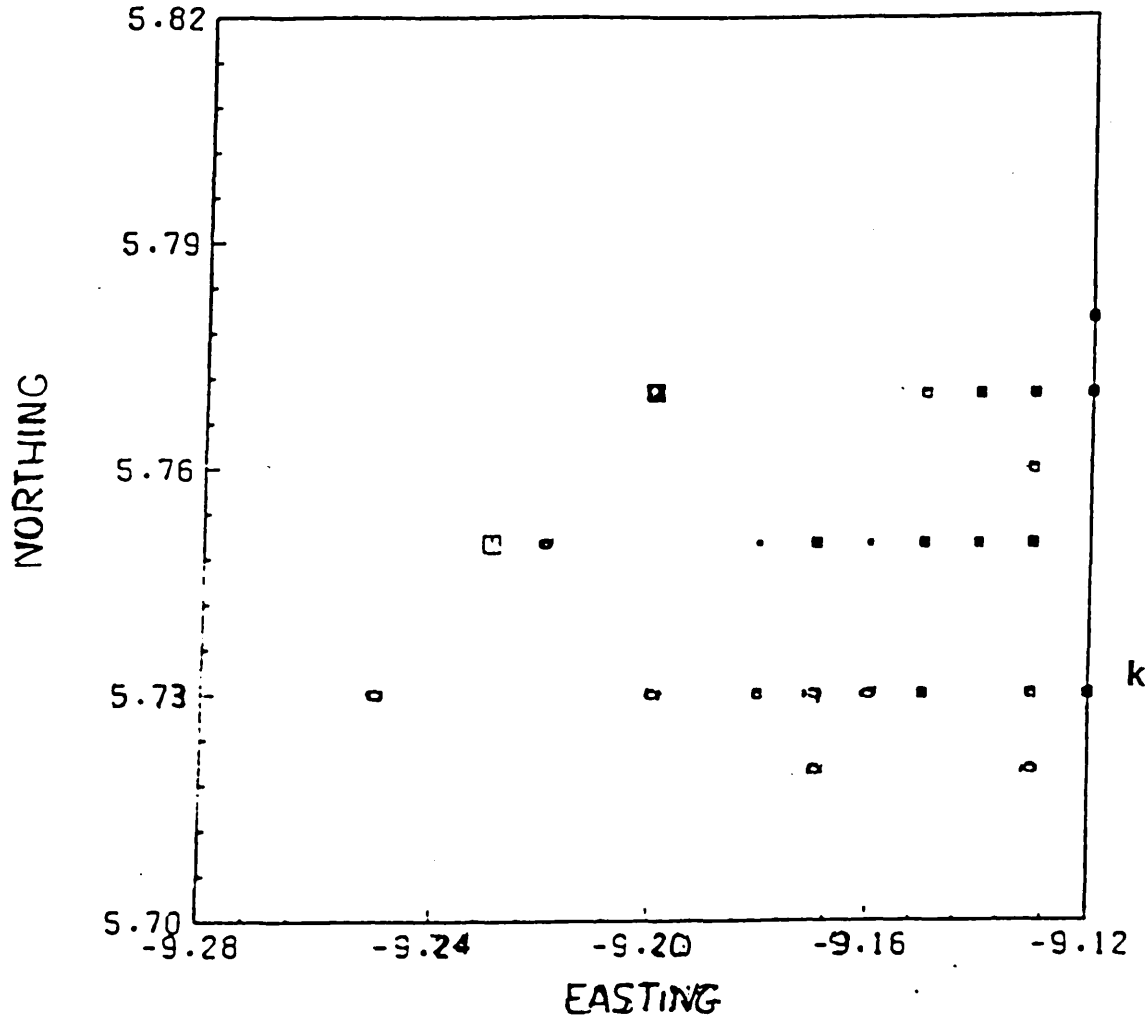
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
j
KEY
• ≥ 0.00
▫ ≥ 300.00
□ ≥ 800.00
ppm Ba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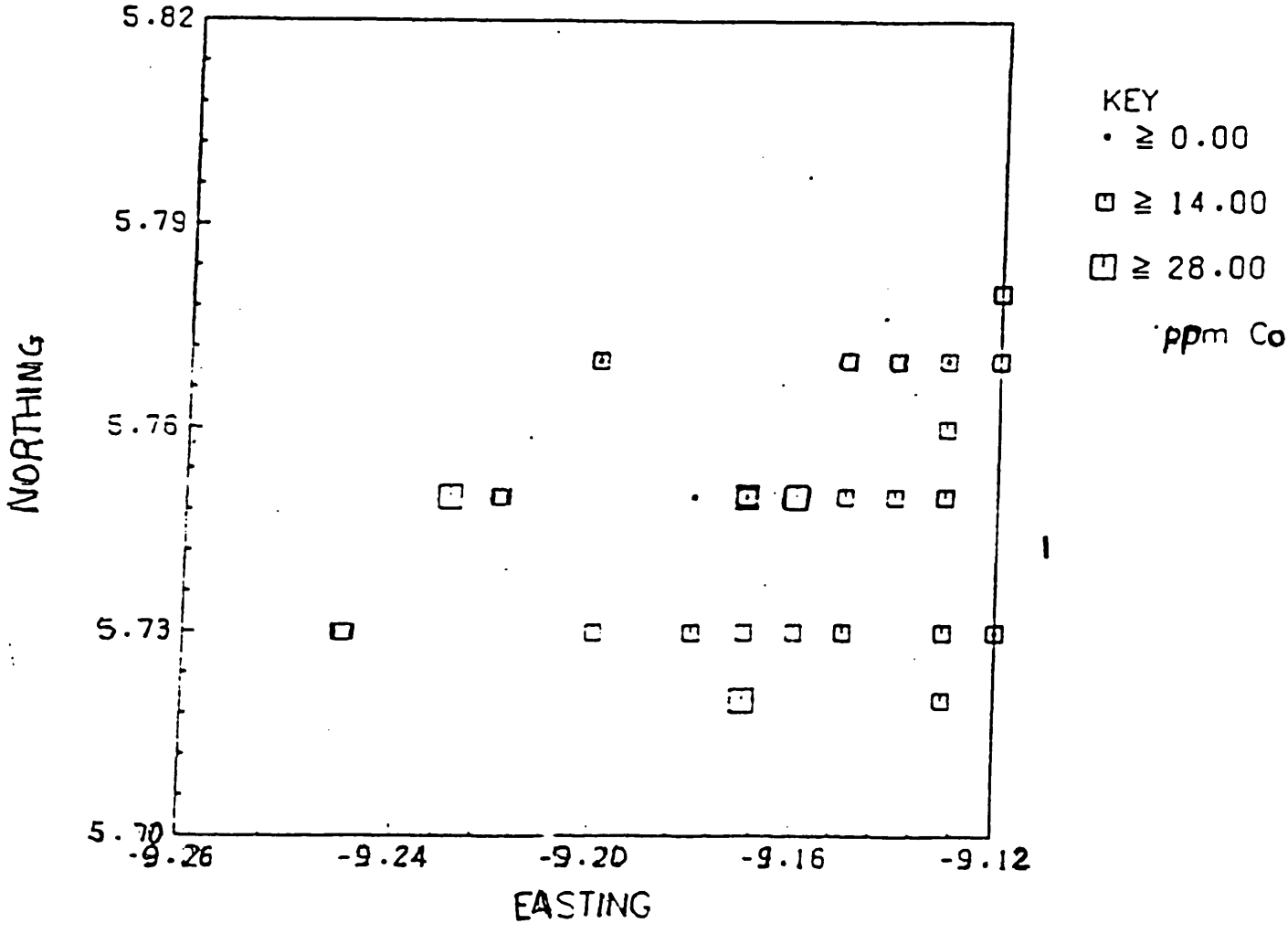
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
k
KEY
• ≧ 0.00
▫ ≧ 1.00
□ ≧ 2.00
ppm Be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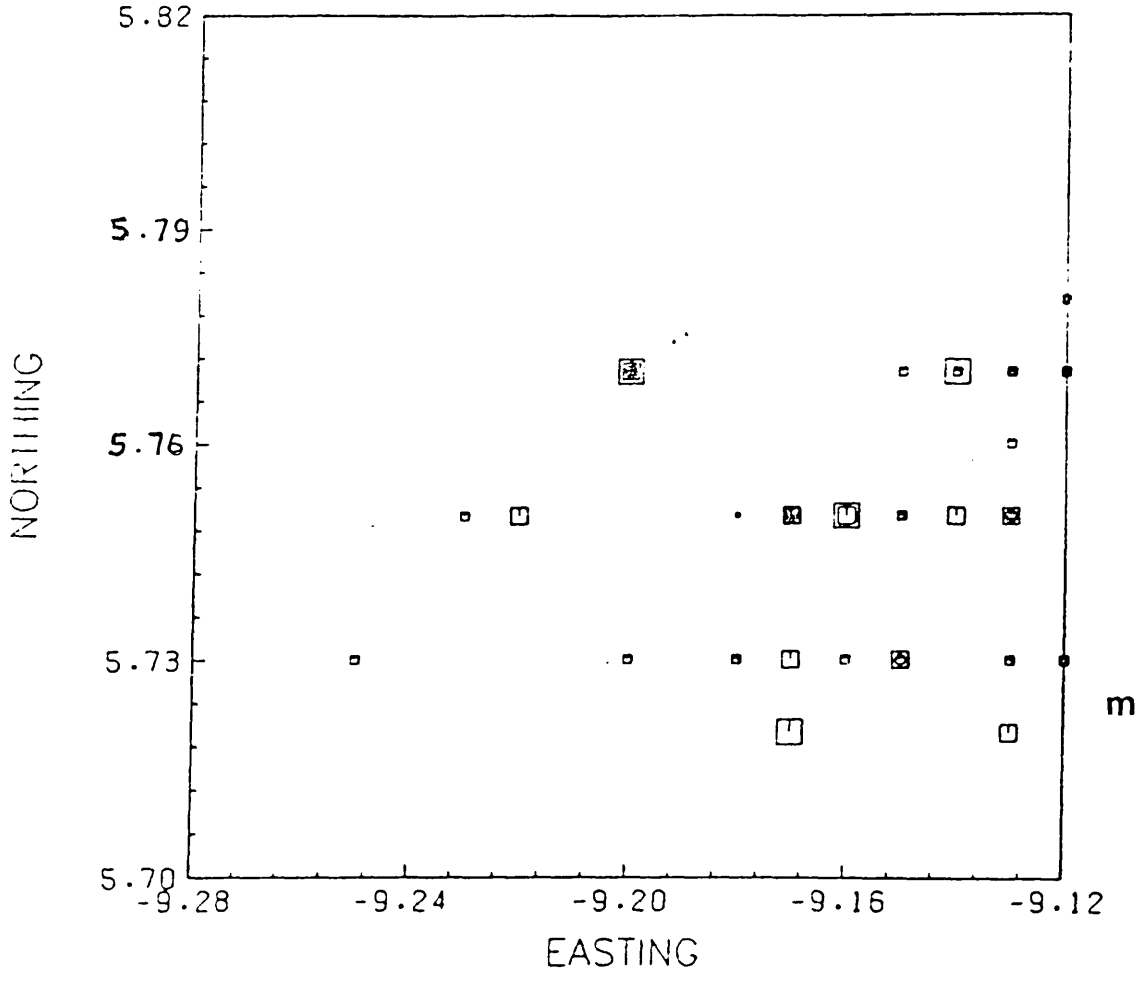
5.73
5.70
NORTHING
-9.26
-9.24
-9.20
-9.16
-9.12
EASTING
l
KEY
• ≧ 0.00
□ ≧ 14.00
⊡ ≧ 28.00
ppm Co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5.70
NORTHING
-9.28
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-9.16
-9.12
EASTING
KEY
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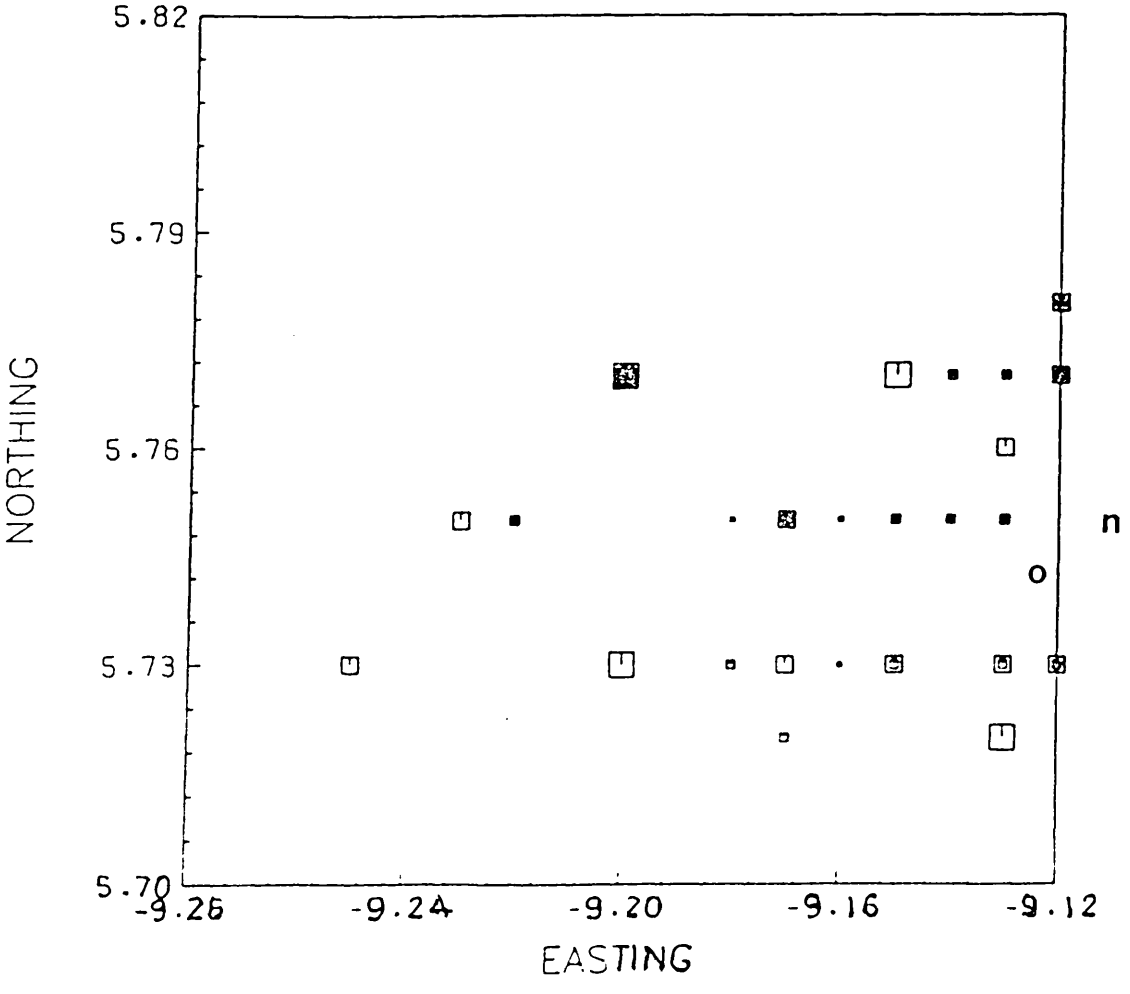
≥ 5.00
≥ 50.00
≥ 100.00
ppm Cu
m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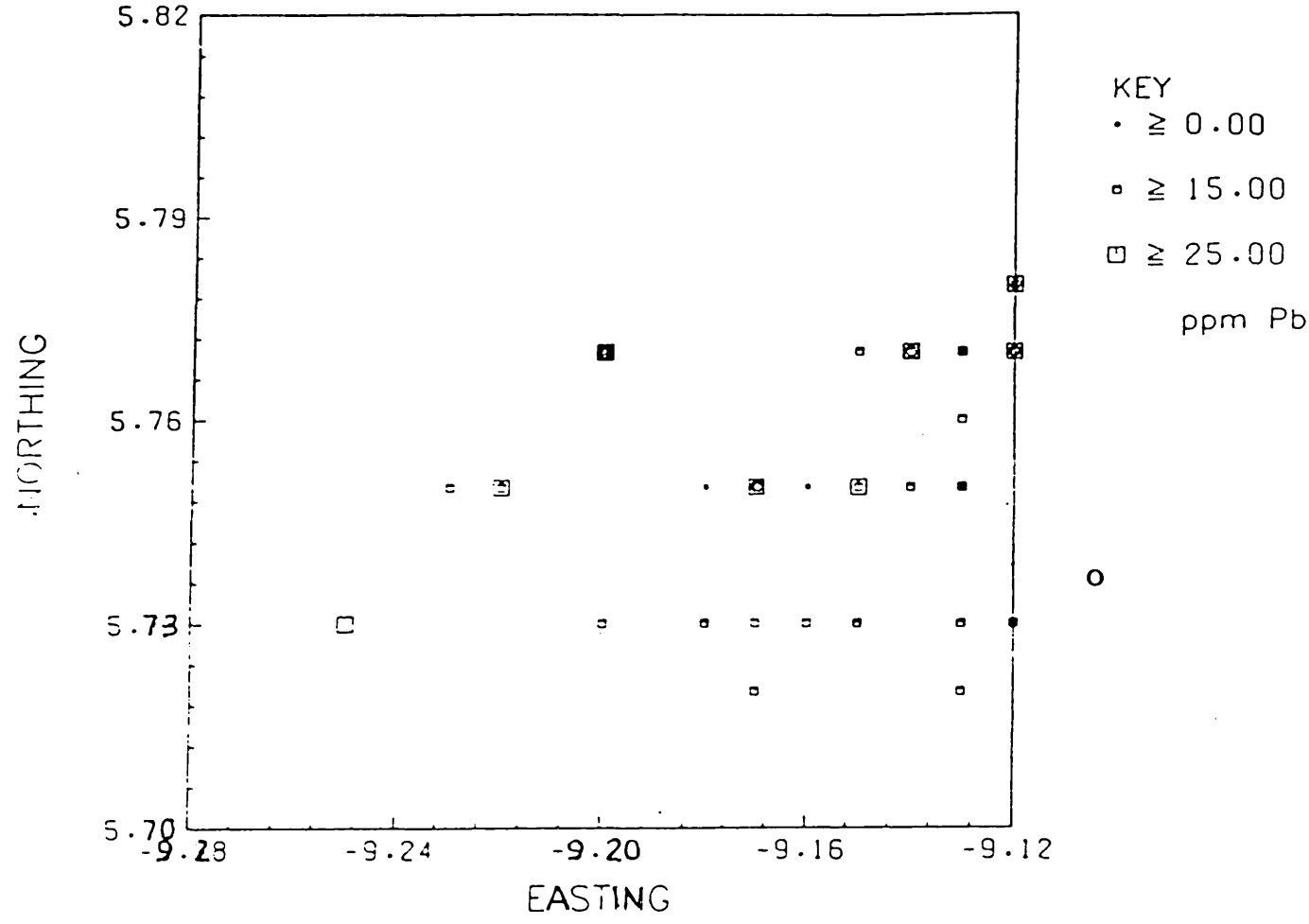
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
KEY
≥ 0.00
≥ 20.00
≥ 30.00
≥ 45.00
ppm La
n
o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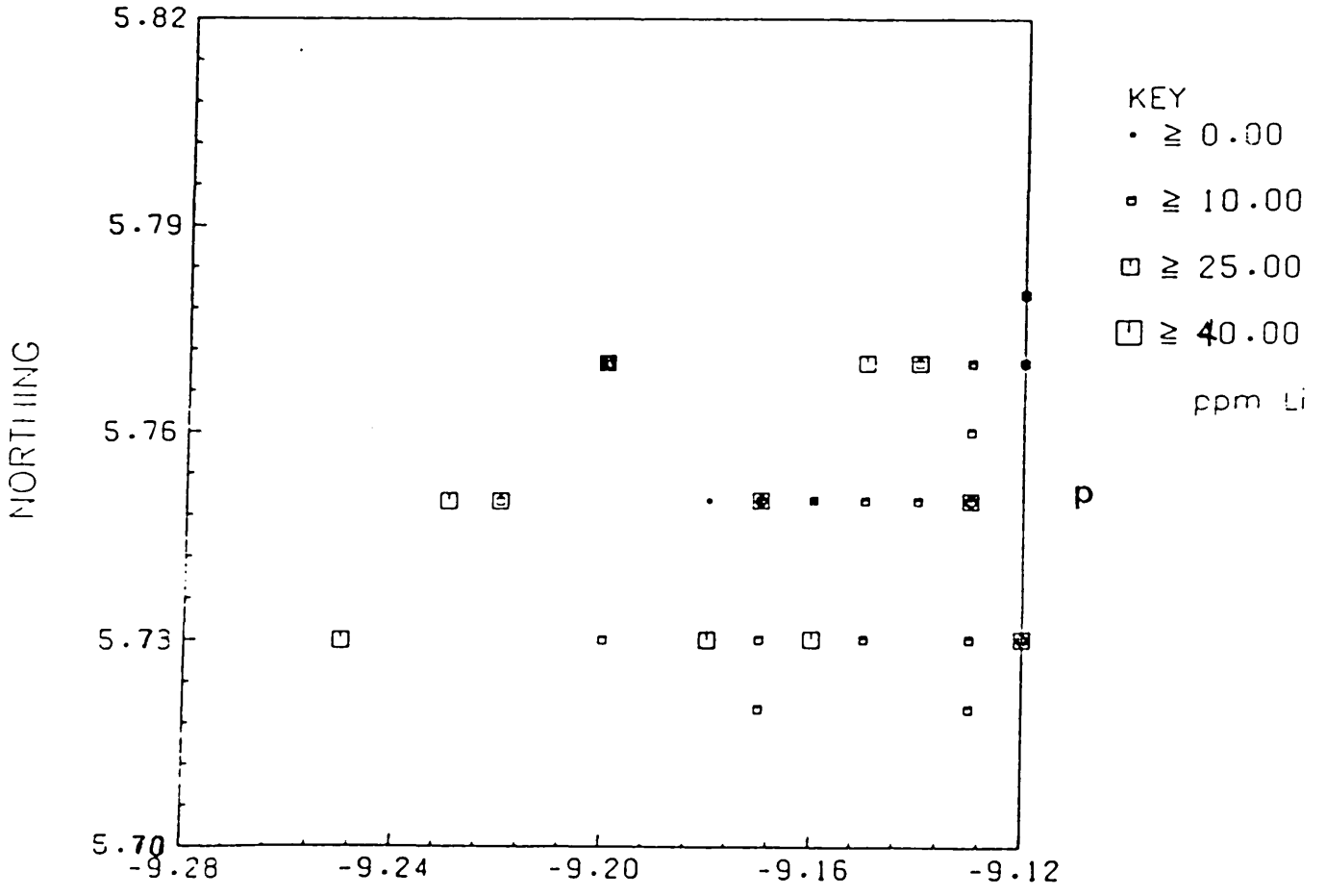
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
KEY
• ≧ 0.00
▫ ≧ 15.00
□ ≧ 25.00
ppm Pb
o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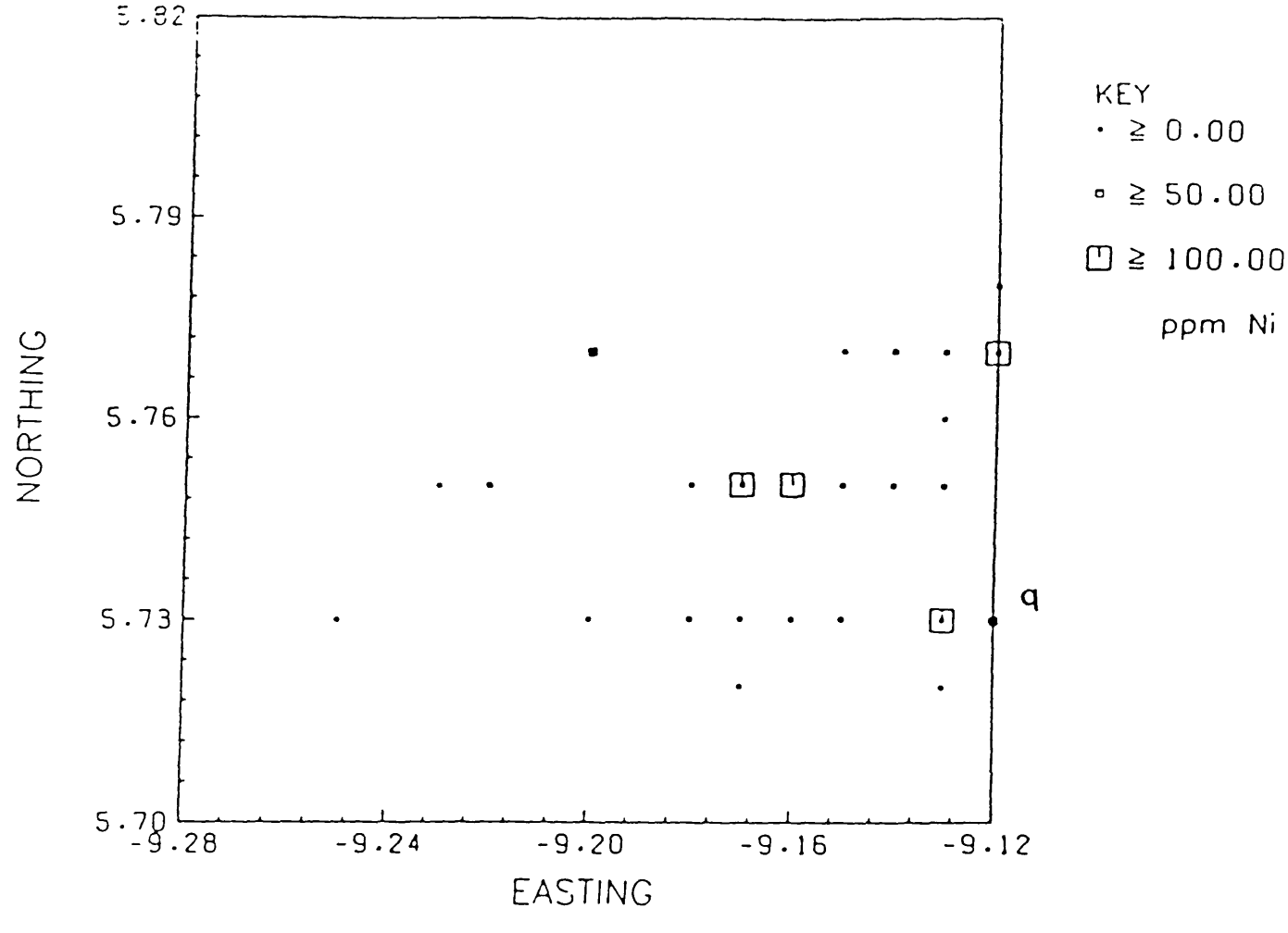
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
KEY
• ≧ 0.00
▫ ≧ 10.00
□ ≧ 25.00
⊡ ≧ 40.00
ppm Li
p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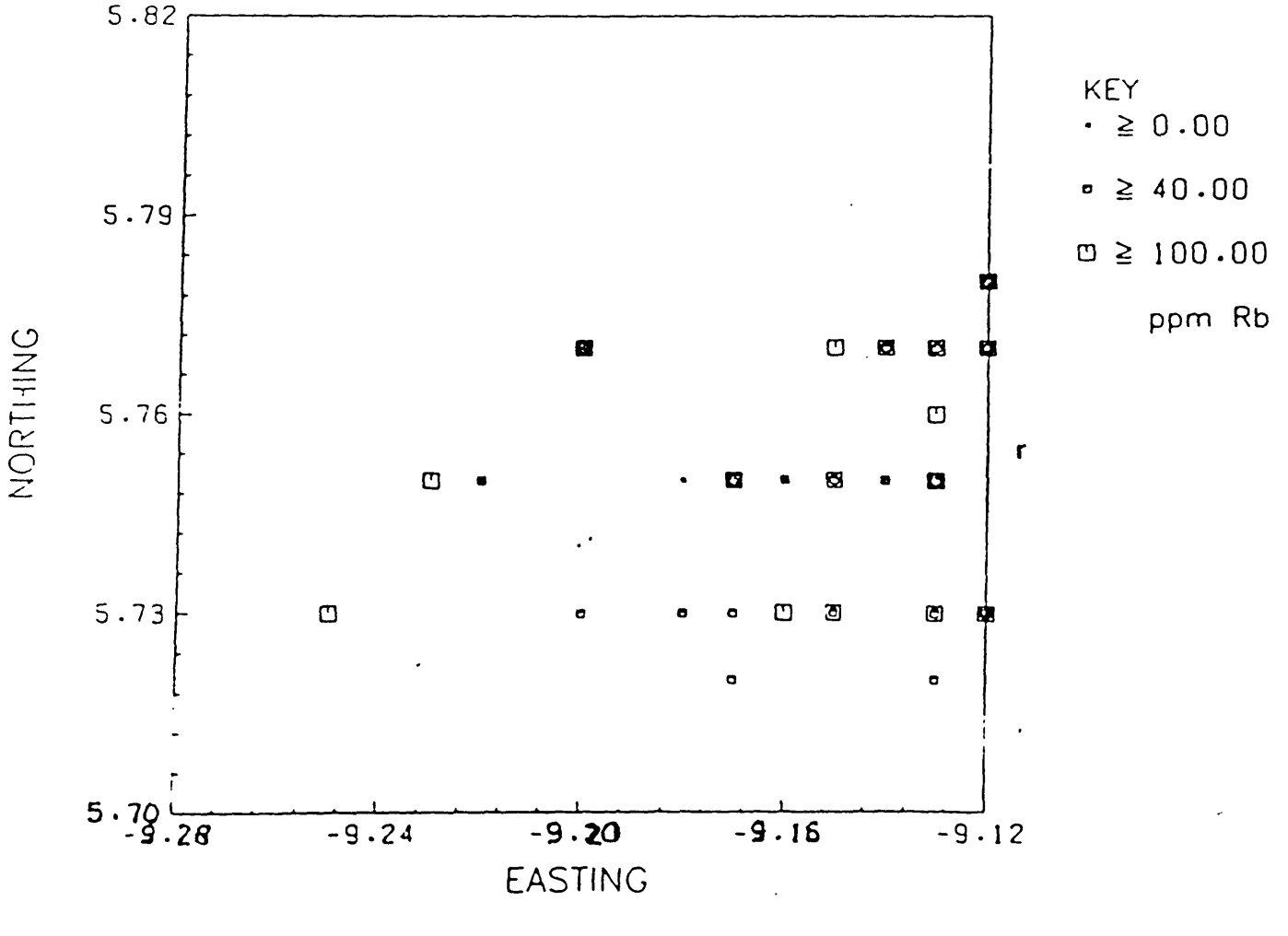
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
q
KEY
· ≧ 0.00
▫ ≧ 50.00
□ ≧ 100.00
ppm Ni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5.70
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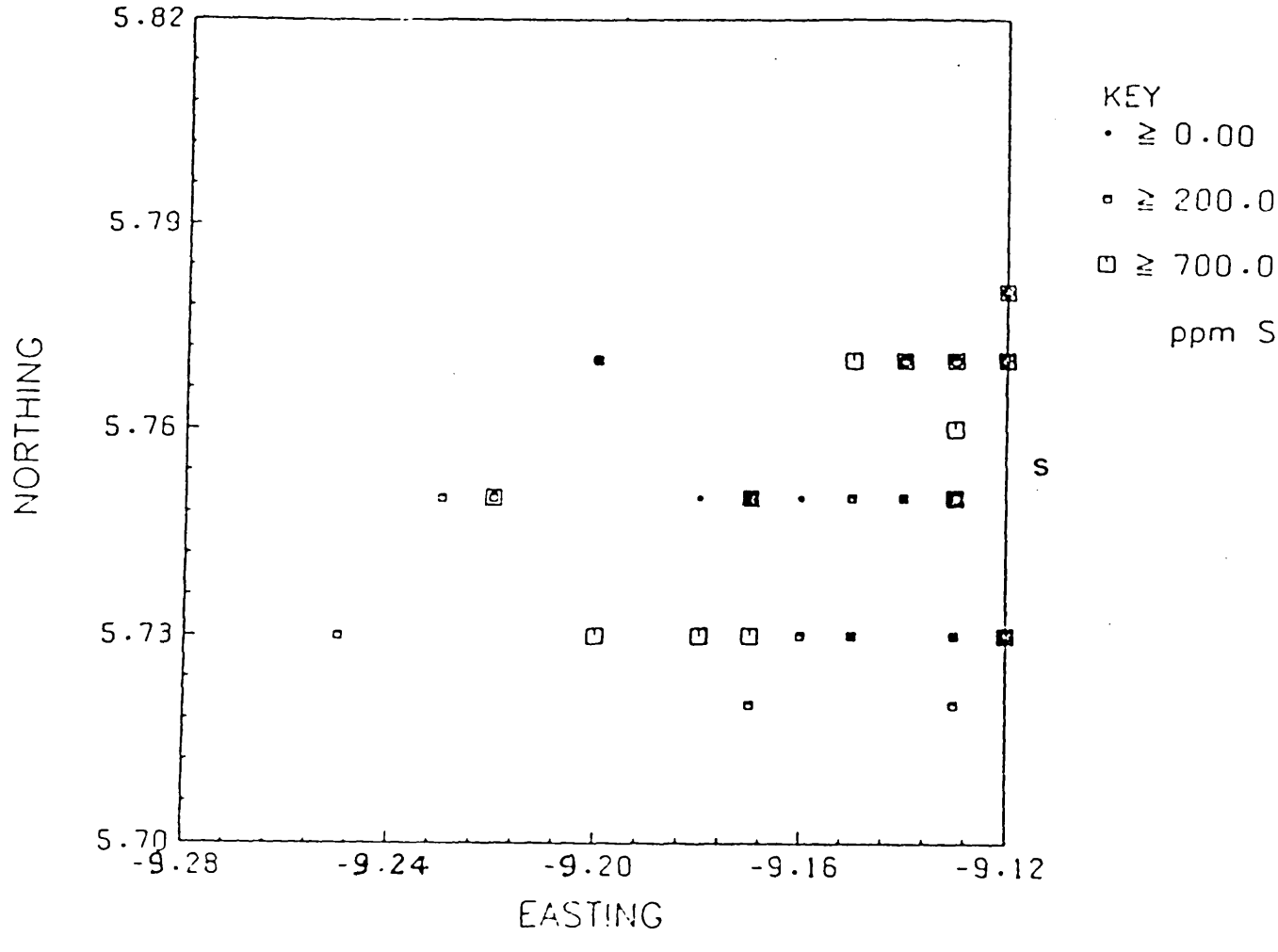
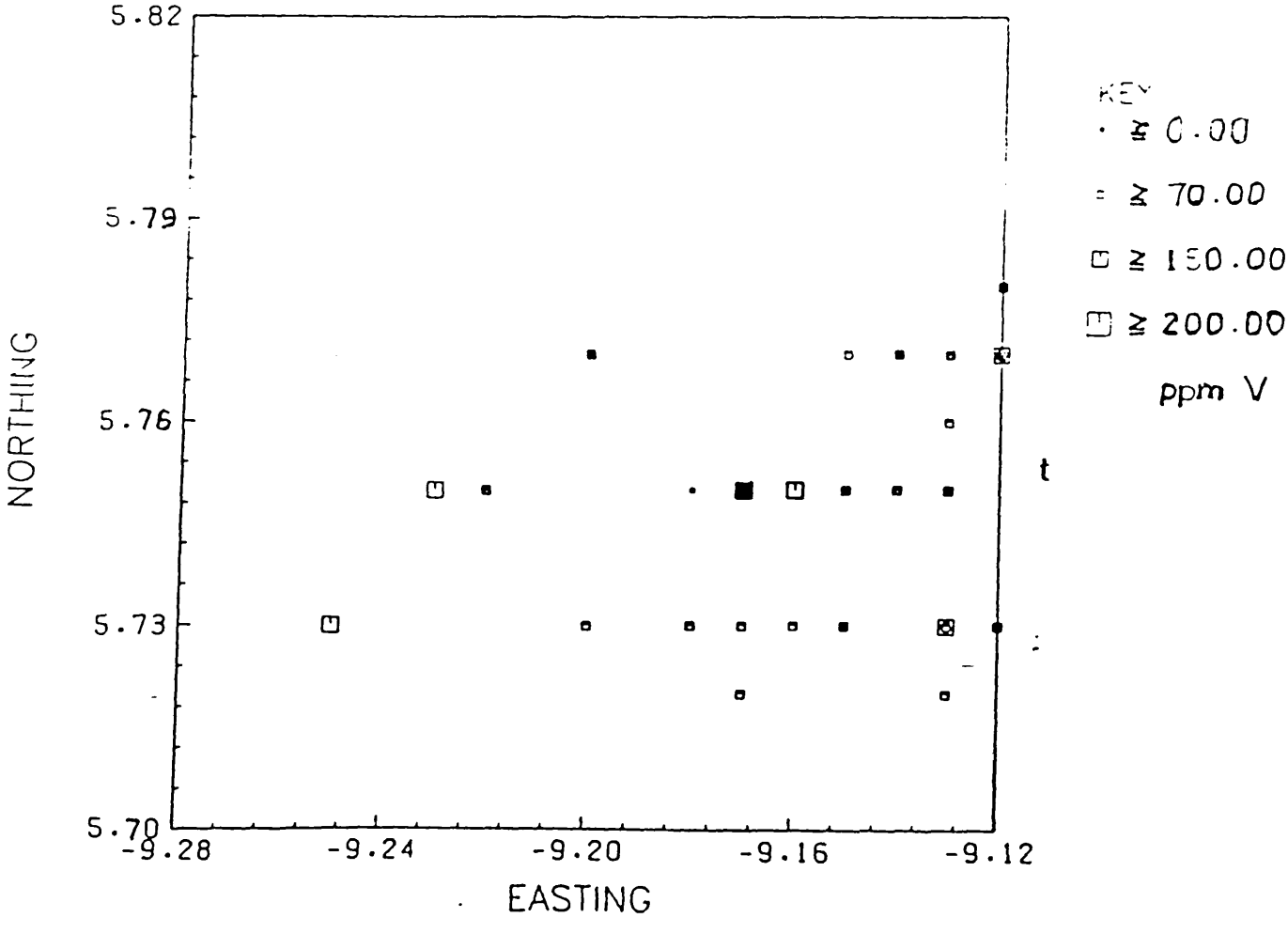
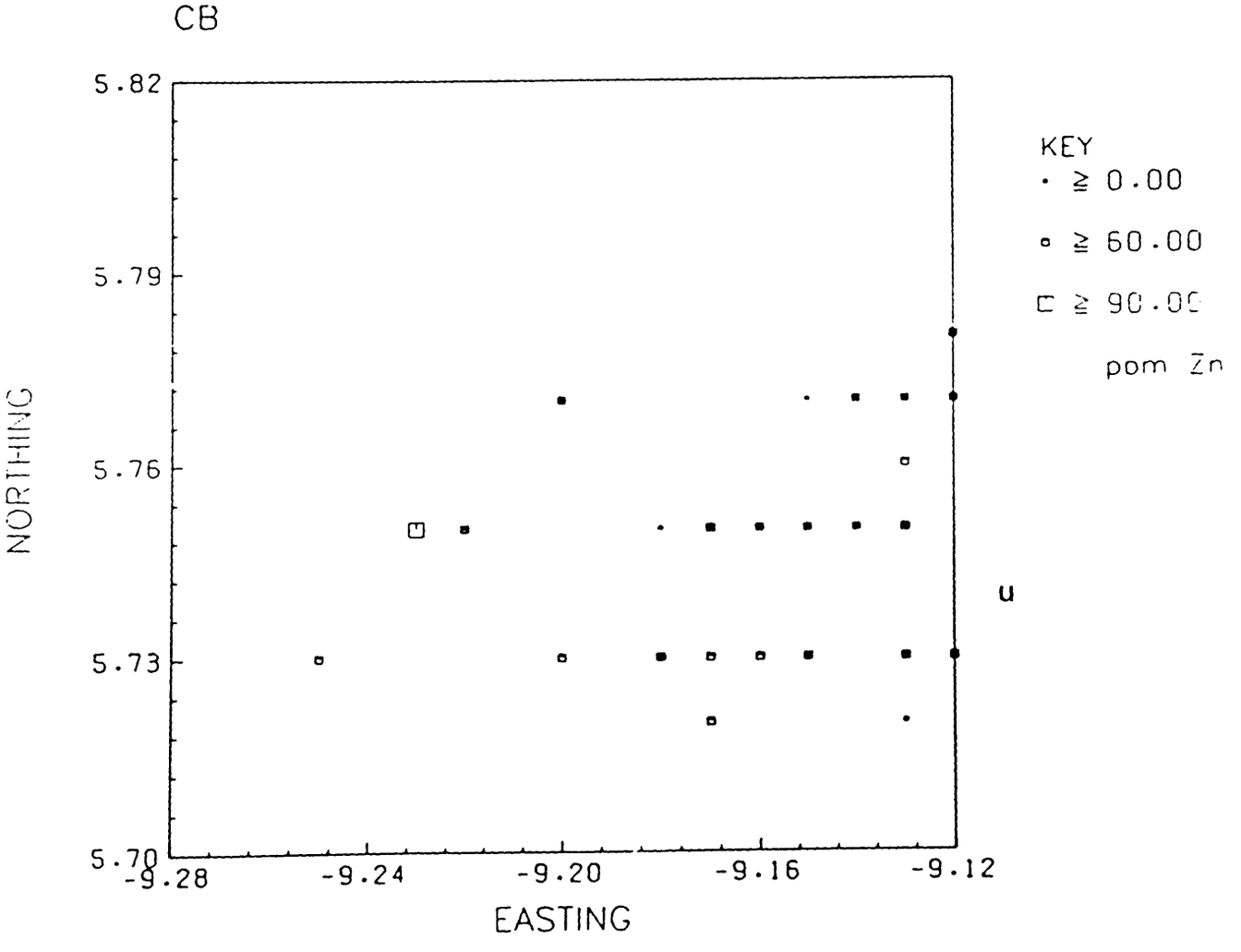
-9.24
-9.20
-9.16
-9.12
EASTING
r
KEY
· ≧ 0.00
▫ ≧ 40.00
□ ≧ 100.00
ppm Rb


5.82
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
KEY
≧ 0.00
≧ 200.0(
≧ 700.0(
ppm Sr
s


5.82
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
KEY
≧ 0.00
≧ 70.00
≧ 150.00
≧ 200.00
ppm V
t


CB
5.82
5.79
5.76
5.73
5.70
NORTHING
-9.28
-9.24
-9.20
-9.16
-9.12
EASTING
KEY
≥ 0.00
≥ 60.00
≥ 90.00
pom Zn

CHAPTER 9

COMPARATIVE GEOCHEMISTRY

9.1 It has become clear from the preceding chapter that the Liberian granitoids show a high degree of variability in their chemistry (and petrology) both at local and regional levels. The central purpose of this chapter is on the one hand to compare the geochemical and petrochemical features of these rocks among themselves, and to compare them as an entity with similar Pre-Cambrian granitoids from elsewhere on the other.

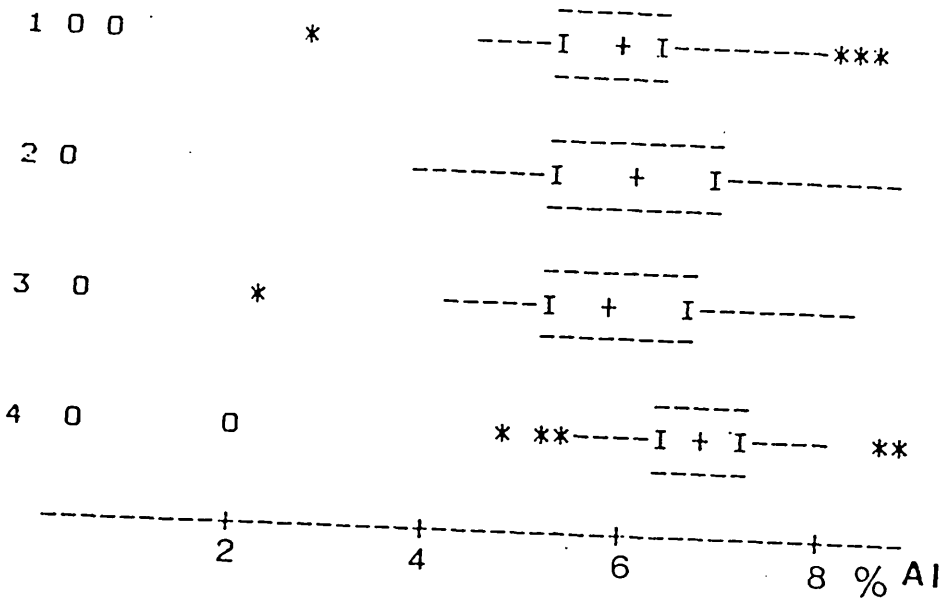
9.2 REGIONAL GEOCHEMISTRY

9.2.1 Element Abundances and Variations

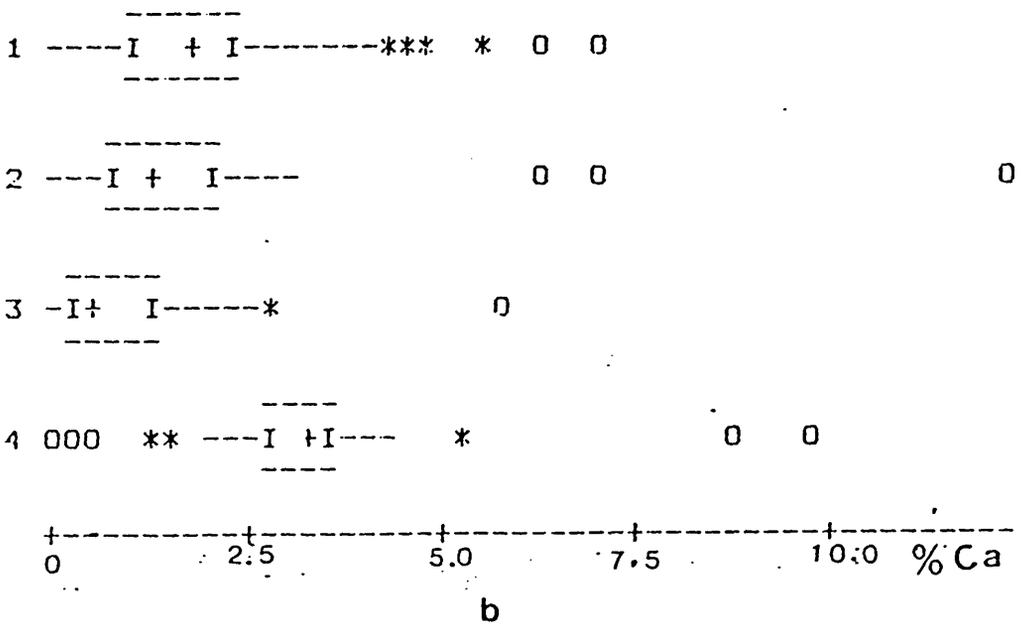
In order to provide a simple means of comparison of element abundance and variation in the different Liberian granitic rocks, boxplots (Wainer, 1981 in Leech, 1984; Howarth, 1984) have been obtained using the Minitab Package for each element determined; these are shown in Fig. 45 (a-u).

The box itself contains the central 50% of the data for each area with the median value indicated by a cross (+). The upper hinge (the right hand end) and the lower hinge (the left hand end) of the box lie respectively at the 75th and 25th percentiles of the data, and lines or whiskers extend from the hinges to the extremes of the data

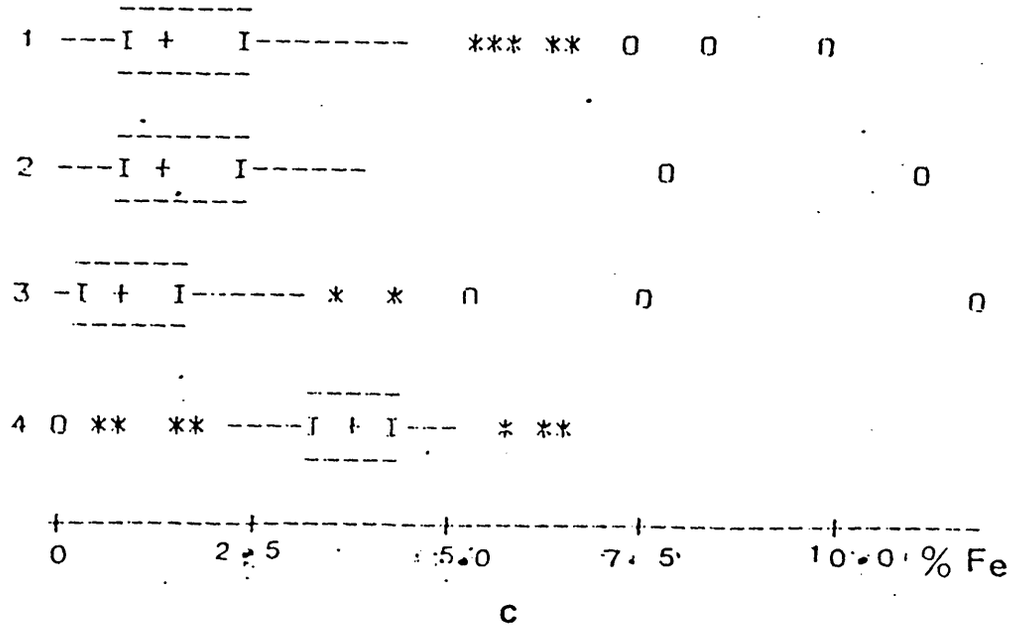
Fig.45(a-u) Boxplots for Al, Ca, Fe, K, Mg, Mn, Na, P, Ti, Ba, Be, Co, Cu, La, Pb, Li, Ni, Rb, Sr, V, Zn.
(1) Northwest Granites and associated gneisses (185);
(2) North Central Corridor suite (n=41); (3) Grebo Town area suite (n=47); (4) Cestos Batholith area suite (n=61).



a


1 ----I + I--------*** * 0 0
2 ---I + I---- 0 0 0
3 -I+ I-----* 0
4 000 ** ---I +I--- * 0 0
0 2.5 5.0 7.5 10.0 % Ca

b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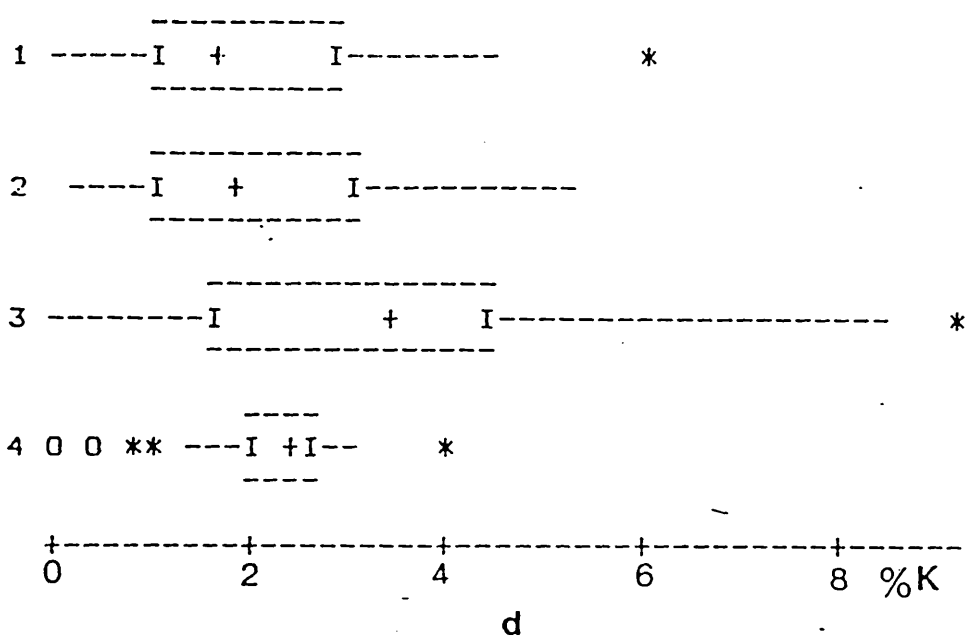
2 ---I + I------ 0 0
3 -I + I------ * * 0 0 0
4 0 ** ** ----I + I--- * **
0 2.5 5.0 7.5 10.0 % Fe

c



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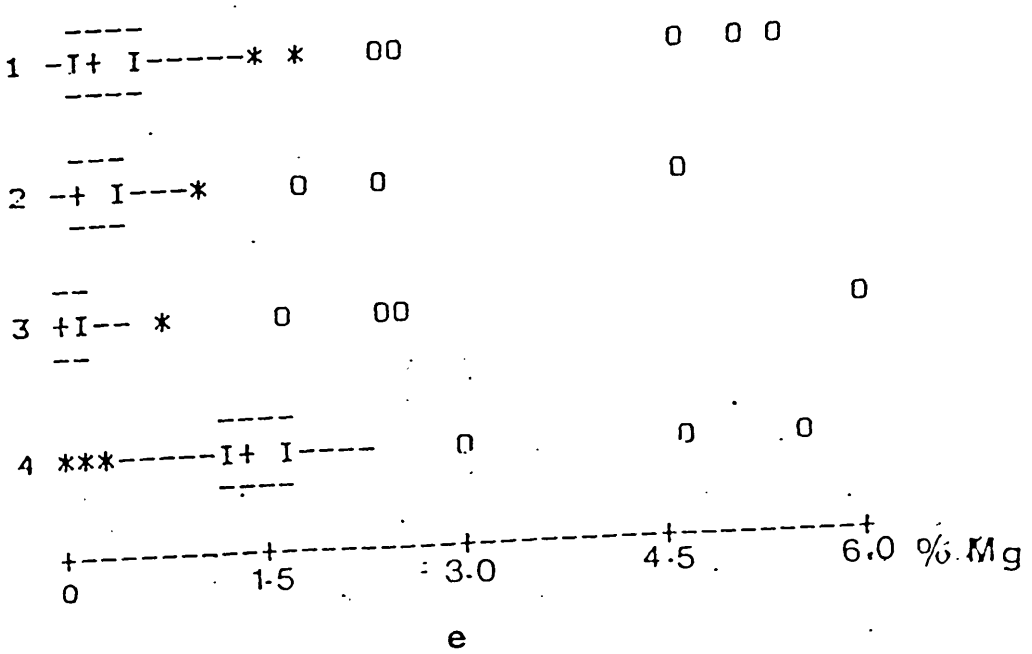

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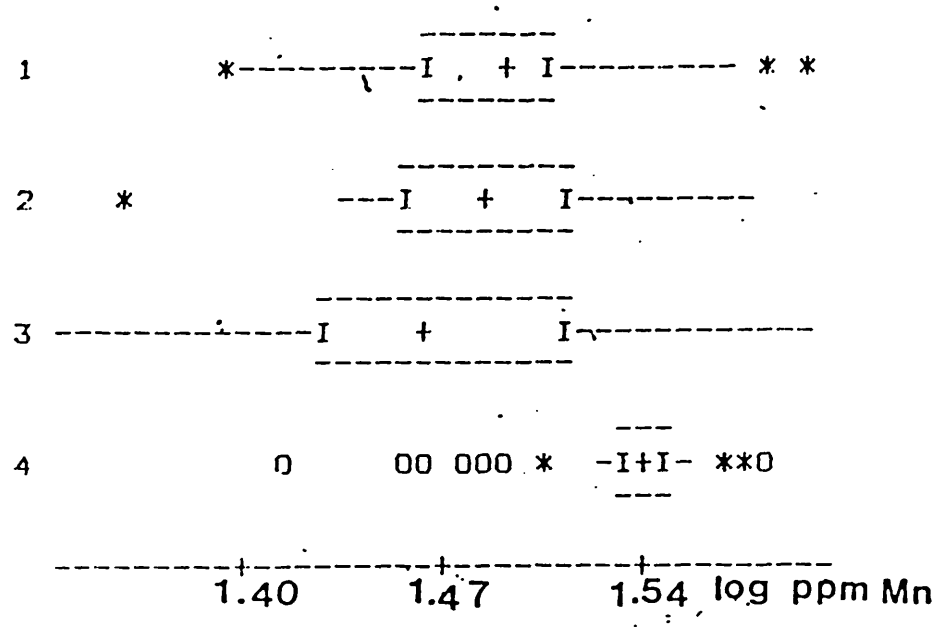

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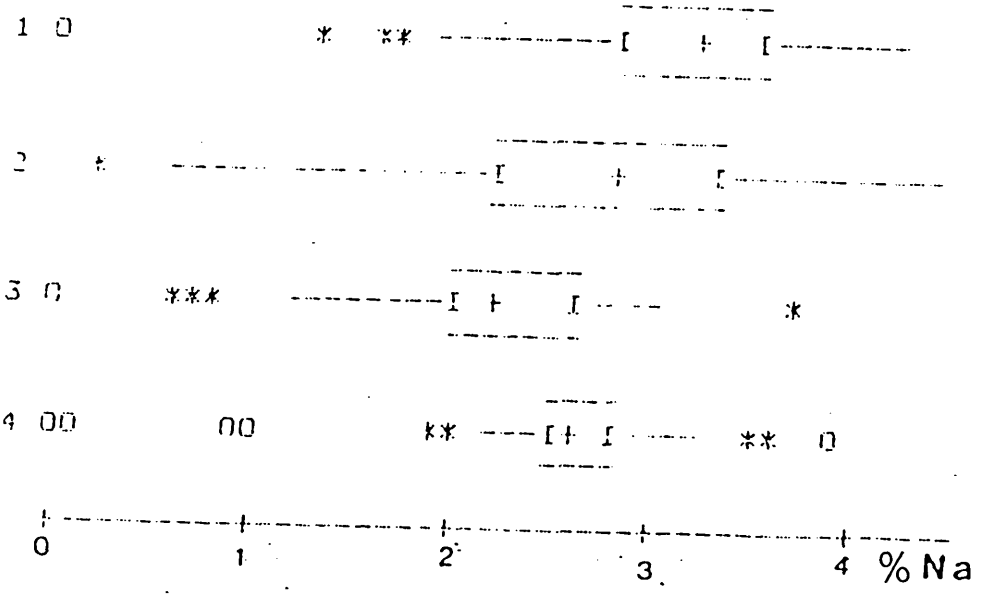

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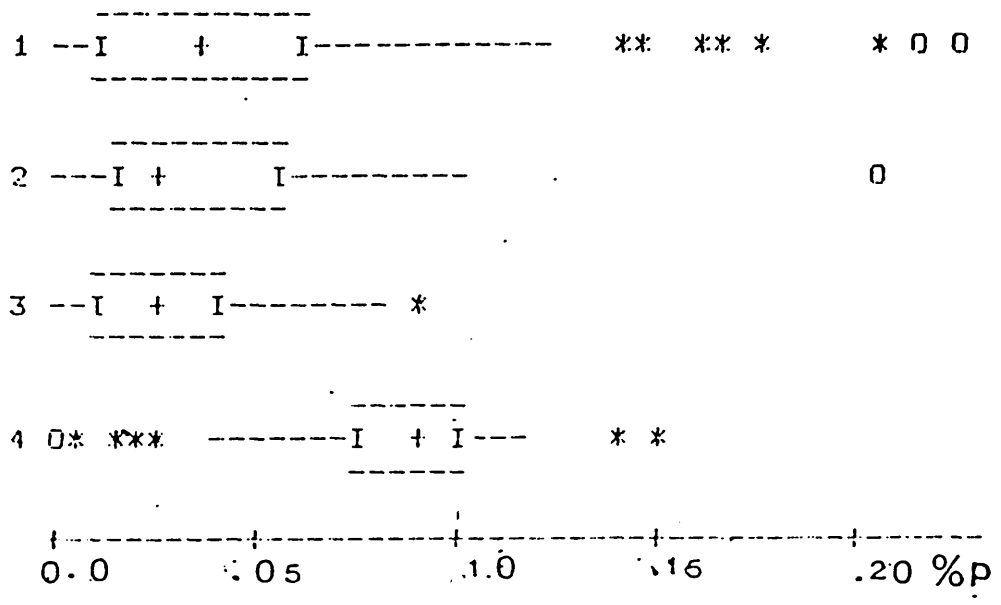

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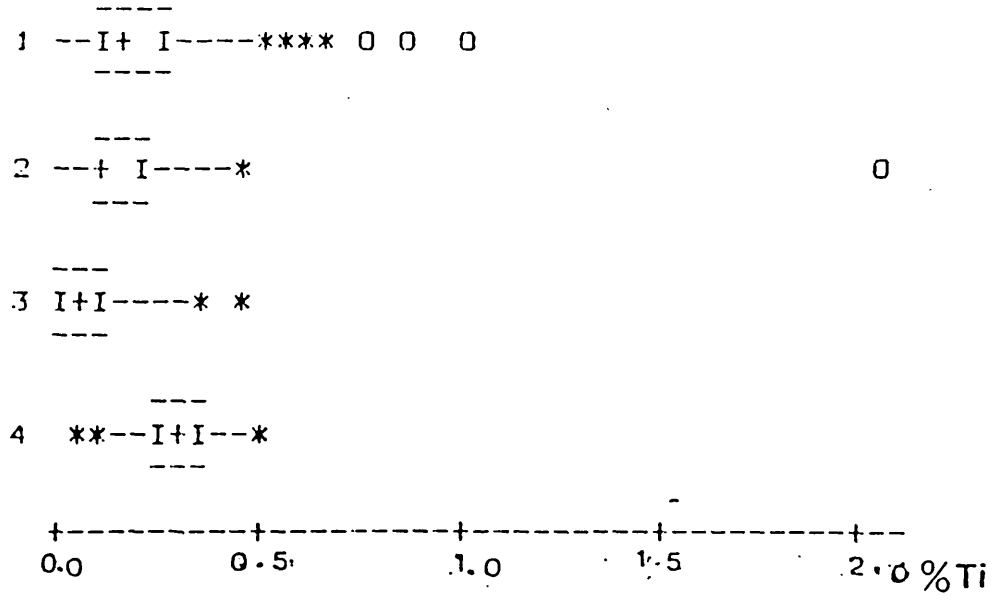

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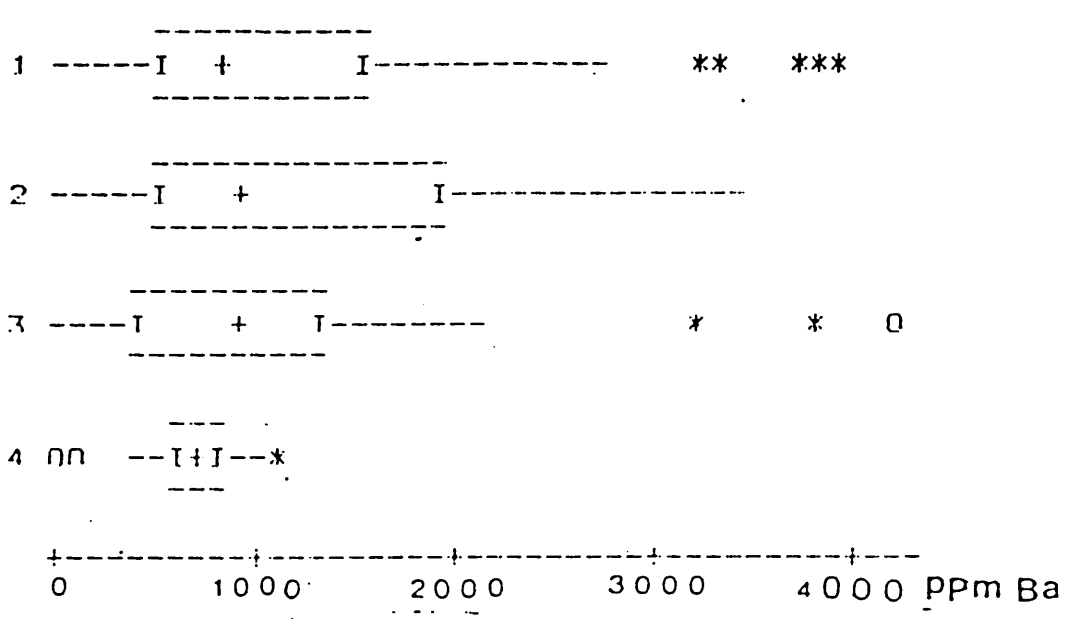

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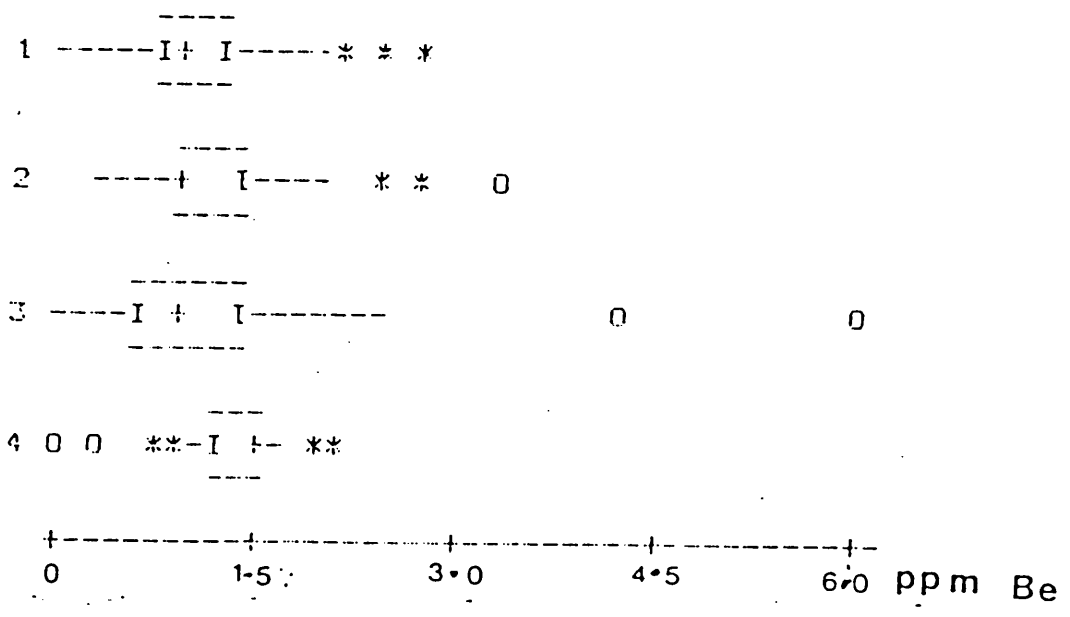

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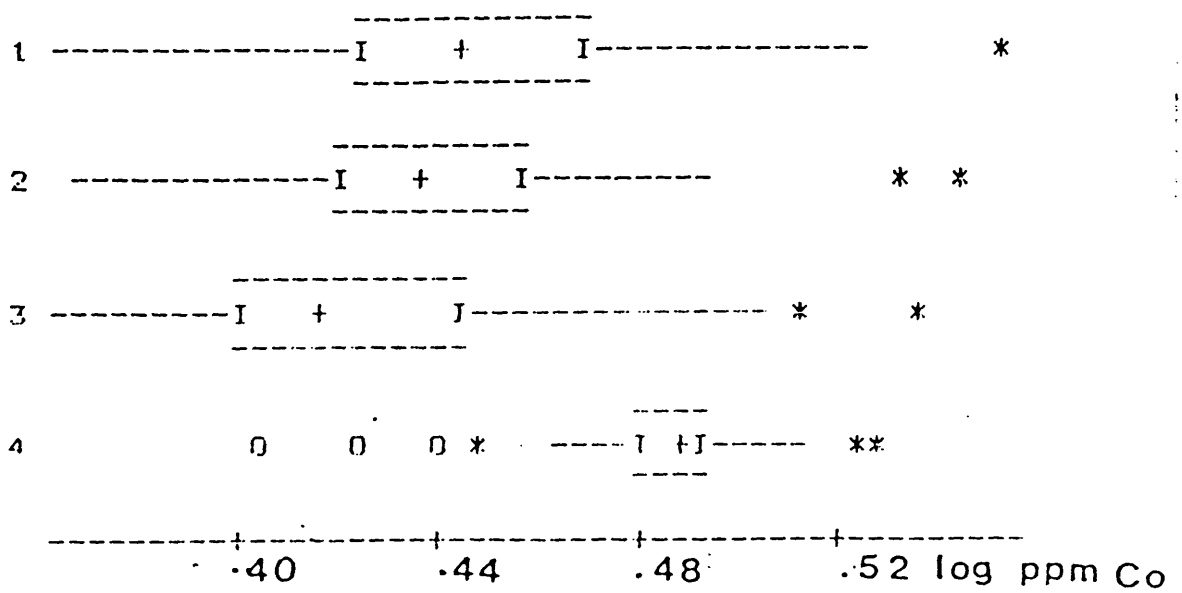

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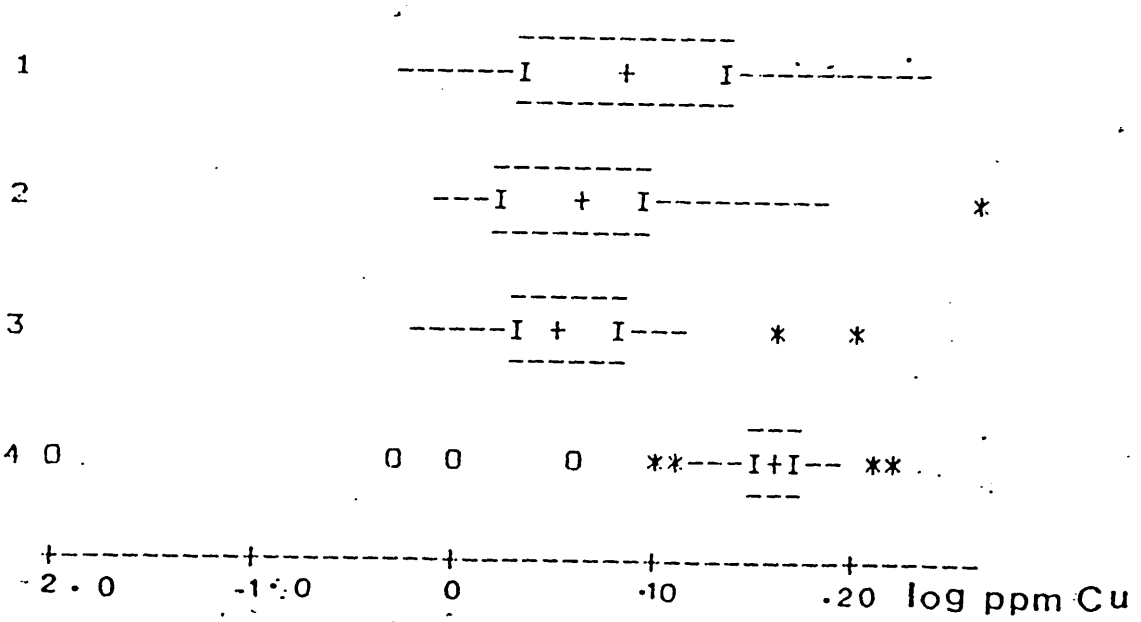

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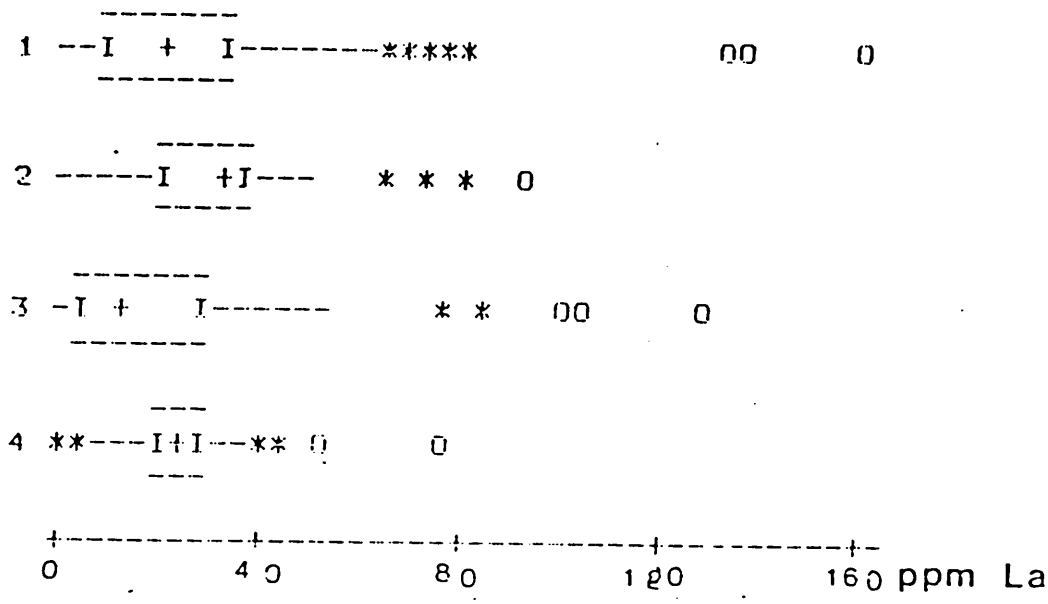

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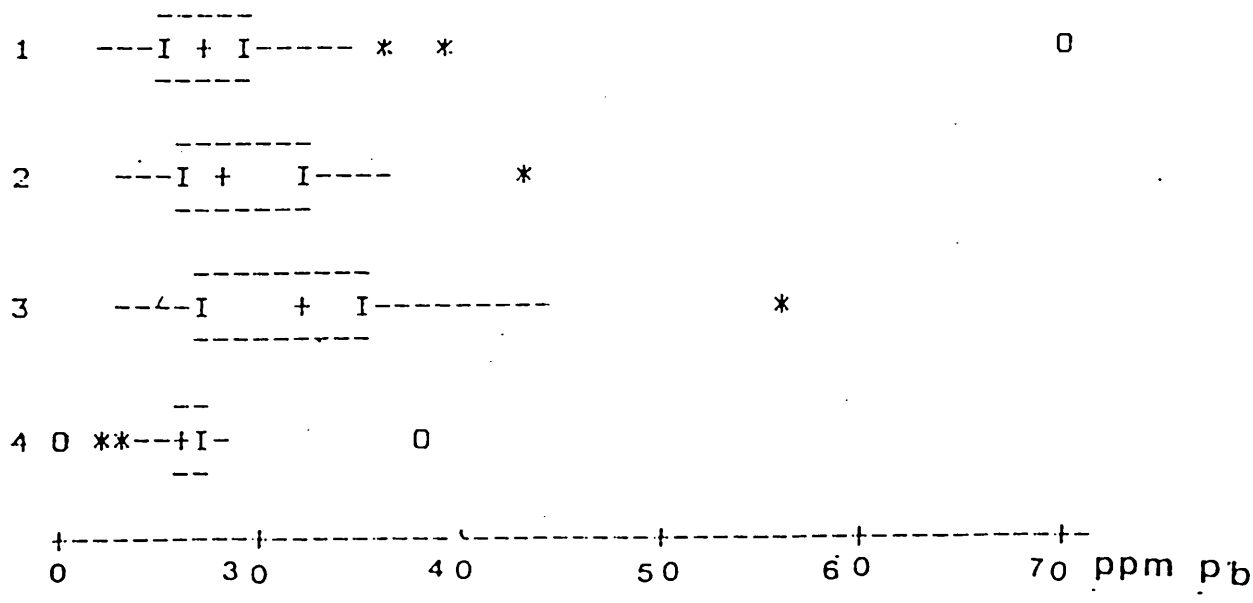

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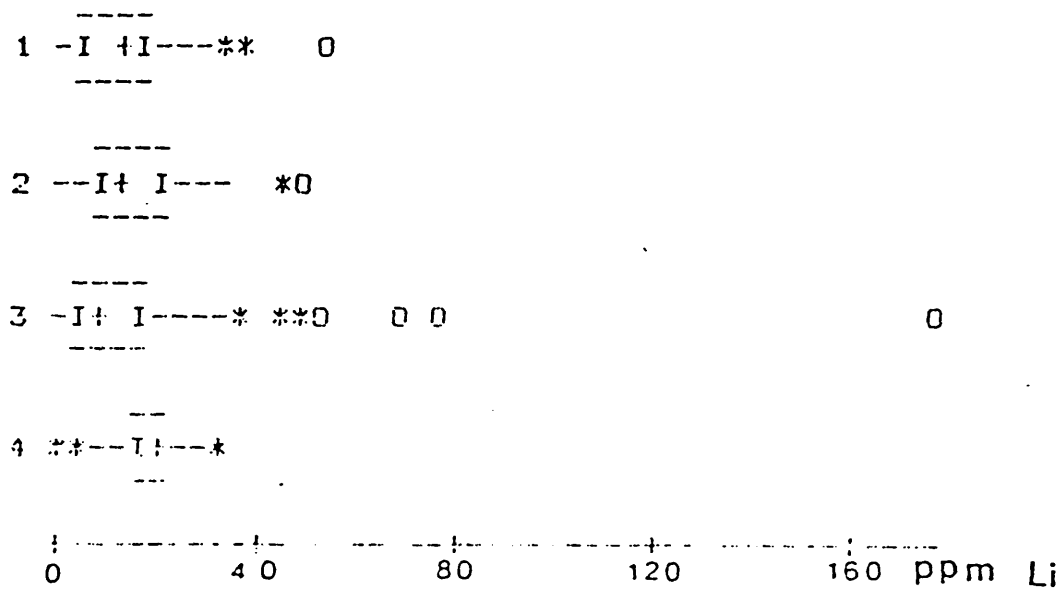

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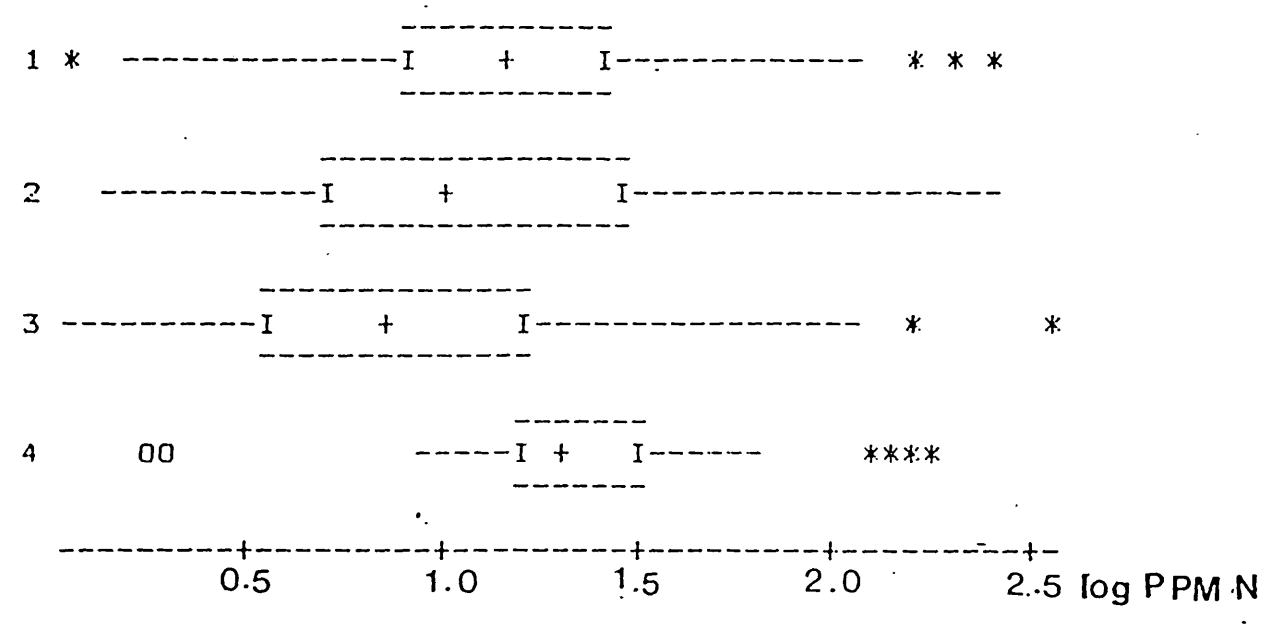

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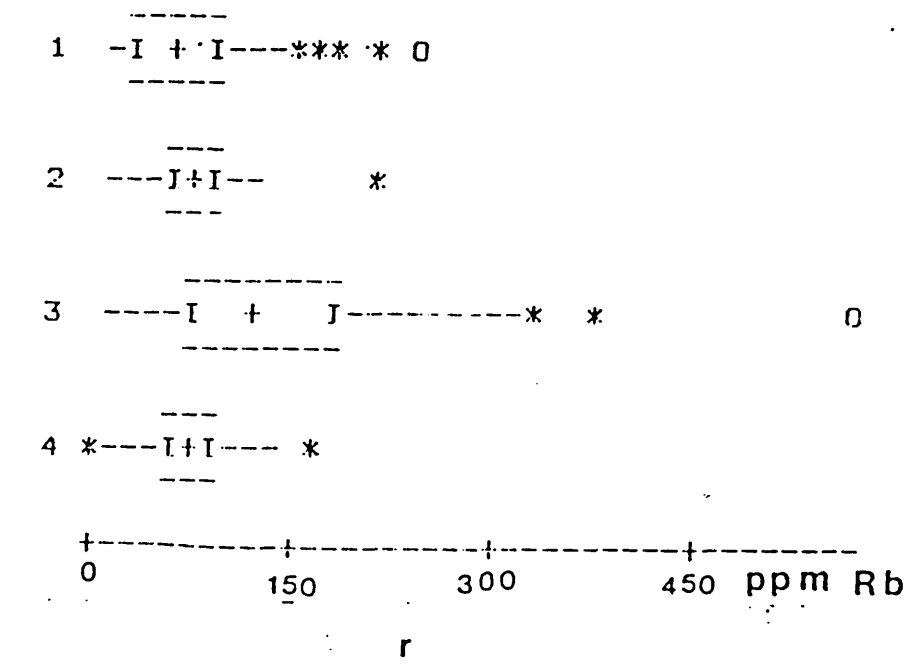

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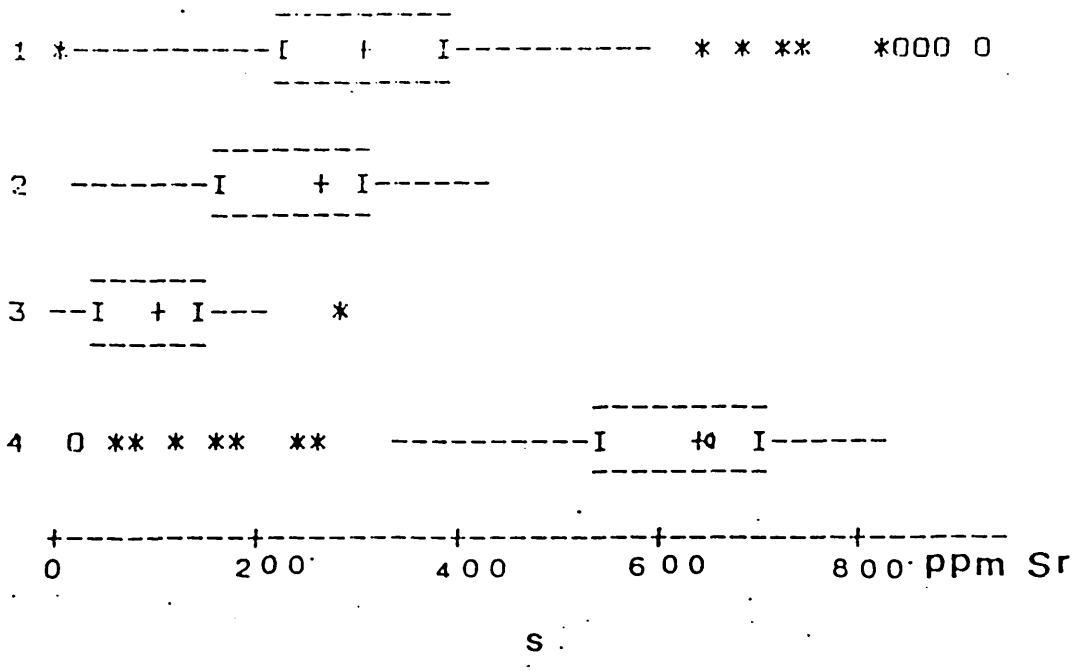

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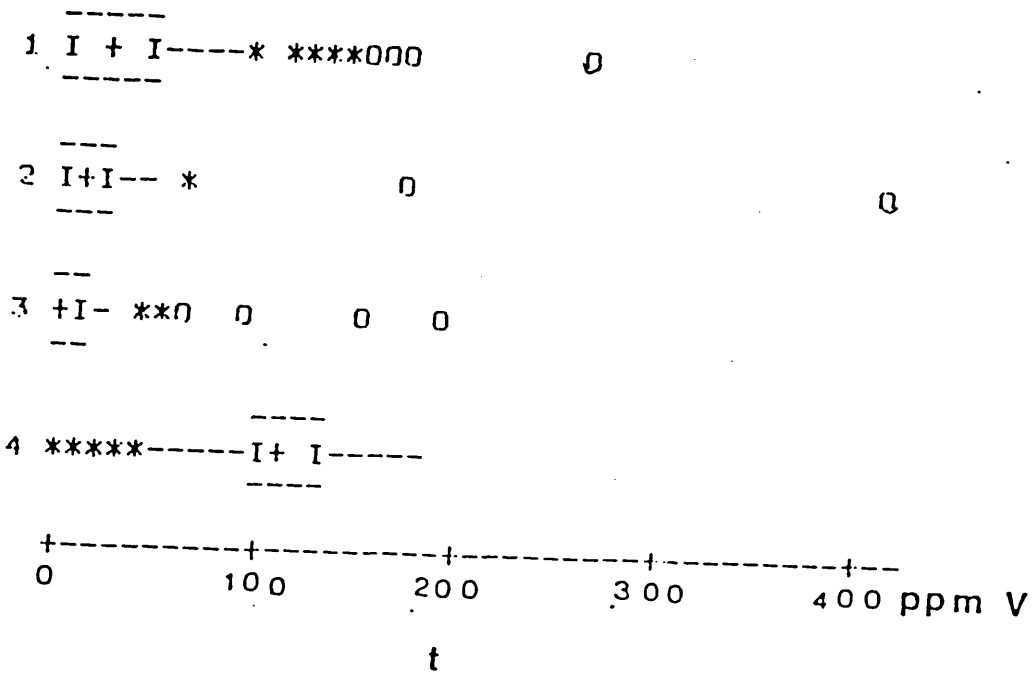
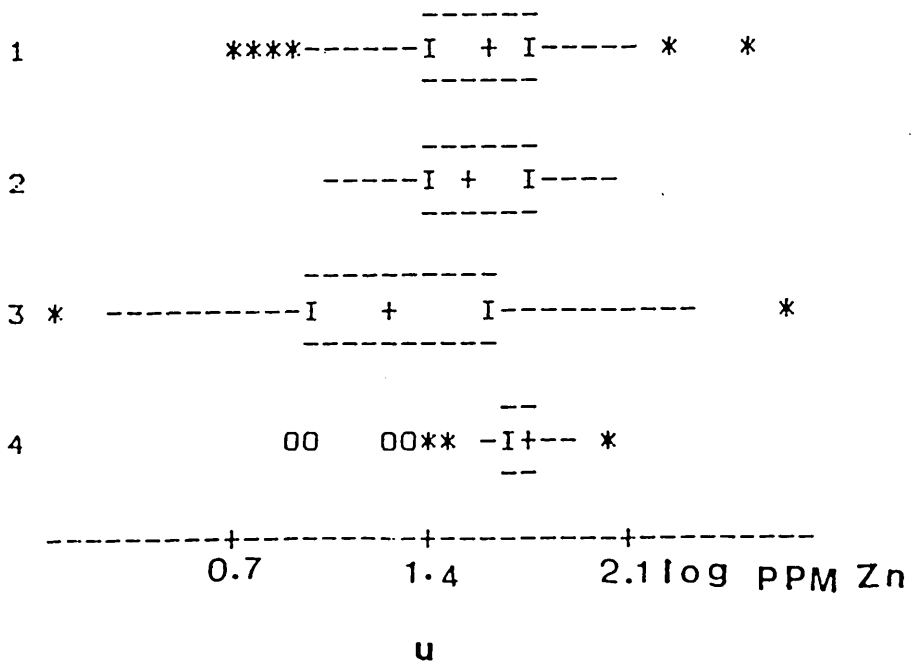

1
2
3
4
0
100
200
300
400 ppm V
t


1
2
3
4
0.7
1.4
2.1 log PPM Zn
u

lying within $\pm$1.5 of the concentration interval between the hinges outwards from the hinges. Possible outliers or wild values are indicated by an asterisk(*), while probable outliers are indicated by (o). The degree of variance of each element in a particular area is also apparent from the figures.

It is obvious from the boxplots that, although all of the suites of rocks under investigation are granitoids, they display to some extent regional as well as local chemical variability. For instance, the figures clearly and simply reveal that the Cestos Batholith and its associated granitic gneisses are the most calcium rich of the suites being studied. This lends support to the conclusion of the petrographic study carried out during the course of this work and the earlier findings of Tysdal (1978) that the rocks from the Cestos Batholith are mainly quartz dioritic, whilst samples from the other areas are chiefly granodioritic to granitic. It is also evident that the suite of rocks from the Grebo Town area is relatively depleted in the compatible elements Ca, Fe, Mg and Sr, but is significantly the most enhanced in the incompatible elements K, Li and Rb, suggesting that the rocks from this area are the most chemically evolved, while those from the Cestos Batholith area are the least fractionated.

In terms of local variability, it is quite apparent that most of the trace and minor elements display high concentration ranges; the major

elements are only slightly to moderately variable in range. This is also shown in Table 30 where the degree of variability of each element in a subset is indicated by the standard deviations.

The application of the Kleiner-Hartigan "Trees" method to the positive residual concentrations of certain trace elements (see Chapters 6 and 8) has also shown some degree of chemical variation (with lithological implications) among the Liberian granitoids. For example, it is apparent from Tables 25 and 29 that elements showing relatively higher residual concentrations in the Grebo Town area are mainly lithophiles (e.g. K, Li, Rb) whereas those from the Cestos Batholith area are mainly chalcophiles (in particular Mo). These differences may be considered a reflection of the petrological differences between the two areas. Similar differences observed in the other areas, such as the amount or kind of mafic minerals present, may likewise be correlated with their petrological and lithological differences.

9.2.2 Ratios

The reasons for the use of a variety of elemental ratios by previous investigations as a means of determining the stage of fractionation (and hence the mineralization potential) of granitoids were summarized in Chapter 5. Some of the ratios, such as (Na+K)/(Ca+Mg), K/Sr and Ca/Sr, are used simply as comparative tools which

TABLE 30 COMPOSITION OF THE GRANITIC ROCKS OF LIBERIA

		Mean	Std dev	Med	Min	Max
Al%	1	5.75	0.99	5.80	0.38	8.40
	2	5.88	1.43	6.10	0.20	8.60
	3	5.92	1.38	5.90	0.46	8.30
	4	6.73	1.24	6.90	0.54	8.90
Ca%	1	1.89	1.08	1.78	0.05	7.10
	2	2.13	2.26	1.39	0.12	12.30
	3	0.96	1.06	0.63	0.01	5.90
	4	3.28	1.50	3.30	1.38	9.80
Fe%	1	1.97	1.54	1.54	0.25	10.00
	2	1.99	1.97	1.35	0.09	11.20
	3	1.54	2.12	0.91	0.05	11.80
	4	3.80	1.24	3.90	0.28	11.80
K%	1	2.03	1.03	1.76	0.06	6.10
	2	2.21	1.30	1.93	0.26	5.40
	3	3.50	2.11	3.60	0.11	9.30
	4	2.32	0.70	2.50	0.11	4.10
Mg%	1	0.57	0.75	0.34	0.01	5.50
	2	0.59	0.84	0.29	0.01	4.80
	3	0.43	1.01	0.12	0.01	6.10
	4	1.49	0.86	1.45	0.09	5.60
Mn%	1	0.03	0.03	0.02	0.01	0.27
	2	0.03	0.03	0.02	0.01	0.16
	3	0.03	0.05	0.01	0.01	0.26
	4	0.07	0.03	0.07	0.04	0.27
Na%	1	3.18	0.60	3.30	0.08	4.30
	2	2.77	0.91	2.90	0.03	4.50
	3	2.24	0.73	2.30	0.03	3.80
	4	2.62	0.66	2.70	0.05	4.00
P%	1	0.05	0.04	0.04	0.01	0.23
	2	0.04	0.04	0.03	0.01	0.21
	3	0.03	0.02	0.03	0.01	0.09
	4	0.09	0.03	0.09	0.01	0.15
Ti%	1	0.20	0.16	0.16	0.01	0.02
	2	0.22	0.32	0.13	0.01	2.10
	3	0.11	0.12	0.06	0.01	0.47
	4	0.30	0.09	0.32	0.05	0.54
Ag ppm	1	1.7	0.7	1.5	1.1	2.9
	2	1.2	0.1	1.1	1.0	1.3
	3	1.3	0.1	1.2	1.2	1.3
	4	0.1	0.1	0.1	0.1	0.1
Ba ppm	1	1146	806	900	2	940
	2	280	956	930	25	3500
	3	1052	920	910	25	4300
	4	744	249	790	20	1130

(1) Northwest granites, n = 185; (2) granite gneisses, n = 41; (3) Grebo Town area, n = 47; (4) Cestos Batholith area, n = 61.

		Mean	Std dev	Med	Min	Max
Be	1	1.2	0.5	1.1	0.1	2.9
ppm	2	1.3	0.6	1.1	0.5	3.4
	3	1.3	1.0	1.0	0.2	6.2
	4	1.5	0.4	1.6	0.1	2.3
Cd	1	1.5	2.7	1.1	0.5	17.2
ppm	2	1.0	0.4	0.8	0.5	2.8
	3	1.0	0.5	1.0	0.5	1.4
	4	0.9	0.6	1.1	0.1	1.6
Co	1	11	11	8	1	94
ppm	2	11	14	7	1	74
	3	8	12	4	1	65
	4	20	8	20	3	94
Cr	1	14	40	6	1	330
ppm	2	28	89	4	1	530
	3	56	182	3	1	960
	4	40	40	32	0.1	220
Cu	1	21	36	8	1	230
ppm	2	20	70	4	1	430
	3	9	18	4	1	108
	4	47	35	40	1	430
La	1	27	22	23	5	164
ppm	2	35	21	34	2	94
	3	26	30	16	2	133
	4	27	11	26	2	78
Li	1	14	8	13	1	55
ppm	2	19	12	15	2	51
	3	20	29	11	2	177
	4	21	6	22	3	34
Mo	1	4.0	1.9	3.8	1.1	7.8
ppm	2	4.5	4.3	3.4	1.1	20.0
	3	3.9	2.7	2.7	1.1	8.5
	4	3.2	3.4	4.3	0.1	20.0
Ni	1	25	35	15	1	270
ppm	2	26	48	11	2	290
	3	28	62	8	1	380
	4	38	42	23	2	380
Rb	1	72	40	66	21	250
ppm	2	83	34	80	29	220
	3	152	104	132	24	580
	4	86	32	89	1	173
Pb	1	25	13	24	6	153
ppm	2	29	13	25	11	70
	3	38	19	38	9	110
	4	20	7	21	1	56
Sr	1	330	162	310	5	490
ppm	2	248	105	270	40	440
	3	107	81	113	1	290
	4	577	204	650	30	840

(1) Northwest granites, n = 185; (2) granite gneisses, n = 41; (3) Grebo Town area, n = 47; (4) Cestos Batholith area, n = 61.

		Mean	Std dev	Med	Min	Max
V	1	34	3	22	2	270
ppm	2	35	69	16	1	420
	3	21	39	7	1	200
	4	112	39	118	4	182
Zn	1	50	38	43	6	360
ppm	2	48	24	42	12	131
	3	44	85	21	1	550
	4	60	18	63	9	121

(1) Northwest granites, n = 185; (2) granite gneisses, n = 41; (3) Grebo Town area, n = 47; (4) Cestos Batholith area, n = 61.

show the relative degree of fractionation from one area to another. For other ratios, previous workers have used pre-set threshold values, below or above which individual intrusive bodies may be considered more or less fractionated. In the present study, both types of ratios have been applied and tables showing the ratios for all samples are given in the appropriate subsequent section.

This section has two main aims: firstly to discuss the individual ratios for each area; secondly, to provide a general comparison of these ratios among the Liberian granitoids studied. These comparisons will form the basis of further comparison of the ratios applicable to the Liberian granitoids with available published data for Pre-Cambrian granitoids from elsewhere in the world in Section 9.3.

9.2.2.1 The Northwest Granites and Associated Gneisses (Table 31)

(a) K/Rb: Disregarding twenty-four disproportionately high values caused by Rb contents below the analytical limit of detection, this ratio ranges from 126.9 (in Sample 4566) to 925.92 (in Sample 4683). Most of the remaining values (161) are above the threshold of 100 below which values may be suggestive of late-stage fractionation (Moseley, 1981). Only samples 4566, 4475, 4461, 4654 and 472 have values (126.9, 147.7, 156.6, 161.0 and 166.7, respectively) in the neighbourhood of this threshold.

TABLE 31 RATIOS OF TRACE AND MAJOR ELEMENTS FOR THE NORTHWEST GRANITES AND ASSOCIATED GNEISSES

Sample No.	K/Rb	K/Ba	Ba/Rb	K/Sr	K/Na	Ca/Sr	Mg/Ti
2083.000	225.564	24.390	9.248	361.446	1.364	53.012	3.420
4405.000	363.636	10.909	33.333	82.759	.828	49.655	1.935
4406.000	373.832	10.000	37.383	137.931	1.667	37.931	1.955
4411.000	329.897	21.333	15.464	179.775	1.067	45.506	1.433
4412.000	362.637	22.148	16.374	203.704	1.179	35.185	1.519
4413.000	373.494	26.496	14.096	168.478	1.033	46.196	1.970
4414.000	293.939	46.190	6.364	50.259	.226	82.383	2.353
4415.000	222.059	30.816	7.206	77.041	.387	71.939	1.990
4416.000	264.516	62.595	4.226	55.782	.248	278.912	2.875
4417.000	359.223	26.241	13.689	185.000	1.423	37.000	2.255
4421.000	300.000	40.714	7.368	42.222	.285	61.852	2.045
4422.000	371.429	13.978	26.571	83.871	.813	37.419	1.966
4423.000	108.0000	9.391	115000.000	25.116	.270	42.093	2.077
4424.000	415.556	6.926	60.000	47.949	.584	37.692	2.329
4425.000	271.154	8.150	33.269	29.375	.371	28.750	2.959
4427.000	224.242	6.727	33.333	18.049	.195	36.585	2.747
4428.000	385.417	6.607	58.333	48.684	.597	37.105	2.244
4431.000	950000.000	16.102	59000.004	27.941	.238	18.529	2.013
4432.000	182.857	17.067	10.714	35.556	.366	51.667	2.194
4433.000	195.122	15.686	12.439	20.513	.216	47.692	2.523
4434.000	275.000	14.070	19.545	29.512	.356	51.220	2.217
4442.000	472.000	11.569	40.800	30.256	.319	64.103	2.690
4443.000	355.263	34.177	10.395	137.056	.818	67.513	2.276
4444.000	207.273	22.353	9.273	36.774	.308	64.194	3.161
4445.000	269.767	17.313	15.581	41.429	.400	75.000	3.057
4446.000	350.000	23.692	14.773	73.333	.467	79.048	1.762
4451.000	375.000	13.793	27.188	77.419	.828	39.032	2.150
4452.000	500000.000	20.833	24000.000	17.241	.125	46.207	1.723
4453.000	269.697	21.190	12.727	26.176	.234	64.706	2.353
4454.000	59000.000	5.673	10400.000	4.275	.034	130.435	4.407
4461.000	156.566	36.905	4.242	87.079	.484	93.820	2.567
4462.000	277.778	16.556	16.778	113.636	.758	35.909	2.012
4463.000	194.915	23.232	8.390	85.185	.719	63.333	2.333
4464.000	245.763	24.576	10.000	69.048	.439	48.095	1.919
4465.000	307.018	15.909	19.298	145.833	1.296	54.583	2.500
4471.000	262.500	20.488	12.813	50.909	.494	63.636	2.607
4472.000	253.623	34.314	7.391	64.815	.500	74.074	2.429
4473.000	276.316	22.581	12.237	77.778	.700	65.185	2.286
4474.000	201.835	19.298	10.459	70.968	.667	57.419	2.545
4475.000	147.692	24.000	6.154	32.000	.267	73.333	2.602
4481.000	260.163	32.000	8.130	180.791	1.067	54.802	1.927
4482.000	654.545	17.143	38.182	87.805	1.500	51.220	4.783
4483.000	410.256	13.333	30.769	96.970	1.231	36.970	2.025
4484.000	440.678	12.381	35.593	55.319	.867	35.319	1.885
4485.000	242.857	28.814	8.429	54.839	.486	80.645	2.581
4486.000	305.769	11.955	25.577	32.449	.482	48.980	1.875
4487.000	416.667	15.909	26.190	102.941	1.000	23.824	1.522
4491.000	369.388	11.313	32.653	27.846	.584	38.462	1.741
4492.000	333.333	14.091	23.656	119.231	1.192	26.154	1.342
4493.000	446.154	7.436	60.000	38.667	.967	45.333	5.333
4494.000	297.500	29.750	10.000	41.034	.331	75.862	2.545
4495.000	337.349	7.368	45.783	37.333	.966	41.333	5.269
4501.000	619.048	13.000	47.619	78.788	.839	51.818	2.600
4502.000	112.0000	17.231	65000.000	29.474	.320	71.053	2.828
4503.000	500.000	10.909	45.833	78.261	1.286	43.261	.924
4504.000	445.946	9.706	45.946	73.333	1.269	41.556	1.050
4506.000	440.000	20.465	21.500	56.774	.677	80.645	4.464
4507.000	432.836	13.182	32.836	96.667	1.115	49.000	2.267
4508.000	680.000	14.783	46.000	130.769	1.172	23.846	1.857
4511.000	295.122	15.125	19.512	29.512	.378	63.415	3.034
4512.000	254.054	10.000	25.405	21.364	.235	61.364	1.960
4513.000	890000.000	11.867	75000.000	22.821	.247	79.487	2.970
4514.000	960000.000	12.973	74000.000	24.615	.310	79.487	2.606

Table 31 Continued..

4515.000	920000.000	23.590	39000.000	29.677	.288	70.968	3.868	
4521.000	355.769	9.250	38.462	71.154	.597	75.000	1.286	
4522.000	256.667	40.526	6.333	64.167	.513	95.833	2.413	
4523.000	235.000	14.030	16.750	26.857	.570	44.286	3.531	
4524.000	316.667	20.822	15.208	49.032	.447	67.742	2.293	
4525.000	283.951	18.699	15.185	82.143	.793	62.143	2.800	
4531.000	319.588	12.917	24.742	55.357	1.192	21.250	2.041	
4532.000	317.742	24.625	12.903	56.286	.597	80.000	2.972	
4533.000	520.833	10.417	50.000	27.778	.758	38.889	6.737	
4534.000	670000.000	14.255	47000.000	29.130	.347	308.696	13.333	
4535.000	400.000	7.500	53.333	60.000	1.111	33.600	2.243	
4541.000	260.606	605.634	.430	1048.780	1.720	104.878	.392	
4542.000	264.706	206.897	1.279	642.857	1.385	105.357	.800	
4543.000	131000.000	545.833	240.000	267.347	1.658	112.245	2.080	
4544.000	444.444	22.472	19.778	68.966	.541	51.034	2.105	
4545.000	436.620	20.000	21.831	103.333	1.033	34.333	.753	
4546.000	336.957	20.530	16.413	103.333	1.000	38.000	1.500	
4547.000	488.889	12.717	38.444	56.410	.579	66.667	1.829	
4548.000	183.908	800.000	.230	2831.858	1.032	168.142	.627	
4549.000	449.275	19.745	22.754	96.875	1.148	35.938	1.514	
4551.000	214.754	24.717	8.689	45.172	.452	93.103	3.767	
4552.000	456.522	21.000	21.739	35.000	.300	90.000	2.300	
4553.000	410.714	19.828	20.714	35.938	.311	87.500	2.226	
4554.000	322.581	20.134	16.022	111.111	1.111	58.148	2.177	
4555.000	245.283	10.400	23.585	29.885	.765	36.782	8.543	
4556.000	271.739	10.870	25.000	30.120	.781	28.916	2.962	
4561.000	212.121	8.235	25.758	29.787	.875	32.979	6.750	
4562.000	172.000	134.375	1.280	661.538	1.955	36.923	1.122	
4563.000	182.320	91.667	1.989	458.333	1.065	73.611	2.102	
4564.000	491.803	22.059	22.295	142.857	1.111	49.524	1.915	
4565.000	230.0000	41.818	55000.000	166.667	1.337	45.652	1.494	
4566.000	126.923	17.742	7.154	117.857	3.882	25.714	4.554	
4567.000	183.871	26.308	6.989	41.707	.743	153.659	9.649	
4571.000	670000.000	23.103	29000.000	9.710	.197	81.159	3.968	
4572.000	530000.000	6.709	79000.000	9.138	.151	84.483	1.794	
4573.000	242.718	15.924	15.243	64.103	.781	40.000	2.594	
4574.000	960000.000	12.973	74000.000	23.415	.246	73.171	3.406	
4575.000	363.265	15.214	23.878	41.395	.539	55.814	4.320	
4581.000	581.481	17.253	33.704	37.381	.449	42.619	4.000	
4582.000	137.0000	22.459	61000.000	27.400	.361	56.000	4.194	
4583.000	286.713	41.000	6.993	341.667	1.640	39.167	1.840	
4591.000	417.582	52.055	8.022	447.059	1.407	50.588	2.143	
4592.000	277.273	92.424	3.000	938.462	2.103	40.000	1.474	
4593.000	440.000	22.564	19.500	200.000	1.692	26.364	1.015	
4601.000	373.737	21.893	17.071	127.586	1.423	27.586	1.742	
4602.000	374.419	21.184	17.674	39.268	.424	40.000	1.409	
4603.000	358.025	17.901	20.000	85.294	1.000	26.176	1.707	
4604.000	387.500	28.182	13.750	33.514	.400	118.919	1.773	
4605.000	370.787	30.841	12.022	122.222	1.100	31.852	1.495	
4611.000	222.727	25.345	8.788	38.684	.377	48.158	1.538	
4612.000	328.571	25.275	13.000	63.889	.676	31.944	1.106	
4613.000	265.896	20.000	13.295	200.000	1.917	33.478	.862	
4615.000	238.462	38.272	6.231	163.158	1.069	56.842	1.923	
4616.000	263.158	37.975	6.930	159.574	1.034	51.064	2.083	
4617.000	358.065	12.065	29.677	32.647	.347	67.647	2.423	
4618.000	180.723	34.483	5.241	157.895	1.000	61.579	2.000	
4622.000	253.704	17.792	14.259	26.863	.415	56.863	5.550	
4623.000	205.128	24.242	8.462	212.766	2.963	207.447	6.582	
4624.000	263.636	25.778	10.227	27.619	.276	78.571	2.766	
4625.000	190.000	33.929	5.600	67.376	.380	219.858	2.058	
4626.000	362.500	9.831	36.875	17.846	.322	64.615	3.143	
4631.000	750000.000	12.295	61000.000	10.135	.221	62.162	2.214	Table 31
4632.000	382.353	24.762	15.441	83.871	.788	32.581	1.452	Continued...
4633.000	344.086	26.230	13.118	145.455	1.032	37.273	1.705	
4634.000	388.889	24.348	15.972	100.000	.875	32.500	1.944	
4635.000	348.837	28.037	12.442	115.385	.938	32.492	2.136	

Table 31 Continued.

4636.000	500.000	9.630	51.923	30.233	.765	34.884	5.524
4642.000	264.286	23.125	11.429	231.250	1.682	34.375	1.281
4643.000	242.667	21.163	11.467	75.833	.552	83.333	2.391
4644.000	277.778	22.222	12.500	157.068	1.111	58.639	1.691
4645.000	338.346	19.565	17.293	225.000	1.875	41.000	2.097
4646.000	174.648	17.465	10.000	32.632	.354	51.579	2.515
4647.000	266.667	15.439	17.273	31.429	.267	55.714	1.549
4651.000	276.923	27.170	10.192	62.609	.379	78.696	3.113
4652.000	211.111	36.944	5.714	63.333	.350	100.000	2.500
4653.000	241.135	32.381	7.447	267.717	1.214	46.457	1.453
4654.000	160.976	49.254	3.268	63.462	.178	122.115	2.158
4656.000	325.843	25.664	12.697	184.713	1.000	50.318	1.717
4662.000	198.182	12.529	15.818	33.030	.330	66.667	2.375
4663.000	522.727	12.500	41.818	31.944	.319	69.444	2.704
4664.000	450.000	12.062	37.308	35.455	.334	63.636	2.333
4665.000	466.667	14.203	32.857	30.625	.297	65.625	2.316
4666.000	230.769	18.045	12.788	88.889	.857	67.778	2.471
4667.000	201.754	19.167	10.526	85.185	.793	64.815	3.000
4671.000	214.706	9.481	22.647	19.211	.203	71.053	2.524
4672.000	221.053	11.200	19.737	24.706	.247	82.353	2.667
4673.000	190.196	10.211	18.627	29.394	.285	81.818	2.552
4674.000	224.419	17.080	13.140	64.333	.623	58.333	2.243
4675.000	388.571	27.755	14.000	46.897	.349	72.414	2.464
4676.000	395.833	32.759	12.083	35.185	.264	81.481	2.034
4677.000	218.000	23.191	9.400	35.161	.287	67.742	2.391
4681.000	538.462	18.325	29.385	120.690	1.250	25.172	1.188
4682.000	940000.000	10.444	90000.000	26.857	.235	71.429	2.095
4683.000	925.926	18.657	49.630	89.286	.735	46.786	1.594
4684.000	474.359	22.289	21.282	119.355	1.000	28.065	1.793
4685.000	400.000	28.571	14.000	139.130	.970	31.739	1.288
4686.000	438.095	10.337	42.381	27.059	.242	70.588	2.000
4691.000	448.000	12.727	35.200	29.474	.311	63.158	2.120
4692.000	160.0000	13.675	117000.000	40.000	.410	70.000	2.970
4693.000	452.174	15.758	28.696	34.667	.325	80.000	2.571
4694.000	630000.000	18.529	34000.000	20.323	.175	67.742	2.426
4701.000	212.281	13.444	15.789	31.842	.367	57.895	2.957
4702.000	511.111	9.650	52.963	33.659	.394	46.341	2.768
4703.000	820000.000	10.933	75000.000	20.000	.228	45.366	2.899
4704.000	215.789	13.085	16.491	27.333	.362	55.556	2.870
4706.000	640000.000	23.704	27000.000	21.333	.168	62.667	2.609
4711.000	375.000	12.676	29.583	22.500	.237	48.750	2.035
4712.000	780000.000	13.448	58000.000	22.286	.223	50.571	1.676
4713.000	275.000	10.476	26.250	75.862	.786	38.966	1.077
4714.000	321.739	11.212	28.696	18.974	.206	50.256	2.642
4715.000	348.315	13.478	25.843	60.784	1.192	22.941	2.134
4721.000	200.000	20.930	9.556	31.034	.250	65.517	2.381
4722.000	328.571	18.852	17.429	34.848	.311	51.212	2.308
4723.000	166.667	20.175	8.261	32.857	.295	56.571	2.172
4731.000	283.721	14.699	19.302	23.922	.305	29.216	1.644
4732.000	378.571	17.097	22.143	17.667	.247	28.667	1.987
4733.000	284.483	18.750	15.172	53.226	.413	51.935	7938.571
4741.000	333.333	16.912	19.710	95.833	.793	47.917	2.035
4742.000	356.164	16.561	21.507	96.296	.788	45.185	1.764
4743.000	970000.000	14.265	68000.000	26.216	.294	127.027	2.383
4744.000	650000.000	14.773	44000.000	17.568	.186	86.486	2.667
4745.000	438.356	16.327	26.849	103.226	1.032	40.000	2.268

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TABLE 31 RATIOS OF TRACE AND MAJOR ELEMENTS FOR THE NORTHWEST GRANITES AND THE ASSOCIATED GNEISSES.

Sample No.	Ba/Ca	Mg/Li	Lix10^3/K	K/Pb	Li/Zn	$\frac{Na+K}{Ca+Mg}$	$\frac{Na+K}{Fe}$	$\frac{K_2O}{Na_2O}$
2083.000	.280	88.601	.643	600.000	.839	8.511	6.933	1.222
4405.000	.153	338.028	.296	888.889	.245	3.155	5.096	.742
4406.000	.364	157.576	.413	1081.081	.471	4.706	5.424	1.494
4411.000	.185	270.909	.172	888.889	.162	6.465	6.263	.956
4412.000	.261	240.000	.152	942.857	.167	8.841	7.176	1.056
4413.000	.138	118.182	.177	1033.333	.385	6.667	15.641	.926
4414.000	.013	200.000	1.649	404.167	.308	2.759	4.355	.202
4415.000	.035	234.940	1.099	539.286	.210	3.006	2.254	.347
4416.000	.003	522.727	2.683	635.659	.234	.785	1.005	.223
4417.000	.191	163.077	.176	1233.333	.295	7.447	11.667	1.275
4421.000	.017	343.511	1.149	456.000	.182	2.425	2.793	.255
4422.000	.160	196.591	.338	866.667	.244	4.351	5.000	.728
4423.000	.064	435.484	.574	556.701	.207	2.442	4.536	.242
4424.000	.184	366.667	.289	779.167	.169	3.040	5.394	.524
4425.000	.125	644.444	.319	440.625	.090	3.120	3.643	.333
4427.000	.073	595.238	.568	308.333	.117	2.594	4.090	.175
4428.000	.199	402.083	.259	804.348	.117	3.088	5.562	.535
4431.000	.036	303.922	1.074	508.021	.176	2.552	3.390	.213
4432.000	.040	219.355	2.422	581.818	.443	1.882	1.770	.328
4433.000	.027	317.647	1.063	380.952	.236	2.113	3.879	.194
4434.000	.041	231.818	1.818	657.609	.386	1.766	2.195	.319
4442.000	.041	634.146	1.042	1372.093	.198	1.488	1.952	.286
4443.000	.059	222.222	.467	900.000	.350	3.727	4.286	.733
4444.000	.026	259.259	1.658	438.462	.411	1.952	2.659	.276
4445.000	.032	256.684	1.612	341.176	.374	1.574	1.400	.359
4446.000	.039	296.000	.812	427.778	.219	2.384	2.616	.418
4451.000	.144	232.323	.413	1090.909	.367	3.681	4.732	.742
4452.000	.018	121.678	2.860	495.050	.318	2.972	5.294	.112
4453.000	.019	205.128	1.753	664.179	.473	1.861	3.722	.210
4454.000	.006	1130.435	38.983	46.825	.181	.409	.316	.030
4461.000	.025	275.000	1.806	620.000	.400	1.947	1.759	.434
4462.000	.191	445.946	.148	806.452	.109	6.073	6.667	.679
4463.000	.058	188.462	1.130	676.471	.510	2.500	2.957	.644
4464.000	.058	267.925	.366	500.000	.230	4.123	7.308	.394
4465.000	.168	300.000	.400	1093.750	.318	3.584	3.924	1.162
4471.000	.039	304.167	1.429	700.000	.364	1.795	2.032	.443
4472.000	.026	439.655	.663	546.875	.204	2.092	2.283	.448
4473.000	.053	150.000	1.524	724.138	.615	2.277	2.865	.627
4474.000	.064	207.407	1.227	880.000	.466	2.350	2.750	.598
4475.000	.018	152.381	2.188	417.391	.538	1.810	3.020	.239
4481.000	.103	107.692	.609	800.000	.513	5.254	5.124	.956
4482.000	.100	666.667	.275	2155.689	.248	2.174	2.727	1.344
4483.000	.197	164.948	.303	1523.810	.262	4.203	6.304	1.103
4484.000	.127	215.569	.642	1326.531	.522	2.772	4.242	.777
4485.000	.024	449.438	1.047	880.829	.292	1.576	2.000	.435
4486.000	.055	368.098	1.025	757.143	.240	1.630	1.397	.432
4487.000	.272	272.281	.263	1166.667	.256	6.863	6.034	.896
4491.000	.064	330.986	.785	861.905	.296	1.653	1.693	.523
4492.000	.324	115.909	.142	861.111	.666	7.798	10.179	1.069
4493.000	.115	2526.316	.197	935.454	.048	1.219	1.553	.866
4494.000	.018	200.000	2.353	629.630	.418	1.736	2.177	.296
4495.000	.123	2322.034	.211	823.529	.053	1.270	1.583	.865
4501.000	.117	295.455	.338	1238.095	.338	2.893	5.229	.752
4502.000	.024	372.727	1.964	1046.729	.367	1.313	1.444	.287
4503.000	.156	331.697	.494	1161.290	.184	2.462	1.829	1.152
4504.000	.185	[illegible]	.582	1137.931	.233	2.360	1.788	1.138
4505.000	.064	[illegible]	[illegible]	[illegible]	.391	.872	.597	.607
4507.000	.130	[illegible]	.644	[illegible]	[illegible]	[illegible]	[illegible]	1.000
4508.000	.671	[illegible]	[illegible]	[illegible]	.184	[illegible]	[illegible]	[illegible]
4511.000	.061	369.877	1.647	720.238	.251	1.276	2.000	.269
4512.000	.065	124.051	.840	408.696	.527	1.766	2.485	.211
4513.000	.024	915.888	1.202	898.990	.156	1.100	1.321	.222
4514.000	.024	666.667	1.344	[illegible]	.215	[illegible]	[illegible]	.278

Table 31 Continued..

4515.000	.018	436.170	1.022	681.481	.303	1.579	4.527	.258
4521.000	.103	269.461	.903	1094.675	.169	2.063	1.768	.535
4522.000	.017	292.105	2.468	770.000	.432	1.331	.841	.460
4523.000	.043	779.310	.771	1086.705	.274	1.225	1.786	.511
4524.000	.035	270.677	.875	932.515	.429	2.000	3.591	.401
4529.000	.071	362.694	.839	958.333	.316	2.131	2.476	.711
4531.000	.202	136.986	.235	1033.333	.456	4.419	8.261	1.069
4532.000	.029	368.966	[illegible]	895.455	.377	1.362	1.597	.535
4533.000	.069	609.524	.840	1190.476	[illegible]	1.213	1.487	.679
4534.000	.007	7058.824	1.015	670000.000	.117	.218	.406	.311
4535.000	.238	155.846	.520	1200.000	.709	2.969	5.544	.996
4541.000	.017	7.846	.302	877.551	1.688	15.448	19.429	1.542
4542.000	.029	13.483	.494	857.143	1.838	10.098	16.757	1.241
4543.000	.004	25.243	7.863	110.084	.298	2.553	.538	1.486
4544.000	.060	223.776	.715	869.565	.367	3.167	3.476	.484
4545.000	.150	84.058	.223	1107.143	.515	5.607	10.893	.926
4546.000	.132	150.000	.374	968.750	.614	4.718	8.493	.896
4547.000	.067	312.500	1.091	785.714	.343	1.791	1.818	.519
4548.000	.021	175.362	.022	640.000	.090	31.173	19.091	.925
4549.000	.137	261.682	.345	1068.966	.297	4.056	3.766	1.029
4551.000	.020	513.636	1.679	850.649	.324	1.099	1.504	.405
4552.000	.019	328.571	2.000	644.172	.269	1.342	1.896	.269
4553.000	.021	313.636	1.913	714.286	.489	1.390	2.021	.279
4554.000	.095	235.294	.453	1304.348	.523	3.016	4.101	.996
4555.000	.078	368.571	1.346	1000.000	.493	1.336	1.765	.685
4556.000	.096	296.154	1.040	862.069	.481	1.798	2.280	.700
4561.000	.110	364.865	1.321	848.485	.425	1.348	1.538	.784
4562.000	.133	10.476	.488	716.667	1.135	24.809	17.105	1.752
4563.000	.068	13.704	.818	804.878	1.957	11.287	16.410	.954
4564.000	.131	329.268	.273	2013.423	.283	4.351	4.488	.996
4565.000	.087	238.532	.474	1150.000	.311	4.517	3.069	1.199
4566.000	.258	170.000	.909	257.813	.345	3.374	.902	3.480
4567.000	.010	2291.667	1.404	1628.571	.205	.340	.668	.666
4571.000	.005	1602.564	2.328	440.789	.147	.502	.690	.177
4572.000	.016	1158.228	2.981	355.705	.115	.599	.601	.136
4573.000	.101	307.407	1.080	735.294	.333	2.385	2.111	.700
4574.000	.025	865.079	1.313	545.455	.175	1.188	1.473	.221
4575.000	.049	850.394	.713	809.091	.202	1.460	1.954	.483
4581.000	.051	1833.333	.306	872.222	.074	1.899	2.305	.402
4582.000	.022	433.333	2.190	698.980	.294	1.261	1.261	.323
4583.000	.213	164.286	.205	911.111	.311	10.855	8.049	1.470
4591.000	.170	67.164	.176	1117.647	.319	13.684	13.265	1.261
4592.000	.254	34.200	.082	1016.667	.526	32.479	21.951	1.885
4593.000	.336	106.250	.145	1333.333	.178	10.802	11.475	1.517
4601.000	.211	407.895	.205	1000.000	.152	5.676	4.228	1.275
4602.000	.046	180.233	1.068	1308.943	.366	2.774	3.074	.380
4603.000	.182	187.500	.386	1160.000	.361	5.273	5.686	.896
4604.000	.010	742.857	1.694	779.874	.108	.728	.434	.359
4605.000	.124	115.441	.412	1375.000	.504	6.195	5.526	.986
4611.000	.032	203.046	1.340	700.000	.318	2.408	2.441	.338
4612.000	.079	146.281	.526	821.429	.303	4.295	4.560	.606
4613.000	.299	196.850	.276	901.961	.295	6.863	3.333	1.718
4615.000	.075	93.750	1.032	1068.966	.762	4.348	4.615	.958
4616.000	.082	111.111	.900	882.353	.659	4.683	4.646	.927
4617.000	.040	470.149	1.207	874.016	.227	1.471	1.959	.311
4618.000	.074	103.226	1.033	810.811	.633	4.027	4.444	.896
4622.000	.027	557.789	1.453	570.833	.293	1.165	1.506	.372
4623.000	.042	945.455	1.375	1739.130	.275	.588	.629	2.656
4624.000	.014	208.000	2.155	446.154	.568	1.403	3.309	.248
4625.000	.009	856.000	1.316	62.092	.035	.827	.908	.341
4626.000	.028	1026.667	1.293	690.476	.170	.829	1.058	.289
4631.000	.013	639.175	2.587	520.833	.220	.711	.659	.198
4632.000	.104	109.278	.373	812.500	.334	5.287	7.108	.706
4633.000	.149	127.119	.184	780.488	.319	7.039	10.000	.925
4634.000	.126	152.174	.246	848.485	.442	5.911	8.219	.784
4635.000	.126	140.000	.300	810.811	.489	6.352	8.732	.840

Table 31
Continued...

4636.000	.090	651.685	.685	1238.095	.258	1.442	1.765	.685	
4642.000	.291	105.128	.105	1275.862	.438	9.983	16.389	1.507	Table31
4643.000	.043	275.000	1.099	520.000	.323	2.008	2.327	.494	Continued..
4644.000	.121	184.000	.417	697.674	.231	4.222	4.351	.996	
4645.000	.280	86.667	.067	1607.143	.462	8.156	27.600	1.681	
4646.000	.036	242.604	1.363	413.333	.232	2.000	2.709	.318	
4647.000	.037	174.603	1.432	400.000	.307	2.348	2.389	.239	
4651.000	.029	254.054	1.285	533.333	.430	2.298	2.787	.340	
4652.000	.017	276.243	1.361	554.167	.362	1.973	3.000	.314	
4653.000	.178	150.980	.150	971.429	.277	9.295	7.294	1.088	
4654.000	.011	120.588	.515	286.957	.250	3.326	15.034	.160	
4656.000	.143	84.259	.372	878.788	.432	6.583	8.529	.896	
4662.000	.040	435.115	1.202	519.048	.252	1.585	2.439	.296	
4663.000	.037	506.944	1.252	766.667	.288	1.471	2.065	.286	
4664.000	.046	500.000	1.077	668.571	.238	1.711	2.224	.300	
4665.000	.033	468.085	.959	644.737	.200	1.685	2.277	.266	
4666.000	.073	283.784	.617	558.140	.218	2.311	2.694	.768	
4667.000	.069	389.189	.804	766.667	.276	2.105	2.476	.711	
4671.000	.029	638.554	1.137	540.741	.224	1.341	2.341	.182	
4672.000	.027	757.895	1.131	525.000	.167	1.205	1.570	.221	
4673.000	.035	582.677	1.309	461.905	.205	1.270	1.619	.256	
4674.000	.065	210.526	.591	689.286	.438	2.528	5.133	.558	
4675.000	.023	192.090	1.301	566.667	.492	2.156	3.603	.313	
4676.000	.013	158.940	1.589	365.385	.431	1.865	3.250	.237	
4677.000	.022	325.444	1.550	340.625	.176	1.845	2.445	.257	
4681.000	.262	152.000	.071	1129.032	.114	8.203	10.328	1.120	
4682.000	.036	280.255	1.670	587.500	.383	1.680	2.839	.211	
4683.000	.102	392.857	.112	1086.957	.275	4.155	7.024	.659	
4684.000	.191	123.810	.114	1233.333	.447	8.026	16.818	.896	
4685.000	.153	200.000	.209	864.865	.209	7.523	5.603	.869	
4686.000	.037	301.370	1.587	460.000	.406	1.662	2.744	.217	
4691.000	.037	375.887	1.259	583.333	.392	1.611	2.384	.279	
4692.000	.042	608.696	1.006	1259.843	.233	1.455	1.964	.368	
4693.000	.028	450.000	1.154	608.187	.250	1.442	2.120	.291	
4694.000	.016	363.889	.571	875.000	.205	1.896	8.633	.157	
4701.000	.041	503.704	1.116	550.000	.211	1.566	2.148	.329	
4702.000	.075	484.375	.464	575.000	.183	2.208	3.725	.353	
4703.000	.040	493.827	.988	706.897	.238	1.956	3.250	.204	
4704.000	.038	431.373	1.244	585.714	.247	1.465	2.013	.324	
4706.000	.014	324.324	1.156	441.379	.224	2.094	4.229	.151	
4711.000	.036	252.747	1.011	452.261	.284	2.156	4.747	.212	
4712.000	.033	302.083	1.231	509.804	.204	2.078	2.277	.200	
4713.000	.186	107.692	.118	758.621	.203	4.318	8.065	.704	
4714.000	.034	400.000	.946	627.119	.269	1.938	4.019	.184	
4715.000	.197	242.373	.190	1033.333	.303	4.341	9.661	1.069	
4721.000	.023	190.476	2.333	1384.615	.568	1.957	3.285	.224	
4722.000	.036	167.513	1.713	611.702	.448	2.401	3.819	.279	
4723.000	.029	204.762	1.826	.001	.382	2.095	3.279	.264	
4731.000	.056	185.870	.754	580.952	.297	3.143	6.289	.273	
4732.000	.036	238.462	1.226	697.368	.333	2.640	4.702	.221	
4733.000	.055	520968.750	1.164	750.000	.505	.006	4.094	.370	
4741.000	.118	129.213	.774	1161.616	.556	3.768	4.228	.711	
4742.000	.129	119.872	.600	1130.435	.520	4.193	6.211	.706	
4743.000	.014	466.667	2.474	687.943	.381	.734	1.068	.263	
4744.000	.014	340.426	2.892	411.392	.276	1.081	1.431	.166	
4745.000	.158	104.762	.656	1333.333	.750	4.315	6.923	.925	

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But the random spatial distribution of the samples weakens any importance one may attach to their ratios. In short, the K/Rb ratios are mainly suggestive of early fractionation.

(b) K/Ba: This ratio ranges from 5.7 to 800, with more than 90% of the values falling below the threshold of 50, above which values may be suggestive of later fractionation (Moseley, 1981). Samples having values greater than the threshold are: Nos. 4591 (52.1), 4416 (62.6), 4563 (91.7), 4592 (92.4), 4562 (134.4), 4542 (206.9), 4549 (545.8), 4541 (605.6) and 4548 (800.0). However, the scattered spatial distribution of these samples tends to reduce the importance of the ratios. Overall, values of these ratios are also indicative of early fractionation.

(c) Ba/Rb: Disregarding those extraordinarily large values attributable to Rb values below detection limit, this ratio ranges from 0.2 to 60.0. The lowest and highest values are found in Samples 4548 and 4513, respectively. Only two out of the 185 samples of this suite have values below the 0.5 threshold, below which values may be indicative of a higher degree of fractionation (Tauson and Kozlov, 1973). The spatial distribution pattern of the sample values is erratic throughout the area, and early fractionation is inferred on the basis of this ratio.

(d) K/Sr: This ratio ranges from 4.3 to 2831.9, with more than 90% of the values below 100. No threshold value is available for this ratio in the literature and it may only be used in a relative sense, increasing with higher degrees of fractionation. In the present study no spatial sub-grouping or clustering of the higher values is observed in any section of the granites. Instead a random distribution pattern is observed, indicating that no conspicuous spatial differences in the degree of fractionation exist within these granites.

(e) K/Na (and K_2O/Na_2O): The K/Na ratio ranges from 0.6 (Sample 4454) to 3.9 (Sample 4566). About 90% of the values are less than the 1.5 threshold value above which values may be considered as indicative of later fractionation (Olade 1980). Samples having values above this threshold are: 4583 (1.64), 4543 (1.66), 4406 (1.67), 4642 (1.68), 4593 (1.69), 4541 (1.72), 4645 (1.87), 4613 (1.91), 4562 (1.95), 4592 (2.10), 4623 (2.96), and 4566 (3.88). Of these "anomalous" samples only 4541 and 4543 are spatially close together enough to warrant further attention; in general these ratios are suggestive of early fractionation. The analogous K_2O/Na_2O ratio gives similar information.

(f) Ca/Sr: This ratio ranges from 21.2 (Sample 4531) to 308.7 (Sample 4534). There is no indication of spatial clustering of the values,

with 171 samples having values below 100. Of the 14 samples showing higher values, only four appear distinctive: 4623, 4625, 4416 and 4534 with values of 207.4, 219.9, 278.9 and 308.7 respectively. No definitive threshold value has been given for this ratio in the literature, and it is generally only used to compare the fractionation stages of two or more different intrusives as it increases with higher stages of fractionation (Moseley, 1981). In this suite of rocks, this ratio has not proved useful in this respect.

(g) Mg/Ti: This ratio ranges from 0.39 (Sample 4541) to 13.3 (Sample 4534). All of the values for this ratio, except the maximum one, are within the 0.3-10 range for specialized granites, as opposed to >40 for normal granites, given by Tischendorf (quoted in Moseley, 1981). This result is in sharp contrast to the other ratios discussed so far, and shoult not be interpreted in isolation.

(h) Ba/Ca: The values for this ratio range from 0.003 (4416) to 0.37 (4508). There does not seem to be any obvious spatial sub-grouping among the values, and such variation as is evident is rather erratic throughout the area. No threshold value for this ratio is quoted in the literature,as it is mostly only used to express a relative degree of fractionation among different intrusive bodies. In this suite or rocks, the

ratio does not seem to give any clue to the existence of intrusives of different degrees of fractionation within the area.

(i) Mg/Li: This ratio ranges from 7.85 (4541) to 7058.85 (4534). Only about 12% of the values are below the threshold of 100 below which values may be indicative of a late stage of differentiation (Moseley, 1981); more than 75% of the rest lie below 500. Two pairs of samples have values below 100 (Samples 4562 and 4563, and Samples 4541 and 4542) and appear to be spatially close enough to warrant further attention. The rest of the "anomalous" values are randomly distributed spatially and may therefore only be background variation.

(j) Lix10^3/K: This ratio ranges from 0.02 (4548) to 38.98 (4454). More than 90% of the values are below the threshold value of 2.4 given by Tauson and Kozlov (1973), above which a higher degree of fractionation may be indicated. Even those samples (4432, 4522, 4723, 4631, 4416, 4452, 4744, 4572, 4543, 4454) which have values above the 2.4 threshold are, in general, so widely dispersed spatially that it is difficult to assess their significance on the basis of this parameter alone.

(k) K/Pb: This ratio ranges from 46.8 (Sample 4454) to 2155.7 (Sample 4482) with more than 80% between 100 and 900. Moseley (1981) has stated that the use of this ratio as a discriminating factor is controversial, and various threshold values have been suggested for this ratio (Turekian and Wedepohl, 1961; Sheraton and Black, 1973; Taylor, 1964) above or below which values may be significant. This ratio is now generally used in a relative sense, with higher degrees of fractionation indicated by lower values. This ratio does not seem to be helpful, in this suite of rocks, as no discernable large areas of consistently low or high values are evident.

(l) Li/Zn: This ratio ranges from 0.03 (4625) to 1.96 (4563). More than 99% of the values are less than 1.1, the threshold above which values may be considered significant in terms of ore potential in the vicinity of hydrothermal activity (Tauson and Kozlov, 1973). Most of the values in this suite of rocks do not suggest a high degree of fractionation and/or ore potential, but high values of 1.68, 1.83, 1.13 and 1.96 in samples 4541, 4542, 4561 and 4562, respectively are perhaps noteworthy.

(m) (Na+K)/(Ca+Mg) and (Na+K)/Fe: These ratios range from 0.22 to 32.48 and 0.32 to 27.60. No threshold values have been given for these ratios in the literature and they are generally only used to compare the fractionation status of

two or more different granitic bodies. The ratios in the Northwest Granites do not show any substantial spatial grouping or clustering, and are therefore not suggestive of any significant different degree of fractionation in any portion of this area.

(n) Clustering of ratios: It is worth mentioning here that certain samples indicate anomalous values in two or more ratios. In this connection, sample 4543 has anomalous values of the K/Na and Lix10^3/K ratios; and sample 4592 shows anomalous values of the K/Ba and K/Na ratios.

Instances of samples located close together having anomalous values of a particular ratio occur in the case of the Mg/Li ratio for Samples 4562, 4563, 4541, 4542. Such instances may warrant further attention, although their paucity is not encouraging.

9.2.2.2 The North Central Corridor Suite (Table 32)

(a) K/Rb: Excluding the extremely large values of this ratio in Samples 2320 and 4381, which are due to the Rb content of being below the analytical limit of detection, this ratio ranges from 67.50 (Sample 4388) to 488.37 (Sample 4765). Most of the values are above the threshold value of 100 (Moseley, 1981) below which higher degree of fractionation may be implied. This suggests that in general the rocks of this suite are an early fraction. The few values close to, or below this

TABLE 32 RATIOS OF TRACE AND MAJOR ELEMENTS FOR THE NORTH CENTRAL CORRIDOR SUITE

Sample No.	K/Rb	K/Ba	Ba/Rb	K/Sr	K/Na	Ca/Sr	Mg/Ti
2310.000	245.455	40.299	6.091	606.742	4.154	13.146	3.833
2320.000	470000.000	188.000	2500.000	117.500	.104	235.000	7.544
4355.000	188.235	18.462	10.196	43.636	1.011	163.636	8.087
4362.000	198.969	23.827	8.351	77.200	.643	116.000	2.488
4363.000	181.356	26.750	6.780	70.395	.585	473.684	9.600
4365.000	198.611	21.029	9.444	51.071	.386	110.714	3.111
4371.000	401.575	14.571	27.559	242.857	2.318	37.619	2.268
4372.000	413.223	14.286	28.926	238.095	2.273	38.095	2.268
4373.000	329.787	12.917	25.532	114.815	1.069	30.741	1.355
4374.000	135.556	69.318	1.956	290.476	1.848	407.143	9.703
4375.000	316.239	13.704	23.077	127.586	1.276	37.931	1.480
4381.000	260000.000	17.333	15000.000	8.966	.286	424.138	3.897
4382.000	264.583	14.941	17.708	50.800	.397	92.000	1.963
4383.000	449.275	12.917	34.783	103.333	1.192	66.667	3.230
4384.000	456.790	20.109	22.716	176.190	1.609	46.190	1.183
4385.000	327.586	55.882	5.862	513.514	1.583	121.622	2.400
4386.000	168.000	67.742	2.480	33.600	.233	92.000	2.050
4387.000	252.874	31.884	7.931	152.778	.733	152.778	1.962
4388.000	67.500	14.211	4.750	34.615	1.800	25.641	2.038
4391.000	158.929	77.391	2.054	109.877	.254	237.037	1.400
4392.000	209.836	19.104	10.984	101.587	.427	166.667	1.522
4393.000	286.207	18.043	15.862	25.938	.202	71.875	2.832
4394.000	264.000	24.906	10.600	44.000	.440	90.000	3.767
4395.000	289.231	20.000	14.462	60.645	.508	43.226	2.222
4396.000	302.326	60.000	5.039	513.158	1.625	125.000	2.247
4404.000	285.000	18.387	15.500	63.333	.475	72.963	2.091
4751.000	391.304	10.800	36.232	69.231	.931	36.410	1.729
4752.000	242.857	5.629	43.143	28.333	.327	32.333	1.746
4753.000	323.232	16.667	19.394	118.519	1.143	38.519	1.654
4754.000	371.429	14.054	26.429	96.296	1.130	40.741	1.571
4761.000	311.688	13.187	23.636	63.158	.800	36.579	1.816
4762.000	165.094	19.886	8.302	54.688	.486	65.625	2.353
4763.000	299.065	16.000	18.692	139.130	1.032	52.174	1.810
4764.000	288.889	20.920	13.810	101.676	.728	56.425	3.043
4765.000	488.372	11.475	42.558	53.846	.600	40.000	1.686
4767.000	113.187	68.667	1.648	46.818	.245	69.091	4.228
4771.000	396.825	10.417	38.095	67.568	.758	34.865	1.667
4773.000	245.098	10.417	23.529	69.444	.806	31.389	1.680
4774.000	226.804	12.571	18.041	57.895	.647	30.526	1.898
4775.000	284.404	13.478	21.101	93.939	1.148	26.364	1.547
4776.000	157.692	27.333	5.769	23.429	.429	180.000	1.190

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Table 32
Continued...

TABLE 32 Contd...

Sample No.	Ba/Ca	Mg/Li	$Lix10^3/K$	K/Pb	Li/Zn	$\frac{Na+K}{Ca+Mg}$	$\frac{Na+K}{Fe}$	$\frac{K_2O}{Na_2O}$
2310.000	1.145	61.333	.278	771.429	1.111	32.057	6.907	3.723
2320.000	.003	25.800	1.064	204.348	500.000	5.216	54.022	.094
4355.000	.014	1223.684	.792	872.727	.345	.422	1.528	.906
4362.000	.028	485.714	1.088	772.000	.296	1.258	1.264	.577
4363.000	.006	2513.089	1.785	636.905	.195	.242	.363	.524
4365.000	.022	533.333	1.469	650.000	.500	1.216	2.332	.346
4371.000	.443	215.686	.200	1214.286	.364	7.228	7.766	2.078
4372.000	.438	231.579	.190	1351.351	.365	7.059	7.660	2.037
4373.000	.289	64.783	.742	738.095	.767	6.129	7.059	.958
4374.000	.010	362.963	2.213	1070.175	.750	.699	1.153	1.657
4375.000	.245	74.000	.541	787.234	.588	5.288	7.857	1.144
4381.000	.001	5136.364	.846	260000.000	.031	.087	.316	.256
4382.000	.037	252.381	1.654	686.486	.344	1.580	1.863	.356
4383.000	.120	368.794	.455	1107.143	.276	2.262	3.032	1.069
4384.000	.190	204.110	.197	880.952	.192	5.362	3.774	1.442
4385.000	.076	101.205	.218	883.721	.664	6.301	10.877	1.419
4386.000	.005	94.286	4.167	604.317	.761	1.688	2.792	.209
4387.000	.031	102.000	2.273	1100.000	.658	1.919	2.000	.657
4388.000	.095	106.000	9.259	306.818	.658	.903	.323	1.613
4391.000	.006	54.902	5.730	423.810	.718	1.995	1.688	.228
4392.000	.032	60.870	3.594	864.865	.754	1.798	2.038	.382
4393.000	.020	293.578	1.313	538.961	.279	1.882	4.695	.181
4394.000	.020	538.095	1.591	992.481	.328	1.128	1.543	.394
4395.000	.070	146.667	.798	552.941	.333	3.577	5.753	.455
4396.000	.068	160.000	.321	780.000	.446	5.478	5.478	1.456
4404.000	.047	282.209	.953	589.655	.190	2.185	2.840	.426
4751.000	.176	115.000	.741	931.034	.625	3.394	4.341	.834
4752.000	.156	166.667	1.553	461.957	.293	2.899	3.382	.293
4753.000	.185	142.742	.388	941.176	.388	4.930	6.383	1.024
4754.000	.168	270.492	.469	1040.000	.254	3.427	2.882	1.013
4761.000	.131	168.468	.463	1043.478	.444	3.424	6.279	.717
4762.000	.042	363.636	1.257	729.167	.306	1.845	1.911	.436
4763.000	.167	275.362	.431	842.105	.226	3.987	3.580	.925
4764.000	.086	312.500	.615	968.085	.431	3.176	4.454	.653
4765.000	.117	189.542	.729	750.000	.364	3.027	4.275	.538
4767.000	.010	179.310	2.816	628.049	.674	2.564	3.874	.220
4771.000	.186	159.722	.576	657.895	.436	3.816	4.754	.679
4773.000	.212	164.063	.512	555.556	.320	4.179	4.828	.723
4774.000	.151	178.846	.473	666.667	.385	4.160	6.022	.580
4775.000	.264	260.784	.165	756.098	.213	5.783	8.788	1.029
4776.000	.005	2688.172	1.134	328.000	.071	.310	.244	.385

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value (67.50, 113.18, 135.60 for Samples 4388, 4767 and 4374 respectively) are too erratically dispersed spatially to allow very meaningful interpretation.

(b) K/Ba: This ratio ranges from 5.62 (Sample 4752) to 188.0 (Sample 2320). However, most of the values are less than the threshold of 50 (Olade, 1980), above which later fractionation may be indicated. Apart from Sample 2320, which shows the highest value, only Samples 4374, 4385, 4386, 4391, 4396, and 4767 (69.31, 55.88, 67.74, 77.39, 60.00 and 68.67 respectively) have values greater than the threshold, but these occurrences are too erratic spatially for meaningful interpretation.

(c) Ba/Rb: Disregarding the extreme values for Samples 4381 and 2320 (again caused by Rb values below detection limit), this ratio ranges from 1.65 to 43.14. All the values are well above the threshold value of 0.5 (Tauson and Kozlov, 1970 and Moseley, 1981), below which late fractionation may be assumed. The spatial distribution of the values in the corridor is again very erratic. On the whole the ratio values favour early fractionation.

(d) K/Sr: Values for this ratio range from 8.97 (4381) to 606.09 (2310) with more than half of values below 100. This high variation is coupled with an absence of spatial sub-grouping

of values in any portion of the area covered, thus precluding any indication of any different lithological/chemical unit along the corridor. The value of this ratio is expected to increase in relative terms, with fractionation.

(e) K/Na (and K_2O/Na_2O): The K/Na ratio ranges from 0.10 (2320) to 4.15 (2310). More than 50% of the values are below the threshold value of 1.2 suggested by several workers (Olade, 1980; Tauson and Kozlov, 1973), below which values are suggestive of early fractionation. Only nine samples have values greater than this threshold: 2310 (4.15), 4371 (2.32), 4372 (2.27), 4374 (1.85), 4375 (1.28), 4384 (1.61), 4385 (1.58), 4388 (1.80), and 4396 (1.62). These values are also erratically distributed spatially throughout the area. Thus the values for this ratio generally correspond to early degree of fractionation. The analogous K_2O/Na_2O ratio also gives similar information. In the present suite of rocks, more than 80% of the values of this ratio fall below 1.0 which, according to Sengputa et al (1983) and Boyle (1974), is indicative of an early fraction.

(f) Ca/Sr: This ratio ranges from 13.5 (Sample 2310) to 473.68 (Sample 4363), with more than 75% of the samples having values below 100. Only five values are significantly higher than 100: 235.00, 474.63, 467.14, 424.13, 237.04 in Samples 2310, 4363, 4374, 4381, and 4391, respectively. These samples, however, are too

spatially dispersed to have any petrological, geochemical or exploration significance. In the southern section of the corridor (from sample 4751 to sample 4775) some degree of spatial clustering of samples with ratio values below 40 occurs. This may simply mean a higher content of Sr relative to Ca, suggesting lower degree of fractionation in this section (Ahrens et al., 1965). On the whole, however, the rocks throughout the corridor below belong to an early fraction suite.

(g) Mg/Ti: This ratio ranges from 1.18 (4384) to 9.70 (4374) with more than 90% of the values lying between 1.18 to 4.23. According to Moseley (1981), quoting Tischendorf (1972), this ratio falls within the range of 0.3-10 for specialized granites as opposed to the value of $>$ 40 encountered in normal granites. There is no indication of spatial sub-grouping of sample ratios, but rather an erratic spatial distribution.

(h) Ba/Ca: This ratio ranges from 0.001 (4381) to 1.14 (2310). With the exception of sample 2310, all the samples have values far less than unity. No threshold has been given in the literature for this ratio, and it may therefore only be used to describe the relative degrees of fractionation of two or more granitic bodies, as it increases with fractionation. In this suite of rocks, no spatial sub-grouping of values has been observed, and there is therefore no indication of differential

fractionation in any portion of the corridor on the basis of this ratio.

(i) Mg/Li: This ratio ranges from 25.80 (2320) to 5136.36 (4381). Most of the values are above the threshold value of 100 (Moseley 1981), below which the ratios may be indicative of later fractionation. Even those few values which are below or near this threshold value (25.8, 64.783, 74.00, 94.286, 54.91, 60.87 and 101 in Samples 2310, 4373, 4375, 4386, 4391, 4396 and 4385 respectively) are too erratically distributed spatially to be meaningful.

(j) $Lix10^3/K$: This ratio ranges from 0.16 (Sample 4775) to 9.26 (Sample 4388). The majority of the samples have ratios less than the 2.4 limit above which values may be considered indicative of a higher degree of fractionation (Tauson and Kozlov, 1973). However, seven samples (4374, 4386, 4387, 4388, 4391, 4392, 4767) have ratios higher than or close to, this threshold (2.21, 4.17, 2.27, 9.26, 5.73, 3.59, and 2.82, respectively). Five of these samples (4386, 4387 4388, 4391, 4392) lie close together spatially in the north of the corridor and may deserve further attention.

(k) K/Pb: Disregarding the extreme value of Sample 4381, where the Pb content was below detection limit, this ratio ranges from 204.35 (2320) to 1351.35 (4372). More than 50% of the

values fall in the range of for normal granodiorite (Turekian and Wedepohl, 1961). Most of the other 50% are above this value for the normal granodiorite, suggesting even lower degree of fractionation. Therefore, overall this ratio is not indicative of higher or later degree of fractionation.

(l) Li/Zn: This ratio ranges from 0.031 (4381) to 500 (2320). Only two samples (2320 and 2310) have values greater than the 1.1, threshold (Tauson and Kozlov, 1973), above which values may be important in terms of higher fractionation. However, these two samples are not close enough together spatially to warrant attention. In general, this ratio does not indicate a high degree of fractionation.

(m) (Na+K)/(Ca+Mg) and (Na+K)/Fe: These ratios range from 0.09 to 32.06 and 0.24 to 54.02 respectively. More than 90% of the values of both (Na+K)/(Ca+Mg) and (Na+K)/Fe are below 5. In general the ratios are erratically distributed throughout the corridor. There is therefore no evidence to indicate any portion of the corridor to be more fractionated than another.

(n) Clustering of ratios: Sample 2310 shows anomalous values for the K/Sr, K/Na, Ba/Sr, Ba/Ca ratios. This is in general consistent with the petrological classification of this rock as pegmatitic granite. This lone anomalous spot

and its immediate vicinity may warrant further investigation.

9.2.2.3 Grebo Town Area Suite (Table 33)

(a) K/Rb: Excluding those values which are disproportionately high, due to a reported content of Rb below the analytical limit of detection, this ratio ranges from 101.72 to 402.30. Most of the values are greater than the threshold value of 100 mentioned by Moseley (1981) for a granitoid to be considered being fractionated above early stage, and generally lie in the range of 150-300 (Govett, 1983) for normal granites. On the other hand, 4854, 4826, and 4863 give values close to the 100 threshold, although these samples are spatially far away from each other. Overall, the K/Rb ratio does not suggest a significant degree of fractionation of any part or all of the Grebo granitoid body.

(b) K/Ba: This ratio ranges from a low of 12.56 to a high of 960. Most of the values are less than the threshold value of 50 (Olade, 1980) above which values may be considered as indicating a significant degree of fractionation. The erratic spatial distribution of the few samples which show values greater than 50 does not permit a meaningful interpretation.

TABLE 33 RATIOS OF TRACE AND MAJOR ELEMENTS FOR THE GREBO TOWN AREA SUITE

Sample No.	K/Rb	K/Ba	Ba/Rb	K/Sr	K/Na	Ca/Sr	Mg/Ti
1872.000	308.725	48.936	6.309	464.646	2.091	44.444	1.023
4782.000	206.667	43.972	4.700	269.565	.925	69.130	3.429
4783.000	270.833	72.222	3.750	1326.531	7.558	18.163	6.243
4784.000	234.921	238.710	.984	672.727	.569	82.273	15.833
4791.000	229.814	234.177	.981	1917.098	1.682	92.228	13.056
4792.000	236.364	20.968	11.273	44.828	.342	59.655	2.143
4793.000	213.636	97.917	2.182	1566.667	1.741	80.000	17.000
4795.000	105000.000	23.864	4400.000	840.000	4.038	40.800	19300.000
4796.000	230.000	44.722	5.143	487.879	.767	100.000	6.633
4801.000	226.316	69.919	3.237	886.598	6.515	7.113	4.296
4802.000	216.216	960.000	.225	3870.968	1.043	253.226	6.962
4803.000	226.804	69.841	3.247	830.189	2.095	101.887	1.605
4804.000	377.358	30.534	12.358	333.333	1.818	59.167	2.447
4811.000	221.591	21.667	10.227	136.364	.629	127.972	2.150
4812.000	297.297	32.673	9.099	314.286	1.435	77.143	2.033
4813.000	228.916	29.688	7.711	145.038	.613	117.557	2.053
4814.000	339.130	26.351	12.870	280.576	1.393	62.590	1.500
4815.000	245.714	57.718	4.257	91.489	.374	627.660	5.319
4816.000	361.818	12.756	28.364	113.714	.737	154.286	1.636
4817.000	301.887	27.350	11.038	235.294	1.231	115.441	2.098
4818.000	237.624	27.907	8.515	186.047	.857	147.287	2.111
4821.000	202.817	15.824	12.817	80.000	.465	161.111	1.649
4822.000	288.000	46.753	6.160	585.366	3.273	18.699	1.121
4823.000	328.125	38.532	8.516	446.809	1.556	52.128	.815
4824.000	291.667	12.564	23.214	312.102	2.227	31.210	1.576
4825.000	282.486	30.864	9.153	413.223	2.174	44.628	.896
4826.000	169.697	46.281	3.667	589.474	3.415	75.789	12.381
4827.000	101.724	88.060	1.155	1552.632	7.867	305.263	12.979
4831.000	366.667	27.731	13.222	286.957	1.269	73.043	2.255
4832.000	295.082	22.500	13.115	395.604	2.250	58.242	2.441
4833.000	402.299	15.909	25.287	212.121	1.458	38.788	2.069
4834.000	360.248	13.488	26.708	335.260	2.762	16.185	1.808
4842.000	260.563	20.556	12.676	240.260	1.370	42.208	1.300
4843.000	273.529	28.182	9.706	628.378	5.167	15.541	3.792
4844.000	225.000	70.588	3.188	705.882	1.286	125.490	1.671
4845.000	237.569	113.158	2.099	1048.780	1.720	131.707	1.484
4846.000	264.550	29.586	8.942	781.250	5.882	9.844	2.891
4847.000	239.766	74.545	3.216	911.111	1.864	117.778	1.760
4852.000	345.000	28.750	12.000	92.617	.750	114.765	6.500
4853.000	230000.000	26.437	8700.000	10.952	.079	133.333	10.000
4854.000	145.946	16.364	8.919	77.143	.559	114.286	2.263
4855.000	266.272	38.793	6.864	368.852	2.045	44.262	1.527
4856.000	284.672	37.143	7.664	345.133	2.131	54.867	1.139
4862.000	213.636	30.323	7.045	382.114	2.043	58.537	1.061
4863.000	178.947	44.737	4.000	333.333	1.172	90.196	.859
4865.000	190000.000	23.171	8200.000	26.027	.083	86.301	4.749
4871.000	200.000	32.215	6.208	26.087	.166	81.522	3.136

Table 33 Continued...

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TABLE 33 Contd...

Sample No.	Ba/Ca	Mg/Li	$Lix10^3/K$	K/Pb	Li/Zn	$\frac{Na+K}{Ca+Mg}$	$\frac{Na+K}{Fe}$	$\frac{K_2O}{Na_2O}$
1872.000	.214	80.000	.120	1000.000	.420	14.050	13.333	1.874
4782.000	.089	162.162	.597	392.405	.561	5.890	4.778	.829
4783.000	1.011	99.123	.175	878.378	.991	36.436	15.333	6.774
4784.000	.034	91.346	.703	435.294	.954	14.783	7.418	.510
4791.000	.089	94.000	.135	787.234	.135	26.222	10.172	1.507
4792.000	.036	128.571	1.615	541.667	.538	2.550	4.113	.307
4793.000	.200	13.421	.243	652.778	3.000	28.986	102.778	1.560
4795.000	.863	27.183	6.762105	000.000	5.726	5.369	2.729	3.620
4796.000	.109	29.545	1.366	958.333	3.793	9.392	10.600	.687
4801.000	1.783	27.619	.049	1283.582	1.826	123.077	125.570	5.840
4802.000	.016	161.765	.142	727.273	.110	22.170	10.682	.935
4803.000	.117	27.639	1.636	1047.619	2.118	8.796	4.577	1.878
4804.000	.185	258.427	.223	975.610	.307	6.596	6.019	1.630
4811.000	.049	259.036	.851	1089.385	.325	2.235	2.405	.564
4812.000	.125	250.685	.221	1031.250	.243	5.639	4.956	1.286
4813.000	.042	286.765	.716	575.758	.252	2.591	2.500	.549
4814.000	.170	90.000	.103	2805.755	.678	7.395	27.917	1.248
4815.000	.003	2380.952	1.221	699.187	.092	.376	.416	.335
4816.000	.058	367.347	.739	1344.595	.245	1.448	1.513	.661
4817.000	.075	275.229	.341	761.905	.222	3.102	3.204	1.103
4818.000	.045	245.614	.713	827.586	.317	2.241	2.476	.768
4821.000	.031	337.017	1.257	533.333	.270	1.293	1.419	.416
4822.000	.670	63.182	.031	1285.714	.458	38.549	36.154	2.933
4823.000	.222	112.821	.093	933.333	.238	12.921	11.129	1.394
4824.000	.796	72.222	.147	1000.000	.447	13.100	14.490	1.996
4825.000	.300	63.077	.052	1063.830	.277	13.120	22.121	1.948
4826.000	.168	329.114	1.411	2545.455	.316	2.181	1.366	3.061
4827.000	.058	344.633	3.000	6082.474	.322	.916	.564	7.051
4831.000	.142	205.357	.170	846.154	.233	6.178	5.728	1.138
4832.000	.302	257.143	.156	947.368	.267	7.715	7.027	2.017
4833.000	.344	214.286	.080	1129.032	.217	8.429	11.346	1.307
4834.000	1.536	254.054	.064	1288.889	.201	21.123	13.860	2.475
4842.000	.277	127.869	.165	1088.235	.339	8.791	7.619	1.228
4843.000	1.435	71.654	.137	845.455	1.134	34.579	32.647	4.631
4844.000	.080	26.939	1.361	720.000	1.633	8.290	7.033	1.152
4845.000	.070	19.574	1.093	1131.579	2.386	10.759	7.473	1.542
4846.000	2.683	11.606	.274	925.926	3.605	74.144	36.563	5.272
4847.000	.104	24.444	1.317	1078.947	2.348	9.517	6.632	1.670
4852.000	.028	433.333	2.826	600.000	.750	.947	.716	.672
4853.000	.003	297.030	4.391	242.105	1.052	1.010	2.046	.071
4854.000	.041	286.667	1.852	600.000	.395	1.387	1.256	.501
4855.000	.215	146.087	.256	1022.727	.250	9.463	4.685	1.833
4856.000	.169	118.421	.195	1392.857	.543	8.070	10.232	1.910
4862.000	.215	167.021	.200	903.846	.261	7.982	6.542	1.832
4863.000	.083	131.250	.424	680.000	.320	5.681	3.539	1.051
4865.000	.013	25.000	17.895	39.583	2.576	3.483	2.441	.074
4871.000	.010	120.130	3.208	328.767	.846	2.006	4.694	.148

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(c) Ba/Rb: This ratio ranges from 0.22 (Sample 4802) to 28.36 (Sample 4816). The lowest values of 0.22, 0.98, 0.98, occur in Samples 4802, 4791, and 4784, respectively, but with the exception of the value of 0.22 in Sample 4802, all the remaining values are well above the threshold value of 0.50 advocated by Tauson and Kozlov, (1973) as the upper limit indicative of later fractionation.

(d) K/Sr: This ratio ranges from 10.95 (Sample 4853) to 3870.95 (Sample 4801) and is one of those originally intended to be used for comparing the degree of fractionation of two or more granitoid bodies. It is therefore expected to be highest in the most fractionated suite. The spatial distribution of values for this ratio doesnot indicate any significant differences in any parts of this area.

(e) K/Na (and K_2O/Na_2O): The K/Na ratio ranges from 0.08 (Sample 4853) to 7.86 (Sample 4783). Most of the values fall above the threshold of 1.2 (Olade, 1980) above which a higher degree of fractionation than that encountered in normal granitoids is indicated. Therefore this ratio appears to indicate a high degree of fractionation for this suite of rocks.

(f) Ca/Sr: This ratio ranges from 7.11 (Sample 4801) to 627.66 (Sample 4815). More than 50% of the values of this ratio are greater than 50, and lie close to 80 (with exceptions of 627.66 in Sample 4815, 305.26 in Sample 4827 and 253.22 in Sample 4802), a level which Turekian and Wedepohl (1961) consider as usual for normal granites. The few samples with ratios below 50 are erratically distributed spatially. This ratio is therefore generally indicative of normal granites.

(g) Mg/Ti: Disregarding the excessive value in Sample 4795 due to the reported content of Ti lying below the analytical detection limit, this ratio ranges from 0.81 (4823) to 17 (4793). More than 90% of the values for this ratio fall within the 0.3-10 range for specialized granitoids (Tischendorf, 1973), as opposed to the values exceeding 40 which correspond to normal granites, and may be suggestive of higher fractionation.

(h) Ba/Ca: This ratio ranges from 0.003 (4815) to 2.68 (4846) but has no threshold value quoted in the literature and may therefore only be used to compare the fractionation status of two or more different granitic bodies (showing a relative increase in the more fractionated body). In this suite of rocks, no spatial sub-grouping of values has been observed, and therefore no sub-area may be considered more fractionated on the basis of this ratio.

(i) Mg/Li: This ratio ranges from 11.61 (4846) to 2380.9 (4815). About 50% of the values are below or close to the threshold of 100, below which values are considered by Moseley (1981) indicative of fractionation above an early stage. No systematic spatial sub-grouping of any sort occurs throughout the area, but the rocks show some indications of a higher degree of fractionation.

(j) $Lix10^3/K$: This ratio ranges from 0.03 (4822) to 17.89 (4865). More than 50% of the samples have values less than 2.4, which Tauson and Kozlov (1973) consider as the threshold above which values are indicative of a higher fractionation. Only six of the samples have ratios falling above this level: 2.83, 3.00, 3.21, 4.4, 6.76 and 17.89 (Samples 4852, 4827, 4871, 4853, 4795 and 4865 respectively). Samples 4852 and 4853 are spatially close together, and as such the locality may warrant further attention. Otherwise the majority of values are not suggestive of a higher degree of fractionation.

(k) K/Pb: This ratio ranges from 39.6 (4865) to 6082 (4827), after excluding one spuriously high value caused by a Pb value below the detection limit. It has not been used by many workers. However, Taylor (1964) considered a value of this ratio of 1160 to typify average granites, and Sheraton and Black (1973) give a value of 620 for the Sn-bearing Esmerald Granite in

Queenland. This implies that a lower value of this ratio is suggestive of a higher degree of fractionation. In this suite of rocks about 50% of the values fall below Taylor's threshold and a few are less than 620, which suggests that the granitoids here may have attained a certain degree of fractionation. The pattern of spatial distribution of these lower values is, however erratic.

(l) Li/Zn: This ratio ranges from 0.09 (4815) to 5.72 (4795) with more than 80% of the values falling below the threshold value of 1.1 above which values may signify a high degree of fractionation or the occurrence of ore potential, especially in the vicinity of hydrothermal activities (Tauson and Kozlov, 1973).

(m) (Na+K)/(Ca+Mg) and (Na+K)/Fe: These two ratios are discussed here together as they express relationship between two alkalics and mafic elements, and are generally used to compare the fractionation status of two or more granitic bodies in relative terms. Values of the ratios increase with the degree of fractionation. In this study the ratios range from 0.38 (4815) to 123.08 (4801) for (Na+K)/(Ca+Mg) and from 0.42 (4815) to 125.57 (4801) for (Na+K)/Fe. There generally seems to be a moderate indication of correspondence between the two ratios, i.e. both seem to be relatively high in the same samples (see individual values for Samples 4801, 4822, 4862, and 4824 in Table).

The spatial distribution of the values does not indicate any degree of clustering or sub-grouping. This in turn suggests that no portion of the granitoids here may be considered more fractionated than the rest.

(n) Clustering of ratios: Throughout the discussion of the individual ratios from this suite, it has not been possible to recognize a sample (or a group of samples) which has anomalous values for two or more ratios in the area. However, these granitoids provide the most encouraging indicators of later fractionation and its ratios will be considered in connection with other indicators to fully assess the degree of fractionation and/or mineralization potential of these rocks in Section 9.2.2.5.

9.2.2.4 The Cestos Batholith Area (Table 34)

(a) K/Rb: Disregarding the disproportionately high values for samples 4922 and 5021, due to the Rb content close to the analytical limit of detection, this ratio ranges from 106.7 (5022) to 617.7. Only two values (106.7 and 141.0 from samples 5022 and 5014, respectively) lie close to the threshold of 100, below which a high degree of fractionation is indicated (Govett, 1983). No real significance can be given to these spatially isolated anomalous values. This ratio mainly implies a low degree of fractionation.

TABLE 34 RATIOS OF TRACE AND MAJOR ELEMENTS FOR THE CESTOS BATHOLITH AREA SUITE

Sample No.	K/Rb	K/Ba	Ba/Rb	K/Sr	K/Na	Ca/Sr	Mg/Ti
4981.000	316.456	23.585	13.418	45.455	.926	56.364	4.219
4882.000	198.198	32.836	6.036	39.286	.815	62.500	4.857
4883.000	402.778	27.103	14.861	46.774	1.160	62.903	4.811
4884.000	313.253	23.009	13.614	46.429	1.000	53.571	4.621
4891.000	290.000	34.940	8.300	40.845	1.000	40.845	4.448
4892.000	320.000	34.286	9.333	33.803	.857	53.521	4.857
4893.000	292.135	27.957	10.449	35.616	.929	47.945	4.969
4894.000	318.182	30.769	10.341	36.364	.966	42.857	4.563
4895.000	260.417	35.211	7.396	32.895	.893	48.684	4.694
4902.000	387.097	24.742	15.645	38.710	.600	35.484	2.941
4903.000	176.471	32.877	5.368	35.294	.889	60.294	5.079
4904.000	245.455	35.526	6.909	44.262	1.000	59.016	4.657
4911.000	259.615	34.615	7.500	37.500	1.000	54.167	4.649
4912.000	282.828	37.333	7.576	44.444	.966	46.032	4.519
4913.000	247.525	24.752	10.000	29.762	.806	42.857	4.303
4914.000	431.034	29.070	14.828	36.232	.926	46.377	4.300
4915.000	298.851	30.233	9.885	34.667	.929	45.333	4.750
4922.000	177000.000	44.250	4000.000	59.000	.994	46.000	1.696
4923.000	270.270	30.769	8.784	25.000	.667	45.000	4.636
4924.000	262.626	37.143	7.071	38.235	.929	48.529	4.667
4925.000	238.462	36.047	6.615	46.269	1.069	43.284	3.735
4926.000	205.479	35.294	5.822	44.118	1.200	54.412	4.452
4931.000	351.351	32.911	10.676	38.235	.897	50.000	4.265
4932.000	280.899	28.736	9.775	34.722	.893	47.222	4.471
4933.000	212.963	44.231	4.815	38.333	1.095	88.333	7.949
4934.000	254.386	37.662	6.754	45.313	1.115	42.188	4.423
4981.000	259.615	31.034	8.365	42.857	.931	55.556	4.697
4982.000	342.857	28.571	12.000	32.000	.828	54.667	4.944
4991.000	264.151	32.184	8.208	36.842	1.000	43.421	4.625
4992.000	266.667	31.461	8.476	36.364	1.000	44.156	4.500
4994.000	236.364	35.135	6.727	41.270	.963	57.143	4.667
5001.000	428.571	22.340	19.184	28.378	.583	41.892	4.182
5002.000	250.000	34.118	7.328	44.615	1.115	40.000	4.593
5004.000	260.000	27.368	9.500	35.135	.963	51.351	5.194
5005.000	369.231	29.630	12.462	36.923	.960	44.615	4.556
5011.000	281.250	30.337	9.271	37.500	1.000	43.056	4.433
5012.000	351.351	26.531	13.243	35.135	1.000	41.892	4.593
5013.000	310.345	33.333	9.310	39.130	.900	44.928	4.786
5014.000	141.026	192.982	.731	67.073	21.154	93.293	5.160
5015.000	201.389	36.250	5.556	40.278	1.000	44.444	4.600
5016.000	276.190	36.250	7.619	42.647	1.036	47.059	4.188
5021.000	112000.000	56.000	2000.000	12.043	.113	1053.763	33.735
5022.000	106.667	40.336	2.644	35.294	.457	654.412	25.967
5023.000	258.442	26.184	9.870	26.184	.686	57.895	5.385
5024.000	275.000	31.731	8.667	44.595	.838	94.595	3.808
5025.000	278.351	34.177	8.144	40.909	1.038	56.061	4.583
5031.000	259.259	28.767	9.012	32.308	.770	53.846	5.000
5032.000	213.592	28.205	7.573	44.000	.880	68.000	4.789
5033.000	285.714	38.095	7.500	37.500	1.200	62.500	4.792
5034.000	212.963	32.394	6.574	41.071	.885	58.929	4.879
5035.000	210.526	32.877	6.404	53.333	.960	73.333	4.243
5041.000	205.085	22.830	8.983	22.000	.367	60.000	4.000
5043.000	349.206	23.656	14.762	81.481	.957	10.370	2.124
5044.000	468.085	32.353	14.468	111.111	.733	33.838	1.897
5045.000	617.647	170.732	3.618	84.000	.808	29.200	4.805
5051.000	154.867	35.714	4.336	47.297	.673	40.541	3.302
5052.000	264.706	33.750	7.843	43.548	1.080	56.452	5.121
5053.000	362.963	16.897	21.481	28.000	.297	62.857	2.558
5061.000	236.994	38.679	6.127	525.641	1.952	66.667	1.804
5063.000	387.234	17.500	22.128	67.407	.628	137.037	2.537

Table 34 Continued...

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TABLE 34 Contd...

Sample No.	Ba/Ca	Mg/Li	Li x 10^3/K	K/Pb	Li/Zn	Na+K / Ca+Mg	Na+K / Fe	K_2O/Na_2O
4881.000	.034	675.000	.800	1190.476	.345	1.169	1.444	.830
4882.000	.019	971.429	.795	1134.021	.254	.942	1.167	.730
4883.000	.027	1028.902	.597	1380.952	.247	.951	1.125	1.040
4884.000	.038	676.768	.762	1300.000	.354	1.198	1.486	.896
4891.000	.029	516.000	.862	1318.182	.424	1.384	1.706	.896
4892.000	.018	708.333	1.000	1043.478	.338	.945	1.182	.768
4893.000	.027	722.727	.846	1181.818	.338	1.061	1.317	.832
4894.000	.028	584.000	.893	1465.969	.379	1.197	1.462	.865
4895.000	.019	603.571	1.120	1190.476	.389	.983	1.205	.800
4902.000	.044	259.740	.321	1283.422	.653	2.667	7.901	.538
4903.000	.018	839.130	.958	923.077	.284	.846	1.063	.797
4904.000	.021	708.696	.852	1125.000	.324	1.033	1.286	.896
4911.000	.020	781.818	.815	1436.170	.333	.961	1.200	.896
4912.000	.026	580.952	.750	1076.923	.375	1.383	1.727	.865
4913.000	.028	676.190	.840	1086.957	.344	1.116	1.474	.723
4914.000	.027	516.000	1.000	2032.520	.431	1.158	1.405	.830
4915.000	.025	690.909	.846	1181.818	.333	1.098	1.350	.832
4922.000	.029	287.879	1.864	177000.000	.375	1.524	1.268	.891
4923.000	.018	566.667	1.350	1092.896	.403	.975	1.250	.598
4924.000	.021	500.000	1.077	1040.000	.452	1.149	1.421	.832
4925.000	.030	529.167	.774	1148.148	.414	1.439	1.765	.958
4926.000	.023	667.857	.933	1111.111	.346	.987	1.100	1.076
4931.000	.023	630.435	.885	1040.000	.343	1.134	1.410	.804
4932.000	.026	608.000	1.000	1190.476	.391	1.077	1.325	.800
4933.000	.010	1000.000	1.348	1000.000	.256	.524	.667	.982
4934.000	.029	460.000	.862	1208.333	.446	1.429	1.719	1.000
4981.000	.025	738.095	.778	1350.000	.339	1.109	1.436	.834
4982.000	.020	809.091	.917	1142.857	.306	.901	1.128	.742
4991.000	.026	672.727	.786	1333.333	.324	1.172	1.436	.896
4992.000	.026	665.217	.821	1272.727	.354	1.136	1.366	.896
4994.000	.021	763.636	.846	1130.435	.319	1.004	1.233	.863
5001.000	.030	686.567	.638	1329.114	.372	1.418	2.280	.523
5002.000	.033	563.636	.759	1208.333	.393	1.432	1.571	1.000
5004.000	.025	890.476	.808	962.963	.292	.935	1.082	.863
5005.000	.028	621.212	.825	1472.393	.347	1.186	1.400	.860
5011.000	.029	554.167	.889	1285.714	.400	1.219	1.459	.896
5012.000	.032	539.130	.885	1677.419	.411	1.198	1.529	.896
5013.000	.026	558.333	.889	1384.615	.381	1.284	1.583	.807
5014.000	.004	537.500	2.182	1325.301	.400	.409	.360	18.960
5015.000	.025	575.000	.828	1115.385	.381	1.266	1.568	.896
5016.000	.025	609.091	.759	1160.000	.361	1.256	1.583	.928
5021.000	.000	9491.525	5.268	112000.000	.116	.072	.184	.101
5022.000	.001	2486.772	3.938	484.848	.315	.113	.255	.410
5023.000	.017	1122.995	.940	1191.617	.249	.752	.959	.615
5024.000	.015	578.947	1.036	959.302	.364	.806	1.207	.751
5025.000	.021	1018.519	.600	1173.913	.245	.991	1.233	.931
5031.000	.021	1011.905	.800	1320.755	.258	.923	1.067	.697
5032.000	.023	700.000	1.182	1366.460	.377	.900	.979	.789
5033.000	.016	1000.000	.958	1200.000	.258	.698	.698	1.076
5034.000	.022	1319.672	.530	958.333	.191	.998	1.225	.793
5035.000	.022	628.000	1.042	1363.636	.379	1.006	1.195	.860
5041.000	.016	473.373	1.397	746.914	.291	1.100	1.879	.329
5043.000	.332	137.931	.791	1182.796	.829	8.654	2.432	.857
5044.000	.101	157.143	.955	1195.652	.808	5.200	3.355	.657
5045.000	.017	627.119	.562	954.545	.381	3.197	1.119	.724
5051.000	.033	417.647	1.943	700.000	.493	1.490	1.012	.603
5052.000	.023	804.762	.778	1227.273	.323	1.002	1.209	.968
5053.000	.026	550.000	.816	628.205	.186	1.621	2.709	.266
5061.000	.204	48.936	.459	732.143	.723	10.131	8.052	1.750
5063.000	.028	913.333	.824	994.536	.188	.931	.944	.563
5064.000	.019	604.167	.941	554.348	.181	1.532	2.744	.247

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(b) K/Ba: This ratio ranges from 16.90 (5053) to 192.98 (5014). There is no obvious spatial grouping or clustering of any kind. All values except 170.73 (5045) and 192.98 (5014) are below the threshold of 50 above which higher degree of fractionation may be inferred (Moseley, 1981 ; Tauson and Kozlov, 1973).

(c) Ba/Rb: Disregarding the extreme values for samples 5021 and 4922 caused by Rb values below detection limit , this ratio ranges from 0.73 (Sample 5014) to 22.13 (Sample 5063). All the values of this ratio are above the threshold value of 0.5 (Tauson and Kozlov, 1973) below which values may be indicative of a significant degree of fractionation. No indication of later fractionation is implied by this ratio.

(d) K/Sr: This ratio ranges from 12.04 (Sample 5021) to 525.64 (Sample 5061). This ratio is usually used to compare the relative degree of fractionation status of different intrusives and has no threshold value. It is expected that this ratio would increase with the degree of fractionation. In this suite of rocks, more than 95% of the values lie between 22 and 47. There is no indication of spatial clustering among the values, suggesting that the degree of fractionation is uniform throughout the area.

(e) K/Na (and K_2O/Na_2O): The K/Na ratio ranges from 0.11 to 21.15. Most of the values are less than the 1.2 threshold (Olade, 1980), suggesting that these rocks formed early in the fractionation sequence. The few values that are equal to,or greater than, the threshold value are generally widely scattered throughout the area, and are therefore not particularly significant.

(f) Ca/Sr: This ratio ranges from 10.37 (Sample 5043) to 1053.76 (Sample 5021). No threshold value has been suggested in the literature for this ratio. It is generally only used to compare the status of differentiation of two or more different intrusives. Only three samples have values greater than 100: 5065 (137.04), 5022 (654.44), and 5021 (1053.76), and no special spatial grouping of values is observed. The degree of fractionation is considered uniform in this area on the basis of this ratio.

(g) Mg/Ti: This ratio ranges from 1.69 (Sample 4922) to 33.73 (Sample 5021), but the majority of the values lie between 2 and 5. According to Tischendorf (1973) quoted in Moseley (1981), values between 0.3 and 10 (and hence the majority of values in this suite) are associated with specialized granites as opposed to values greater than 40 for normal granites.

(h) Ba/Ca: This parameter ranges from 0.001 (Sample 5022) to 0.33 (Sample 5043), with 90% of the values lying between 0.01 and 0.03; thus the majority of the samples have similar values. No spatial clustering or sub-grouping of values is observed. This ratio has no threshold value quoted in the literature, and is usually used only to indicate relative degrees of fractionation from one granitic body to another. In the present study, no portion of the body appears to be more highly fractionated on the basis of this ratio.

(i) Mg/Li: This ratio ranges from 48.94 (5061) to 9491.51 (5021). With the exception of a value of 48.94 in Sample 5061, all the values are above the threshold value of 100 (Tauson and Kozlov,1973), below which the ratios may be indicative of later fractionation of granitoids. The values in these rocks do not suggest late stage fractionation.

(j) Lix10^3/K: This ratio ranges from 0.32 (4902) to 5.26 (5021). More than 95% of the values of this ratio are less than the threshold value of 2.4 (Tauson and Kozlov,1973) above which the ratio may be suggestive of a degree of fractionation beyond the early stage. Only an early stage of fractionation is indicated for this suite of rocks on the basis of this ratio.

(k) K/Pb: Disregarding the extreme values in Samples 5021 and 4922, caused by the Pb content of these samples being close to the analytical limit of detection, this ratio ranges from 484.85 (5022) to 2032.52 (4914). The usefulness of this ratio as an indicator of the degree of fractionation in granitoids is controversial (Moseley, 1981). Taylor (1964) thinks that values in the general neighbourhood of 1160 are common for normal granites. The ratios for 90% of this suite of rocks are in the neighbourhood of 1000, and are therefore suggestive of early fractionation.

(l) Li/Zn: This ratio ranges from 0.12 (5012) to 0.8 (5043), with most of the values lying between 0.10 and 0.40. There is no pattern of spatial sub-grouping among the values. According to Tauson and Kozlov (1973) ratios in the range encountered in these rocks are indicative of early fractionation as they are below 1.1; above this threshold value a higher degree of fractionation and/or hydrothermal activity may be inferred.

(m) (Na+K)/(Ca+Mg) and (Na+K)/Fe: These ratios range from 0.07 (Sample 5021) to 10.13 (Sample 5061) and 0.18 (Sample 5021) to 8.05 (Sample 5061) respectively. No threshold values for these parameters have been suggested in the literature, but they are generally used to compare the status of fractionation of two or more intrusives. As such they may be used to distinguish different generations of intrusives. No indica-

cation of such phenomenon has been observed in these rocks.

(n) Clustering of ratios: It is interesting to note that the values for the Mg/Ti ratio for this suite are generally within the range of 0.3-10.0 mentioned by Tischendorf and Kozlov (1973) as corresponding to specialized granites (and hence may be indicative of higher degree of fractionation). But this implication should not be accepted in isolation of other factors. In fact, on the basis of all of the other factors, the Cestos Batholith suite must be considered an early fractionation product.

9.2.2.5 Ratio Variation between Liberian Granites

From the above, it is apparent that the various types of ratios dealt with in this study indicate variation within and between the granites.

Some of the ratios mentioned have been used by earlier workers solely for comparing between granitoids, and this can be usefully done for the Liberian granites. The Ba/Ca ratio tends to be highest (0.01 to 2.68) for the Grebo Town suite, with more than 60% of values above 0.1, whereas it tends to be lowest (0.01 to 0.33) for the Cestos Batholith suite with more than 90% of values in the range of 0.02-0.04. Similar comparison shows that the Grebo Town suite also has the highest values for (Na+K)/Ca+Mg, Na+K/Fe, and K/Sr. According to Govett (1983), relatively

higher values of these ratios from one granitoid body to another may indicate different degree of fractionation, with the highest value(s) corresponding to the most fractionated suite. Therefore, on the basis of such comparative ratios, it is evident that the Grebo Town area suite is the most fractionated among the Liberian granites.

The Grebo Town area seems to have the lowest average value for the Ba/Rb ratio among the granitic rocks studied. This most probably underscores its relatively higher contents of Rb which may in turn be related to a higher degree of fractionation. The local and regional variations observed for the other ratios with published thresholds may similarly be related to the lithological and/or chemical differences in and among the different suites.

However, caution should be exercised in comparing some of these ratios from one area to another as real differences could be masked by other factors. For instance, the overall K/Rb ratio values from the pegmatitic Grebo Town area suite are not radically different from those of the Cestos Batholith area suite, which is mainly quartz diorite. This may be due to the fact that the lower content of Rb in the latter is compensated for by a higher content of K in the former. The implications of some of these ratios should not, therefore, be looked at in isolation from other factors.

Table 35 summarizes the elemental ratios.

TABLE 35 COMPARISON OF PUBLISHED RATIO THRESHOLD VALUES WITH THOSE FOR THE LIBERIAN GRANITOIDS

RATIO	PUBLISHED THRESHOLD VALUES	SUITES STUDIED			
		NWG	NCC	GTA	CB
K/Rb	-100	0	0	0	0
Ba/Rb	-0.50	0	0	0	0
K/Ba	+50	0	0	0	0
K/Sr	X	I	I	H	0
K/Na	+1.2	0	0	H	0
(or K_2O/Na_2O)	+1.5	0	0	H	0
Ca/Sr	X	I	I	H	0
Mg/Ti	0.3-10	H	H	H	H
Ba/Ca	X	I	I	H	0
Mg/Li	-100	0	0	H	0
$Lix10^3/K$	+2.4	0	0	0	0
K/Pb	X	I	I	I	0
Li/Zn	+1.1	0	0	0	0

EXPLANATION:

NWG = Northwest Granites and associated gneisses (n = 185); NCC = North Central Corridor suite (n = 41); Grebo Town area suite (n = 47); Cestos Batholith area suite (n = 61).

- = indicates threshold below which value of ratio suggests high degree of fractionation; + = indicates threshold above which value of ratio suggests high degree of fractionation; X = no threshold published in literature, or threshold controversial.

H = ratio suggests high degree of fractionation.

0 = ratio suggests low degree of fractionation.

I = ratio suggests intermediate degree of fractionation.

(These symbols are used in a relative sense where no threshold is published.).

On the basis of these ratios, the Grebo Town area suite is the only one of the Liberian granitoids in the present study which seems to have reached a fractionation status above an early stage.

9.2.3 Ternary Relationships

9.2.3.1 Ba-Sr-Rb system

The relative Ba-Sr-Rb contents are shown individually for each of the areas sampled, as triangular diagrams, in Figure 46 (a-d), and superimposed as a composite plot in Figure 47. From these figures it is apparent that there is a high degree of variation for these elements in each area, and when superimposed a considerable amount of overlapping occurs among the different suites (note especially the distinctive similarity between the Northwest Granites and associated gneisses and the suite from the North Central Corridor). Of the four suites, the Cestos Batholith seems to be the least variable in terms of these elements, with the Rb proportion remaining consistently very low. On the other hand, the other three suites each show greater enrichment of both Ba and Rb.

On the basis of these diagrams the rocks studied here range from diorite through quartz diorite and granidiorite to normal granites, with the Grebo Town suite falling generally in the field of the normal granites. Using the

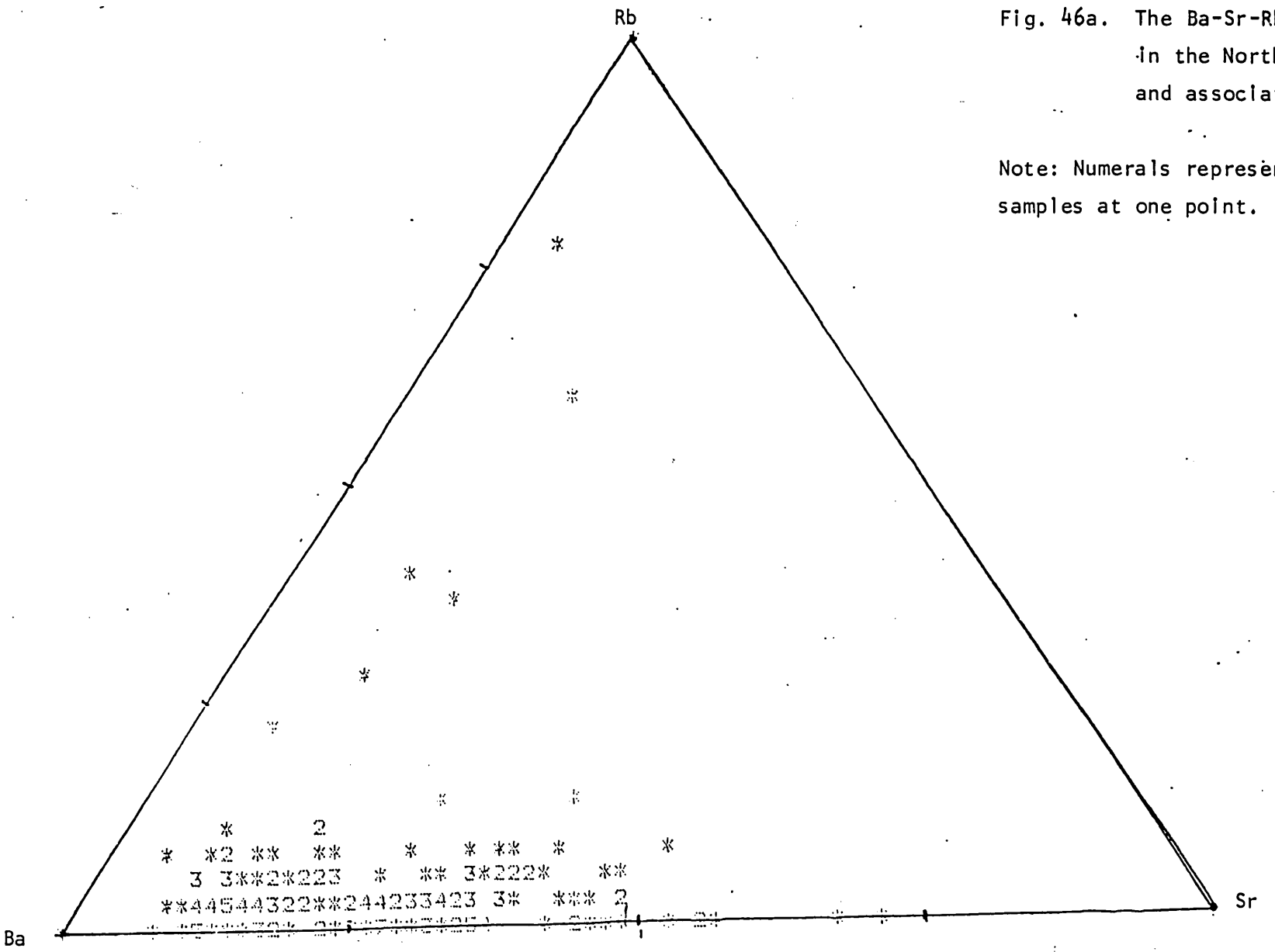


Fig. 46a. The Ba-Sr-Rb relationship in the Northwest granites and associated gneisses.

Note: Numerals represent two or more samples at one point.

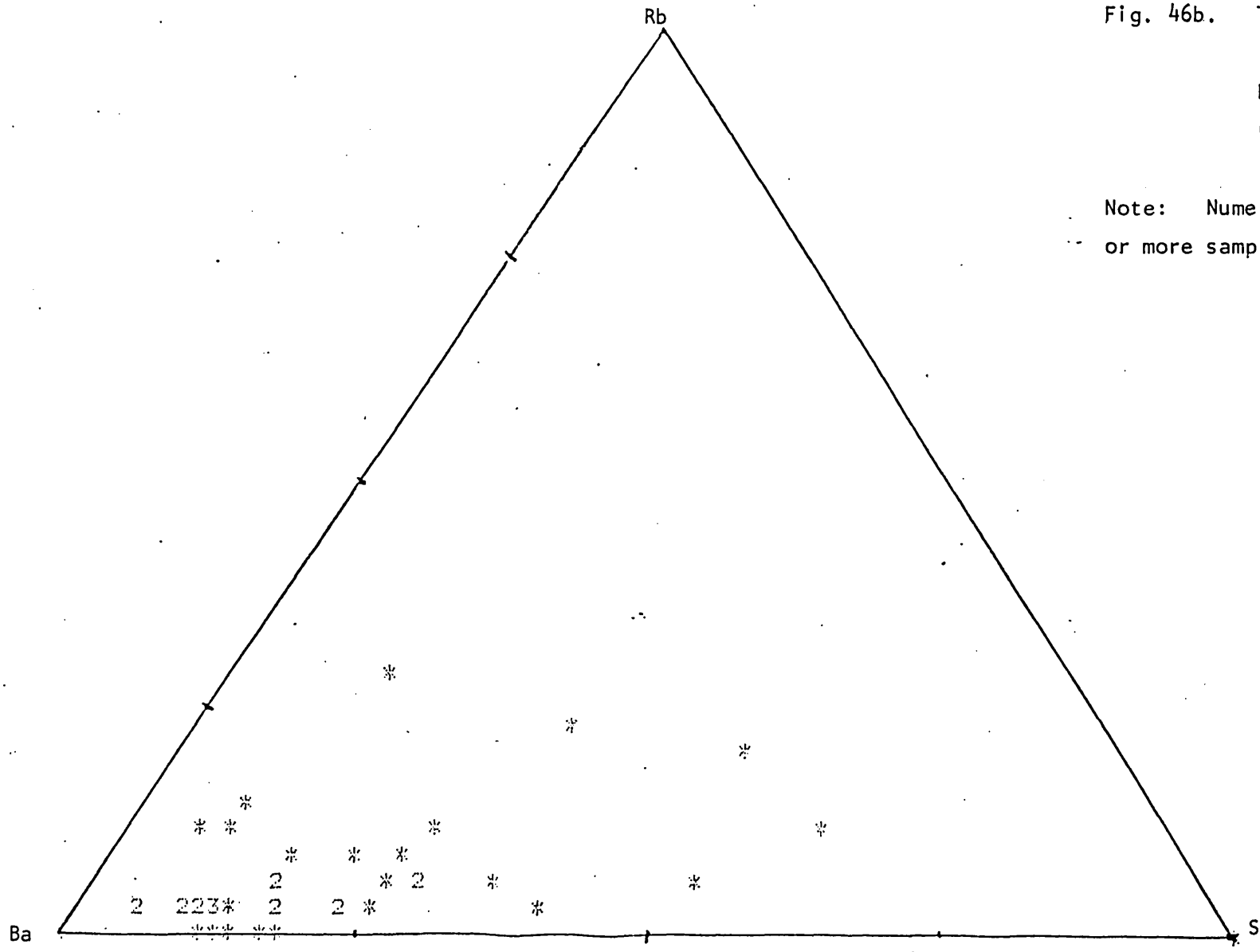


Fig. 46b. The Ba-Sr-Rb relationship in the North Central Corridor suite.

Note: Numerals represent two or more samples at one point.

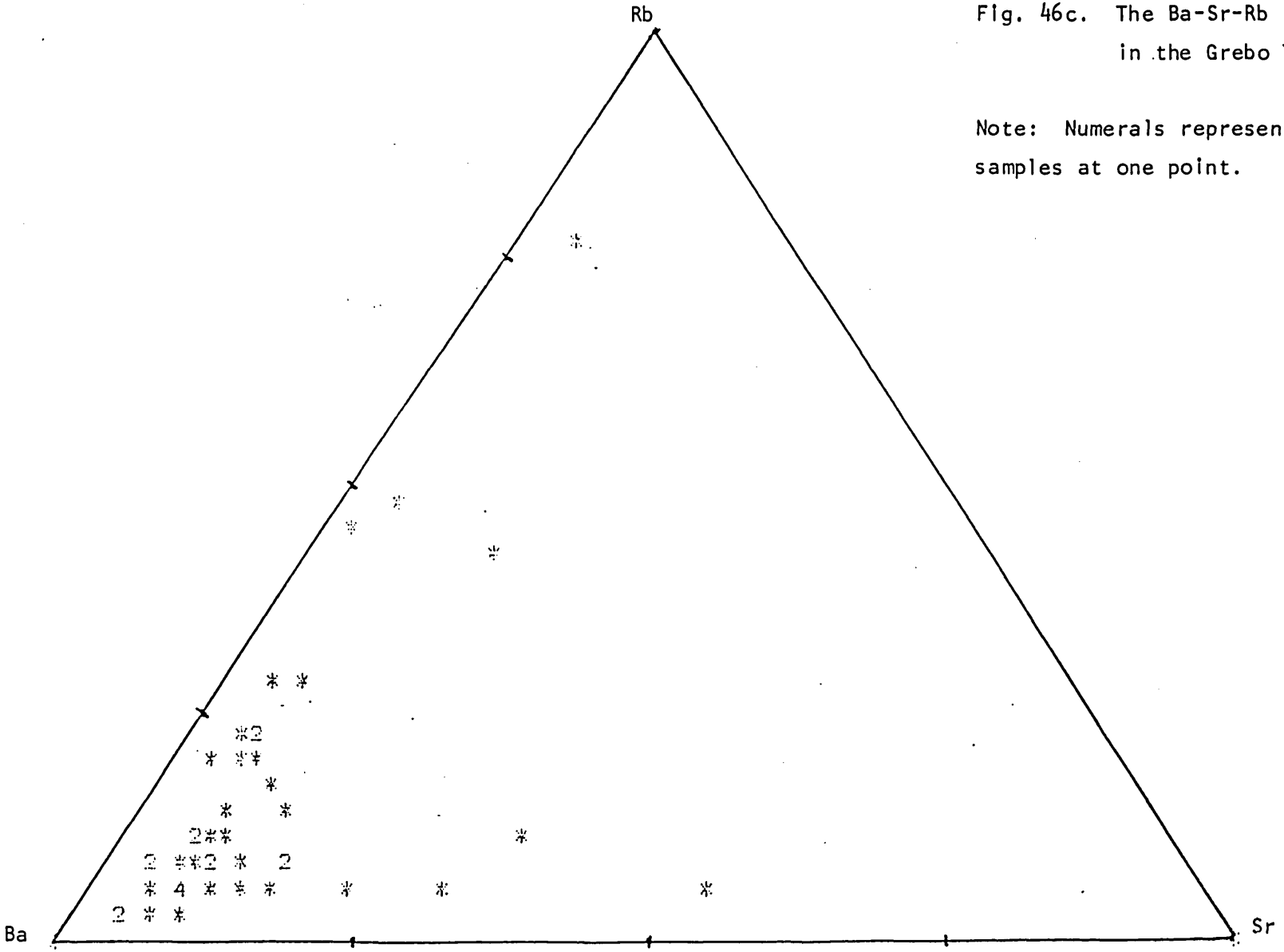


Fig. 46c. The Ba-Sr-Rb relationship in the Grebo Town area suite.

Note: Numerals represent two or more samples at one point.

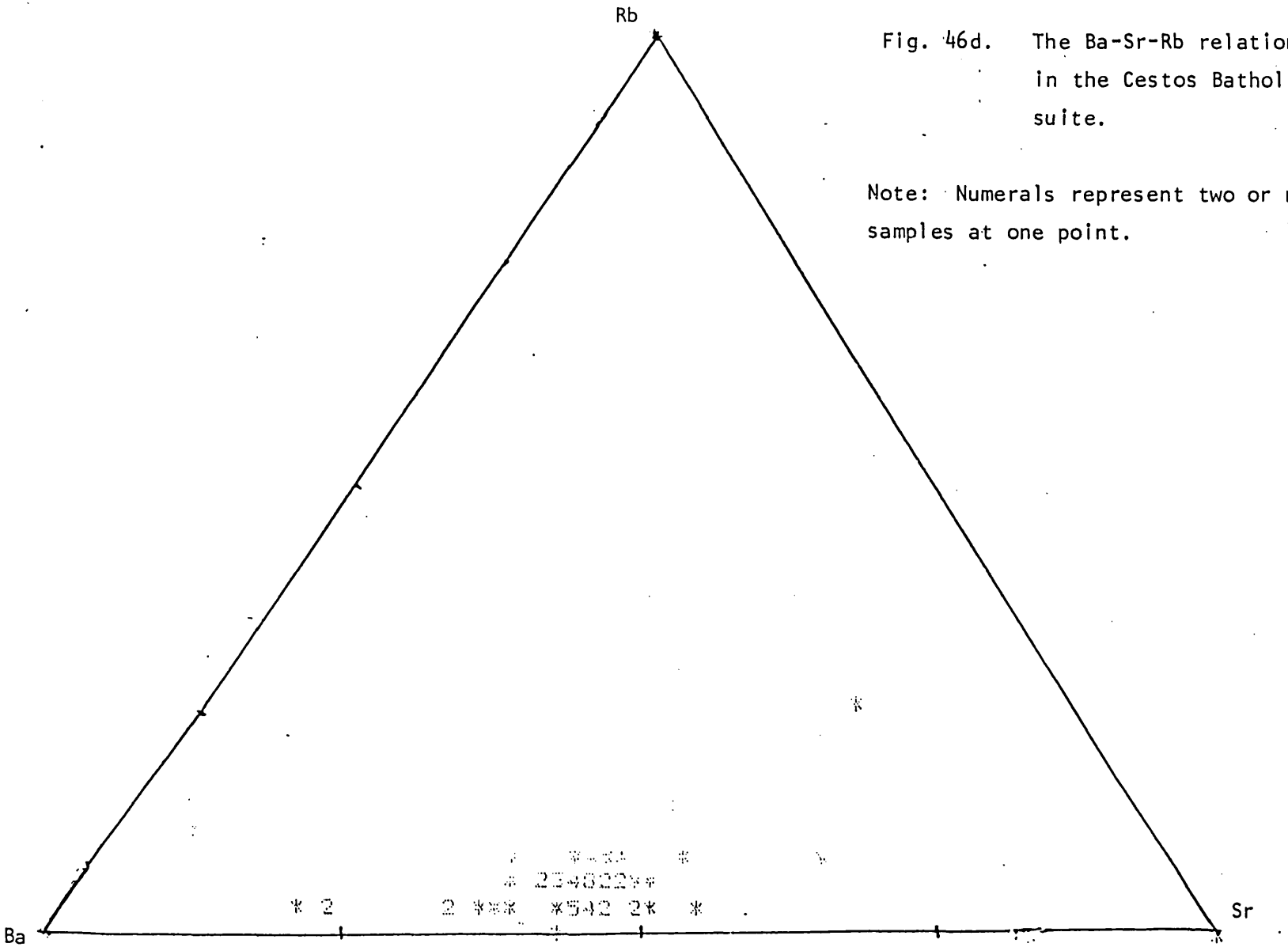


Fig. 46d. The Ba-Sr-Rb relationship in the Cestos Batholith suite.

Note: Numerals represent two or more samples at one point.

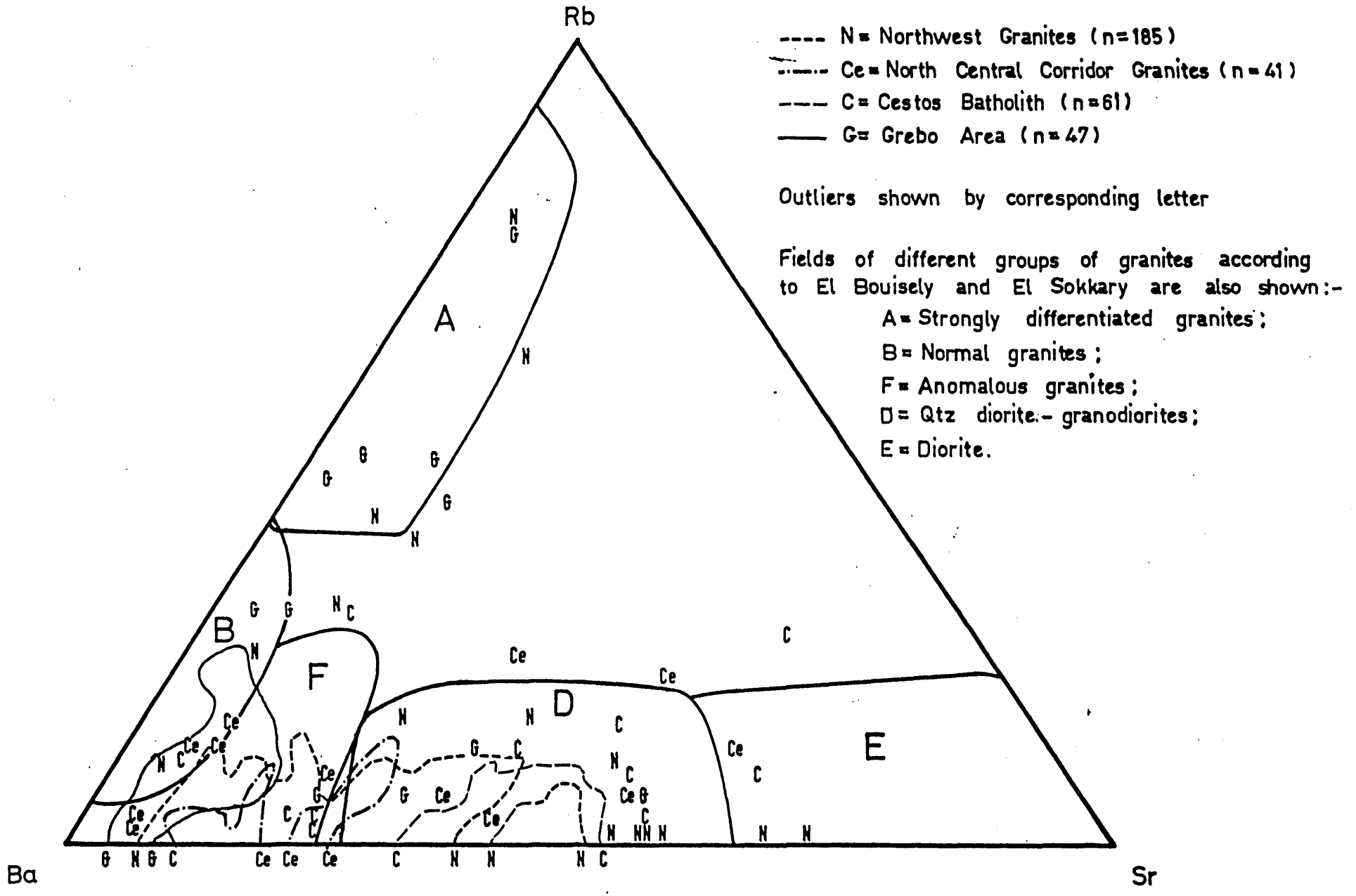


Fig. 47 :- The Superimposed Rb - Ba - Sr Relationship of the four granitoid suites.

boundaries originally suggested by El Bouisely and El Sikkary (1975), it can be seen that most of the Grebo Town samples, and significant portions of the Northwest Granite and the North Central suites can also be classified as "anomalous granites". This type, according to El Bouisely and El Sokkary (1975), was possibly affected by hydrothermal activity at one time or another. A few samples - six from the Grebo Town suite (Samples 4791, 4793, 4816, 4843); four from the Northwest Granite suite (4571, 4543, 4454, 4631); and one from the North Central corridor suite (43852) - fall within their "strongly differentiated field" on the diagram. On the basis of this diagram the Grebo Town suite is overall the most fractionated among the granites in this study, whilst the Cestos Batholith suite is the least fractionated. The Northwest Granites and the North Central Corridor suites appear to occupy an intermediate position.

9.2.3.2 The (Na+K)-Mg-Fe system

The plot of this system was originally used by Juniper and Kleeman (1979) to discriminate between Sn-mineralizing granites and barren ones in New South Wales. It has been used here to determine if it could assist detection of Sn-mineralization potential in any of the suites. The (Na+K)-Mg-Fe ternary plots for the four different suites of granitoids are shown in Figures 48(a-d). The fields occupied by all

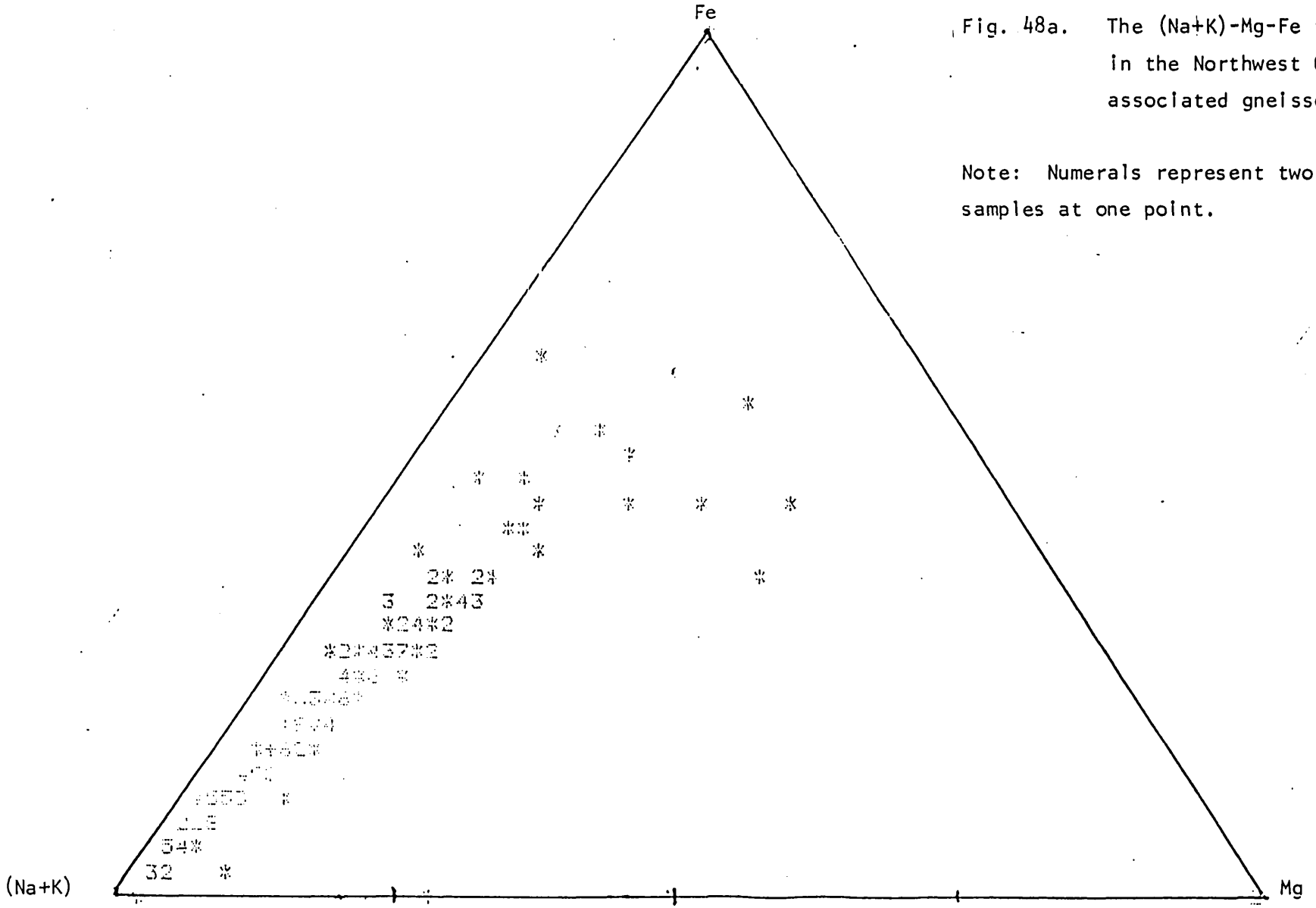


Fig. 48a. The (Na+K)-Mg-Fe relationship in the Northwest Granites and associated gneisses.

Note: Numerals represent two or more samples at one point.

Fig. 48b. The (Na+K)-Mg-Fe relationship in the North Central Corridor suite

Note: Numerals represent two or more samples at one point.

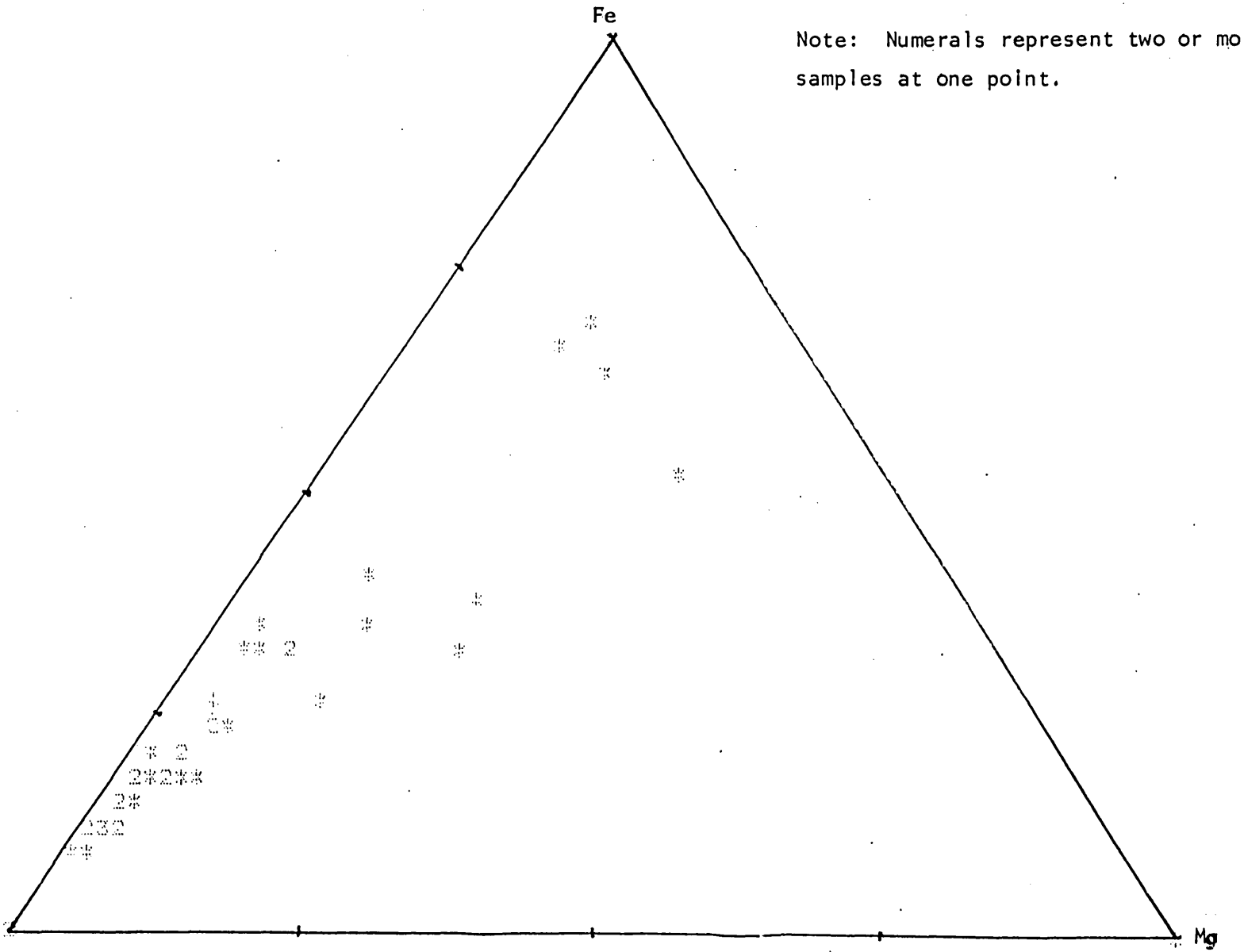


Fig. 48c. The (Na+K)-Mg-Fe relationship in the Grebo Town suite.

Note: Numerals represent two or more samples at one point.

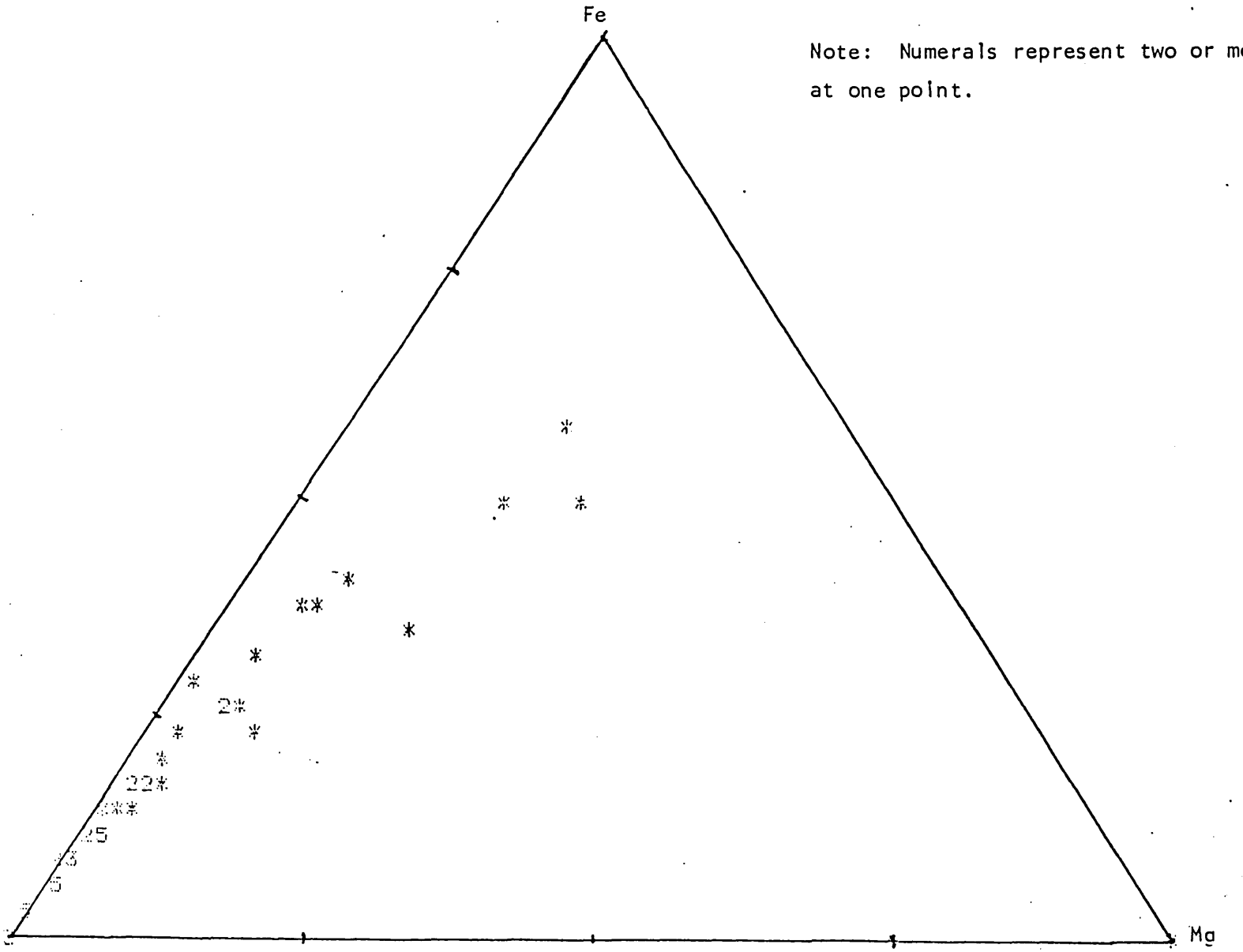
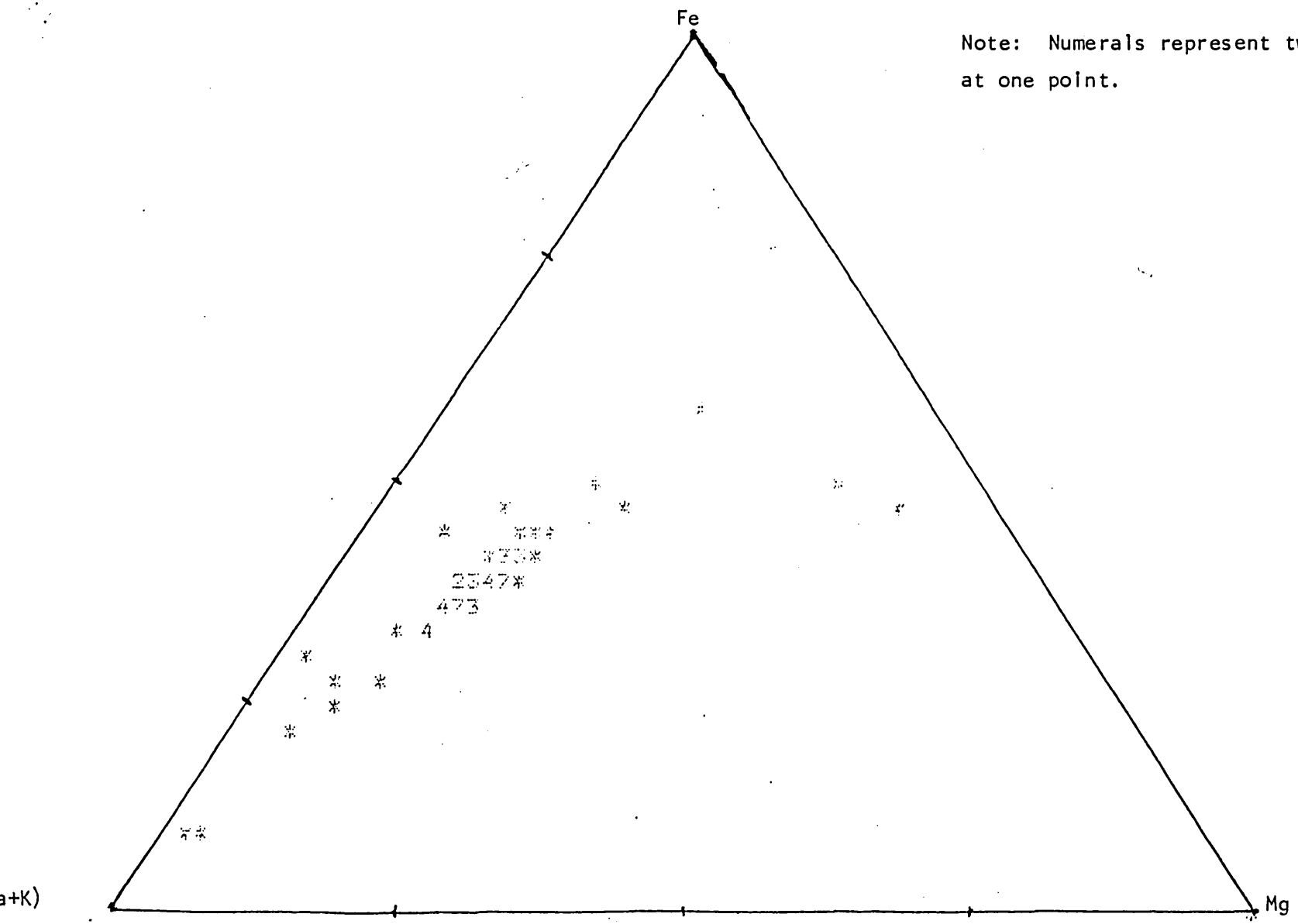


Fig. 48d. The (Na+K)-Mg-Fe relationship in the Cestos Batholith suite.

Note: Numerals represent two or more samples at one point.



of these data, with the boundaries for Sn-mineralizing granites suggested by Juniper and Kleeman (1979) superimposed (Figure 49) show that there is a great deal of overlapping between the Liberian suites, but with the Grebo Town suite appearing to be relatively most anomalous. However, only the Cestos Batholith suite out of the four areas, (with the exception of samples: 4932 and 5043 which are clearly outliers) is not represented in the "Sn-mineralizing granites field" by a sizable number of samples. Given the less encouraging findings from most ratios, the applicability of this technique in the present situation seems dubious, and no useful conclusion may be drawn for the mineralization potential of the Liberian granitoids investigated here on the basis of the Na+K-Mg-Fe system.

9.2.4 Petrochemical/Petrological Classification

For reasons given earlier on in Chapter 5, many investigators nowadays attempt to classify granitoids according to one of two schemes: (i) the I- and S-type granites of White and Chappell (1974, 1977); or (ii) the Magnetite/Ilmenite Series of Ishihara (1975). The characteristics of these two systems of classification were given in Tables 7 and 8 respectively.

The chemical and petrological data available on the Liberian granitic rocks to date lacks information on many of their criteria (e.g. $^{87}Sr/^{86}Sr$ values, ^{18}O values, CIPW normative

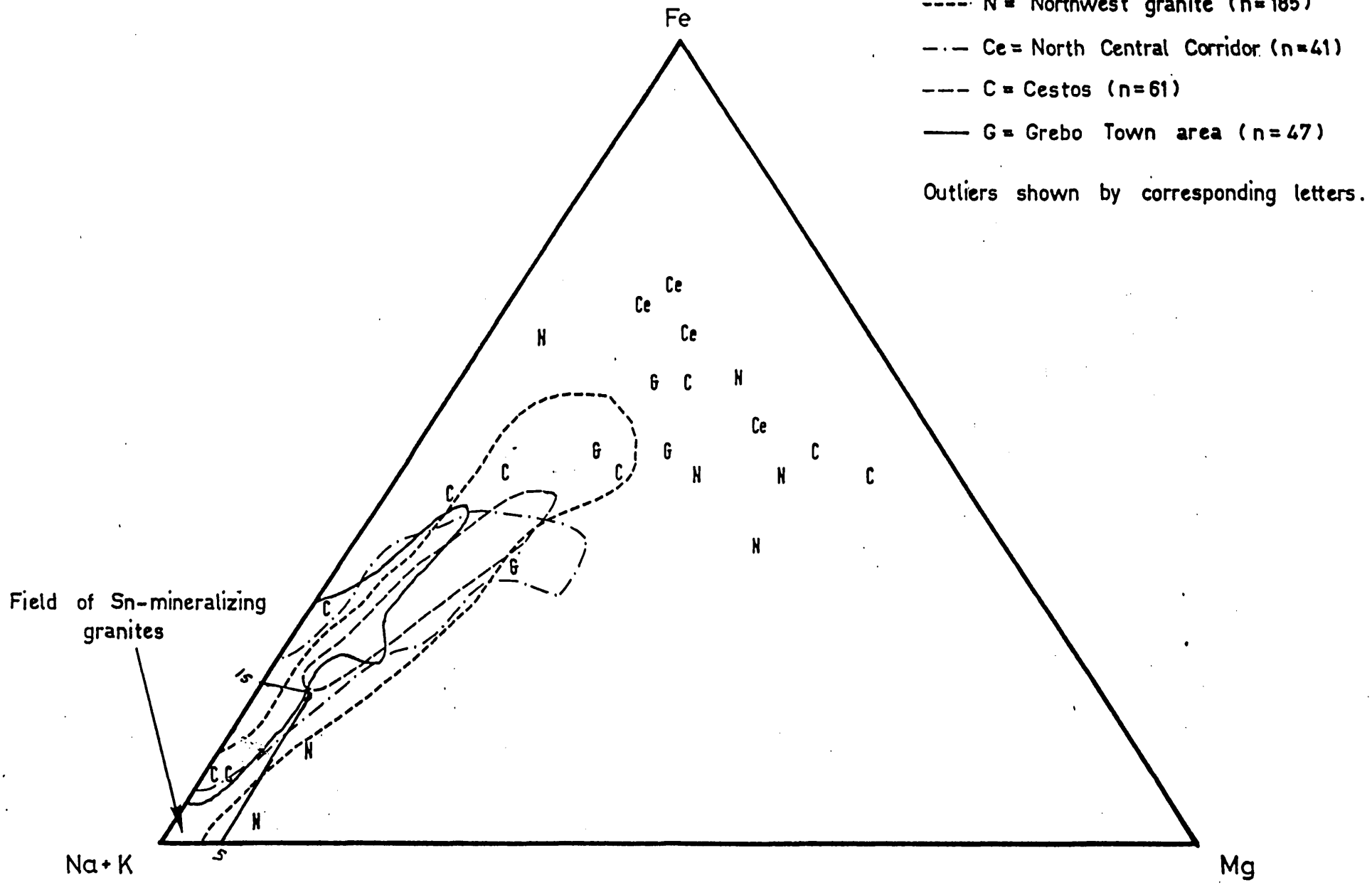


Fig. 49: The Superimposed Na + K - Mg - Fe Systems for the Liberian granitoids studied.

diopside or corundum, SiO_2, isochron patterns, bulk Fe_2O/FeO ratios, and magnetic susceptibility) which are essential for such classifications. Furthermore, those criteria available on the Liberian granitic rocks are conflicting among themselves, both locally and regionally.

However, on a tentative basis, it is possible to suggest that the Cestos Batholith area rocks are comparable to the I-type granitoids, as hornblende is a common component of these rocks in addition to the Al_2O_3/K_2O+Na_2O+CaO (moles) ratio being less than unity. On the other hand, the granitoids from the other areas may be superficially comparable to the S-type granitoids, as biotite and muscovite are commoner in these rocks.

Since all of the Liberian granitoids are relatively depleted in the lithophile elements, they can be regarded as being superficially comparable to granitoids of the Magnetite Series.

Plant et al. (1980) developed criteria based on the combined use of petrological, mineralogical, geophysical and geochemical characteristics to classify granitoids of the Scottish Caledonides as either normal or metalliferous.

Table 36 presents the results of the application of a similar scheme to the granitic rocks of the present study. From this, it is

TABLE 36 COMPARISON BETWEEN LIBERIAN GRANITOIDS AND CRITERIA FOR MINERALIZED/METALLIFEROUS GRANITES OF PLANT ET AL (1980)

	NORTHWEST GRANITES	NORTH CENTRAL CORRIDOR SUITE	CESTOS BATHOLITH AREA	GREBO TOWN AREA SUITE
I. PETROGRAPHIC FEATURES				
2-mica granite, mus replacing bte?	Y	Y	r	Y
Feldspars — sericite/kaolinite?	Y	Y	Y	Y
Ferromags — chlorite/epidote?	Y	Y	Y	Y
Ferromags — haematite?	Y	Y	Y	Y
Tourmalinization?	?	?	?	Y
Greissenization?	r	?	?	Y
II. ACCESSORY MINERALS PRESENT				
Fluorite?	N	N	N	?
Topaz?	N	N	N	?
Beryl?	?	?	?	?
Cassiterite?	N	N	N	Y
Columbite-tantalite?	N	N	N	?
Uranite or uranothorite?	N	N	N	N
Thorite?	N	N	N	N
Xenotime?	?	?	?	?
Monzonite?	Y	Y	Y	Y
Apatite?	Y	Y	Y	Y
III. GEOCHEMICAL CHARACTERISTICS				
(a) Metalliferous				
Ba 10-800ppm?	Y	Y	Y	Y
K 3-7%?	N	N	N	Y
Li 20-600ppm	N	N	N	N
Rb 200-1000ppm	N	N	N	N
Sr 40-150ppm	N	N	N	N
(b) Normal				
Ba 700-4000ppm	Y	Y	Y	Y
K 1-7%?	Y	Y	Y	Y
Li 5-40ppm?	Y	Y	Y	Y
Rb 50-200ppm	Y	Y	Y	Y
Sr 150-2000ppm	Y	Y	Y	Y
IV. GEOPHYSICAL CHARACTERISTICS				
+V magnetic anomaly around granite?	N	N	N	N
Zone of high heat flow?	?	?	?	?

EXPLANATION OF SYMBOLS USED IN TABLE

Y (Yes) - observed or known.

N (No) - not known.

? - not certain.

r - rare occurrence.

evident that a few petrographic features in all of the Liberian granitic suites might be regarded as positive indicators of a "mineralized" granitoid, but the Grebo Town suite in particular, which shows some tourmalinization, gneisenization and K enrichment, has the strongest similarity to the "mineralized" granitoid type of Plant et al (1980). Even in the case of the Grebo Town suite, however, there are many criteria that are not fulfilled, so the resemblance to the "mineralized" granitoid type is rather weak at best.

9.3 GLOBAL CONSIDERATION

In the preceding chapter the four Liberian granitic suites studied were compared with different appropriate Pre-Cambrian granitoids from various parts of the world. The preceding section compared and contrasted the chemical and petrochemical features of the Liberian granitoids among themselves, with particular reference to their degree of fractionation, which will be related to their possible mineralization potential in Chapter 10.

This section aims to briefly compare these Pre-Cambrian granitoids of Liberia as a whole with other Pre-Cambrian granitoids of the world.

The available bulk chemical data suggest that the granitic rocks of Liberia are not unique among the Pre-Cambrian rocks of the world. The wide ranges of chemical composition associated with other Pre-Cambrian granitoids (Marmo, 1971; Neary

et al, 1976; Clifford and Gass, 1969) have been observed in the Liberian suites. This may be a reflection of their lithological variability which is also characteristic of most Pre-Cambrian terrains. On the whole, however, the granitic rocks of Liberia, with the exception of the rocks from the Grebo Town area, appear to have relatively higher contents of the ferromagnesian elements. In the classification system of Turekian and Wedepohl (1961), the Liberian granitoids fall in the category of high-Ca granite. This is also in agreement with the idea of several workers (Barker, 1979 and Glikson, 1979) that the typical Archaean granitoids from all over the world fall in the field of tonalite, tronhjemite and granodiorite. An inspection of the mean chemical compositions of these granitoids (see Tables 14, 18, 22, 26 and 30 with a particular reference to the Li contents) may suggest that they are comparable to the normal granitoids of Tischendorf (1977).

From the discussion in Section 9.2.1, it is also evident that most of the elemental ratios determined in the present study have wide ranges of variation on both the local and regional scales. This is not a unique characteristic of the granitic rocks of Liberia, as many Pre-Cambrian granitoids from elsewhere are also characterised by wide variation of elemental ratios (Condie and Hunter, 1976; Lenthal and Hunter, 1977; Sengputa et al., 1983) (see Chapter 8). In general, the granitic

rocks of Liberia display ratios which are indicative of a low degree of fractionation. This too is not unique to the granitic rocks of Liberia, for many Pre-Cambrian granitoids comprised mainly of tonalite to granodiorite (Balasubrahmanyan, 1978; Barker, 1979) also exhibit poor fractionation.

To conclude this chapter, it should be emphasized that the paucity of chemical and petrological data on Pre-Cambrian granites of West Africa as a whole, and the lack of a comprehensive survey to date of the geochemistry of the remaining Liberian (Pre-Cambrian) granites in particular, precludes any exhaustive comparison on a regional scale at the present time. However, the evidence collected by various workers such as Marmo (1955a, 1965, 1971) and James (1965), who had the opportunity to study Pre-Cambrian granites elsewhere in Africa (Marmo's data are summarised in Appendix C), suggests that the granitic rocks of Liberia are, on the basis of this study, in general chemically comparable to other Pre-Cambrian granitoids of West Africa.

CHAPTER 10

DISCUSSION AND CONCLUSIONS

10.1 INTRODUCTION

The first aim of this chapter is to typify the granitoids dealt with in this study through the use of the geochemical and petrochemical features and/or characteristics which have been the subject of the last three chapters. This will then be followed by a brief discussion of the mineralization potential of the granitic rocks of Liberia on the basis of features discussed in Chapter 5. Finally, recommendations and suggestions for further work will be made.

10.2 CLASSIFICATION OF THE GRANITOIDS

Several workers have attempted to typify granitoids on the basis of geochemical and petrochemical (and/or petrological) criteria. For example, according to Tauson (1984), efforts by several Russian investigators in this respect have resulted in the recognization of twelve geochemical types of granitoids (Table 37). Similar classifications have been used by other investigators (e.g. White and Chappell, 1974; Ishihara and Ulrikson, 1973; Lopez-Escober et al., 1979; Olade, 1980; Campiligio and Darling, 1975).

TABLE 37

Trace-element characteristics of the geochemical granitoid types

Geochemical granitoid types	K (%)	Na (%)	F (%)	Li (ppm)	Rb (ppm)	Sr (ppm)	Ba (ppm)	Sn (ppm)	Pb (ppm)	Zn (ppm)	K/Rb	$\frac{F(Li + Rb)}{(Sr + Ba)}$	Relative distribution (%)
1	0.26	3.1	0.015	5	4	140	60	3	3	75	650	6	2
2	2.0	3.0	0.07	18	100	260	550	2	10	43	200	100	8
3	3.5	3.4	0.08	21	125	700	1700	5	23	70	280	50	5
4	3.6	4.0	0.2	105	270	12	40	18	46	390	130	15000	2
5	3.3	2.8	0.08	50	175	330	830	6	27	51	190	155	40
6	3.9	2.8	0.27	180	440	70	175	22	28	40	90	6800	5
7	4.1	3.5	0.05	27	140	650	1550	4	19	64	300	40	15
8	3.8	3.1	0.09	52	270	170	500	6	20	43	140	430	3
9	1.1	2.4	0.05	12	22	280	450	2	3	50	500	25	4
10	3.3	2.4	0.10	15	90	300	1000	2.5	10	50	370	80	3
11	4.5	2.4	0.17	30	250	110	1400	7	40	90	180	300	5
12	5.0	2.0	0.02	10	140	260	2300	3	12	35	360	12	8
A	3.3	2.9	0.08	42	160	340	1020	6	22	70	200	120	
B	3.3	2.8	0.08	40	200	300	830	3	20	60	160	170	

1 = plagiogranites, tholeiitic series; 2 = granitoids, andesitic series; 3 = granites, latitic series; 4 = agpaitic rare-metal granites; 5 = palingenic granitoids, calcareous-alkaline series; 6 = plumasitic rare-metal leucogranites; 7 = palingenic granitoids, alkaline series; 8 = rare-metal granitoids, alkaline series; 9 = enderbites; 10 = charnockites; 11 = rapakivi; 12 = ultrametamorphic granites; A = average granite; B = average granite after Vinogradov (1962).

(From Tauson, 1984)

On the basis of the available data, an attempt has also been made to classify the Liberian granitoids into similar categories.

These data indicate that although the Liberian rocks studied are superficially alike, there are both local and regional scale variations in their major and trace element abundances. This is consistent with their variable lithology as revealed by the petrographic study. In general, the Liberian granitic rocks can be classified as high-Ca granites of Turekian and Wedepohl (1961), and most closely correspond to the normal granites of Taylor (1964), Tischendorf (1977) and Plant et al, (1980). According to the scheme of Tauson (1984), the Liberian granites could be classified as either plagiogranites, tholeiitic series or granitoids, andesitic series.

The contents of sodium and calcium are relatively higher than those of potassium in the Northwest Granites, Cestos Batholith area, and the North Central Corridor traverse suites. This is consistent with petrographic study which showed that the rocks from the Northwest granites and the Central Corridor traverse are mainly granodiorite whilst those from the Cestos Batholith area are principally quartz diorite. Also the general higher content of Na relative to K may suggest that these rocks are mainly synkinematic (James, 1965; Marmo, 1971). These suites generally have relatively low contents of granitophile elements (Li, Rb, K) and higher contents of the high-

temperature elements such as Mg, Co and Ca which are generally mostly associated with early differentiated rocks. On the other hand, when compared with the other suites, the Grebo Town area suite has higher contents of the granitophiles but lower contents of the mafic elements. This shows that the rocks from this area are the most fractionated of the suites under study, substantiating the petrographic and petrochemical characteristics of this suite as discussed earlier. These rocks also have a higher content of potassium relative to sodium and calcium, suggesting that they are more granitic.

On the basis of the available petrochemical and/or petrological evidence, the Cestos Batholith rocks were classified as comparable to the I-type granitoids, while the rocks from the other areas were said to be close to the S-type granitoids. The Liberian granitic rocks may also be considered comparable to the Magnetite Series of Ishihara (1981) which has characteristics of both the I- and S-type granitoids of White and Chappell (1974).

10.3 POTENTIAL FOR MINERALIZATION

The application of petrochemical and other relevant criteria to determining the potential of granitoids for rare-metal mineralization (e.g. Sn, W, Mo, Be, Li, Nb and Ta) has received a considerable amount of attention from many investigators (Chapter 5). This subject need not be

reviewed again here, but it must be emphasized that the use of geochemical, petrographic and petrochemical criteria for this purpose has been fruitful in many parts of the world.

The assessment of the potential for mineralization in these granitoids is dependent on the geological and petrochemical characteristics discussed in the last three chapters .

The available data have indicated that, with possible exception of the suite from the Grebo Town, the granitic rocks examined during this study do not seem to have any obvious potential for rare-metal mineralization. The rocks are in general severely depleted in granitophile elements such as K, Li, and Rb, relative to the granitophobe ones (e.g. Ca, Mg, Sr, V, Fe). This trend strongly suggests that these Liberian granitoids are less fractionated when compared to most known mineralized granitoids, and therefore their potential for mineralization (especially for the rare-metals) is very low. The lack of positive petrological features such as the presence of higher quantities of free quartz, fluorite, tourmaline, and deviant paragenetic sequence of crystallization in most of these rocks is also consistent with this conclusion.

However, the Grebo Town area granitoids are both chemically and petrologically unique among the suites studied, since they not only host some cassiterite mineralization, but contain the highest concentration of granitophile elements. They are

more quartz-rich than the other granitoids and the presence of large crystals of tourmaline in these rocks may also be considered a favourable petrological factor for high degrees of water-rock interaction and hence have at least some potential for rare-metal mineralization.

10.4 RECOMMENDATIONS

On a broad basis the present project has been fruitful in many ways. As the first of its kind to be undertaken by, or on behalf of the Liberian Geological Survey, the results yield the first systematic geochemical information on the major rock type of the country. Furthermore, it has afforded the author the opportunity of acquiring more useful knowledge of modern techniques for analysing and interpreting geochemical data.

It is suggested that a more comprehensive investigation be undertaken in the Grebo Town area. The project should include:

I. A photogeological study of a larger region including, and adjacent to, the already studied Grebo Town area. This study will be necessary to detect and delineate any linear features which may subsequently be grounchecked and identified.

II. Radiometric and magnetic survey. The available radiometric data are not very suitable to help interpretation as they are total radiation counts. It is suggested that a new radiometric survey

be carried out along the whole of the shear zone, using a special instrument to separate radiation due to potassium from that due to thorium and uranium respectively.

Simultaneously, the available magnetic data may be re-interpreted or re-run at closer spacing for better interpretation. This magnetic survey should be aimed at relating any observed magnetic anomaly to the possible mineralization potential of these granitoids (Plant et al., 1980; Pecherskiy, 1965).

III. Heavy mineral surveys.

(i) The collection of heavy mineral concentrates from stream sediments from creeks encountered in the area. Buried stream sediment samples may also be collected simultaneously.

(ii) The concurrent collection of soil samples and panned heavy mineral concentrates from soil overburden at selected points and at predetermined depth intervals. Such heavy mineral concentrates may indicate the underlying rock type at a particular locality.

IV. Detailed geological mapping of this area with the objective of localizing more pegmatite zones or lenses and other granitic rocks.

V. Lithogeochemical survey.

During this survey fresh rock samples should be collected at higher density and more

systematically from all available outcrops of granitic rocks. In addition to these, samples from appropriate contacts between the granitic rocks and the enclosing schists should also be collected. From such contact samples migration patterns of some elements may be deduced.

VI. Laboratory Analyses.

(i) Heavy mineral study:

The heavy mineral concentrates from the stream sediments and soil should be microscopically analysed. The results of such analyses will be able to indicate the percentage of each mineral constituent. In the case of the soil samples, results may also give some clues as to the underlying bedrock type. It should be noted that the results from the stream sediment mineral concentrates may not be readily related to the source rocks. Heavy mineral concentrates from fresh crushed rocks should also be studied in order to ascertain "in situ" mineralization.

(ii) Petrological study:

Representative portions of all, or a selected number of the rock samples should be petrologically studied with the aim of identifying petrological and/or mineralogical features which may be related to the mineralization potential of these rocks.

(iii) Chemical analyses:

The rock, soil and stream sediment samples should be analysed for different suites of both trace and major elements using various analytical techniques. The results of the analyses of the rock samples will be useful indicators of the primary distribution and abundance patterns of and inter-relationship among the elements. Special attention should be paid to the determination of the rare metals and fluorine and chlorine in these rock samples. The results from the analyses of the soil and stream sediment samples may be related to the bedrock where not exposed, in terms of geology, geochemistry and mineralization potential.

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Appendix A

REPRODUCIBILITY TESTS

INTRODUCTION

The need to get a true representative specimen of a geologic material for investigation cannot be over-emphasized. This is especially critical in any geochemical investigation where only a very small portion of the material is generally analysed. Consequently, a considerable amount of attention has been given to this aspect of geochemical investigation. Recent work in this area include Baird et al., (1967b); Miesch (1971) and Mittlefehldt and Miller (1980). While each approaches the subject from a different point of view, and thus treats it to a varying depth, it is easy to realise that they consider sub-sampling to be of a crucial importance. As a result of these studies, certain criteria are now known to be used to ensure that proper sampling and sub-sampling are carried out both in the field and laboratory. In this regard special attention has been drawn to factors such as (1) the size of the sample (with due consideration of the grain size or texture) taken from the larger geologic material; (2) proper mixing (homogenization) of the sample at the different stages of sample preparation; (3) sample location points and (4) mode of occurrence, abundance, and distribution patterns of the elements of interest. It is often the case, however, that not one of these criteria can unequivocally be considered the most important factor. As a result, most field workers now use a combination of these criteria which can be tested through statistical methods, such as reproducibility tests,

in order to ensure that proper sampling has been achieved.

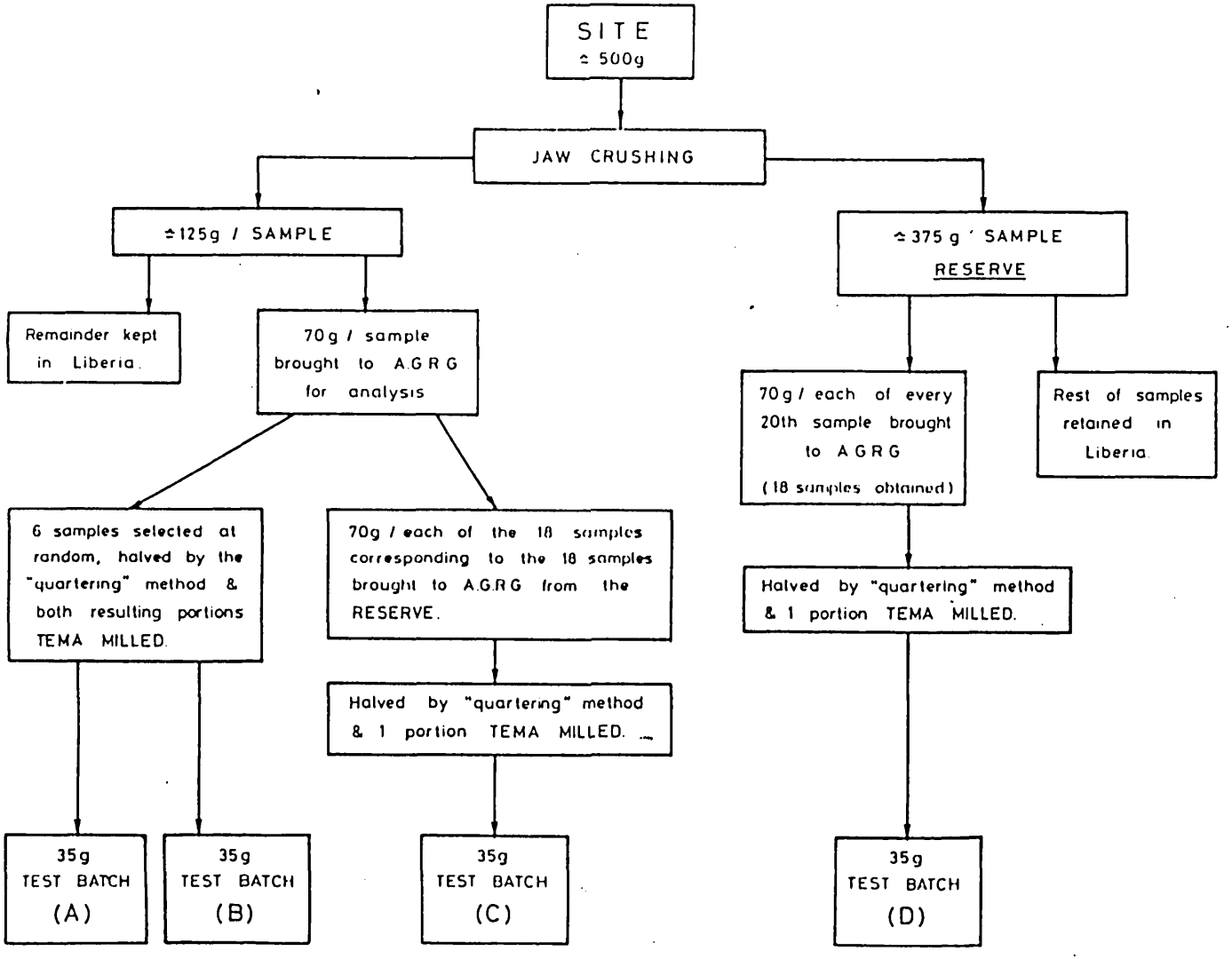
Accordingly, it was necessary to determine whether or not the sub-samples to be used in the present investigation were truly representative of the larger samples collected in the field.

The first stage of sub-sampling was carried out after it was realized that the samples could not be shipped or airfreighted as collected in the field because of the expense involved. This in essence required the reduction, through proper sub-sampling, of each sample in Liberia. It was also later discovered that even the amount of each sample brought to the laboratories of AGRG in London had to be reduced before pulverization in order to avoid unnecessary waste of time and energy. At this stage, one-half of the 70gm of each sub-sample at the crushing stage was pulverized (see Fig. A1).

REPRODUCIBILITY AT THE CRUSHING STAGE

In order to determine whether or not the sub-samples of 70gms each, taken from the one-quarter portion of each of the samples after crushing and homogenizing, could in fact be duplicated with a similar portion from the three-quarter portion of each sample (also obtained after the crushing stage), it was decided to sub-sample every twentieth sample within the three-quarter batch ($\sim$ 350 samples in all). Thus a total of 18 samples were obtained. These were brought to the AGRG laboratories together with the regular 70gm aliquots from the original one-quarter sub-samples (Fig. A1), resulting in a total of 36 samples.

Fig.A1. Schematic diagram showing the subsampling procedures used in this study.



REPRODUCIBILITY TEST AT THE PULVERIZING STAGE

To determine to what extent the sub-sampling at this stage would affect the final analytical data of this investigation, another reproducibility test had to be designed. Six of the original 350 70gm samples brought to AGRG were randomly selected for this. Each of these samples was divided into two (nearly) equal portions and pulverized, each portion being put into a separate paper bag with a special serial number. Altogether 12 sub-samples were used from this source for the test.

CHEMICAL ANALYSIS

The two batches, comprising 48 samples, were then analysed for Na, K, Mg, Ca, Al, Fe, Mn, Ti, P, Li, Rb, Sr, Ba, La, Cr, Ni, Cu, Zn, Mo, Co, Pb, Ag, Cd, Be and V, using the ICPAES method. Sample preparation and analytical procedures are described elsewhere (Appendix B). Replicates, reagent blanks and reference samples were used for quality control.

RESULTS AND DISCUSSION

The analytical results are given in Table A-1, whilst the degree of precision for selected elements are shown in Figs. A2(a-e). It is clear that despite the general level of good precision, few elements (mostly trace elements) appear to be abnormally erratic. For some elements the poor precisions can easily be explained, whereas for others explanations are not straightforward.

For instance, the poor reproducibility for the chromium (Fig. A2-a) results can be attributed to its normal poor response especially, at low concentration, in the analytical method employed. Its level of concentration may possibly be

TABLE 4 -1 THE ANALYTICAL RESULTS FOR THE EXPERIMENT - I, DUPLICATES AT PULVERIZING STAGE; II, DUPLICATES AT JAW-CRUSHING STAGE

I

Majors (%)

Sample No.	Al	Ca	Fe	K	Mg	Mn	Na	P	Ti	Ag	Ba	Be	Cd	Co
4671F	6.2	2.30	1.47	0.92	0.25	0.02	3.5	0.02	0.12	<1	280	1.35	0.50	4.0
4672F	5.6	2.20	1.40	0.95	0.24	0.2	3.6	0.02	0.12	<1	290	1.38	0.50	4.1
4711D	5.6	1.98	1.04	6.9	0.25	0.01	3.3	0.02	0.99	<1	620	0.74	0.67	5.3
4711D	6.1	2.0	1.06	6.6	0.25	0.01	3.3	0.02	0.97	<1	600	0.74	0.50	6.1
4731B	5.4	1.80	1.11	0.99	0.27	0.02	4.0	0.01	0.97	<1	560	0.91	0.50	4.0
4732B	5.4	1.75	1.34	0.96	0.26	0.04	3.8	0.01	1.44	<1	550	0.88	0.50	4.5
4831C	5.3	0.61	0.52	3.70	0.06	0.01	2.3	0.01	0.03	<1	2200	0.70	0.50	1.0
4832C	5.4	0.64	1.38	3.50	0.06	0.01	2.4	0.01	0.03	<1	2200	0.73	0.50	1.0
5001E	6.7	2.90	3.50	2.6	1.20	0.07	2.6	0.08	0.27	<1	820	1.56	0.50	16.5
5002E	6.4	2.90	1.55	2.4	1.20	0.02	2.5	0.08	0.27	<1	810	1.55	0.53	6.70
5041D	4.9	0.67	1.55	2.2	0.33	0.02	3.0	0.05	0.17	<1	680	1.21	0.53	6.7
5042D	5.1	0.71	1.53	2.3	0.33	0.02	3.0	0.04	0.17	<1	670	1.16	0.53	6.7

Trace (ppm)

	Cr	Cu	La	Pb	Li	Mo	Ni	Rb	Sr	V	Zn
4671F	3.5	7.10	10.4	17.80	14.7	2.6	13.0	20	280	22	30.0
4672F	4.2	9.30	11.8	26.0	15.11	4.0	8.6	24	270	22	35.0
4711D	2.4	2.60	4.1	11.30	7.40	1.31	9.10	20	380	15.7	26.0
4711D	3.0	2.50	4.7	14.30	7.20	1.82	11.10	20	390	15.9	24.0
4731B	2.5	4.90	8.0	22.0	12.9	1.63	5.10	20	580	15.6	38.0
4732B	12.3	4.40	8.0	14.80	12.4	3.60	21.0	20	530	16.9	39.0
4831C	1.88	2.50	15.61	24.0	2.70	2.50	2.70	96	162	2.80	7.50
4832C	2.80	7.0	16.10	31.0	2.90	2.40	3.50	87	165	3.50	12.90
5001E	20.0	30.0	19.50	62.1	20.0	4.7	26.60	63	690	96	57.0
5002E	21.0	42.0	25.0	57.0	20.0	4.6	14.50	65	650	101	26.0
5041D	18.4	42.0	20.0	18.4	21.0	3	14.5	47	198	54	26.0
5042D	21.0	36.0	18.5	17.1	21.0	2.3	48.0	49	210	53	27.0

Contd/..

TABLE A2-1 THE ANALYTICAL RESULTS FOR THE EXPERIMENT - 1, DUPLICATES AT PULVERIZING
Contd.. STAGE; II, DUPLICATES AT JAW-CRUSHING STAGE

II

Sample No.	Majors (%) Al	Ca	Fe	K	Mg	Mn	Na	P	Ti	Ag	Ba	Be	Cd	Co
17Q	0.01	0.01	0.01	0.002	0.001	0.001	0.006	0.001	0.001	<1	2.5	0.05	0.05	1
2017Q	0.02	0.01	0.01	0.003	0.001	0.001	0.004	0.001	0.001	<1	2.3	0.05	0.05	1
29Q	0.07	0.01	0.01	0.06	0.002	0.002	0.003	0.01	0.001	<1	15.2	0.05	0.54	1.4
2018Q	0.06	0.01	0.02	0.06	0.003	0.002	0.002	0.01	0.001	<1	15.6	0.05	0.50	1
440A	5.4	0.89	0.60	3.2	0.05	0.01	2.6	0.03	0.04	<1	2200	0.58	0.62	3.60
201A	5.0	0.87	0.45	3.0	0.04	0.01	2.7	0.04	0.03	<1	2100	0.60	0.80	1.48
443D	5.8	2.1	2.1	1.2	0.51	0.03	3.4	0.05	0.23	<1	860	1.09	0.55	10.20
202D	5.9	2.1	2.1	1.2	0.52	0.03	3.4	0.04	0.24	<1	870	1.10	0.50	10.50
448B	6.5	2.1	2.2	3.6	0.60	0.04	2.4	0.07	0.14	<1	2100	1.20	0.50	10.30
203B	5.9	2.2	2.2	3.3	0.71	0.04	2.4	0.07	0.14	<1	2100	1.25	0.50	10.90
451D	6.3	3.1	3.1	0.96	0.88	0.04	3.1	0.08	0.33	<1	740	1.17	0.63	17.0
204D	6.8	3.2	3.2	1.20	0.86	0.04	3.3	0.08	0.33	<1	760	1.12	0.50	16.6
4541	5.9	1.15	1.5	3.3	0.28	0.03	2.8	0.04	0.19	<1	1570	0.76	0.50	8.0
458B	7.2	2.8	4.1	1.37	1.30	0.08	3.9	0.13	0.31	<1	610	1.81	0.56	19.8
206B	7.4	2.8	4.0	1.36	1.29	0.08	3.8	0.12	0.30	<1	590	1.80	0.50	18.60
463A	7.4	4.6	6.3	0.75	1.24	0.08	3.4	00.21	0.56	<1	610	1.09	1.10	30.0
207A	7.1	4.7	6.7	0.69	2.23	0.08	3.5	0.20	0.58	<1	540	1.13	0.60	33.0
466D	6.8	2.3	2.2	1.11	0.63	0.03	3.2	0.06	0.24	<1	920	0.79	0.50	11.4
208D	6.8	2.3	2.1	1.08	0.59	0.03	3.2	0.05	0.26	<1	910	0.90	0.50	12.2
469C	6.8	2.4	2.0	1.04	0.54	0.03	3.2	0.05	0.21	<1	660	0.96	0.50	11.2
209C	6.3	2.6	2.3	1.16	0.59	0.03	3.3	0.05	0.24	<1	730	0.98	0.50	9.7
474C	7.0	4.7	4.0	0.96	1.12	0.04	3.3	0.15	0.47	<1	680	1.54	0.50	23.0
2010C	7.2	4.6	3.9	0.97	1.14	0.03	3.2	0.15	0.48	<1	670	1.52	0.50	23.0
478B	2.2	0.16	0.27	0.62	0.06	0.01	0.67	0.02	0.02	<1	141	0.97	0.50	1.15
2011B	2.2	0.18	0.22	0.60	0.06	0.01	0.73	0.02	0.02	<1	133	1.02	0.50	1.0
481F	5.9	2.7	3.10	2.0	0.54	0.05	2.7	0.07	0.33	<1	1560	1.31	0.57	14.6
2012F	6.0	2.7	3.10	2.10	0.55	0.05	2.60	0.07	0.35	<1	1510	1.32	0.74	14.9
484G	5.5	0.53	0.95	4.1	0.13	0.01	2.2	0.03	0.08	<1	550	0.96	0.50	3.20
2013G	5.5	0.53	0.96	4.0	0.14	0.01	2.4	0.03	0.08	2.2	540	1.02	0.50	3.20
491D	6.2	3.20	3.70	2.5	1.20	0.07	2.7	0.97	0.28	<1	860	1.47	0.68	18.40
2014D	6.6	3.30	3.60	2.4	1.25	0.07	2.7	0.95	0.30	2.2	862	1.48	0.30	18.90
501B	6.3	3.10	3.40	2.6	1.24	0.07	2.6	0.09	0.27	<1	980	1.61	0.59	17.0
2015B	6.4	3.30	3.40	2.4	1.30	0.07	2.6	0.08	0.27	<1	920	1.59	0.50	17.80
505C	6.2	2.2	1.58	0.96	0.43	0.03	3.3	0.04	0.17	<1	580	1.03	0.50	8.7
2016C	5.6	2.1	1.38	0.97	0.43	0.02	3.4	0.04	0.17	<1	580	1.04	0.60	8.6
2051	6.1	1.16	1.5	3.1	0.29	0.02	2.7	0.04	0.17	<1	1620	0.76	0.62	7.5

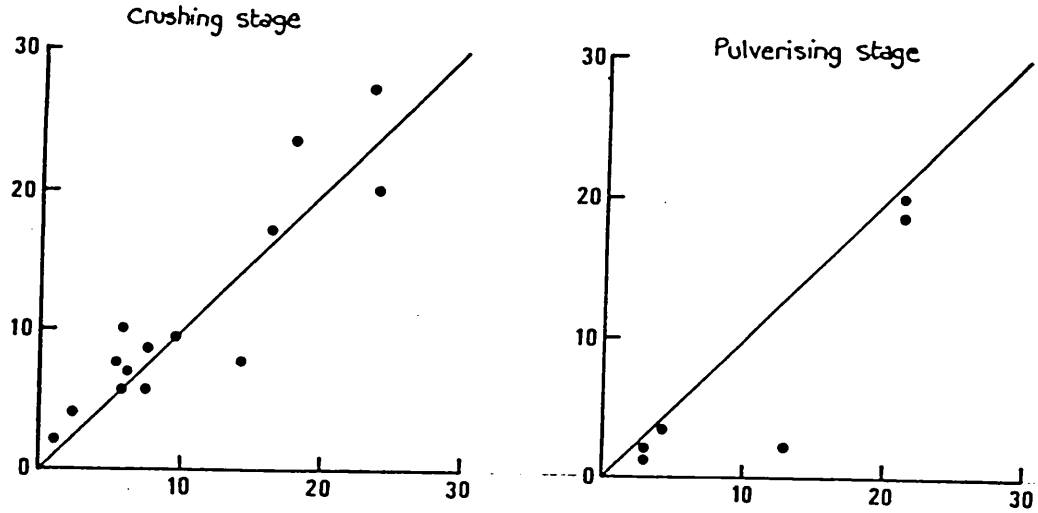
Contd/...

TABLE A2-1 THE ANALYTICAL RESULTS FOR THE EXPERIMENT - I, DUPLICATES AT PULVERIZING
Contd/.. STAGE; II, DUPLICATES AT JAW-CRUSHING STAGE

II

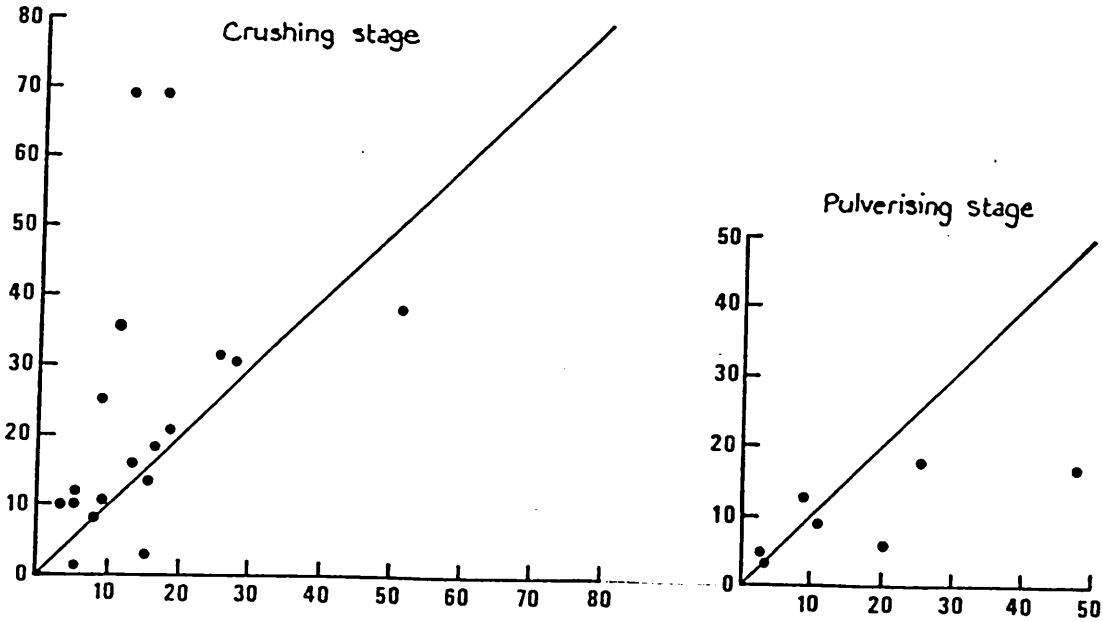
	Trace (ppm)										
Sample No.	Cr	Cu	La	Pb	Li	Mo	Ni	Rb	Sr	V	Zn
17Q	<1	0.50	1	5.0	2.7	<1	2.2	20	1.10	0.50	1.08
2017Q	<1	0.50	1	5.0	2.6	<1	15.9	20	1.0	0.50	1
29Q	1.6	0.50	1	5.0	1.41	<1	1.50	20	0.54	0.50	1.89
2018Q	1	0.50	1	5.0	1.35	<1	5.20	20	0.51	0.50	1.0
440A	1.65	0.50	5.1	27.0	5.2	<1	9.9	78	290	5.1	11.60
201A	1.35	0.50	4.6	38.0	4.9	<1	2.2	74	280	4.4	11.0
443D	8.1	4.9	37.0	19.0	22.0	<1	10.6	44	410	38.0	64.0
202D	7.4	5.0	34.0	18.4	22.0	1.8	9.40	35	420	38.0	67.0
448B	7.2	22.0	10.8	16.70	9.90	<1	35.0	55	410	36.0	40.0
203B	14.5	24.0	12.9	19.0	10.10	<1	17.0	49	400	39.0	43.0
451D	9.8	4510	23.0	11.2	12.9	2.1	21.0	20	390	49.0	59.0
204D	9.3	46.0	22.0	16.0	16.0	2.8	17.0	21	400	49.0	61.0
4541	6.0	3.1	53.0	29.0	10.70	1.33	7.9	69	320	19.6	36.0
2051	5.5	3.4	44.0	38.0	11.0	1.0	7.9	65	330	19.8	37.0
458B	17.9	74.0	26.0	19.60	30.0	1.13	38.0	20	500	72.0	102.0
206B	17.0	77.0	24.0	18.70	30.0	1.0	52.0	20	490	71.0	100.0
463A	6.4	57.0	26.0	14.0	19.4	1.69	32.0	20	740	270.0	88.0
207A	4.6	59.0	23.0	14.0	19.1	1.0	25.0	20	720	300.0	89.0
466D	5.1	3.3	36.0	12.7	13.4	2.8	15.4	31	340	45.0	59.0
208D	6.8	1.7	30.0	25.0	13.6	1.8	12.8	31	330	43.0	70.0
469C	5.5	8.20	10.6	17.10	12.0	<1	12.9	23	300	41.0	48.0
209C	6.0	10.10	9.9	11.5	13.2	<1	13.8	20	310	45.0	49.0
474C	23.0	59.0	22.0	14.10	2.4	1.70	31.0	20	370	80.0	71.8
2010C	18.7	58.0	22.0	12.9	2.4	1.59	28.0	20	370	80.0	71.3
478B	1.39	0.50	5.4	15.8	3.7	<1	9.3	30	23	1.96	6.6
2011B	1.51	0.50	4.8	8.7	3.6	<1	2.1	20	25	2.3	5.2
481F	5.3	11.4	53.0	14.8	14.7	<1	35.0	55	175	42.0	49.0
2012F	5.3	11.4	59.0	18.0	15.91	<1	11.7	53	174	43.0	60.0
484G	3.2	0.68	15.6	38.0	54.0	1.7	11.7	171	45	6.8	23.0
2013G	2.1	0.50	18.2	175.0	55.0	<1	3.0	173	48	6.7	26.0
491D	28.0	41.6	21.0	52.9	25.0	2.9	69.0	58	690	108.0	65.0
2014D	23.0	38.0	18.0	53.8	24.0	1.7	14.9	52	740	107.0	68.0
501B	20.0	22.0	23.0	15.5	23.0	2.8	18.1	74	740	100.0	56.0
2015B	24.0	26.0	24.0	19.7	22.0	4.2	15.1	72	710	102.0	53.0
505C	11.2	23.0	23.0	15.60	8.0	1.59	26.0	27	350	26.0	43.0
2016C	5.6	23.0	21.0	14.80	7.4	1.61	7.9	27	350	25.0	42.0

Fig.A2(a-e). Graphical display of the precisions obtained for a selected number of elements determined at the different stages of subsampling. Major elements are expressed in percentage, whereas the trace elements are given in Ppm.



Cr

Fig A2 (a)



Ni

Fig A2 (b)

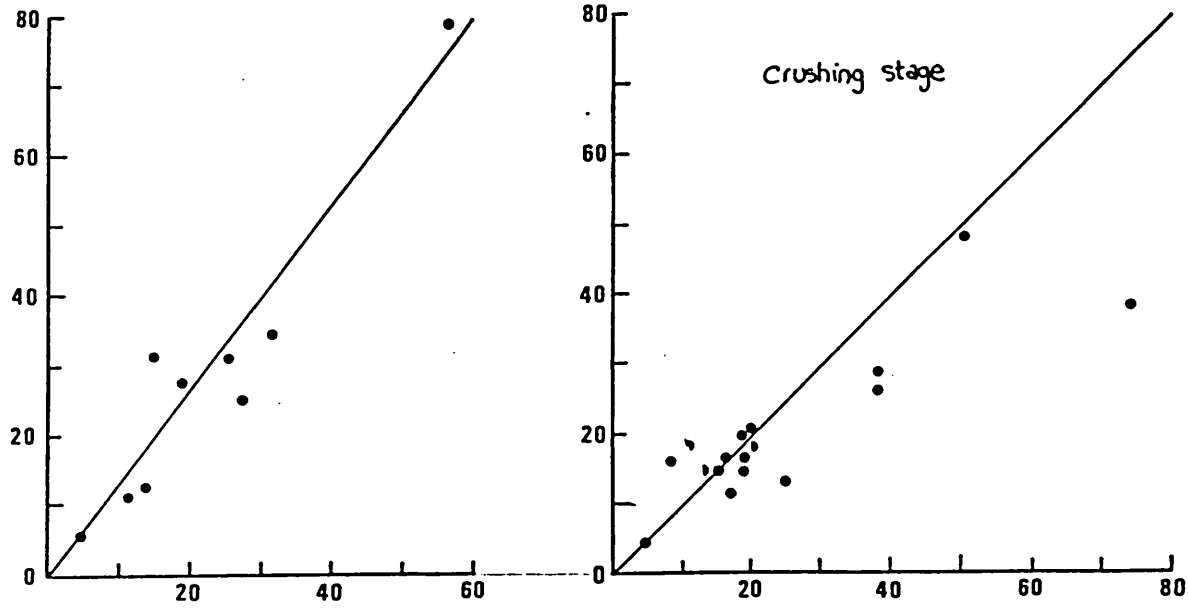


Fig A 2 (c)

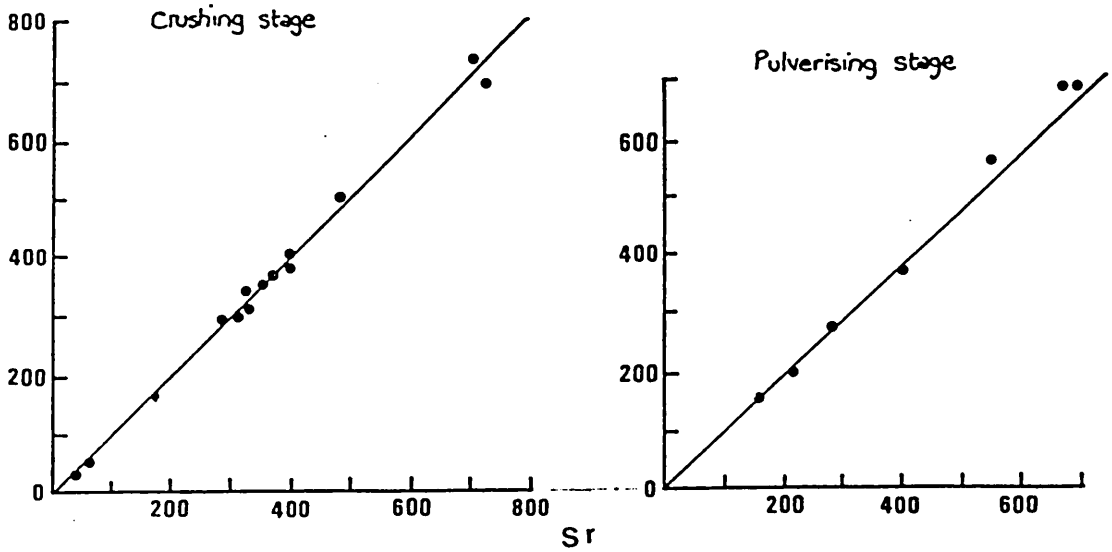


Fig A 2 (d)

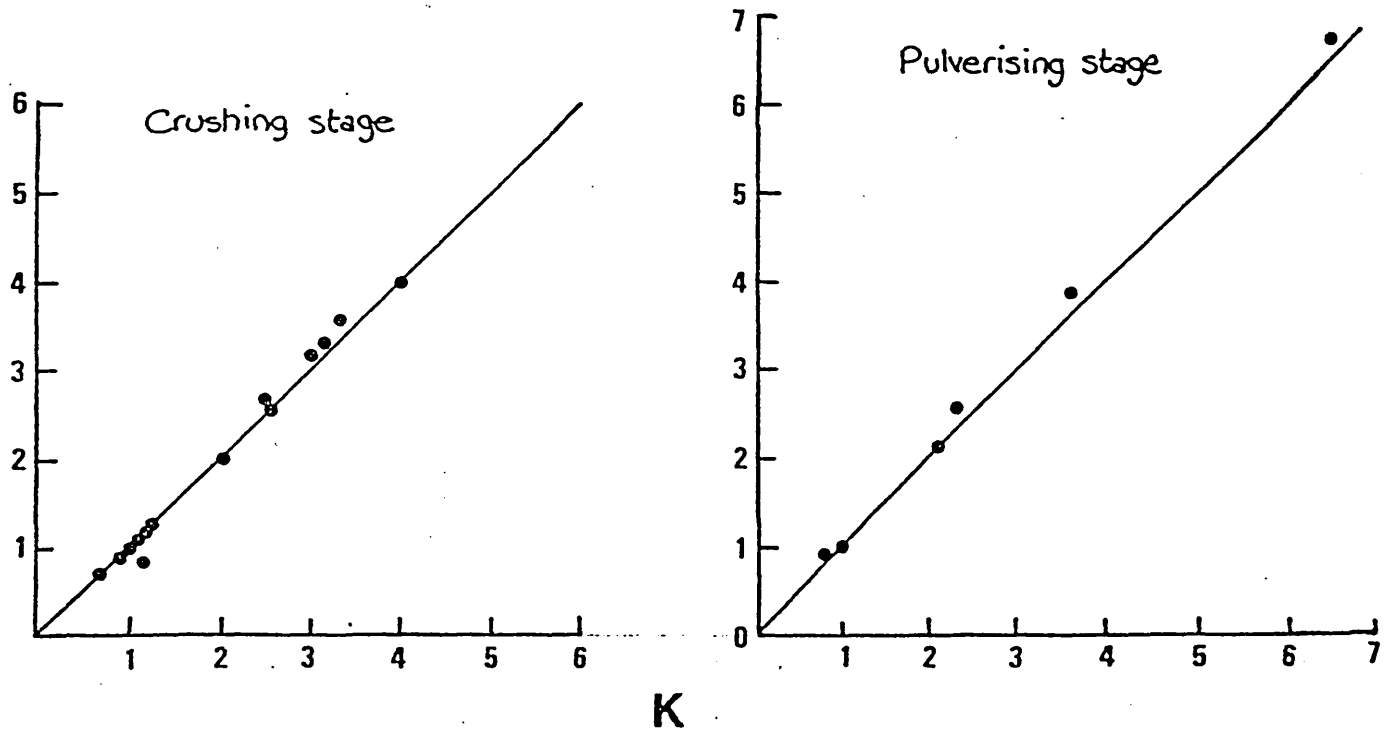


Fig A 2 (e)

close to or below the detection limit (1ppm). Several Cr minerals are known in nature, but none of them is an important accessory mineral in granitic rocks. Therefore it is likely that whatever amount of this element may be present in these specimens could be occurring mainly on atomic levels, possibly substituting for elements such as vanadium and iron, the former being the more likely one to be substituted for, but also less commonly associated with granitic rocks (Kobel, 1958). Alternatively, it might be associated with minerals such as spinel (picotite) and chromite which commonly occur as submicroscopic crystals in other minerals, notably the mafics, and are at most sparingly dissolved by the sample attack used. Anyone of these factors either alone or in combination with others could have adversely affected the reproducibility of the chromium results.

The poor precision for nickel (Fig.A2b) could similarly be explained, as it too is not normally associated with granitic rocks. In other words, the granitic rocks do not ordinarily provide a good geochemical environment for this element. Furthermore, field observation during this investigation revealed that the mafic minerals, mainly biotite and/or hornblende in which this element could partly substitute for Mg by admission,occur in most cases as clots to the extent of defying complete homogenization, whence the poor reproducibility of the nickel results.

On the other hand, the erratic behaviour of Pb (Fig.A2c) cannot be as simply explained. This difficulty arises firstly as Pb responds fairly well to the analytical method employed, especially when the instrument is well calibrated.

However, Pb is considered to be one of the granotophile elements and substitutes for K to a limited degree in the K-feldspars. The observed poor reproducibility of the results for Pb may,therefore, mainly be attributed to its sporadic distribution in the present granitic rocks.

CONCLUSION

It becomes clear from the foregoing discussion of the data that reproducibility is generally good for most of the elements despite the several stages of sub-sampling carried out. This is especially true for the major elements. In the case of the trace elements, however, there are some exceptions which is not unexpected for reasons such as (1) the usual low levels of concentration of these elements and (2) the poor distribution patterns of some of the elements in the type of rocks being studied. Nickel is of particular concern in this respect. In almost all the samples, its values are erratic whereas its values are within reasonable limits in the case of the reference materials. This could be a ground for believing that the high dispersion of the nickel content in these rocks is most probably due to its poor distribution pattern. However, the effect of this erratic behaviour of nickel is not expected to be too critical for the final result of this investigation. For it is one of those elements which are less associated with granitic rocks in general.

HYDROFLUORIC, NITRIC AND PERCHLORIC ACID ATTACK FOR ROCK, SOIL, OR SEDIMENT

Reagents

a) Hydrofluoric acid (40%)
b) Perchloric acid (60%)
c) Nitric acid (70%)
d) Hydrochloric acid (6M). Dilute hydrochloric acid (534ml, 36% acid) to 1 l with water.

Equipment

a) PTFE tubes
b) Graduated flasks (25ml) or graduated test tubes (10ml)
c) Hotplate sited in a suitable fume cupboard
d) Polythene measuring cylinder and plastic tray for dispensing hydrofluoric acid
e) Liquid dispensers (4)

Procedure

a) Weigh each sample (0.100g, -200 mesh) into a clean,dry, numbered PTFE tube
b) Weigh standard and duplicate samples, and leavy empty tubes at random intervals for blank determinations
c) Add nitric acid (20ml) followed by perchloric acid (1.0ml) to each beaker
d) Then add hydrofluoric acid (5ml) to each tube.
e) Heat the tubes, on a hot block, for 3 hours at 90°C
f) Heat overnight at 140°C
g) Raise temperature to 160°C and evaporate to dryness
h) Remove each tube into a rock in the fume chamber, and allow them all to cool
i) Add hydrochloric acid (2.0ml if the final volume is 10ml or 5.0ml if the final volume is 25ml) to each tube and leach for 1 hour at 70°C
l) Transfer the solutions from the tubes to either graduated flasks (25ml for a dilution factor of 100) or to graduated test tubes (10ml for a dilution factor of 40) and dilute to volume with water.

Remarks

a) This method will completely digest most constituents of rocks, soils, and sediments. A few minerals will partly or completely resist attack, e.g. barite, chromite, cassiterite, tourmaline, kyanite, some spinels and magnetites, rutile, zircon and wolframite.

b) When using PTFE beakers on a hotplate, care should be taken not to exceed the temperature at which PTFE becomes plastic (240°C).

c) A shortened form of this method can be used for less resistant samples by omitting steps f, g, and i from the above method. The double fuming with perchloric acid is necessary for calcerous samples (i.e. 10% Ca) to destroy the insoluble calcium fluoride residue.

d) This method must not be attempted on samples containing oil or bitumen.

Appendix C

Data from V. Marmo (1956a)

TABLE 1
Analyses of West African Granitic Rocks

No.	Description	Locality	Authority	Analyst	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O-	H_2O+	Total
1	Biotite-muscovite granite, J 15 500	Kumasi Dist., Gold Coast	Junner and James (1947)	H. L. Riley	72.59	0.12	15.18	0.13	1.01	0.02	0.15	1.17	3.86	4.52	0.27	0.71	0.14	100.20*
2	Biotite granite, J 933	Winneba, Gold Coast	"	"	67.00	0.58	15.86	0.81	2.62	0.03	0.96	3.04	3.61	3.64	0.16	1.15	0.21	99.82*
3	Porphyritic biotite granite, J 3238	Busarowa, N. Terr., Gold Coast	"	"	68.46	0.48	15.39	0.80	2.00	0.04	1.02	2.98	4.40	3.13	0.17	0.98	0.19	100.21*
4	Pinkish quartz-rich biotite granite, J 3197	Winneba, Gold Coast	"	"	73.53	0.09	14.95	0.86	0.16	0.06	0.39	0.97	3.78	4.52	0.05	0.48	0.17	100.12*
5	Similar to J 3197, dike in it, J 3198	Winneba, Gold Coast	"	"	71.16	0.05	14.49	0.59	0.33	0.02	0.33	1.09	3.58	4.32	0.03	0.58	0.17	99.88*
6	Similar to J 3197, dike in it, J 3199	Winneba, Gold Coast	"	"	72.65	0.11	14.72	0.80	0.32	0.02	0.35	1.28	4.48	4.08	0.05	0.56	0.20	99.76*
7	Porphyritic biotite granite, H 3608	Ashanti, Axim Dist., Gold Coast	"	Miss R. C. Graves	68.57	0.34	16.01	1.06	1.48	0.03	0.77	2.47	5.14	2.96	0.12	0.68	0.12	99.93*
8	Soda granite, J 15638	Obuasi, Gold Coast	"	H. L. Riley	72.34	0.08	14.52	0.13	0.75	0.06	0.47	1.72	6.13	1.85	0.27	0.66	0.10	99.88*
9	Sodic hornblende-biotite granite, J 2360	Axim Dist., Gold Coast	"	W. H. Bennett	70.58	0.23	14.78	1.08	1.17	0.07	1.23	2.05	4.66	2.42	0.05	1.13	0.29	99.89*
10	Saussuritic soda-rich granite, J 1468	Divcove, Axim Dist., Gold Coast	"	H. F. Harwood	64.44	0.32	17.82	1.91	1.33	0.07	1.14	5.12	5.06	1.29	0.16	1.70	0.08	100.58*
11	Granodiorite, J 1192	Goaso, Ashanti, Gold Coast	"	"	64.79	0.46	16.16	2.17	1.48	0.07	2.10	3.75	4.70	2.54	0.18	1.48	0.34	100.23*
12	Sodic granite porphyry, J 96	Obuasi, Gold Coast	"	W. H. Bennett	63.06	0.30	15.51	0.02	3.00	0.06	2.13	4.25	4.14	0.94	0.19	1.12	0.10	100.07*
13	Gneissic granodiorite, J 1553	Masapo-Bombirri, Gold Coast	"	"	62.00	0.60	13.94	1.25	4.38	0.10	4.72	5.18	3.54	2.19	0.24	1.64	0.20	100.24*
14	Porphyritic biotite granite, J 1519	Akrokeri mine, Gold Coast	"	"	65.14	0.55	16.49	0.12	2.94	0.05	2.56	3.63	3.11	2.25	0.26	1.36	0.23	99.83*
15	Biotite granite, J 1503	Akrokeri mine, Gold Coast	"	"	64.29	0.55	15.36	0.83	2.94	0.06	2.31	3.70	4.33	3.19	0.25	1.32	0.09	99.92*
16	Biotite-hornblende granite, 3113	French Guinea	Bodin (1951, p. 33)	P. Rose	67.96	0.70	15.20	1.54	2.12		1.41	3.10	3.60	3.48	0.15	0.32	0.19	99.77
17	Biotite-hornblende granite, 4785	Senegal	" (1951, p. 33)	B. Martinet	62.90	0.80	15.38	1.50	4.00		3.10	4.50	4.85	1.80	0.22	0.70	0.10	100.10
18	Porphyritic granodiorite, 1696	Mankono, French Guinea	" (1951, p. 34)	J. Patureau	72.02	0.20	15.57	1.92	1.00	0.07	0.61	1.94	2.83	2.40	0.09	0.08	0.02	99.93
19	Porphyritic biotite granite, 4679	Haute Volta	" (1951, p. 35)	"	72.10	0.35	13.05	1.60	1.17	0.01	2.35	2.45	2.65	3.85	0.07	0.50	0.10	100.25
20	Porphyritic biotite-hornblende granodiorite, 5097	Segnéla, Ivory Coast	" (1951, p. 36)	B. Martinet	69.65	0.30	15.70	0.65	1.30		1.45	1.80	3.55	5.35	0.12	0.44	0.12	100.43
21	Granitized amphibolite, 4583	Marchorie	" (1951, p. 40)	J. Patureau	61.37	0.60	17.10	2.65	3.60	0.10	3.50	6.10	2.55	1.94	0.30	0.22	0.20	100.18
22	Biotite-hornblende granodiorite, 1874	Golé, Ivory Coast	" (1951, p. 52)	"	70.70	0.32	14.05	1.95	1.25	0.02	1.45	2.90	3.55	2.65	0.09	0.38	0.23	99.54
23	Granodiorite, 1985	Koumbia, Haute Volta	" (1951, p. 54)	"	68.07	0.75	15.05	1.43	2.76	0.08	1.91	4.12	2.95	2.40	0.15	0.13	0.40	100.25
24	Quartz diorite, 1600	Lome, Moyenne, Ivory Coast	" (1951, p. 54)	"	57.60	0.47	17.70	3.30	4.25	0.10	3.15	6.95	2.90	1.60	0.06	1.75	0.20	100.13
25	Granodiorite, 634	Basse, Ivory Coast	" (1951, p. 55)	"	65.15	0.30	15.60	1.84	2.11	0.07	2.17	4.10	4.50	2.12	0.10	0.70	0.02	99.71
26	Granodiorite, 1192	Basse, Ivory Coast	" (1951, p. 55)	W. H. Bennett	64.79	0.46	16.16	2.17	1.48	0.07	2.10	3.75	4.70	2.54	0.18	1.48	0.34	100.22
27	Granodiorite, 4703	Haute Gambia	" (1951, p. 57)	P. Rose	63.10	0.33	16.45	1.56	2.48		2.10	5.30	4.20	2.60	0.18	1.20	0.17	99.77
28	Microgranodiorite, 3903	Haute Gambia	" (1951, p. 59)	J. Patureau	67.19	0.30	16.19	1.82	1.58	0.14	1.57	3.57	3.60	2.40	0.12	0.23	0.25	99.66*
29	Alkeritic granite, 4792	Haute Volta	" (1951, p. 62)	B. Martinet	68.90	0.25	14.35	1.30	1.80		0.75	2.80	6.00	1.20	0.16	0.05	0.35	99.66
30	Alkeritic granite, 2340	Haute Volta	" (1951, p. 63)	J. Patureau	76.20	0.35	11.65	1.90	0.78	0.04	0.28	2.05	3.60	2.75	0.04	0.55	0.25	100.41

TABLE 1 (Continued)

No.	Description	Locality	Authority	Analyst	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O+	H_2O-	Total
31	Biotite-amphibole granite, 1748	Ivory Coast	" (1951, p. 33)	B. Martinet	66.35	0.60	15.00	0.85	2.70		2.10	3.50	4.40	2.00	0.26	0.75	0.35	99.56*
32	Biotite-chlorite granite.	Mont Oursa, French Guinea	" (1951, p. 31)	J. Patureau	68.30	0.30	15.58	1.80	1.85		1.32	3.85	2.35	3.40	0.10	0.10	0.70	99.65
33	Biotite granite, 3119	Famorea sur la Niger, French Guinea	" (1951, p. 31)	P. Rose	72.52	0.36	14.10	1.57	0.70		0.51	1.36	3.01	5.10	0.01	0.40	0.10	99.65
34	Biotite granite, 1031	Segnéla, Ivory Coast	" (1951, p. 31)	B. Martinet	73.90	0.30	12.90	1.40	0.80		0.45	1.05	2.60	6.20	0.10	0.28	0.13	100.11
35	Muscovite-biotite granite, 4737	Bouaké, AOF	" (1951, p. 29)	J. Patureau	73.02	0.25	14.13	1.04	1.00	0.03	1.05	1.62	2.65	4.80	0.13	0.12	0.30	100.17
36	Muscovite-biotite granite, 4756	Saraya, Senegal	" (1951, p. 29)	P. Rose	70.40	0.10	14.35	2.00	0.62		0.65	1.90	3.78	4.93	0.13	1.23	0.35	100.44
37	Muscovite-biotite granite, 4739	Bouaké	" (1951, p. 25)	J. Patureau	73.25	0.20	15.25	0.77	0.57	0.03	0.19	1.21	2.46	5.50	0.02	0.12	0.30	99.87
38	Akeritic granite, 4683	Ouéré, Haute Volta	" (1951, p. 63)	"	70.25	0.35	14.50	1.09	0.99	0.06	1.04	3.00	5.70	2.85	0.15	0.60	0.20	100.78
39	Sodic granite, 3265	Kekoro	" (1951, p. 61)	B. Martinet	73.65	0.10	14.10	0.80	1.25		0.20	1.05	6.60	1.70	0.20	0.45	0.10	100.20
40	Monzonitic granite, 5089	long. 6°46'W; lat. 11°50'N	" (1951, p. 65)	"	70.10	0.45	15.00	1.55	1.50		0.30	1.10	4.55	4.60	0.15	0.60	0.25	100.15
41	Monzonitic granite, 536	Basse, Ivory Coast	" (1951, p. 65)	J. Patureau	75.80	0.20	12.55	0.70	1.73	0.04	0.24	1.50	3.10	3.30	0.01	0.35	0.30	99.82
42	Monzonitic granite, K	Ivory Coast	" (1951, p. 66)	"	67.76	0.68	15.34	1.52	2.10	0.08	1.40	3.08	3.58	3.68	0.19	0.31	0.19	99.91
43	Monzonitic granite, 4748	Haute Volta	" (1951, p. 67)	B. Martinet	76.20	0.15	12.10	0.65	1.65		0.17	0.94	3.22	4.35		0.30	0.23	99.96
44	Charnockite.	Gbon, Djola, Ivory Coast	Obermuller (1941, p. 39)															
45	Porphyritic granodiorite	Yomen, Ivory Coast	" (1941, p. 43)	P. Rose	71.80	0.16	14.90	1.10	1.08	n.d.	0.39	2.20	4.17	4.11		0.60		100.51
46	Biotite granite	Baradou, Ivory Coast	" (1941, p. 43)		71.13	0.22	14.58	1.01	0.72		0.19	1.80	5.60	2.46		0.45		98.88
47	Biotite granite	Poste de Makenta	" (1941, p. 42)		73.48	0.28	13.87	1.12	0.80		0.22	2.26	5.43	2.20	0.12	0.15		99.93
48	Biotite gneiss	2 km east of Sierra Leone frontier	" (1941, p. 42)		70.93	0.30	15.91	1.42	0.71		0.78	3.32	4.37	1.83	0.18	0.25	0.05	100.02
49	Granodiorite	19 km southwest of Makenta	" (1941, p. 42)		71.40	0.32	15.35	1.42	0.82		0.30	1.78	5.70	1.90	0.15	0.60		99.64
50	Granodiorite	Yarakolloro, Ivory Coast	" (1941, p. 42)		71.03	0.20	16.26	1.05	0.70		0.47	2.30	4.87	1.82		0.50		99.20
51	Biotite granodiorite gneiss	G'Béké, Ivory Coast	" (1941, p. 66)	P. Rose	70.30	0.22	16.40	1.10	0.72		0.72	2.80	5.53	2.01	0.05	0.32	0.05	100.22
52	Mylonitic biotite gneiss	Mabosson, Ivory Coast	" (1941, p. 67)	"	65.55	0.12	19.30	0.12	2.93	=	1.10	4.05	3.82	1.66	0.14	0.74	0.16	100.29
53	Leucocratic banded gneiss, K 150	Osi area, Nigeria	King and Swardt (1949, p. 20)	W. H. Bennett	71.55	0.18	14.85	0.22	0.70	0.05	0.63	2.88	1.40	3.62		0.52	0.17	99.82
54	Granite gneiss, A 28	Osi area, Nigeria	" (1949, p. 20)	"	70.70	0.48	13.79	0.83	1.77	0.03	0.87	1.83	2.83	5.71	0.13	0.65	0.01	100.09*
55	Coarse porphyritic granite, K 115	Osi area, Nigeria	" (1949, p. 20)	"	64.30	0.95	14.99	1.50	3.90	0.13	1.06	2.83	3.17	5.53	0.29	0.80	0.12	100.19*
56	Aplogranite, K 50	Osi area, Nigeria	" (1949, p. 20)	L. C. Chadwick	69.49	0.11	14.65	0.82	1.82	0.03	0.65	1.72	2.95	6.51	0.13	0.60	0.09	100.21*
57	Granite	Makong, Sierra Leone	Rep. of Min. Geol. Surv. Deptm. Sierra Leone (1930-1931, p. 10)		72.25	0.23	14.02	0.59	1.25	0.01	0.51	1.10	3.00	5.80	0.05	0.46	0.09	99.98*
58	Leucocratic biotite granite, 1638-3233	Irigle, Ivory Coast	Bolgarsky (1950, p. 43)	P. Rose	74.88	0.015	14.98	0.26	0.40	0.22	0.01	0.90	4.88	2.98	0.06	0.46	0.05	100.165*
59	Biotite-amphibole granite, 199-4344	Gouékan, Ivory Coast	" (1950, p. 41)	B. Martinet	72.17	0.19	14.16	0.91	0.90		1.38	0.25	7.08	1.29	tr.	1.22		99.60
60	Leucocratic granite, 1622-3233	Namarakouma, Ivory Coast	" (1950, p. 45)	P. Rose	71.05	0.90	15.10	1.19	1.14		2.32	0.60	4.35	1.90	"	1.50		100.45
					73.00		15.50		0.18			1.12	4.84	5.02		1.22		99.55

* See supplementary table 1-A below for minor elements.

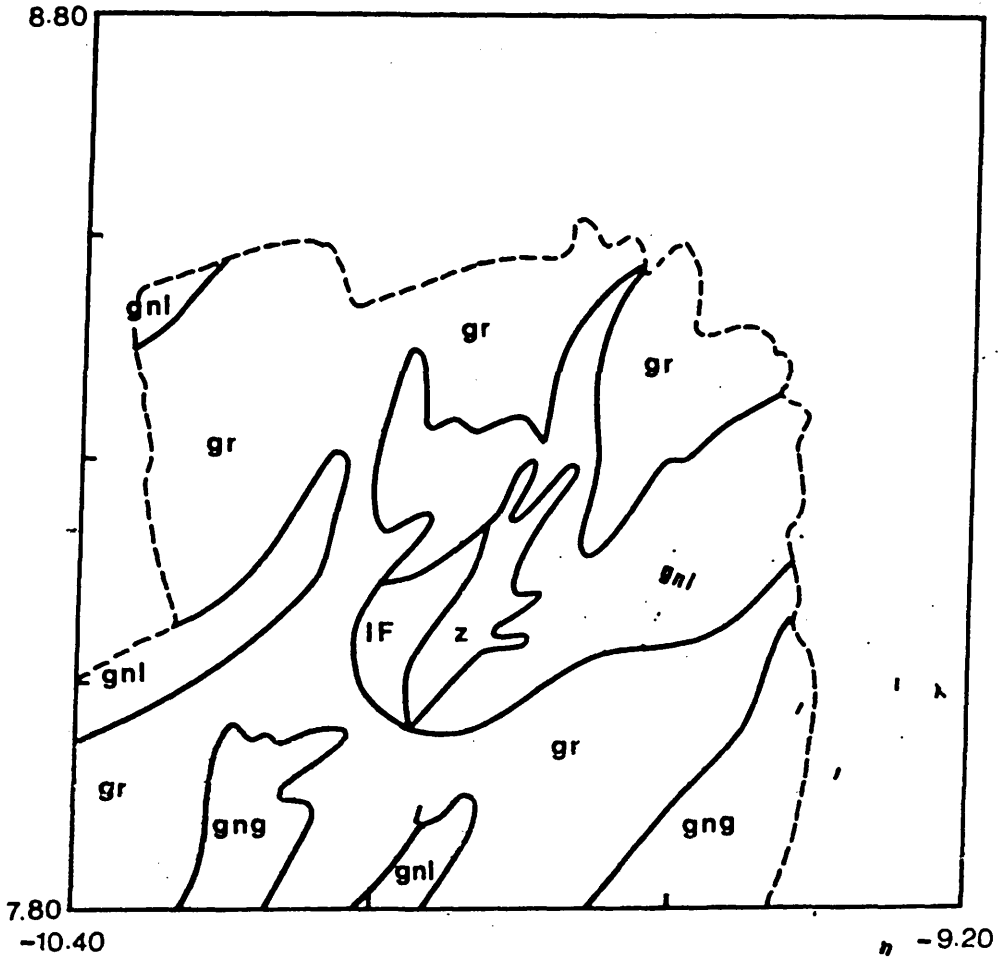
TABLE 1-A
Minor Elements in West African Granitic Rocks

No.	Description	Locality	Authority	Analyst	B_2O	SrO	ZrO_2	Cr_2O_3	$LiO2$	Rare Earth	V_2O_5	CO_2	F	Cl	S	Less O for S, F
1	Biotite-muscovite granite, J 15500	Kumasi Dist., Gold Coast	Junner and James (1947)	H. L. Riley										tr.	0.05	0.02
2	Biotite granite, J 933	Winneba, Gold Coast	"	"	0.12	0.01			tr.					tr.	0.03	0.01
3	Porphyritic biotite granite, J 3238	Bustrowa, N. Terr., Gold Coast	"	"	0.12	0.04			tr.					tr.	0.01	
4	Pinkish quartz-rich biotite granite, J 3197	Winneba, Gold Coast	"	"	0.10										0.01	
5	Similar to J 3197, dike in it, J 3198	Winneba, Gold Coast	"	"	0.13										0.01	
6	Similar to J 3197, dike in it, J 3199	Winneba, Gold Coast	"	"	0.13										0.01	
7	Porphyritic biotite granite, H 3608	Ashanti, Axim Dist., Gold Coast	"	Miss R. C. Graves	0.16							n. d.			0.03	0.01
8	Soda granite, J 15638	Obuasi, Gold Coast	"	H. L. Riley	tr.	tr.						0.77		tr.	0.04	0.01
9	Sodic hornblende-biotite granite, J 2360	Axim Dist., Gold Coast	"	W. H. Bennett	0.11		0.02	tr.							0.04	0.02
10	Saussuritic soda-rich granite, J 1468	Dixcove, Axim Dist., Gold Coast	"	H. F. Harwood	0.08	0.01	tr.		tr.			none		0.01	0.02	0.01
11	Granodiorite, J 1192	Gouso, Ashanti, Gold Coast	"	"				tr.			tr.	n. d.			0.01	
12	Sodic granite porphyry, J 96	Obuasi, Gold Coast	"	W. H. Bennett								5.06			0.19	
13	Gneissic granodiorite, J 1553	Masapo-Bombirri, Gold Coast	"	"	0.01			0.02			0.01	0.20			0.03	0.01
14	Porphyritic biotite granite, J 1519	Akrokeri mine, Gold Coast	"	"	0.10			0.01			0.01	0.71			0.02	
15	Biotite granite, J 1503	Akrokeri mine, Gold Coast	"	"	0.13			0.01			0.01	0.30			0.25	
16	Biotite-hornblende granite, 3113	French Guinea	Bodin (1951, p. 33)	P. Rose												
17	Biotite-hornblende granite, 4785	Senegal	" (1951, p. 33)	B. Martinet								0.25				
18	Porphyritic granodiorite, 1696	Mankono, French Guinea	" (1951, p. 34)	J. Patureau												
19	Porphyritic biotite granite, 4679	Haute Volta	" (1951, p. 35)	"												
20	Porphyritic biotite-hornblende granodiorite, 5097	Segnéla, Ivory Coast	" (1951, p. 36)	B. Martinet												
21	Granitized amphibolite, 4583	Marchorie	" (1951, p. 40)	J. Patureau												
22	Biotite-hornblende granodiorite, 1874	Golé, Ivory Coast	" (1951, p. 52)	"												
23	Granodiorite, 1985	Koumbia, Haute Volta	" (1951, p. 54)	"												
24	Quartz diorite, 1600	Lomé, Moyenne, Ivory Coast	" (1951, p. 54)	"												
25	Granodiorite, 634	Basse, Ivory Coast	" (1951, p. 55)	"												
26	Granodiorite, 1192	Basse, Ivory Coast	" (1951, p. 55)	W. H. Bennett												
27	Granodiorite, 1703	Haute Gambia	" (1951, p. 57)	P. Rose								0.70				
28	Microgranodiorite, 3603	Haute Gambia	" (1951, p. 59)	J. Patureau												
29	Akeritte granite, 1792	Haute Volta	" (1951, p. 62)	B. Martinet												
30	Aplitic granite, 3249	Haute Volta	" (1951, p. 63)	J. Patureau												

TABLE 1-A (Continued)

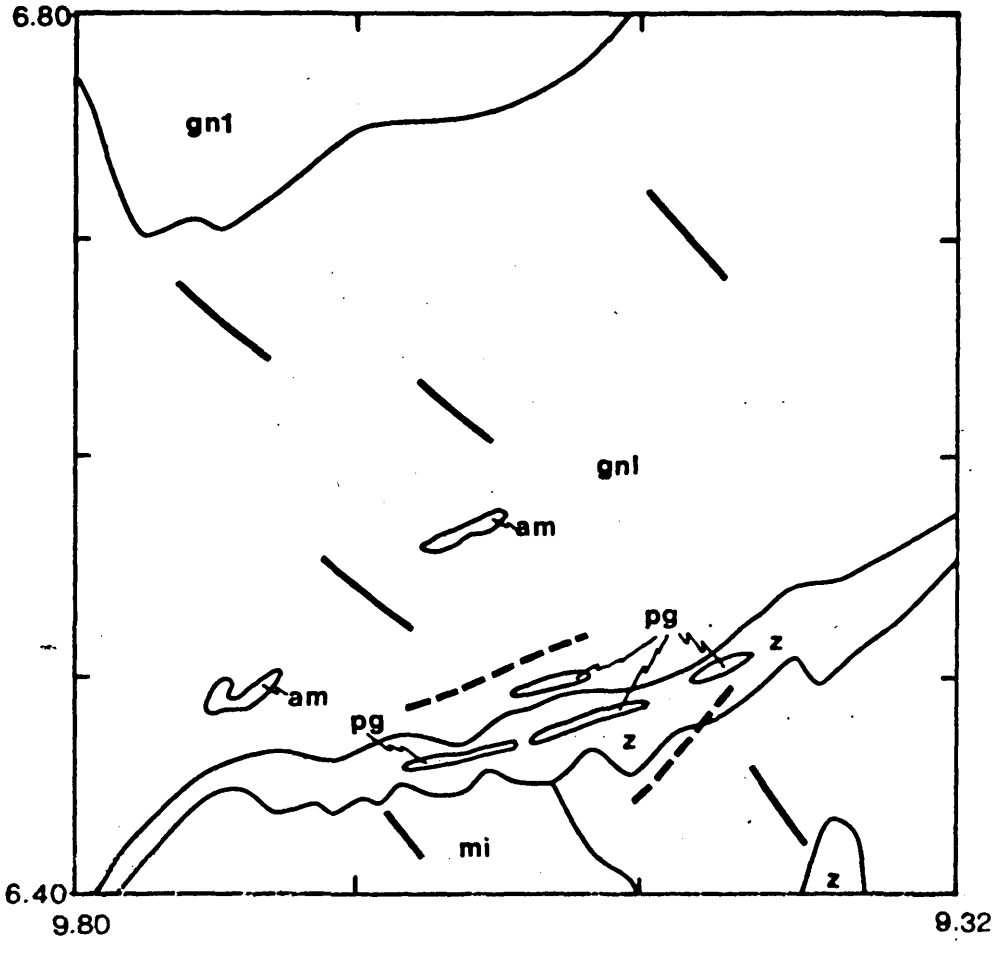
No.	Description	Locality	Authority	Analyst	BaO	SrO	ZrO_2	Cr_2O_3	LiO2	Rare Earth	V_2O_5	CO_2	F	Cl	S	Less O for S, F
31	Biotite-amphibole granite, 1748	Ivory Coast	" (1951, p. 33)	B. Martinet								0.70				
32	Biotite-chlorite granite.	Mont Oursa, French Guinea	" (1951, p. 31)	J. Patureau												
33	Biotite granite, 3119	Fanoutea sur la Niger, French Guinea	" (1951, p. 31)	P. Rose												
34	Biotite granite, 1031	Segnéla, Ivory Coast	" (1951, p. 31)	B. Martinet												
35	Muscovite-biotite granite, 4737	Bouaké, AOF	" (1951, p. 29)	J. Patureau												
36	Muscovite-biotite granite, 4756	Sataya, Senegal	" (1951, p. 29)	P. Rose												
37	Muscovite-biotite granite, 4739	Bouaké	" (1951, p. 25)	J. Patureau												
38	Akeritic granite, 4683	Ouéré, Haute Volta	" (1951, p. 63)	"												
39	Sodic granite, 3265	Kekoro	" (1951, p. 64)	B. Martinet												
40	Monzonitic granite, 5089	long. 6°46'W; lat. 11°50'N	" (1951, p. 65)	"												
41	Monzonitic granite, 536	Basse, Ivory Coast	" (1951, p. 65)	J. Patureau												
42	Monzonitic granite, K	Ivory Coast	" (1951, p. 66)	"												
43	Monzonitic granite, 4748	Haute Volta	" (1951, p. 67)	B. Martinet												
44	Charnockite.	Ghon, Djola, Ivory Coast	Obermuller (1941, p. 39)													
45	Porphyritic granodiorite	Yomen, Ivory Coast	" (1941, p. 43)	P. Rose												
46	Biotite granite	Baradou, Ivory Coast	" (1941, p. 43)													
47	Biotite granite	Poste de Makenta	" (1941, p. 42)													
48	Biotite gneiss	2 km east of Sierra Leone frontier	" (1941, p. 42)													
49	Granodiorite	19 km southwest of Makenta	" (1941, p. 42)													
50	Granodiorite	Yarakoldoro, Ivory Coast	" (1941, p. 42)													
51	Biotite granodiorite gneiss	G'Béké, Ivory Coast	" (1941, p. 66)	P. Rose												
52	Mylonitic biotite gneiss	Malossou, Ivory Coast	" (1941, p. 67)	"												
53	Leucocratic banded gneiss, K 150	Oji area, Nigeria	King and Swardt " (1949, p. 20)	W. H. Bennett	0.15	0.007	0.04	n.d.	0.03	0.05		0.07	0.08		0.03	0.05
54	Granite gneiss, A 28	Oji area, Nigeria	" (1949, p. 20)	"	0.14	0.009	0.09	n.d.	0.02	0.04		0.17	0.10		0.03	0.06
55	Coarse porphyritic granite, K 115	Oji area, Nigeria	" (1949, p. 20)	"	0.11	0.006	0.04	n.d.	0.02	0.04		0.06	0.03		0.03	0.04
56	Aplogranite, K 50	Oji area, Nigeria	" (1949, p. 20)	L. C. Chadwick	0.08	0.005	0.02	n.d.	0.02	0.03		n. d.	0.06		0.05	0.05
57	Granite	Makong, Sierra Leone	Sierra Leone Dept. Min. Geol. Survey Rept. (1930-1931, p. 10)						tr.	NiO: tr.				0.01		
58	Leucocratic biotite granite, 1638-3233	Irigle, Ivory Coast	Bolgarsky (1950, p. 43)	P. Rose												
59	Biotite-amphibole granite, 199-4344	Gouékan, Ivory Coast	" (1950, p. 44)	B. Martinet												
60	Leucocratic granite, 1622-3233	Namarakouma, Ivory Coast	" (1950, p. 45)	P. Rose												

Simplified geology overlay for the North West Granite



gr	Massive or slightly foliated granite
gnl	Leucocratic granitic gneiss
gng	granitic gneiss
IF	Iron formation (oxide and silicate facies)
Z	Composite unit, amphibolite, schist, etc.

Simplified geology overlay for the Grebo Area



gn1 Composite granitic gneiss with subordinate amphibolite

gnl Leucocratic gneiss

am Amphibolite

pg Pegmatite lenses

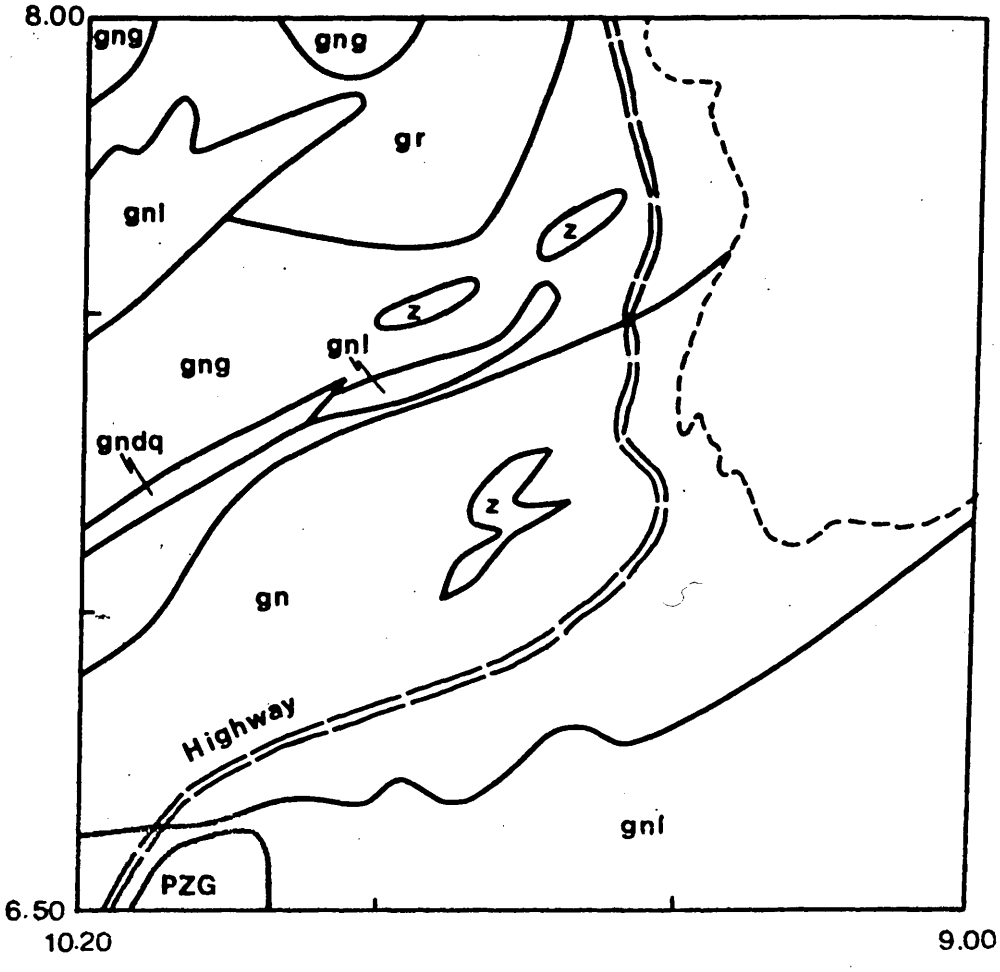
z Composite unit of schist, amphibolite and iron formation (silicate and oxide facies)

mi Migmatite

Fault

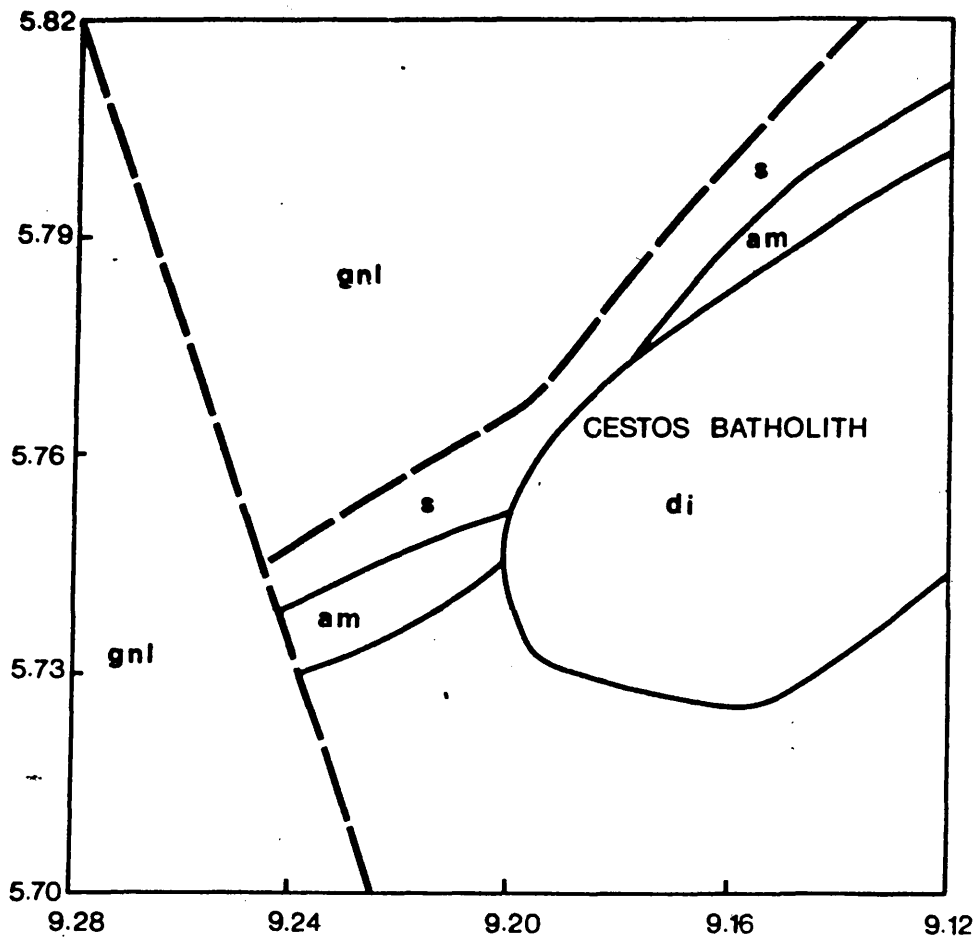
Dolerite

Simplified geology overlay for the North Central Corridor



gng	*Granitic* gneiss
gnl	Leucocratic gneiss
gndq	Quartzdiorite gneiss
z	Composite unit : schist, amphibolite, etc.
gn	Composite gneiss
PZG	Gibi formation, conglomerates, shales and sandstones

Simplified geology overlay for Cestos Batholith area



gnl	Leucocratic gneiss
di	Quartz diorite
s	Schist
am	Amphibolite
— —	Fault

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These are the analytical data for the Cestos Batholith area samples with their coordinates.

Format:

Id long. lat. Li Na K Rb Be Mg Ca Sr

Ba Al La Ti V Cr Mo Mn Fe Co

Ni Cu Ag Zn Cd Pb P

(All concentrations are in Ppm.)

4881.	9.1500	5.7300	20.0000	27000.0000	25000.0000	79.0000	1.4600	13500.0000	31000.0000	550.0000
1060.0000	65000.0000	34.0000	3200.0000	112.0000	33.0000	.0100	730.0000	36000.0000	19.3000	
14.5000	90.0000	.0100	58.0000	.0100	21.0000	780.0000				
4882.	9.1500	5.7300	17.5000	27000.0000	22000.0000	111.0000	1.6000	17000.0000	35000.0000	560.0000
670.0000	65000.0000	27.0000	3500.0000	135.0000	43.0000	.0100	770.0000	42000.0000	22.0000	
35.0000	48.0000	.0100	69.0000	1.0700	19.4000	930.0000				
4883.	9.1300	5.7300	17.3000	25000.0000	29000.0000	72.0000	1.4400	17800.0000	39000.0000	620.0000
1070.0000	72000.0000	22.0000	3700.0000	152.0000	37.0000	.0100	950.0000	48000.0000	26.0000	
19.0000	47.0000	.0100	70.0000	1.2100	21.0000	1140.0000				
4884.	9.1300	5.7200	19.8000	26000.0000	26000.0000	83.0000	1.4200	13400.0000	30000.0000	560.0000
1130.0000	65000.0000	45.0000	2900.0000	110.0000	29.0000	.0100	690.0000	35000.0000	19.2000	
15.2000	69.0000	.0100	56.0000	.0100	20.0000	740.0000				
4891.	9.1500	5.7700	25.0000	29000.0000	29000.0000	100.0000	1.6800	12900.0000	29000.0000	710.0000
830.0000	69000.0000	46.0000	2900.0000	102.0000	25.0000	4.6000	650.0000	34000.0000	17.5000	
34.0000	35.0000	.0100	59.0000	1.1500	22.0000	850.0000				
4892.	9.1700	5.7300	24.0000	28000.0000	24000.0000	75.0000	1.7200	17000.0000	38000.0000	710.0000
700.0000	67000.0000	31.0000	3500.0000	137.0000	36.0000	5.6000	890.0000	44000.0000	24.0000	
28.0000	53.0000	.0100	71.0000	1.5200	23.0000	1050.0000				
4893.	9.2000	5.7300	22.0000	28000.0000	26000.0000	89.0000	1.6600	15900.0000	35000.0000	730.0000
930.0000	71000.0000	56.0000	3200.0000	127.0000	32.0000	5.4000	790.0000	41000.0000	21.0000	
13.8000	48.0000	.0100	65.0000	1.5800	22.0000	960.0000				
4894.	9.1800	5.7300	25.0000	29000.0000	28000.0000	88.0000	1.6300	14600.0000	33000.0000	770.0000
910.0000	71000.0000	25.0000	3200.0000	116.0000	31.0000	.0100	740.0000	39000.0000	20.0000	
25.0000	45.0000	.0100	66.0000	1.1200	19.1000	980.0000				
4895.	9.1800	5.7300	28.0000	28000.0000	25000.0000	96.0000	1.6300	16900.0000	37000.0000	760.0000
710.0000	72000.0000	26.0000	3600.0000	134.0000	35.0000	5.4000	850.0000	44000.0000	23.0000	
21.0000	47.0000	.0100	72.0000	1.1800	21.0000	1070.0000				
4902.	9.1700	5.7500	7.7000	40000.0000	24000.0000	62.0000	1.8600	2000.0000	22000.0000	620.0000
970.0000	71000.0000	9.5000	680.0000	20.0000	2.6000	.0100	180.0000	8100.0000	4.6000	
12.9000	4.7000	.0100	11.8000	1.1600	18.7000	280.0000				
4903.	9.1700	5.7500	23.0000	27000.0000	24000.0000	136.0000	1.7000	19300.0000	41000.0000	680.0000
730.0000	79000.0000	34.0000	3800.0000	148.0000	41.0000	5.9000	920.0000	48000.0000	26.0000	
186.0000	59.0000	.0100	81.0000	1.3200	26.0000	1050.0000				
4904.	9.1300	5.7700	23.0000	27000.0000	27000.0000	110.0000	1.5700	16300.0000	36000.0000	610.0000
760.0000	73000.0000	26.0000	3500.0000	131.0000	41.0000	5.9000	760.0000	42000.0000	22.0000	
21.0000	31.0000	.0100	71.0000	1.4700	24.0000	920.0000				
4911.	9.1300	5.7600	22.0000	27000.0000	27000.0000	104.0000	1.5500	17200.0000	39000.0000	720.0000
780.0000	81000.0000	30.0000	3700.0000	138.0000	34.0000	4.3000	850.0000	45000.0000	22.0000	
17.4000	39.0000	.0100	66.0000	1.2400	18.8000	970.0000				
4912.	9.1500	5.7500	21.0000	29000.0000	28000.0000	99.0000	1.5900	12200.0000	29000.0000	630.0000
750.0000	66000.0000	24.0000	2700.0000	100.0000	29.0000	.0100	670.0000	33000.0000	17.9000	
26.0000	16.9000	.0100	56.0000	.0100	26.0000	770.0000				
4913.	9.1200	5.7300	21.0000	31000.0000	25000.0000	101.0000	1.6900	14200.0000	36000.0000	840.0000
1010.0000	77000.0000	33.0000	3300.0000	112.0000	30.0000	4.8000	780.0000	38000.0000	19.3000	
21.0000	38.0000	.0100	61.0000	1.3500	23.0000	1040.0000				
4914.	9.1200	5.7300	25.0000	27000.0000	25000.0000	58.0000	1.4700	12900.0000	32000.0000	690.0000
860.0000	62000.0000	21.0000	3000.0000	108.0000	28.0000	2.9000	730.0000	37000.0000	18.4000	
69.0000	42.0000	.0100	58.0000	.6800	12.3000	910.0000				
4915.	9.1200	5.7300	22.0000	28000.0000	26000.0000	87.0000	1.6500	15200.0000	34000.0000	750.0000
860.0000	68000.0000	25.0000	3200.0000	121.0000	34.0000	5.5000	800.0000	40000.0000	20.0000	
27.0000	40.0000	.0100	66.0000	1.1500	22.0000	1020.0000				
4922.	9.1800	5.7500	3.3000	1780.0000	1770.0000	.0100	.1000	950.0000	1380.0000	30.0000
40.0000	5400.0000	1.5800	560.0000	9.4000	.0100	.0100	44.0000	2800.0000	2.9000	
2.3000	.5400	.0100	8.8000	.0100	.0100	52.0000				
4923.	9.1400	5.7700	27.0000	30000.0000	20000.0000	74.0000	1.5800	15300.0000	36000.0000	800.0000
650.0000	75000.0000	26.0000	3300.0000	120.0000	30.0000	.0100	750.0000	40000.0000	22.0000	
14.8000	32.0000	.0100	67.0000	1.3900	18.3000	980.0000				
4924.	9.1400	5.7700	28.0000	28000.0000	26000.0000	99.0000	1.8300	14000.0000	33000.0000	680.0000
700.0000	67000.0000	27.0000	3000.0000	114.0000	29.0000	5.4000	750.0000	38000.0000	19.4000	
18.3000	134.0000	.0100	62.0000	.0100	25.0000	950.0000				
4925.	9.1400	5.7700	24.0000	29000.0000	31000.0000	130.0000	1.7900	12700.0000	29000.0000	670.0000
860.0000	66000.0000	26.0000	3400.0000	106.0000	24.0000	5.2000	650.0000	34000.0000	18.5000	
14.8000	36.0000	.0100	58.0000	1.3900	27.0000	870.0000				
4926.	9.2500	5.7300	28.0000	25000.0000	30000.0000	146.0000	1.6800	18700.0000	37000.0000	680.0000
850.0000	74000.0000	35.0000	4200.0000	152.0000	41.0000	7.3000	970.0000	50000.0000	26.0000	
26.0000	38.0000	.0100	81.0000	1.2300	27.0000	1200.0000				
4931.	9.2200	5.7500	23.0000	29000.0000	26000.0000	74.0000	1.5900	14500.0000	34000.0000	680.0000
790.0000	69000.0000	22.0000	3400.0000	119.0000	29.0000	.0100	760.0000	39000.0000	22.0000	
19.1000	50.0000	.0100	67.0000	1.0400	25.0000	1020.0000				
4932.	9.2200	5.7500	25.0000	28000.0000	25000.0000	89.0000	1.6200	15200.0000	34000.0000	720.0000
870.0000	68000.0000	21.0000	3400.0000	119.0000	31.0000	4.3000	720.0000	40000.0000	21.0000	
36.0000	51.0000	.0100	64.0000	.0100	21.0000	1030.0000				
4933.	9.2300	5.7500	31.0000	21000.0000	23000.0000	108.0000	2.3000	31000.0000	53000.0000	600.0000
520.0000	77000.0000	35.0000	3900.0000	169.0000	220.0000	.0100	1570.0000	66000.0000	32.0000	
41.0000	34.0000	.0100	121.0000	.0100	23.0000	1170.0000				
4934.	9.1300	5.7500	25.0000	26000.0000	29000.0000	114.0000	1.6800	11500.0000	27000.0000	640.0000
770.0000	65000.0000	25.0000	2600.0000	92.0000	33.0000	5.7000	630.0000	32000.0000	16.5000	
22.0000	27.0000	.0100	56.0000	1.1900	24.0000	780.0000				
4981.	9.15	5.7500	21.0000	29000.0000	27000.0000	104.0000	1.6200	15500.0000	35000.0000	630.0000
870.0000	72000.0000	22.0000	3300.0000	120.0000	34.0000	4.7000	770.0000	39000.0000	20.0000	
22.0000	47.0000	.0100	62.0000	1.1500	20.0000	860.0000				
4982.	9.1300	5.7500	22.0000	29000.0000	24000.0000	70.0000	1.6300	17800.0000	41000.0000	750.0000
840.0000	71000.0000	26.0000	3600.0000	145.0000	39.0000	6.5000	960.0000	47000.0000	24.0000	
22.0000	35.0000	.0100	72.0000	1.2600	21.0000	1110.0000				
4991.	9.1300	5.7500	22.0000	28000.0000	28000.0000	106.0000	1.6300	14800.0000	33000.0000	760.0000
870.0000	73000.0000	26.0000	3200.0000	118.0000	31.0000	5.5000	740.0000	39000.0000	20.0000	
18.5000	27.0000	.0100	68.0000	1.2400	21.0000	960.0000				
4992.	9.1300	5.7500	23.0000	28000.0000	28000.0000	105.0000	1.6300	15300.0000	34000.0000	770.0000
890.0000	75000.0000	28.0000	3400.0000	122.0000	32.0000	6.0000	750.0000	41000.0000	20.0000	
19.3000	34.0000	.0100	65.0000	1.2600	22.0000	1030.0000				
4994.	9.1300	5.7500	22.0000	27000.0000	26000.0000	110.0000	1.6900	16800.0000	36000.0000	630.0000
740.0000	69000.0000	26.0000	3600.0000	136.0000	34.0000	5.3000	840.0000	43000.0000	22.0000	
33.0000	70.0000	.0100	69.0000	1.0600	23.0000	970.0000				
5001.	9.13	5.7700	13.4000	36000.0000	21000.0000	49.0000	1.7100	9200.0000	31000.0000	740.0000
940.0000	69000.0000	16.4000	2200.0000	76.0000	13.1000	.0100	500.0000	25000.0000	13.4000	
37.0000	32.0000	.0100	36.0000	1.0100	15.8000	700.0000				
5002.	9.13	5.7700	22.0000	26000.0000	29000.0000	116.0000	1.7000	12400.0000	26000.0000	650.0000
850.0000	62000.0000	22.0000	2700.0000	104.0000	25.0000	4.3000	560.0000	35000.0000	17.2000	
38.0000	10.7000	.0100	56.0000	1.2300	24.0000	870.0000				
5004.	9.1200	5.7700	21.0000	27000.0000	26000.0000	100.0000	1.6800	18700.0000	38000.0000	740.0000
950.0000	67000.0000	37.0000	3600.0000	152.0000	210.0000	20.0000	900.0000	49000.0000	25.0000	
160.0000	41.0000	.0100	72.0000	1.1900	27.0000	1080.0000				
5005.	9.1200	5.7700	19.8000	25000.0000	24000.0000	65.0000	1.5500	12300.0000	29000.0000	650.0000
810.0000	64000.0000	25.0000	2700.0000	101.0000	21.0000	4.6000	690.0000	35000.0000	16.5000	
26.0000	33.0000	.0100	57.0000	.0100	16.3000	840.0000				
5011.	9.1200	5.7700	24.0000	27000.0000	27000.0000	96.0000	1.6300	13300.0000	31000.0000	720.0000
890.0000	65000.0000	20.0000	3000.0000	109.0000	28.0000	5.2000	690.0000	37000.0000	18.9000	
15.0000	44.0000	.0100	60.0000	1.1900	21.0000	880.0000				
5012.	9.1200	5.7700	23.0000	26000.0000	26000.0000	74.0000	1.6100	12400.0000	31000.0000	740.0000
980.0000	63000.0000	23.0000	2700.0000	100.0000	20.0000	2.8000	660.0000	34000.0000	17.0000	
18.1000	25.0000	.0100	56.0000	.0100	15.5000	880.0000				
5013.	9.1200	5.7800	24.0000	30000.0000	27000.0000	87.0000	1.7200	13400.0000	31000.0000	690.0000
810.0000	70000.0000	18.7000	2800.0000	108.0000	23.0000	.0100	680.0000	36000.0000	17.8000	
27.0000	32.0000	.0100	63.0000	.0100	19.5000	920.0000				
5014.	9.1200	5.7800	24.0000	520.0000	11000.0000	78.0000	.4000	12900.0000	15300.0000	164.0000
57.0000	20000.0000	34.0000	2500.0000	85.0000	18.4000	.0100	640.0000	32000.0000	16.6000	
34.0000	33.0000	.0100	60.0000	.0100	8.3000	910.0000				
5015.	9.1200	5.7800	24.0000	29000.0000	29000.0000	144.0000	1.8500	13800.0000	32000.0000	720.0000
800.0000	71000.0000	23.0000	3000.0000	110.0000	27.0000	4.9000	710.0000	37000.0000	17.2000	
39.0000	26.0000	.0100	63.0000	1.0600	26.0000	950.0000				
5016.	9.1200	5.7800	22.0000	28000.0000	29000.0000	105.0000	1.8200	13400.0000	32000.0000	680.0000
800.0000	68000.0000	40.0000	3200.0000	107.0000	26.0000	5.7000	750.0000	36000.0000	19.1000	
19.1000	32.0000	.0100	61.0000	1.6000	25.0000	910.0000				
5021.	9.1600	5.7500	5.9000	9900.0000	1120.0000	.0100	.2000	56000.0000	98000.0000	93.0000
20.0000	87000.0000	4.4000	1660.0000	172.0000	135.0000	.0100	1400.0000	60000.0000	46.0000	
136.0000	86.0000	.0100	51.0000	.0100	.0100	64.0000				
5022.	9.1600	5.7500	18.9000	10500.0000	4800.0000	45.0000	.4000	47000.0000	89000.0000	136.0000
119.0000	89000.0000	8.1000	1810.0000	172.0000	128.0000	.0100	1910.0000	60000.0000	53.0000	
132.0000	151.0000	.0100	60.0000	1.3400	9.9000	179.0000				
5023.	9.1700	5.7500	18.7000	29000.0000	19900.0000	77.0000	1.6200	21000.0000	44000.0000	760.0000
760.0000	80000.0000	27.0000	3900.0000	162.0000	43.0000	4.7000	950.0000	51000.0000	27.0000	
23.0000	51.0000	.0100	75.0000	1.4100	16.7000	1200.0000				
5024.	9.14	5.7500	17.1000	19700.0000	16500.0000	60.0000	.8600	9900.0000	35000.0000	370.0000
520.0000	54000.0000	18.6000	2600.0000	101.0000	24.0000	.0100	830.0000	30000.0000	15.2000	
21.0000	83.0000	.0100	47.0000	1.1000	17.2000	690.0000				
5025.	9.0800	5.7500	16.2000	26000.0000	27000.0000	97.0000	1.5600	16500.0000	37000.0000	660.0000
790.0000	72000.0000	28.0000	3600.0000	132.0000	37.0000	6.3000	830.0000	43000.0000	23.0000	
24.0000	63.0000	.0100	66.0000	1.3900	23.0000	980.0000				
5031.	9.1700	5.7200	16.8000	27000.0000	21000.0000	81.0000	1.5100	17000.0000	35000.0000	650.0000
730.0000	68000.0000	24.0000	3400.0000	140.0000	32.0000	.0100	930.0000	45000.0000	28.0000	
14.7000	141.0000	.0100	65.0000	1.1500	15.9000	970.0000				
5032.	9.1700	5.7500	26.0000	25000.0000	22000.0000	103.0000	1.4200	18200.0000	34000.0000	500.0000
780.0000	67000.0000	27.0000	3800.0000	150.0000	42.0000	.0100	910.0000	48000.0000	35.0000	
19.1000	48.0000	.0100	69.0000	1.0600	16.1000	1020.0000				
5033.	9.1700	5.7500	23.0000	20000.0000	24000.0000	84.0000	1.4200	23000.0000	40000.0000	640.0000
630.0000	73000.0000	28.0000	4800.0000	182.0000	67.0000	7.1000	1520.0000	63000.0000	35.0000	
161.0000	94.0000	.0100	89.0000	1.4400	20.0000	1540.0000				
5034.	9.13	5.7300	12.2000	26000.0000	23000.0000	108.0000	1.4400	16100.0000	33000.0000	560.0000
710.0000	67000.0000	30.0000	3300.0000	126.0000	56.0000	.0100	850.0000	40000.0000	21.0000	
174.0000	42.0000	.0100	64.0000	.0100	24.0000	940.0000				
5035.	9.16	5.7300	25.0000	25000.0000	24000.0000	114.0000	1.3800	15700.0000	33000.0000	450.0000
730.0000	62000.0000	16.0000	3700.0000	134.0000	45.0000	.0100	710.0000	41000.0000	23.0000	
18.0000	49.0000	.0100	66.0000	1.0700	17.6000	930.0000				
5041.	9.12000	5.7300	16.9000	33000.0000	12100.0000	59.0000	1.1700	8000.0000	33000.0000	550.0000
530.0000	65000.0000	12.5000	2000.0000	61.0000	23.0000	.0100	600.0000	24000.0000	11.5000	
9.8000	14.8000	.0100	58.0000	1.2800	16.2000	520.0000				
5043.	9.2000	5.7700	17.4000	23000.0000	22000.0000	63.0000	.9100	2400.0000	2800.0000	270.0000
930.0000	53000.0000	20.0000	1130.0000	46.0000	31.0000	.0100	105.0000	18500.0000	8.4000	
26.0000	11.1000	.0100	21.0000	.0100	18.6000	250.0000				
5044.	9.2000	5.7700	21.0000	30000.0000	22000.0000	47.0000	1.2100	3300.0000	6700.0000	198.0000
680.0000	49000.0000	20.0000	1740.0000	54.0000	18.4000	3.0000	169.0000	15500.0000	6.7000	
14.5000	45.0000	.0100	26.0000	.5300	18.4000	460.0000				
5045.	9.0000	5.7300	11.8000	26000.0000	21000.0000	34.0000	2.1000	7400.0000	7300.0000	250.0000
123.0000	55000.0000	14.2000	1540.0000	82.0000	35.0000	6.4000	220.0000	42000.0000	23.0000	
50.0000	193.0000	.0100	31.0000	.0100	22.0000	1050.0000				
5051.	9.0300	5.7300	34.0000	26000.0000	17500.0000	113.0000	1.7700	14200.0000	15000.0000	370.0000
490.0000	72000.0000	31.0000	4300.0000	133.0000	87.0000	5.9000	560.0000	43000.0000	21.0000	
38.0000	34.0000	.0100	69.0000	.0100	25.0000	950.0000				
5052.	9.2800	5.8800	21.0000	25000.0000	27000.0000	102.0000	1.6700	16900.0000	35000.0000	620.0000
800.0000	72000.0000	29.0000	3300.0000	129.0000	41.0000	5.7000	850.0000	43000.0000	22.0000	
16.0000	57.0000	.0100	65.0000	1.2700	22.0000	880.0000				
5053.	9.2800	5.8800	8.0000	33000.0000	9800.0000	27.0000	1.0500	4400.0000	22000.0000	350.0000
580.0000	62000.0000	24.0000	1720.0000	26.0000	11.2000	1.1900	340.0000	15800.0000	8.7000	
26.0000	26.0000	.0100	43.0000	.0100	15.6000	430.0000				
5061.	9.1800	5.9000	18.8000	21000.0000	41000.0000	173.0000	.9700	920.0000	5200.0000	78.0000
1060.0000	68000.0000	26.0000	510.0000	4.3000	.0100	.0100	123.0000	7700.0000	3.0000	
1.9100	.0100	.0100	26.0000	1.0300	56.0000	107.0000				
5063.	9.0700	5.7500	15.0000	29000.0000	18200.0000	47.0000	1.7000	13700.0000	37000.0000	270.0000
1040.0000	79000.0000	78.0000	5400.0000	85.0000	36.0000	4.0000	640.0000	50000.0000	24.0000	
32.0000	32.0000	.0100	80.0000	1.5700	18.3000	1450.0000				
5064.	9.0700	5.7500	9.6000	37000.0000	10200.0000	39.0000	1.0400	5800.0000	25000.0000	380.0000
480.0000	73000.0000	40.0000	2100.0000	31.0000	9.9000	.0100	240.0000	17200.0000	8.4000	
54.0000	1.0600	.0100	53.0000	1.1100	18.4000	540.0000				

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These are the analytical data for the Grebo Town area samples with their coordinates.

Format:

Id long. lat. Li Na K Rb Be Mg Ca Sr

Ba Al La Ti V Cr Mo Mn Fe Co

Ni Cu Ag Zn Cd Pb P

(All concentrations are in Ppm.)

```
 1872.      9.5900     6.4500     5.5000  22000.0000  46000.0000    149.0000      .8200   440.0000  4400.0000     99.0000
940.0000  47000.0000   12.8000   430.0000      5.5000     -99.0000      3.1000    72.0000  5100.0000     4.1000
  1.3100     2.4000    -99.0000    13.1000    -99.0000     46.0000     36.0000
 4782.      9.5300     6.4800     3.7000   6700.0000   6200.0000     30.0000      .9700   600.0000  1590.0000     23.0000
141.0000  22000.0000    5.4000   175.0000      1.9600      1.3900    -99.0000     49.0000  2700.0000     1.1500
  9.3000    -99.0000   -99.0000     6.6000    -99.0000     15.8000    173.0000
 4783.      9.5300     6.4800    11.4000   8600.0000  65000.0000    240.0000     1.2900  1130.0000   890.0000     49.0000
900.0000  79000.0000    4.8000   181.0000      4.7000      2.1000    -99.0000     80.0000  4800.0000     3.3000
 67.0000     4.5000    -99.0000    11.5000    -99.0000     74.0000    510.0000
 4784.      9.5500     6.5000    10.4000  26000.0000  14800.0000     63.0000     6.2000   950.0000  1810.0000     22.0000
 62.0000  56000.0000    2.4000    60.0000      1.9600      2.9000    -99.0000    720.0000  5500.0000    -99.0000
  5.1000     1.4500    -99.0000    10.9000    -99.0000     34.0000    540.0000
 4791.      9.6700     6.4800     5.0000  22000.0000  37000.0000    161.0000      .4000   470.0000  1780.0000     19.3000
158.0000  63000.0000    2.8000    36.0000      1.8000    -99.0000    -99.0000     74.0000  5800.0000    -99.0000
  1.4900     4.9000    -99.0000    37.0000    -99.0000     47.0000    850.0000
 4792.      9.6700     6.4800    21.0000  38000.0000  13000.0000     55.0000     1.0800  2700.0000 17300.0000    290.0000
620.0000  67000.0000   14.4000  1260.0000     13.9000      2.5000    -99.0000    240.0000 12400.0000     5.7000
 13.0000     2.7000    -99.0000    39.0000    -99.0000     24.0000    240.0000
 4793.      9.6700     6.4800    11.4000  27000.0000  47000.0000    220.0000     1.5700   153.0000  2400.0000     30.0000
480.0000  68000.0000    2.0000     9.0000       .8300    -99.0000    -99.0000     42.0000   720.0000     2.4000
  1.8300     1.0400    -99.0000     3.8000       .5800     72.0000    480.0000
 4795.      9.5700     6.4800     7.1000    260.0000   1050.0000    -99.0000    -99.0000   193.0000    51.0000      1.2500
 44.0000  4600.0000    -99.0000   -99.0000       .7700    -99.0000    -99.0000    -99.0000   480.0000   -99.0000
-99.0000      .6700    -99.0000     1.2400       .5500    -99.0000     13.1000
 4796.      9.5800     6.4700    22.0000  21000.0000  16100.0000     70.0000      .5900   650.0000  3300.0000     33.0000
360.0000  69000.0000    2.3000    98.0000      3.2000      2.9000    -99.0000     82.0000  3500.0000     1.3200
  6.8000     5.0000    -99.0000     5.8000    -99.0000     16.8000    440.0000
 4801.      9.5200     6.4800     4.2000  13200.0000  86000.0000    380.0000      .7400   116.0000   690.0000     97.0000
1230.0000  83000.0000    9.2000    27.0000      1.9800      1.2400    -99.0000    -99.0000   790.0000   -99.0000
  1.3700     1.9100     1.2100     2.3000      1.0800     67.0000    410.0000
 4802.      9.5600     6.5000     3.4000  23000.0000  24000.0000    111.0000      .2000   550.0000  1570.0000      6.2000
 25.0000  63000.0000    2.7000    79.0000      1.2100    -99.0000    -99.0000     30.0000  4400.0000    -99.0000
  1.5900      .8700    -99.0000    31.0000    -99.0000     33.0000    940.0000
 4803.      9.5200     6.4900    72.0000  21000.0000  44000.0000    194.0000      .9300  1990.0000  5400.0000     53.0000
630.0000  67000.0000   42.0000  1240.0000     10.8000      4.4000    -99.0000     75.0000 14200.0000     5.4000
  4.2000     1.2300    -99.0000    34.0000    -99.0000     42.0000    220.0000
 4804.      9.5200     6.5000     8.9000  22000.0000  40000.0000    106.0000     1.0300  2300.0000  7100.0000     120.0000
1310.0000  52000.0000   23.0000   940.0000     14.4000      1.3300    -99.0000    132.0000 10300.0000     4.4000
  8.8000    40.0000    -99.0000    29.0000    -99.0000     41.0000    210.0000
 4811.      9.4500     6.5700    16.6000  31000.0000  19500.0000     88.0000     1.7500  4300.0000 18300.0000    143.0000
900.0000  62000.0000   38.0000  2000.0000     27.0000      5.4000    -99.0000    390.0000 21000.0000     8.2000
  7.7000     2.4000    -99.0000    51.0000    -99.0000     17.9000    450.0000
 4812.      9.4600     6.5700     7.3000  23000.0000  33000.0000    111.0000     1.1700  1830.0000  8100.0000     105.0000
1010.0000  52000.0000   17.0000   900.0000     13.2000      2.1000    -99.0000    230.0000 11300.0000     4.2000
 16.9000     7.9000    -99.0000    30.0000    -99.0000     32.0000    196.0000
 4813.      9.4600     6.5600    13.6000  31000.0000  19000.0000     83.0000     1.8100  3900.0000 15400.0000    131.0000
640.0000  56000.0000   30.0000  1900.0000     26.0000      2.7000    -99.0000    400.0000 20000.0000     7.5000
  8.4000     6.6000    -99.0000    54.0000      1.3400     33.0000    460.0000
 4814.      9.4600     6.5600     4.0000  28000.0000  39000.0000    115.0000     1.1300   360.0000  8700.0000     139.0000
1480.0000  57000.0000    3.9000   240.0000      3.1000    -99.0000    -99.0000     22.0000  2400.0000     3.4000
  5.8000     6.3000    -99.0000     5.9000    -99.0000     13.9000     31.0000
 4815.      9.4600     6.5600    10.5000  23000.0000   8600.0000     35.0000     2.6000 25000.0000 59000.0000      94.0000
149.0000  70000.0000   16.9000  4700.0000    200.0000     91.0000    -99.0000   1760.0000 76000.0000    38.0000
 35.0000   108.0000    -99.0000   114.0000      1.4500     12.3000    280.0000
 4816.      9.4400     6.5800    14.7000  27000.0000  19900.0000     55.0000     1.3100  5400.0000 27000.0000     175.0000
1560.0000  59000.0000   53.0000  3300.0000     42.0000      5.3000    -99.0000    500.0000 31000.0000    14.6000
 35.0000    15.1000    -99.0000    60.0000       .5900     14.8000    680.0000
 4817.      9.4800     6.5700    10.9000  26000.0000  32000.0000    106.0000     1.5200  3000.0000 15700.0000     136.0000
1170.0000  58000.0000   31.0000  1430.0000     24.0000      1.7400    -99.0000    450.0000 18100.0000     7.1000
  6.0000     5.3000    -99.0000    49.0000    -99.0000     42.0000    430.0000
 4818.      9.4800     6.5700    17.1000  28000.0000  24000.0000    101.0000     1.7600  4200.0000 19000.0000     129.0000
 860.0000  59000.0000   35.0000  1990.0000     26.0000      5.4000      1.8400    420.0000 21000.0000     8.3000
 20.0000     3.7000    -99.0000    54.0000       .9300     29.0000    440.0000
 4821.      9.4200     6.5200    18.1000  31000.0000  14400.0000     71.0000     2.5000  6100.0000 29000.0000     180.0000
 910.0000  69000.0000   56.0000  3700.0000     47.0000      3.4000    -99.0000    520.0000 32000.0000    14.3000
  4.9000    10.8000    -99.0000    67.0000    -99.0000     27.0000    770.0000
 4822.      9.5300     6.5200     2.2000  22000.0000  72000.0000    250.0000      .6600   139.0000  2300.0000     123.0000
1540.0000  71000.0000    4.0000   124.0000      2.7000    -99.0000    -99.0000     18.6000  2600.0000     1.9600
  6.8000     1.6600    -99.0000     4.8000      1.2000     56.0000     53.0000
 4823.      9.5300     6.5300     3.9000  27000.0000  42000.0000    128.0000      .9500   440.0000  4900.0000      94.0000
1090.0000  51000.0000   16.4000   540.0000      6.0000    -99.0000    -99.0000     54.0000  6200.0000     1.3100
  8.2000     4.2000    -99.0000    16.4000    -99.0000     45.0000    111.0000
 4824.      9.5300     6.5300     7.2000  22000.0000  49000.0000    168.0000      .6600   520.0000  4900.0000     157.0000
3900.0000  55000.0000   14.1000   330.0000      2.5000    -99.0000    -99.0000     58.0000  4900.0000     1.1700
 16.0000     3.9000    -99.0000    16.1000    -99.0000     49.0000     80.0000
 4825.      9.5300     6.5300     2.6000  23000.0000  50000.0000    177.0000     1.1000   164.0000  5400.0000     121.0000
1620.0000  54000.0000    6.4000   183.0000      4.4000    -99.0000    -99.0000     59.0000  3300.0000     1.2800
 23.0000     2.0000    -99.0000     9.4000      1.2600     47.0000     24.0000
 4826.      9.5400     6.5300    79.0000  16400.0000  56000.0000    330.0000     2.4000 26000.0000  7200.0000      95.0000
1210.0000  75000.0000    8.3000  2100.0000     69.0000    410.0000    -99.0000   1180.0000 53000.0000    30.0000
 168.0000     2.3000    -99.0000   250.0000    -99.0000     22.0000    156.0000
 4827.      9.5300     6.5100   177.0000   7500.0000  59000.0000    580.0000     4.3000  61000.0000 11600.0000      38.0000
 670.0000  82000.0000   11.9000  4700.0000     159.0000    960.0000    -99.0000   2600.0000 118000.0000    65.0000
 380.0000     2.2000    -99.0000   550.0000      1.2900     9.7000    300.0000
 4831.      9.5000     6.5200     5.6000  26000.0000  33000.0000     90.0000      .9100  1150.0000  8400.0000     115.0000
1190.0000  53000.0000   23.0000   510.0000      6.9000      1.3600    -99.0000    158.0000 10300.0000     2.4000
  4.1000     6.3000    -99.0000    24.0000    -99.0000     39.0000     78.0000
 4832.      9.5000     6.5200     5.6000  16000.0000  36000.0000    122.0000      .6100  1440.0000  5300.0000      91.0000
1600.0000  44000.0000   21.0000   590.0000      6.9000    -99.0000    -99.0000    118.0000  7400.0000     3.2000
  6.5000     3.6000    -99.0000    21.0000    -99.0000     38.0000     31.0000
 4833.      9.5000     6.5300     2.8000  24000.0000  35000.0000     87.0000      .7300   600.0000  6400.0000     165.0000
2200.0000  54000.0000   16.1000   290.0000      3.5000      2.8000      2.4000    44.0000  5200.0000    -99.0000
  3.5000     7.0000    -99.0000    12.9000    -99.0000     31.0000     41.0000
 4834.      9.5000     6.5300     3.7000  21000.0000  58000.0000    161.0000      .5000   940.0000  2800.0000     173.0000
4300.0000  61000.0000   13.0000   520.0000      4.6000      1.6900    -99.0000     50.0000  5700.0000     2.7000
  3.0000     2.8000    -99.0000    18.4000    -99.0000     45.0000    115.0000
 4842.      9.4800     6.5300     6.1000  27000.0000  37000.0000    142.0000     1.0700   780.0000  6500.0000     154.0000
1800.0000  62000.0000  109.0000   600.0000      4.6000      1.3200    -99.0000    146.0000  8400.0000     1.5800
 61.0000     3.8000     1.3300    18.0000       .8300     34.0000    165.0000
 4843.      9.5200     6.4800    12.7000  18000.0000  93000.0000    340.0000      .5000   910.0000  2300.0000     148.0000
3300.0000  78000.0000    6.2000   240.0000      9.0000    -99.0000      6.3000     43.0000  3400.0000     2.8000
  3.3000     4.0000    -99.0000    11.2000      1.2000    110.0000    470.0000
 4844.      9.5200     6.4800    49.0000  28000.0000  36000.0000    160.0000      .9300  1320.0000  6400.0000      51.0000
 510.0000  56000.0000   21.0000   790.0000      9.3000      2.0000    -99.0000     61.0000  9100.0000     2.9000
  4.8000     2.8000    -99.0000    30.0000    -99.0000     50.0000    260.0000
 4845.      9.5200     6.4800    47.0000  25000.0000  43000.0000    181.0000      .6500   920.0000  5400.0000      41.0000
 380.0000  60000.0000   22.0000   620.0000      5.2000      2.7000    -99.0000    116.0000  9100.0000     3.1000
  7.7000     1.4800    -99.0000    19.7000       .7100     38.0000    280.0000
 4846.      9.5200     6.4800    13.7000   8500.0000  50000.0000    189.0000      .3000   159.0000   630.0000      64.0000
1690.0000  42000.0000   17.1000    55.0000      2.3000    -99.0000    -99.0000      6.4000  1600.0000    -99.0000
  3.3000     2.7000    -99.0000     3.8000      1.0100     54.0000    270.0000
 4847.      9.5800     6.5000    54.0000  22000.0000  41000.0000    171.0000      .9600  1320.0000  5300.0000      45.0000
 550.0000  55000.0000   15.6000   750.0000      6.8000      3.2000      1.7300    104.0000  9500.0000     3.2000
  11.7000     4.3000    -99.0000    23.0000    -99.0000     38.0000    310.0000
 4852.      9.5000     6.5000    39.0000  18400.0000  13800.0000     40.0000       .8800 16900.0000 17100.0000      149.0000
 480.0000  62000.0000   23.0000  2600.0000     92.0000    165.0000    -99.0000    680.0000 45000.0000    25.0000
  84.0000    48.0000    -99.0000    52.0000    -99.0000     23.0000    430.0000
 4853.      9.5100     6.5000    10.1000  29000.0000   2300.0000    -99.0000     1.2900  3000.0000 28000.0000      210.0000
  87.0000  63000.0000    7.0000   300.0000     14.9000     22.0000    -99.0000    360.0000 15300.0000     4.4000
  16.2000     4.8000    -99.0000     9.6000    -99.0000      9.5000    470.0000
 4854.      9.5200     6.5200    30.0000  29000.0000  16200.0000    111.0000     1.8200  8600.0000 24000.0000      210.0000
 990.0000  58000.0000   88.0000  3800.0000     60.0000     21.0000    -99.0000    660.0000 36000.0000    17.3000
  15.5000    15.8000    -99.0000    76.0000      1.0100     27.0000    940.0000
 4855.      9.4700     6.7200    11.5000  22000.0000  45000.0000    169.0000     1.0100  1680.0000  5400.0000      122.0000
1160.0000  64000.0000  133.0000  1100.0000     11.3000      1.7400      8.5000    290.0000 14300.0000     5.3000
  14.4000     3.1000     1.2000    46.0000       .6800     44.0000    230.0000
 4856.      9.5200     6.5300     7.6000  18300.0000  39000.0000    137.0000      .9200   900.0000  6200.0000      113.0000
1050.0000  52000.0000   22.0000   790.0000      6.3000    -99.0000    -99.0000     53.0000  5600.0000     2.8000
  3.3000      .7000    -99.0000    14.0000    -99.0000     28.0000    150.0000
 4862.      9.5300     6.5500     9.4000  23000.0000  47000.0000    220.0000     1.3100  1570.0000  7200.0000      123.0000
1550.0000  52000.0000   81.0000  1480.0000     16.8000    -99.0000    -99.0000    176.0000 10700.0000     5.1000
  2.6000     3.1000    -99.0000    36.0000      1.1000     52.0000    300.0000
 4863.      9.5300     6.5500    14.4000  29000.0000  34000.0000    190.0000     1.6900  1890.0000  9200.0000      102.0000
 760.0000  73000.0000  104.0000  2200.0000     19.2000     45.0000      5.8000    320.0000 17800.0000     8.3000
 126.0000    11.6000    -99.0000    45.0000      1.1600     50.0000    155.0000
 4865.      9.5500     6.4700    34.0000  23000.0000   1900.0000    -99.0000     1.0200   850.0000  6300.0000      73.0000
  82.0000  73000.0000   16.1000   179.0000      9.8000     14.2000    -99.0000    210.0000 10200.0000     4.0000
  36.0000     7.6000    -99.0000    13.2000      1.0400     48.0000    680.0000
 4871.      9.1300     6.1700    15.4000  29000.0000   4800.0000     24.0000     2.0000  1850.0000 15000.0000      184.0000
 149.0000  51000.0000   15.7000   590.0000      9.8000      4.3000      1.0700     86.0000  7200.0000     3.4000
   7.6000    41.0000    -99.0000    18.2000       .6300     14.6000    114.0000
 EOI ENCOUNTERED.
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These are the analytical data for the North Central corridor samples with their coordinates.

Format:

Id long. lat. Li Na K Rb Be Mg Ca Sr

Ba Al La Ti V Cr Mo Mn Fe Co

Ni Cu Ag Zn Cd Pb P

(All concentrations are in Ppm.)

IMPERIAL COLLEGE LONDON
CENTRAL LIBRARY

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 2310.     10.4000     6.7500    15.0000  13000.0000  54000.0000    220.0000     2.1000    920.0000   1170.0000     89.0000
1340.0000 58000.0000    2.4000   240.0000      1.4800    -99.0000      3.4000    65.0000   9700.0000      3.6000
   1.6500   -99.0000   -99.0000    13.5000    -99.0000     70.0000    115.0000
 2320.     10.4000     6.7500     5.0000  45000.0000   4700.0000    -99.0000     1.9000    129.0000   9400.0000     40.0000
  25.0000 51000.0000    4.2000    17.1000    -99.0000    -99.0000    -99.0000    10.7000    920.0000      1.9900
 -99.0000   -99.0000   -99.0000   -99.0000    -99.0000     23.0000     91.0000
 4355.      9.1700     5.8300    15.2000  19000.0000  19200.0000    102.0000     1.1200  18600.0000  72000.0000    440.0000
1040.0000 64000.0000   25.0000  2300.0000     68.0000     68.0000      4.8000   650.0000  25000.0000     17.2000
  33.0000    6.3000   -99.0000    44.0000    -99.0000     22.0000    490.0000
 4362.      9.4500     7.1200    21.0000  30000.0000  19300.0000     97.0000     2.5000  10200.0000  29000.0000    250.0000
 810.0000 79000.0000   75.0000  4100.0000     66.0000     25.0000      2.4000   700.0000  39000.0000     18.2000
  26.0000   18.8000   -99.0000    71.0000      1.0400     25.0000    970.0000
 4363.      9.4500     7.1200    19.1000  18300.0000  10700.0000     59.0000     1.0000  48000.0000  72000.0000    152.0000
 400.0000 63000.0000   12.8000  5000.0000    179.0000    530.0000      5.2000  1510.0000  80000.0000     58.0000
 290.0000   47.0000   -99.0000    98.0000    -99.0000     16.8000    430.0000
 4365.      9.4500     7.1100    21.0000  37000.0000  14300.0000     72.0000     1.8400  11200.0000  31000.0000    280.0000
 680.0000 68000.0000   10.6000  3600.0000     45.0000     75.0000     20.0000   280.0000  22000.0000     24.0000
  77.0000    4.3000   -99.0000    42.0000      1.0900     22.0000   1020.0000
 4371.      9.4300     7.2000    10.2000  22000.0000  51000.0000    127.0000      .6600   2200.0000   7900.0000    210.0000
3500.0000 48000.0000   30.0000   970.0000     5.6000    -99.0000      4.0000    63.0000   9400.0000      3.9000
   5.5000    8.5000   -99.0000    28.0000    -99.0000     42.0000    880.0000
 4372.      9.4300     7.2000     9.5000  22000.0000  50000.0000    121.0000      .6300   2200.0000   8000.0000    210.0000
3500.0000 47000.0000   29.0000   970.0000     5.0000    -99.0000      3.1000    62.0000   9400.0000      4.8000
   5.0000    8.8000   -99.0000    26.0000    -99.0000     37.0000    860.0000
 4373.      9.4300     7.2500    23.0000  29000.0000  31000.0000     94.0000     1.0200   1490.0000   8300.0000    270.0000
2400.0000 52000.0000   26.0000  1100.0000     9.1000      1.8500      3.8000    94.0000   8500.0000      3.2000
   6.4000    1.8300   -99.0000    30.0000      1.1000     42.0000    113.0000
 4374.      9.4800     7.2700    27.0000   6600.0000  12200.0000     90.0000      .6600   9800.0000  17100.0000     42.0000
 176.0000 40000.0000   15.9000  1010.0000     22.0000     37.0000      3.8000   630.0000  16300.0000     10.3000
  30.0000   21.0000   -99.0000    36.0000    -99.0000     11.4000     32.0000
 4375.      9.4200     7.2500    20.0000  29000.0000  37000.0000    117.0000     1.0700   1480.0000  11000.0000    290.0000
2700.0000 67000.0000   38.0000  1000.0000     9.2000      1.3800    -99.0000    99.0000   8400.0000      4.2000
   6.9000    1.8600   -99.0000    34.0000      1.1500     47.0000    151.0000
 4381.      9.5000     7.3000     2.2000   9100.0000   2600.0000    -99.0000     3.4000  11300.0000 123000.0000    290.0000
 150.0000 86000.0000   32.0000  2900.0000     43.0000     89.0000    -99.0000   690.0000  37000.0000     14.5000
  95.0000    2.2000   -99.0000    70.0000    -99.0000    -99.0000    186.0000
 4382.      9.5000     7.3300    21.0000  32000.0000  12700.0000     48.0000     1.7700   5300.0000  23000.0000    250.0000
 850.0000 67000.0000   39.0000  2700.0000     30.0000      8.2000    -99.0000   360.0000  24000.0000     11.9000
  12.3000    6.9000   -99.0000    61.0000      .8300     18.5000    610.0000
 4383.      9.5000     7.3300    14.1000  26000.0000  31000.0000     69.0000     1.4600   5200.0000  20000.0000    300.0000
2400.0000 76000.0000   83.0000  1610.0000     32.0000      8.8000    -99.0000   340.0000  18800.0000     10.4000
  14.9000   67.0000   -99.0000    51.0000      .9200     28.0000    590.0000
 4384.      9.5000     7.3800     7.3000  23000.0000  37000.0000     81.0000      .8900   1490.0000   9700.0000    210.0000
1840.0000 55000.0000   37.0000  1260.0000     18.7000      4.6000      1.0900   144.0000  15900.0000      5.0000
   7.0000    1.5100     1.0400    38.0000      .8300     42.0000    190.0000
 4385.      9.5000     7.5500     8.3000  24000.0000  38000.0000    116.0000      .5200    840.0000   9000.0000     74.0000
 680.0000 56000.0000   43.0000   350.0000     2.9000      1.8900    -99.0000   125.0000   5700.0000      1.2900
  45.0000    1.7800   -99.0000    12.5000      .7800     43.0000     90.0000
 4386.      9.4800     7.4500    35.0000  36000.0000   8400.0000     50.0000     1.1900   3300.0000  23000.0000    250.0000
 124.0000 71000.0000   26.0000  1610.0000     18.4000      3.9000    -99.0000   270.0000  15900.0000      6.9000
   6.5000    8.9000   -99.0000    46.0000      .6800     13.9000    350.0000
 4387.      9.4800     7.4500    50.0000  30000.0000  22000.0000     87.0000     1.0500   5100.0000  22000.0000    144.0000
 690.0000 68000.0000   34.0000  2600.0000     28.0000      5.8000      1.1800   490.0000  26000.0000      9.1000
  18.5000    5.4000   -99.0000    76.0000      .7000     20.0000   1040.0000
 4388.      9.4800     7.4500    50.0000   3000.0000   5400.0000     80.0000     1.1300   5300.0000   4000.0000    156.0000
 380.0001  2000.0000   38.0000  2600.0000     29.0000      4.3000      1.1000   420.0000  26000.0000     12.1000
   7.1000    3.9000   -99.0000    76.0000      .8500     17.6000    890.0000
 4391.      9.4200     7.6700    51.0000  35000.0000   8900.0000     56.0000     1.5500   2800.0000  19200.0000     81.0000
 115.0000 62000.0000   35.0000  2000.0000     9.6000      1.4100    -99.0000   550.0000  26000.0000      7.7000
   3.4000    2.7000   -99.0000    71.0000    -99.0000     21.0000    360.0000
 4392.      9.4200     7.7000    46.0000  30000.0000  12800.0000     61.0000     1.0200   2800.0000  21000.0000    126.0000
 670.0000 53000.0000   35.0000  1840.0000     19.7000      2.8000    -99.0000   310.0000  21000.0000      7.5000
  13.8000    8.0000   -99.0000    61.0000    -99.0000     14.8000    350.0000
 4393.      9.4300     7.7500    10.9000  41000.0000   8300.0000     29.0000     1.1500   3200.0000  23000.0000    320.0000
 460.0000 71000.0000   24.0000  1130.0000     9.1000      5.5000      1.2300   210.0000  10500.0000      3.9000
  34.0000    1.2600   -99.0000    39.0000      .5500     15.4000    186.0000
 4394.      9.4300     7.7500    21.0000  30000.0000  13200.0000     50.0000     1.2500  11300.0000  27000.0000    300.0000
 530.0000 75000.0000   37.0000  3000.0000     48.0000     38.0000      1.6100   570.0000  28000.0000     17.6000
  53.0000    3.7000   -99.0000    64.0000      .8300     13.3000    280.0000
 4395.      9.4300     7.7800    15.0000  37000.0000  18800.0000     65.0000     1.3300   2200.0000  13400.0000    310.0000
 940.0000 58000.0000   12.5000   990.0000     13.3000      4.5000      2.5000   200.0000   9700.0000      2.7000
  28.0000    6.1000    1.3000    45.0000      .8800     34.0000    230.0000
 4396.      9.5000     7.5400    12.5000  24000.0000  39000.0000    129.0000      .5600   2000.0000   9500.0000     76.0000
 650.0000 60000.0000   34.0000   890.0000      5.0000    -99.0000    -99.0000   143.0000  11500.0000      3.8000
   1.6200    2.3000   -99.0000    28.0000    -99.0000     50.0000     96.0000
 4404.      9.4800     7.8800    16.3000  36000.0000  17100.0000     60.0000     2.1000   4600.0000  19700.0000    270.0000
 930.0000 61000.0000   32.0000  2200.0000     30.0000      7.9000    -99.0000   370.0000  18700.0000      9.3000
  11.4000    6.3000   -99.0000    86.0000      1.0700     29.0000    830.0000
 4751.      9.5800     6.9700    20.0000  29000.0000  27000.0000     69.0000     1.2000   2300.0000  14200.0000    390.0000
2500.0000 61000.0000   41.0000  1330.0000     15.3000      2.7000    -99.0000   114.0000  12900.0000      5.1000
   4.2000     .8900   -99.0000    32.0000      .9900     29.0000    450.0000
 4752.      9.5800     6.9700    13.2000  26000.0000   8500.0000     35.0000      .9400   2200.0000   9700.0000    300.0000
1510.0000 38000.0000   42.0000  1260.0000     14.3000      1.8700    -99.0000    99.0000  10200.0000      5.1000
   3.3000   -99.0000   -99.0000    45.0000      .7500     18.4000    280.0000
 4753.      9.7200     6.9300    12.4000  28000.0000  32000.0000     99.0000      .8400   1770.0000  10400.0000    270.0000
1920.0000 65000.0000   44.0000  1070.0000      7.4000      2.2000    -99.0000   139.0000   9400.0000      4.2000
   7.5000    1.4800   -99.0000    32.0000      .5000     34.0000    210.0000
 4754.      9.7000     6.8800    12.2000  23000.0000  26000.0000     70.0000     1.2200   3300.0000  11000.0000    270.0000
1850.0000 56000.0000   94.0000  2100.0000     19.6000      5.4000    -99.0000   240.0000  17000.0000      6.6000
   8.7000    7.1000   -99.0000    48.0000    -99.0000     25.0000    510.0000
 4761.      9.7200     6.8800    11.1000  30000.0000  24000.0000     77.0000     1.0300   1870.0000  13900.0000    380.0000
1820.0000 64000.0000   51.0000  1030.0000      8.6000      2.4000    -99.0000    89.0000   8600.0000      2.1000
   2.5000    1.7200   -99.0000    25.0000      .7200     23.0000    166.0000
 4762.      9.7200     6.8800    22.0000  36000.0000  17500.0000    106.0000     2.5000   8000.0000  21000.0000    320.0000
 880.0000 73000.0000   67.0000  3400.0000     38.0000     12.3000    -99.0000   540.0000  28000.0000     15.8000
  29.0000   40.0000   -99.0000    72.0000      .7300     24.0000    950.0000
 4763.      9.7200     6.8800    13.8000  31000.0000  32000.0000    107.0000     1.5100   3800.0000  12000.0000    230.0000
2000.0000 64000.0000   83.0000  2100.0000     25.0000      7.2000    -99.0000   240.0000  17600.0000      7.2000
  11.1000    4.1000    1.1300    61.0000      .7400     38.0000    490.0000
 4764.      9.7200     6.8800    11.2000  25000.0000  18200.0000     63.0000     1.1100   3500.0000  10100.0000    179.0000
 870.0000 38000.0000   13.2000  1150.0000     14.7000      3.9000    -99.0000   145.0000   9700.0000      5.3000
  40.0000   22.0000   -99.0000    26.0000    -99.0000     18.8000    260.0000
 4765.      9.7200     6.8800    15.3000  35000.0000  21000.0000     43.0000      .9200   2900.0000  15600.0000    390.0000
1830.0000 53000.0000   34.0000  1720.0000     16.5000      3.1000      2.8000   118.0000  13100.0000      9.0000
   2.8000     .8300   -99.0000    42.0000    -99.0000     28.0000    360.0000
 4767.      9.7700     6.8700    29.0000  42000.0000  10300.0000     91.0000     2.9000   5200.0000  15200.0000    220.0000
 150.0000 72000.0000   14.3000  1230.0000     14.6000      6.8000    -99.0000   280.0000  13500.0000      6.1000
  20.0000    1.1900   -99.0000    43.0000      .7000     16.4000    154.0000
 4771.      9.8000     6.8500    14.4000  33000.0000  25000.0000     63.0000     1.0800   2300.0000  12900.0000    370.0000
2400.0000 54000.0000   51.0000  1380.0000     11.8000      1.9600      2.5000   118.0000  12200.0000      9.3000
   1.8100    2.3000   -99.0000    33.0000    -99.0000     38.0000    280.0000
 4773.      9.9500     6.7700    12.8000  31000.0000  25000.0000    102.0000     1.0900   2100.0000  11300.0000    360.0000
2400.0000 52000.0000   37.0000  1250.0000     12.1000      1.9000      7.4000   119.0000  11600.0000      5.3000
  11.7000    3.4000   -99.0000    40.0000      1.2000     45.0000    200.0000
 4774.      9.9700     6.7700    10.4000  34000.0000  22000.0000     97.0000     1.3600   1860.0000  11600.0000    380.0000
1750.0000 48000.0000   28.0000   980.0000     12.1000      2.5000      5.6000   102.0000   9300.0000      4.4000
   4.5000    5.7000   -99.0000    27.0000      1.1300     33.0000    158.0000
 4775.     10.7000     6.7500     5.1000  27000.0000  31000.0000    109.0000      .6800   1330.0000   8700.0000    330.0000
2300.0000 46000.0000   22.0000   860.0000      7.8000      1.8700      6.6000    73.0000   6600.0000      3.8000
   7.4000    3.3000   -99.0000    24.0000      1.1100     41.0000     59.0000
 4776.      9.7500     6.8800     9.3000  19100.0000   8200.0000     52.0000     2.1000  25000.0000  63000.0000    350.0000
 300.0000 69000.0000   32.0000 21000.0000    420.0000     32.0000     11.3000  1620.0000 112000.0000     74.0000
  49.0000   430.0000   -99.0000   131.0000      2.8000     25.0000   2100.0000
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These are the analytical data for the Northwest Granite and associated gneiss samples with their coordinates.

Format:

Id long. lat. Li Na K Rb Be Mg Ca Sr

Ba Al La Ti V Cr Mo Mn Fe Co

Ni Cu Ag Zn Cd Pb P

(All concentrations are in Ppm.)

2083. .9 8.8800 19.3200 22000.0000 30000.0000 133.0000 1.1800 1710.0000 4400.0000 83.0000
1230.0000 44000.0000 9.4600 -99.0000 5.9700 5.9300 3.6000 128.0000 7500.0000 6.2000
5.8000 .7800 -99.0000 23.0000 -99.0000 24.0000 66.0000
2405. 9.5300 7.9900 47000.0000 -99.0000 -99.0000 66.0000 .7700 2400.0000 14400.0000 290.0000
2200.0000 59000.0000 45.0000 1750.0000 9.8000 2.8800 1.2900 85.0000 10400.0000 4.6000
5.1000 1.1700 -99.0000 -99.0000 .8100 27.0000 137.0000
2406. 9.5500 7.8500 14.5500 24000.0000 8000.0000 .6200 2600.0000 11000.0000 290.0000
4000.0000 72000.0000 84.0000 1330.0000 8.8000 3.2000 3.3300 84.0000 11800.0000 5.8000
10.8000 3.1000 1.1700 35.0000 .8500 37.0000 490.0000
2411. 9.5500 7.9700 5.5000 30000.0000 32000.0000 97.0000 .4000 1490.0000 8100.0000
1500.0000 55000.0000 37.0000 1040.0000 3.9900 1.9400 132.0000 9900.0000 4.4000
1.2700 2.1000 -99.0000 -99.0000 -99.0000 159.0000
2412. 9.5500 7.9700 -99.0000 28000.0000 .8000 91.0000 .4000 1200.0000 7500.0000 162.0000
1690.0000 54000.0000 34.0000 790.0000 4.7300 1.8400 121.0000 8500.0000 3.7000
4.6000 -99.0000 -99.0000 -99.0000 -99.0000 112.0000
2413. 9.5700 7.9900 5.5000 30000.0000 31000.0000 83.0000 .4500 650.0000 8500.0000 184.0000
1170.0000 53000.0000 5.9900 470.0000 4.1000 1.8200 50.0000 3900.0000 3.3000
4.0000 1.0700 -99.0000 -99.0000 -99.0000 55.0000
2414. 9.5700 7.9800 14.4000 43000.0000 9700.0000 33.0000 .8600 3200.0000 15900.0000 193.0000
1210.0000 52000.0000 47.6000 1360.0000 8.0800 3.0000 156.0000 12100.0000 5.1100
8.6000 5.2000 -99.0000 -99.0000 -99.0000 135.0000
2415. 9.5700 7.9900 16.6900 39000.0000 15100.0000 68.0000 .7700 3900.0000 14100.0000 196.0000
1490.0000 54000.0000 19.4000 1950.0000 10.1000 4.1900 240.0000 14000.0000 6.2000
4416. 9.5700 7.9900 22.4000 33000.0000 8200.0000 31.0000 1.2900 11500.0000 41000.0000 147.0000
1310.0000 71000.0000 26.6000 4000.0000 114.0000 26.0000 1.4800 780.0000 41000.0000 19.1000
41.9000 -99.0000 -99.0000 64.0000 -99.0000 12.9000 1000.0000
2417. 9.5800 7.9900 6.5000 36000.0000 37000.0000 103.0000 .4000 1160.0000 7400.0000 200.0000
1410.0000 54000.0000 4.1000 470.0000 4.0000 1.8600 82.0000 5400.0000 2.9000
10.7000 7.6400 -99.0000 23.0000 -99.0000 30.0000 148.0000
2421. 9.6000 7.9700 13.1300 40000.0000 11400.0000 38.0000 1.2200 4500.0000 16700.0000 270.0000
1430.0000 57000.0000 33.0000 2200.0000 21.0000 7.6000 4.7000 320.0000 18400.0000 8.4000
27.6000 17.3000 -99.0000 72.0000 -99.0000 25.0000
2422. 9.6200 8.0700 8.8000 32000.0000 26000.0000 70.0000 1.2000 1730.0000 11600.0000 310.0000
1860.0000 48000.0000 11.5000 1100.0000 9.7200 5.1400 3.3000 159.0000 11400.0000 5.2000
7.1000 .5000 -99.0000 36.0000 -99.0000 30.0000
2423. 9.6400 8.1000 6.2000 40000.0000 10800.0000 -99.0000 .8700 2700.0000 18100.0000 420.0000
1150.0000 59000.0000 13.9900 1300.0000 14.4400 3.8900 2.9900 117.0000 11200.0000 3.8000
4.2000 1.1700 30.0000 -99.0000 -99.0000 320.0000
2424. 9.6700 8.1300 5.4600 32900.0000 11700.0000 45.0000 .8400 1980.0000 14700.0000 390.0000
1290.0000 58000.0000 10.7000 850.0000 13.1000 3.5100 149.0000 9400.0000 4.9000
7.4000 1.1700 -99.0000 32.0000 -99.0000 24.0000 61.0000
2425. 9.7200 8.1300 4.5500 33000.0000 14100.0000 57.0000 .8700 2900.0000 13800.0000 480.0000
1370.0000 53000.0000 23.0000 980.0000 11.9900 7.9900 210.0000 14300.0000 5.7000
19.7000 5.2000 -99.0000 -99.0000 -99.0000 410.0000
2427. 9.7500 8.1500 4.2900 38000.0000 7400.0000 33.0000 .9700 2500.0000 15000.0000 410.0000
1100.0000 44000.0000 37.0000 910.0000 17.2000 3.5000 95.0000 11100.0000 4.9000
7.3000 2.5000 -99.0000 36.0000 -99.0000 24.0000 490.0000
2428. 9.8000 8.1800 4.8800 31000.0000 18500.0000 46.0000 .8000 1930.0000 14100.0000 380.0000
2800.0000 51000.0000 5.3000 860.0000 12.4600 2.7000 122.0000 8900.0000 4.1000
26.4000 4.1700 -99.0000 41.0000 -99.0000 23.0000 52.0000
2429. 9.8200 8.1600 10.2000 40000.0000 -99.0000 1.3100 3100.0000 16300.0000 340.0000
590.0000 49000.0000 21.0000 1540.0000 16.4600 3.8500 124.0000 14400.0000 8.0000
41.9000 -99.0000 -99.0000 58.0000 -99.0000 18.7000 406.0000
2430. 9.7700 8.1700 31.0000 35000.0000 17800.0000 1.2900 4800.0000 18600.0000 360.0000
750.0000 49000.0000 51.0000 3100.0000 14.0000 5.1100 400.0000 27000.0000 12.3000
12.5000 3.4000 -99.0000 70.0000 -99.0000 22.0000 4.5500
2433. 9.7300 8.2000 8.5000 37000.0000 8000.0000 41.0000 1.2000 2700.0000 18600.0000 390.0000
510.0000 53000.0000 15.5000 7.8800 13.4600 1670.0000 14.4000 7.8800 240.0000 11600.0000 6.0000
34.0000 7.7000 -99.0000 36.0000 -99.0000 26.0000 220.0000
2434. 9.7500 8.2000 22.6000 34000.0000 17100.0000 44.0000 1.2100 5100.0000 21000.0000 410.0000
860.0000 58000.0000 37.0000 2300.0000 38.0000 7.4000 1.1100 270.0000 21000.0000 10.5000
44.7000 9.7000 -99.0000 57.0000 -99.0000 18.4000 485.0000
2437. 9.7700 8.3000 12.3000 37000.0000 11800.0000 25.0000 .9600 2800.0000 25000.0000 390.0000
1020.0000 60000.0000 31.0000 2990.0000 42.0000 8.5000 -99.0000 360.0000 25000.0000 8.5000
27.5000 21.0000 -99.0000 67.0000 -99.0000 8.6000 630.0000
2439. 9.7700 8.3100 12.4000 33000.0000 7700.0000 76.0000 1.0900 2800.0000 13300.0000 197.0000
790.0000 59000.0000 17.3000 1230.0000 13.0000 4.4000 -99.0000 280.0000 14000.0000 7.0000
7.8800 12.7000 -99.0000 -99.0000 -99.0000 94.0000
2444. 9.7800 9.4500 18.9000 37000.0000 11400.0000 55.0000 1.7600 4900.0000 19700.0000 310.0000
1010.0000 64000.0000 10.0000 1590.0000 36.0000 5.0600 310.0000 18200.0000 9.4000
16.9000 7.5000 -99.0000 46.0000 -99.0000 26.0000 360.0000
2445. 9.7800 8.4000 18.7000 29000.0000 11600.0000 43.0000 1.5200 4800.0000 21000.0000 410.0000
670.0000 60000.0000 83.0000 1570.0000 55.0000 25.0000 -99.0000 600.0000 29000.0000 10.4000
2520.0000 51.0000 -99.0000 -99.0000 12.1300 14.0000 420.0000
2446. 9.9500 8.4300 12.5000 33000.0000 15400.0000 44.0000 1.2100 3700.0000 16600.0000 210.0000
650.0000 61000.0000 27.0000 2100.0000 25.5000 5.8100 1.1600 260.0000 15000.0000 8.0000
11.9000 53.0000 -99.0000 57.0000 -99.0000 16.3000 420.0000
2447. 9.8700 8.4100 9.4500 29000.0000 24000.0000 64.0000 .8400 2300.0000 12100.0000 310.0000
1740.0000 44000.0000 31.0000 2700.0000 13.2900 9.5500 181.0000 11200.0000 5.9000
14.2500 5.4000 -99.0000 -99.0000 -99.0000 127.0000
2452. 9.8800 8.4300 14.3000 40000.0000 5900.0000 -99.0000 .9400 1740.0000 13400.0000 290.0000
2960.0000 58000.0000 14.7000 1010.0000 7.4600 -99.0000 123.0000 8500.0000 4.8000
3.8000 8.5000 -99.0000 45.0000 -99.0000 10.1000 148.0000
4453. 9.8800 8.4300 15.6000 38000.0000 -99.0000 1.3200 3200.0000 22000.0000 340.0000
420.0000 59000.0000 10.7000 1360.0000 22.0000 -99.0000 169.0000 -99.0000 12600.0000 6.6000
4.8000 10.5000 -99.0000 32.0000 -99.0000 13.4000 365.0000
4454. 9.9300 8.4600 23.0000 17400.0000 -99.0000 .5700 26000.0000 18000.0000 139.0000
104.0000 55000.0000 6.9900 5990.0000 145.0000 37.0000 5.7900 1080.0000 5700.0000 94.0000
83.0000 7.7000 -99.0000 127.0000 -99.0000 12.6000 440.0000
4461. 9.9700 8.4900 28.1000 32000.0000 11500.0000 -99.0000 1.6500 770.0000 16700.0000 178.0000
16.0000 50000.0000 16.0000 3000.0000 37.0000 29.0000 4.4600 450.0000 27000.0000 14.0000
36.0000 24.2000 -99.0000 -99.0000 -99.0000 25.0000 450.0000
4462. 9.9300 8.4600 3.2900 33000.0000 25900.0000 90.0000 1.0400 1650.0000 7900.0000 220.0000
1510.0000 57000.0000 51.0000 926.0000 7.2300 3.1000 240.0000 8700.0000 4.5000
51.0000 2.5000 -99.0000 24.0000 -99.0000 31.0000 197.0000
4463. 9.8800 8.4200 27.0000 33000.0000 15400.0000 118.0000 1.6400 4900.0000 17100.0000 270.0000
990.0000 47000.0000 21.0000 2100.0000 32.0000 9.8800 6.8800 280.0000 18600.0000 9.2000
19.7000 11.4000 -99.0000 -99.0000 34.0000 -99.0000 59.0000
4464. 9.9000 8.4300 5.3000 33000.0000 14500.0000 59.0000 .8200 1420.0000 10100.0000 210.0000
599.0000 44000.0000 15.9900 740.0000 6.4600 2.5200 240.0000 7500.0000 3.5000
5.9800 8.5500 -99.0000 23.0000 -99.0000 29.0000 58.0000
4465. 9.9200 8.4000 14.9000 27000.0000 35000.0000 114.0000 1.1800 4200.0000 13100.0000 240.0000
2200.0000 49000.0000 33.0000 1680.0000 31.0000 5.2000 240.0000 15800.0000 9.4000
21.0000 12.2000 -99.0000 -99.0000 -99.0000 620.0000
4471. 10.0000 9.1800 24.0000 34000.0000 16700.0000 44.0000 1.5700 7300.0000 21000.0000 330.0000
829.0000 55000.0000 10.2000 2800.0000 45.0000 10.1000 370.0000 25000.0000 10.5000
29.4000 17.5000 -99.0000 66.0000 -99.0000 24.0000 880.0000
4472. 9.9900 8.4000 11.6000 35900.0000 17500.0000 69.0000 1.1800 5100.0000 20000.0000 270.0000
510.0000 63000.0000 14.6000 2100.0000 33.0000 6.8000 1.3400 290.0000 23000.0000 9.1000
18.4000 7.1000 -99.0000 57.0000 -99.0000 32.0000 680.0000
4473. 10.1000 9.3800 32.0000 30000.0000 21000.0000 76.0000 1.5400 4800.0000 17600.0000 270.0000
1170.0000 44000.0000 14.5000 2100.0000 28.0000 4.9900 240.0000 17800.0000 14.1000
9.0000 11.6000 -99.0000 52.0000 -99.0000 29.0000 520.0000
4474. 10.1000 9.3800 27.0000 33000.0000 23000.0000 109.0000 1.8300 5600.0000 17800.0000 310.0000
1140.0000 53000.0000 29.0000 2900.0000 34.0000 6.5000 -99.0000 320.0000 20000.0000 8.7000
12.7000 9.4000 -99.0000 58.0000 -99.0000 25.0000 860.0000
4475. 10.0000 9.3700 21.0000 36000.0000 9600.0000 45.0000 2.1000 3200.0000 22000.0000 300.0000
400.0000 57000.0000 24.0000 1570.0000 29.0000 4.9900 210.0000 15100.0000 8.0000
24.0000 19.5000 1.5300 39.0000 -99.0000 23.0000 630.0000
4481. 10.0000 9.3700 19.5000 30000.0000 32000.0000 123.0000 .9400 2100.0000 9700.0000 177.0000
1000.0000 54000.0000 32.0000 1090.0000 9.9000 4.1000 -99.0000 170.0000 12100.0000 3.5000
5.1000 .2500 -99.0000 38.0000 -99.0000 40.0000 280.0000
4482. 10.0000 9.1800 9.9900 24000.0000 3600.0000 25.0000 1.2000 6400.0000 21000.0000 410.0000
10.8000 46000.0000 14.5000 1180.0000 7.4000 2.1000 550.0000 22000.0000 10.3000
35.0000 26.0000 -99.0000 40.0000 -99.0000 16.7000 740.0000
4483. 10.0000 9.3600 13.7000 29000.0000 32000.0000 78.0000 1.0400 1600.0000 12200.0000 330.0000
2400.0000 58000.0000 13.7000 790.0000 15.2000 2.7000 91.0000 9700.0000 5.4000
6.8000 23.0000 -99.0000 37.0000 -99.0000 21.0000 170.0000
4484. 10.0000 9.2700 16.7000 30000.0000 26000.0000 59.0000 1.3300 3600.0000 16600.0000 470.0000
2100.0000 59000.0000 33.0000 1710.0000 7.0000 5.1000 128.0000 12300.0000 6.2000
10.3000 34.0000 -99.0000 32.0000 -99.0000 19.0000 340.0000
4485. 10.0000 9.3800 17.8900 35000.0000 17000.0000 70.0000 2.1000 8000.0000 25000.0000 310.0000
590.0000 54000.0000 22.0000 3100.0000 51.0000 8.7000 2.7000 350.0000 26000.0000 13.3000
24.0000 17.9000 -99.0000 41.0000 -99.0000 19.3000 520.0000
4486. 10.1000 9.3700 16.3000 33000.0000 15900.0000 52.0000 1.5700 6000.0000 24000.0000 490.0000
1330.0000 65000.0000 24.0000 2500.0000 28.0000 4.9000 350.0000 30000.0000 10.3000
23.0000 30.0000 -99.0000 -99.0000 -99.0000 25.0000 720.0000
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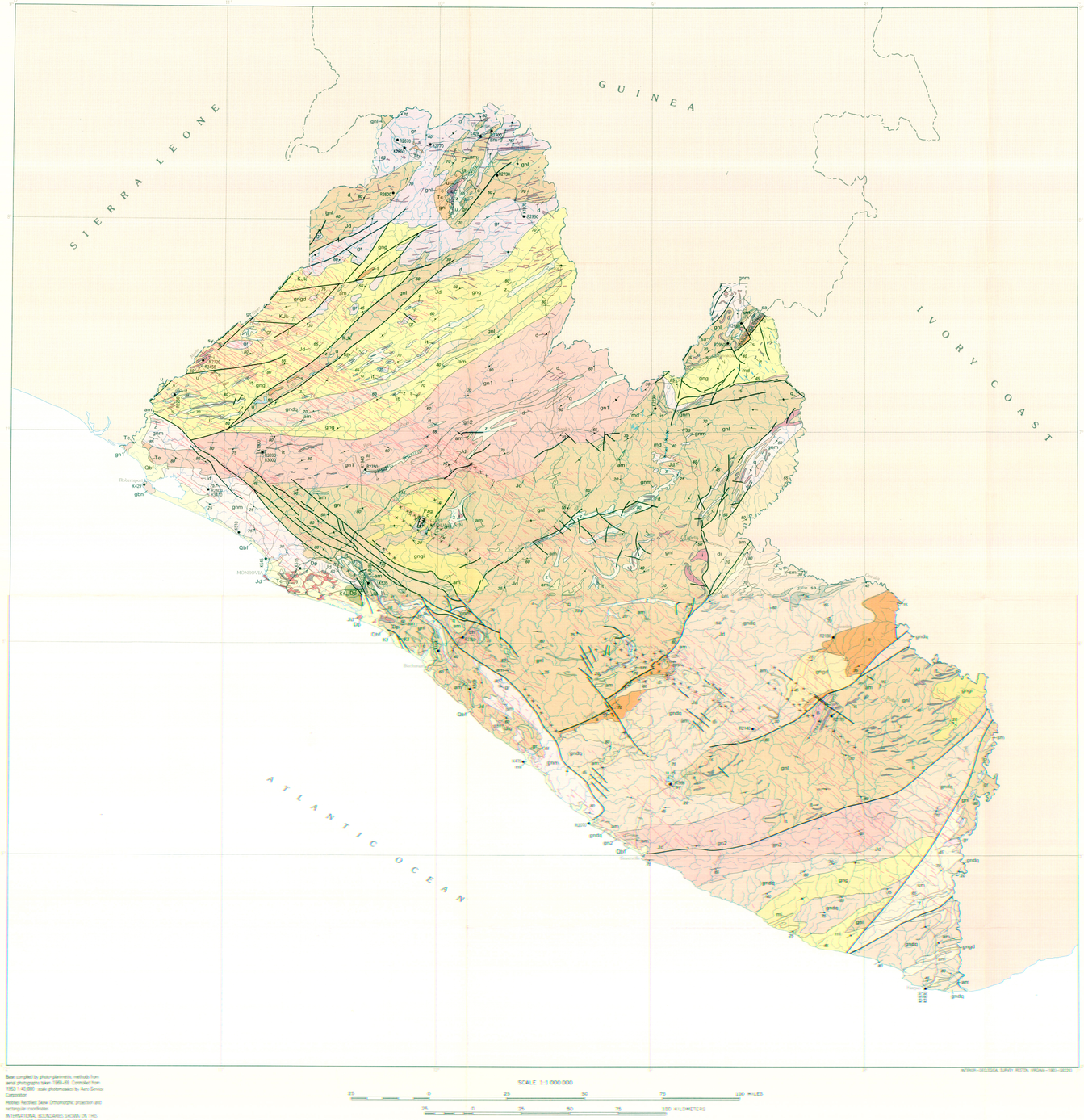
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Saint Paul River
Mano River
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