1973/110
Copy 4

Restricted until after publication.
Manuscript submitted for publication
to: JOURNAL EXPLORATION GEOCHEMISTS

CANCELLED

DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD NO. 1973/110

014553

GEOCHEMISTRY OF MINERALIZED GRANITIC ROCKS OF NORTHEAST QUEENSLAND

by

J.W. Sheraton and L.P. Black

Record 1973/110

GEOCHEMISTRY OF MINERALIZED GRANITIC ROCKS OF NORTHEAST QUEENSLAND

by

J.W. Sheraton and L.P. Black

GEOCHEMISTRY OF MINERALIZED GRANITIC ROCKS OF NORTHEAST QUEENSLAND

J.W. Sheraton and L.P. Black

ABSTRACT

Tin-bearing granitic rocks of Northeast Queensland range in age from Precambrian to Permian. They are high-level granites or adamellites enriched in volatile elements, such as Li, Be, B, and F. Tin contents are significantly higher than those of non-stanniferous granites, but lower than values reported for many tin granites elsewhere. A distribution of tin in which a high proportion of samples have tin contents significantly higher than background values, appears to be a useful criterion of potential tin mineralization. An uneven distribution of tin in the crust (or possibly the upper mantle) would explain the difference in tin contents of granites associated with tin mineralization, compared with granites from areas which do not contain tin deposits.

No correlation of granite geochemistry with lead/zinc or copper mineralization was found. In particular, granites associated with such mineralization do not show anomalous abundances of Pb, Zn, or Cu. If mineralization is regarded as an independent by-product of magma generation rather than the result of differentiation processes, then this lack of correlation is explicable.

Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T., Australia. Published with permission of the Director.

Introduction

In 1970 the Bureau of Mineral Resources began a geochemical investigation of the acid igneous rocks of northeast Queensland. The purpose of this study was to investigate any correlation between the geochemistry of the granitic rocks and the type of associated mineralization in order to discover possible geochemical criteria of general use in delineating areas of potential mineralization. The area chosen for the investigation includes a large part of northeast Queensland, covering the Georgetown Inlier and much of the Hodgkinson Basin between Cooktown in the north and Ingham in the south (Fig. 1). The general geology of the area has been described by de Keyser and Wolff (1964), White (1965), de Keyser and Lucas (1968), and Blake (1972). Intrusive and extrusive acid igneous rocks of many types are present, and associated with them is a rather wide variety of economic mineralization, including gold, tin, copper, lead, zinc, silver, molybdenum, tungsten, bismuth, antimony, and minor uranium and tantalum.

In the first part of the project about 600 acid igneous rocks were analysed for a large number of major and trace elements, including Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, Rb, Sr, Pb, and Th (by X-ray fluorescence) and Li, Be, Cr, Co, Ni, Cu, Zn, and Sn (by atomic absorption spectroscopy). Ferrous iron, water, carbon dioxide, and fluorine were determined by the Australian Mineral Development Laboratories. In the next stage ferromagnesian minerals (mostly biotites) from both granitic rocks and mineral veins will be analysed. Only a summary of the chemical results will be presented here; complete listings of the analyses, together with more detailed descriptions of the various rock units, will be reported elsewhere (Sheraton and Labonne, in prep.).

Geology of the Granitic rocks

The acid igneous rocks of the area range in age from Precambrian to Permian. They intrude the Precambrian metamorphics and sediments of the Georgetown Inlier, as well as the Middle Palaeozoic sediments of the Hodgkinson Basin, a part of the Tasman Geosyncline. The approximate ages of the main granitic rocks are given in Table 1, which also lists the associated economic mineralization.

The oldest granitic rocks form part of the Forsayth Batholith, which occupies much of the central part of the Georgetown Inlier. The Forsayth Granite includes a variety of rock types, ranging from granite to quartz diorite, which have not yet been mapped in detail. Some of these rocks could well be as old as 1600 m.y., whereas others may be only about 400 m.y. old (Black, in prep.). Geochemically the Forsayth Granite forms an extremely heterogeneous group of granitic rocks and consequently will not be considered in detail.

The Esmeralda Granite and comagmatic Croydon Volcanics, although originally correlated with the Upper Palaeozoic acid igenous rocks by Branch (1966), have now been dated at about 1475 m.y. (Webb, 1971; Black, 1973). The Esmeralda Granite, which forms several intrusion on the western side of the Georgetown Inlier (Fig. 1), is typically a grey medium to coarse-grained biotite adamellite, grading into granite. Tourmaline is a widespread accessory, and greisens are common in some localities. The Esmeralda Granite is a high-level (epizonal) intrusion which crystallized under a volcanic cover estimated by Branch (1966) to be only 300 - 600 m thick. Associated economic mineralization includes gold and tin, which are restricted to the granites and volcanics of the western part of the area. A little silver/lead and copper has also been mined, but only gold has been produced in significant quantities (White, 1965; Branch, 1966).

Table 1.

	Approx. age (m.y.)	Associated mineralization
Finlayson Granite	262	Sn
Mareeba Granite	288	Sn, W, Cu
Almaden Granite	300	Cu, Pb, Ag, Zn
Herbert River Granite	300	(Cu, Pb, W)
Elizabeth Creek Granite	320	Sn, Mo, W, Pb, Cu (Au, Bi, Ag, Sb)
Dumbano Granite, Dido Granodiorite	400 - 420	no economic mineralization
Esmeralda Granite	1475	Au, Sn (Pb, Ag, Cu)
Forsayth Granite	?400 - 1600	Au (Pb, Ag, Cu, Ta)

Major granitic rocks of northeast Queensland, showing approximate ages and economic mineralization associated with each unit. Economic mineralization of only minor importance is given in brackets.

The Dumbano Granite and Dido Granodiorite occur in the southern part of the Georgetown Inlier (Fig. 1). Isotopic dating has indicated a Siluro-Devonian age for both (Richards et al., 1966; Black, 1973). The Dumbano Granite is typically a light grey to pink medium-grained biotite adamellite with pink feldspar phenocrysts, although leucogranite, granodiorite, biotite trondhjemite, and quartz diorite also occur. The Dido Granodiorite consists mainly of hornblende-biotite tonalite and diorite. No economic mineralization is known to be associated with either the Dumbano Granite or the Dido Granodiorite.

The Upper Palaeozoic acid igneous rocks of the Georgetown Inlier have been described in detail by Branch (1966). They occupy a total area of about 30 000 km^2 within the inlier and in the Hodgkinson Basin to the north and east (Fig. 1). The intrusive rocks consist of adamellite, subordinate granite and granodiorite, and minor diorite and gabbro. They are high-level intrusions, some of which crystallized under a cover estimated to be only 150 to 600m thick (Branch, 1966). The extensive comagmatic volcanic rocks consist of rhyodacite welded tuff sheets and flows, with subordinate rhyolite, dacite, andesite, and basalt. They occur in eleven cauldron subsidence areas and five associated ring complexes within, or adjacent to, the Georgetown Inlier (Branch, 1966).

Five groups of Upper Palaeozoic granitic rocks will be considered in more detail. The Elizabeth Creek Granite forms numerous batholiths and stocks, mostly in the northeastern part of the Georgetown Inlier, but extending into the adjacent shelf zone of the Hodgkinson Basin. Isotopic dating suggests an age for most of the granite of about 320 m.y., although there is evidence that some is younger, such as the small stocks at Bamford Hill and Wolfram Camp (about 50 km west-southwest of Mareeba) with which tungsten-molybdenum-bismuth mineralization is associated (Black and Richards, 1972a; Black, in prep.). The most common variety is a pink leucocratic biotite adamellite. Fluorite is a characteristic accessory, and greisenization is common, particularly in areas where the granite is mineralized. The most important economic minerals associated with the Elizabeth Creek Granite are those of tin, molybdenum, and tungsten, although copper, silver, lead, bismuth, zinc, antimony, and gold have also been mined. The Herberton Tinfield is economically the most important area, and up to 1968 had yielded over 107 000 tons of tin oxide, or 15 percent of Australia's total tin production (Blake and Smith, 1970; Blake 1970). Primary deposits include greisen lodes in granite, chlorite-cassiterite lodes, quartz-cassiterite lodes, and complex sulphide lodes with cassiterite (Blake, 1970, 1972). The main source of production at the present time is alluvial cassiterite in the Mount Garnet area. Blake and Smith (1970) have related the mineral deposits of the Herberton area to four zones: a tungsten zone is confined mainly within the Elizabeth Creek Granite and passes outwards into tin, copper, and finally lead zones.

The Herbert River Granite crops out in the same general area as the Elizabeth Creek Granite but is rather younger, with a mean rubidium-strontium age of about 300 m.y. (Black, in prep.). In the Herberton/Mount Garnet area, a number of intrusions originally mapped as Herberton River Granite (Best, 1962; Branch, 1966) have since been shown to consist of separate, and now separately named, masses of slightly different ages (Blake, 1972). The Herbert River Granite is rather more heterogeneous than the Elizabeth Creek Granite, and ranges in composition from biotite granite to hornblende-biotite granodiorite, although grey biotite adamellite predominates. According to Branch (1966), copper, lead, and tungsten mineralization are associated with contaminated varieties of the Herbert River Granite, although the deposits, with the exception of those of the Chillagoe area (discussed below), are of little economic importance.

The related Almaden Granite is typically a hornblende-biotite granodiorite, but also includes adamellite, quartz diorite, and quartz gabbro. Branch (1966) considered that the Almaden Granite was derived from Herbert River magma by contamination with basic magma; the strontium isotope data presented by Black and Richards (1972a) are consistent with such an interpretation. The copper and silver/lead mineralization of the Chillagoe area appears, on field evidence, to be genetically associated with this granite. The deposits, which also contain sphalerite, are contact-replacement lodes in limestone or along contact faults (de Keyser and Wolff, 1964).

The Mareeba Granite comprises several large intrusions and a number of smaller stocks which intrude the Middle Palaeozoic sediments and metamorphics of the Hodgkinson Basin between Innisfail in the south and the Bloomfield River (about 50 km south of Cooktown) in the north (Fig. 1). The most common rock types are grey, generally porphyritic biotite and biotite-muscovite adamellites, although leucogranites and granodiorites also occur. Tourmaline is a common accessory, and greisens are fairly common. The Mareeba Granite is significantly younger than the Herbert River Granite, rubidium-strontium dating indicating an age of about 288 m.y. (Black in prep.). Tin, tungsten, and copper mineralization are associated with it. Mount Carbine, about 60 km north-northwest of Mareeba, has been an important producer of wolfram, ranking with Wolfram Camp and Bamford Hill as one of the three main sources of tungsten in Queensland (Amos and de Keyser, 1964; de Keyser and Lucas, 1968).

The Finlayson Granite forms a number of intrusions in the Annan River Tinfield, south of Cooktown. The main rock types are medium to coarse-grained porphyritic biotite adamellite and granite, frequently tourmaline-bearing. Potassium-argon dating has given a Permian age of 247 ± 6 m.y. (Richards et al., 1966), or 262 m.y. if a 6% upwards adjustment is used to attempt a more meaningful comparison (see Black and Richards, 1972a). The tin mineralization of the Annan River Tinfield, which includes both greisen and stanniferous quartz-tourmaline deposits, is associated with the Finlayson Granite.

Geochemistry of the Granitic Rocks

The Esmeralda Granite, as well as the Croydon Volcanics, has a fairly restricted range of composition (SiO_2 contents mostly lie between 69 and 75%). Variation diagrams show normal calc-alkaline trends for most major elements, although K_2O and FeO (total) are high, and Na_2O and MgO relatively low (Sheraton and Labonne, in prep.). This leads to rather high Niggli k values and low mg values (Fig. 2a). Trace element abundances are mostly close to average for fractionated granitic rocks - Rb, and to some extent Li and Th, are relatively high, whereas Cr, Ni, Cu, and Sr are low (Table 2). K/Rb (average 143) and Mg/Li (average 44) ratios are low. Sn, Pb, and Zn contents are all rather higher than abundances given by Turekian and Wedepohl (1961) for average low-calcium granite, and by Taylor (1968) for average granite (Table 2; Figs 3, 4).

Several lines of evidence suggest an origin for the Esmeralda Granite magma by anatexis of sialic crustal rocks (Sheraton and Labonne, in prep.). Many samples plot within the alkali feldspar field on a normative Or-Ab-An diagram, so that an origin by differentiation of basic magma is unlikely (unless extensive contamination by K-rich material is involved). The trend on an AFM diagram lies outside the normal limits for calc-alkaline rocks as given by Best (1969), suggesting a source material with unusually high FeO/MgO. Finally, high initial Sr^{87}/Sr^{86} ratios of about 0.730 (Webb, 1971) suggest a predominantly crustal origin for the

Table 2. Average composition of Northeast Queensland granitic rocks compared to average granites.

	1.	2.	3.	4.	5.	6.	7.	8.	A	B	C
SiO_2	72.1	72.8	63.5	76.4	73.6	65.1	72.8	74.7	66.9	71.2	74.2
TiO_2	0.31	0.15	0.58	0.10	0.24	0.55	0.25	0.25	0.57	0.40	0.20
Al_2O_3	13.3	14.9	17.0	12.4	13.4	15.4	14.3	13.3	15.7	14.7	13.6
Fe_2O_3	0.93	0.4[illegible]	1.88	0.32	0.43	1.45	0.29	0.35			
FeO	1.99	0.89	2.98	0.95	1.52	3.25	1.71	1.36	3.78*	3.24*	1.83*
MnO	0.05	0.03	0.10	0.03	0.05	0.08	0.06	0.05	0.08	0.05	0.05
MgO	0.29	0.34	1.92	0.11	0.42	2.38	0.43	0.41	1.57	0.55	0.27
CaO	1.39	2.24	5.93	0.71	1.59	4.94	1.40	0.77	3.56	2.00	0.71
Na_2O	2.6	4.2	3.6	3.55	3.65	2.8	3.2	2.9	3.84	3.54	3.48
K_2O	5.02	3.36	1.50	4.74	4.18	2.91	4.25	4.79	3.07	4.18	5.05
P_2O_5	0.14	0.03	0.24	0.02	0.06	0.09	0.13	0.17	0.21	0.16	0.14
H_2O	1.42	0.58	0.77	0.66	0.51	1.00	0.74	0.69			
TOTAL	99.54	100.00	99.96	99.99	99.65	99.95	99.56	99.54			
Li	39	6	7	31	29	19	69	94	25	30	40
Be	4.4	2.6	2.2	5.6	3.8	2.0	3.6	3.5			3
F	~1350			~2100							
Cr	~4	6	11	~3	4	32			30	10	4.1
Co				~3	~7	~11	5	4	10	2	1.0
Ni	~3	~3	4	<3	<3	9	<3	3	15	4	4.5
Cu	7	3	26	6	3	14	6	8	25	10	10
Zn	79	42	66	33	28	45	50	32			39
Rb	291	127	45	427	233	146	356	389	110	145	170
Sr	78	374	812	26	101	196	88	43	440	285	100
Sn	~5	<4	<4	~6	<4	<4	9	16	2	3	3
Pb	51	28	8	32	28	18	26	25	15	30	19
Th	27	14	5	46	29	19	14	17	10	17	17
Mg/Li	44	340	1650	21	87	750	38	26	380	110	40
Rb/Sr	3.7	0.34	0.055	16.4	2.3	0.74	4.1	9.1	0.25	0.51	1.7
K/Rb	14[illegible]	220	277	92	149	165	99	102	230	240	250
Ca/Sr	127	43	52	195	113	180	114	128	58	50	51
K/Pb	820	1000	1560	1230	1330	1340	1360	1590	1700	1160	2210
mg	0.15	0.31	0.42	0.12	0.28	0.48	0.27	0.31	0.43	0.23	0.20
k	0.56	0.34	0.22	0.47	0.43	0.41	0.47	0.52	0.35	0.44	0.49
No. of samples	30	19	12	73	40	15	23	6			

1. Esmeralda Granite
2. Dumbano Granite
3. Dido Granodiorite
4. Elizabeth Creek Granite
5. Herbert River Granite
6. Almaden Granite
7. Mareeba Granite
8. Finlayson Granite

A. Average granodiorite (Taylor, 1968)
B. Average granite (Taylor, 1968)
C. Average low-calcium granite (Turekian & Wedepohl, 1961)

Means for F, Cr and Co are based on fewer analyses than those for other elements.

*Total iron as FeO.

magmas (see review by Faure and Powell, 1972, pp. 43-54).

The Dumbano Granite and Dido Granodiorite form a chemically rather heterogeneous group. Samples do not plot on smooth variation curves, so at least two parent magmas were presumably involved in the formation of these rocks. Thus, the Dumbano trondhjemites do not appear to be chemically related to the group which includes the granites, adamellites, and granodiorites, as well as the Dido tonalites. The Dido quartz diorites form another chemically distinct group, and lie on a fractionation trend which is characterized by relatively high K/Na (Sheraton and Labonne, in prep.).

Abundances of most trace elements, including Sn, Pb, and Zn are close to average values given by Turekian and Wedepohl (1961) and Taylor (1968) for the appropriate rock types (granite or granodiorite) although Li, Ni, Cr, and possibly Th are relatively low. Cu is low in all except the Dido quartz diorites, and is particularly low in the granodiorites and tonalites. Sn is below the detection limit of 4 ppm in all but one sample (Table 2; Figs 3, 4).

The Upper Palaeozoic igneous rocks form a geochemically homogeneous group. The intrusive and extrusive rocks exhibit similar variation trends and abundances of both major and trace elements, supporting Branch's (1966) hypothesis of their comagmatic nature. The volcanics have a greater range of alkali ratios (K/Na), however, which is partly attributed to post-consolidational metasomatism.

The intrusive rocks have a rather restricted range of compositions (94% of the analysed samples contain more than 65% SiO_2). Chemical variation trends for most elements are similar to those for many other calc-alkaline intrusive suites (e.g., Larsen, 1948; Bateman et al., 1963; Erikson, 1969).

Most trace elements show normal variations with fractionation, i.e., depletion in Sr, Cr, Co, Ni, Cu, and Zn and enrichment in Pb, Th, U, Li, Be, and Rb. The most highly fractionated granites, including the Elizabeth Creek, Mareeba (in part), and Finlayson Granites, are relatively low in Fe, Mn, Mg, Ca, Ti, Sr, Cr, Ni, Co, and Cu, and rich in Si, K, Pb, Li, Rb, and Th (Table 2). K/Rb and Mg/Li ratios are low in these granites, whereas Niggli k values are fairly high, and mg tends to be low (Fig. 2b). The Elizabeth Creek Granite is particularly rich in Rb and Th, and the Finlayson and Mareeba Granites have very high Li contents. Zn and Be show little systematic variation, although the former tends to be lower and the latter higher in the most fractionated rocks. The Almaden Granite is relatively low in Li, Rb, Pb, and Th, but the concentrations are near normal for granodiorites (Table 2). The Herbert River Granite has an average composition between those of the Almaden and Elizabeth Creek Granites, although there is considerable overlap of the compositional fields. Only the Elizabeth Creek, Mareeba, and Finlayson Granites have mean Sn contents significantly greater than the detection limit of 4 ppm. The Finlayson Granite is particularly rich in Sn (average 16 ppm) (Fig. 4).

Preliminary isotopic data, although at present far from conclusive, suggest that the isotopic composition of the Precambrian metamorphics and Palaeozoic geosynclinal sediments (at the time of granite emplacement) was generally higher than the rather uniform value for the initial ratio of about 0.710 found for the majority of the intrusive rocks (Black, in prep.). Moreover, the evidence presented by Sheraton and Labonne (in prep.) does not favour an origin for the granites directly from upper crustal rocks. These authors postulate an origin by anatexis of either a mixture of mantle and crustal material or Rb-poor deep crustal material along a subduction zone. Such an origin has been suggested for the granitic rocks of southwest England (Floyd, 1972) and elsewhere (Hamilton, 1969; Gilluly, 1971; James, 1971).

Relationship of Geochemistry to Mineralization

Tin. The tin-bearing Esmeralda, Elizabeth Creek, Mareeba, and Finlayson Granites are fractionated granites or adamellites in which greisenization is common. Niggli k values are relatively high (> 0.4), particularly in the Esmeralda Granite, whereas mg values tend to be low (generally less than 0.32) (Fig. 2). Neither of these factors seems to be, by itself, a significant indicator of potential tin mineralization, even in a single province, because high k values and low mg values are also found in non-stanniferous granites (e.g., the Herbert River Granite and some phases of the Dumbano Granite). Trace elements which become concentrated during magmatic differentiation (notably Li, Rb, and, in the case of the Elizabeth Creek Granite, Th) are high, whereas K/Rb and Mg/Li ratios are low (Table 2). Particularly noteworthy are the high concentrations of volatile elements, suggested by the presence of fluorite and/or tourmaline. Fluorite is common in the Elizabeth Creek Granite (the average fluorine content of 22 samples is 2100 ppm) and tourmaline is a characteristic accessory mineral in the Esmeralda, Mareeba, and Finlayson Granites. The two latter granites also have particularly high Li contents (Table 2; Fig. 3). The common association of tin deposits with late-stage, leucocratic and generally potassic granites has been demonstrated by many authors (e.g., Gotman and Rub, 1961; Rattigan, 1963; Klomínský and Groves, 1970), and the importance of volatile elements has also been noted (Gotman and Rub, 1961; Lyakhovich, 1965; Hosking, 1967; Rub, 1972; Tischendorf et al., 1972). Tauson et al. (1968) have shown that a high level of volatiles is necessary for the enrichment of the apical parts of intrusions in rare elements such as Li, Be, Sn, W, Nb, and Ta. These authors considered that the highest potential for mineralization is shown by hypabyssal intrusions with high volatile contents.

Only the granite types associated with tin mineralization have mean Sn contents significantly greater than the detection limit of 4 ppm (Fig. 4). Sixty-seven percent of the analysed samples of Esmeralda Granite contain 4 ppm or more Sn; corresponding figures for the Elizabeth Creek, Mareeba, and Finlayson Granites are 60 percent, 69 percent, and 100 percent, respectively. The Esmeralda and Elizabeth Creek Granites have average Sn contents of about 5 ppm, which, although significantly greater than values for the non-stanniferous granites of northeast Queensland, are considerably lower than values reported for many tin granites from elsewhere (Rattigan, 1963; Ivanova, 1963; Lyakohovich, 1965; Mulligan, 1966; Ivanov and Narnov, 1970; Cotelo Neiva, 1972). The Mareeba and Finlayson Granites have rather higher Sn contents (average 9 and 16 ppm, respectively). None of the investigated tin granites (except possibly the Finlayson Granite) is uniformly high in tin - individual samples may have relatively high or low concentrations. Similarly, Hosking (1971) found that granitic dykes (elvans) occurring in the vicinity of tin-bearing veins in Cornwall have variable tin contents, whereas dykes not associated with tin veins are always low in tin. The significance of variable tin contents in tin-bearing granites, and the necessity of a statistical approach to sampling, have been emphasized by Beus and Sitnin (1968) and Bolotnikov and Kravchenko (1970). It is apparent that sampling must be reasonably extensive if the tin-bearing potential of an intrusion is to be realistically assessed. A non-uniform distribution of tin, with a high proportion of samples having tin contents significantly higher than background values, appears to be an important indicator of potential tin mineralization, although a uniformly high tin content would also, of course, be significant.

Copper. Several authors (e.g., Brownlow et al., 1967; Brabec and White, 1971) have found little or no correlation between the Cu content of acid igneous rocks and copper mineralization. However, some authors have reported that areas of copper mineralization are reflected in anomalously high Cu contents of either rocks or, more particularly, biotites from associated plutonic bodies (Putman and Burnham, 1963; Lovering et al., 1970; Al-Hashimi and Brownlow, 1970).

There is no apparent relationship between Cu content and mineralization for the northeast Queensland granitic rocks. The variation in copper in the various intrusive rocks is that expected for normal differentiation trends - the most fractionated rocks contain less copper (Fig. 3). Copper mineralization does not show any preferential association with particular granitic rock types - granodiorite, adamellite or granite - but may occur with any of these. Only minor copper mineralization is associated with the Esmeralda Granite, and Cu contents are close to those of average low calcium granite of Turekian and Wedepohl (1961) (Table 2). The Dumbano Granite and Dido Granodiorite are uniformly low in copper, except for three samples of quartz diorite from the Dido Granodiorite which have relatively high Cu contents, but no known associated economic mineralization. Some copper mineralization appears to be genetically related to the Elizabeth Creek and Herbert River Granites, but these granites are also very low in copper. Copper mineralization is associated with the Mareeba Granite near Mount Molloy (about 35 km north of Mareeba), but, although the mean Cu content is slightly higher than that of the Elizabeth Creek Granite, it is close to the average low calcium granite of Turekian and Wedepohl (1961).

The Almaden Granite, which appears on field evidence to have been responsible for the most important copper mineralization in the area - the contact replacement deposits around Chillagoe - tends to have a rather lower Cu content than the average granodiorite (Table 2).

Lead and zinc. A number of authors (e.g., Barsukov, 1967; Tauson, 1967; Blaxland, 1971) have noted the absence of any systematic relationships between lead/zinc deposits and the lead and zinc contents of associated granitic rocks. Bradshaw (1967), however, found that the lead contents of muscovites, biotites, and feldspars from the mineralized granites of southwest England were significantly higher than those of non-mineralized granites from Scotland. Only the feldspars from the granites of southwest England were higher in zinc.

Minor lead and zinc deposits are related to the Elizabeth Creek, Herbert River, and Esmeralda Granites; the major lead/zinc mineralization of the Chillagoe area is spatially associated with the Almaden Granite. Isotopic data for the contact metasomatic deposits of the Chillagoe area preclude a direct relationship between the Almaden Granite and the nearby lead deposits, however (Black and Richards, 1972b). Zn contents of the various granites show little systematic variation, although they tend to be lower in the more fractionated granites (Elizabeth Creek, Herbert River) compared with the granodiorites (Almaden, Dido) (Fig. 3). The Esmeralda Granite is relatively high in zinc compared with the average granite of Taylor (1968) (Table 2). Lead varies more systematically, being higher in the more acid rocks (e.g., Elizabeth Creek Granite) (Fig. 3). The Esmeralda Granite is relatively rich in lead compared with the Devonian and Upper Palaeozoic granitic rocks and the average granite of Taylor (1968).

All these distribution-patterns may be related to magmatic differentiation trends, and there is no evidence for either significant enrichment or depletion of lead or zinc in the mineralized, as compared with the non-mineralized, granitic rocks.

Discussion and Conclusions

There is a notable lack of correlation between the geochemistry of the granitic rocks of northeast Queensland and lead/zinc or copper mineralization. Granites associated with such mineralization do not show any systematic enrichment or depletion in Cu, Pb, or Zn. Granitic rocks associated with tin mineralization, however, have fairly well-defined geochemical characteristics. Like tin granites from many other parts of the world, they are high-level, strongly fractionated granites or adamellites, enriched in volatile elements such as B, Be, Li, and F. They are characterized by tin contents which are significantly higher than those of the non-stanniferous granites, although average tin concentrations are lower than values reported for many tin granites elsewhere. A distribution of tin in which a high proportion of samples have tin contents significantly higher than background values appears to be a characteristic feature of granites associated with tin mineralization.

The occurrence in the same area of two groups of tin-bearing granites, of widely different ages and apparently different origins, is noteworthy. The Precambrian Esmeralda Granite was probably derived by anatexis of sialic crustal rocks which may well have been the source of the tin and other ore metals. However, isotopic evidence suggests that the Upper Palaeozoic tin-bearing and other granitic rocks, with their associated ore metals, may be of deeper origin. Magma generation associated with a subduction zone (Mitchell and Garson, 1972; Sillitoe, 1972; Wright and McCurry, 1973) is considered to be the most likely mechanism in this case. According to these authors, metals such as Cu, Pb, and Zn were probably derived from subducted oceanic crust, whereas Noble (1970), investigating the distribution of metal provinces in the western United States, concluded that these metals have a mantle origin. Noble considered the role of igneous intrusion in mineralization to be merely one of structural control rather than a source of ore metals. If mineralization is regarded as an independent by-product of magma generation rather than a direct result of differentiation processes, as has also been suggested by Wright and McCurry (1973), there is no reason why acid intrusives which have lead, zinc, or copper mineralization associated with them should have anomalous abundances of these metals. The general lack of correlation between the contents of Cu, Pb, and Zn in intrusive bodies and their association with economic deposits of these metals is thus explicable. Supporting evidence for this concept has come from the isotopic studies of Black and Richards (1972b), who found that lead deposits which are spatially associated with the Almaden Granite are not directly related to it.

Schuiling (1967) has argued that the restriction of the economic tin deposits of the world to well-defined "tin provinces" suggests an inhomogeneous distribution of this metal in the crust, and that the crust may be the main source of tin. Wright and McCurry (1973) have proposed that "geochemical culminations" may exist in the deep crust or upper mantle, and the importance of source rock composition in the formation of tin granites has been emphasized by Flinter (1971) and Hesp (1971). The existence of geochemical inhomogeneities, either in the crust or the upper mantle, would explain the presence of tin granites with ages covering a period of over 1000 m.y. in northeast Queensland. Such a concept would also explain the higher tin contents of granites associated with tin mineralization compared with granites from areas which do not contain tin deposits. Not all granitic rocks (or even fractionated granites) within a tin province have associated tin mineralization, however, and it is apparent that a combination of factors, including tin-rich source rocks, well advanced magmatic differentiation, and the presence of volatiles, are necessary if economic deposits of tin are to be formed.

Acknowledgements

We are indebted to W.B. Dallwitz, K.R. Walker, and A.Y. Glikson for critically reading the manuscript. Atomic absorption analyses were carried out by R.W. Powell and G. Willcocks. This paper is published with the permission of the Director, Bureau of Mineral Resources, Geology and Geophysics.

References

AL-HASHIMI, A.R.K., and BROWNLOW, A.H., 1970 - Copper content of biotites from the Boulder Batholith, Montana. Econ. Geol., 65, 985-992.

BARSUKOV, V.L., 1967 - Metallogenic specialization of granitoid intrusions. In: A.P. Vinogradov (Ed.), Chemistry of the Earth's crust, Vol. 2. Israel Prog. Sci. Trans., Jerusalem, pp. 211-31.

BATEMAN, P.C., CLARK, L.D., HUBER, N.K., MOORE, J.G., and RINEHART, C.D., 1963 - The Sierra Nevada Batholith - a synthesis of recent work across the central part. U.S. geol. Surv. prof. Pap. 414D, 46 pp.

BEST, J.G., 1962 - Atherton, Queensland - 1:250 000 Geological Series. Bur. Miner. Resour. Aust. explan. Notes E55/5.

BEST, M.G., 1969 - Differentiation of calc-alkaline magmas. In: A.R. McBirney (Ed.), Proc. Andesite Conf., Oregon, 1968. State of Oregon Bull. 65, 65-75.

BEUS, A.A., and SITNIN, A.A., 1968 - Geochemical specialization of magmatic complexes as criteria for the exploration of hidden deposits. Rep. 23rd int. geol. Cong., Sec. 6, 101-105.

BLACK, L.P., 1973 - Tables of isotopic ages from the Georgetown Inlier, north Queensland. Bur. Miner. Resour. Aust. Rec. 1973/50 (unpubl.).

BLACK, L.P., in prep. - Bur. Miner. Resour. Aust. Bull.

BLACK, L.P., and RICHARDS, J.R., 1972a - Rb-Sr study of some igneous rocks near Chillagoe and Herberton, northeastern Queensland. J. geol. Soc. Aust., 19, 271-279.

BLACK, L.P., and RICHARDS, J.R., 1972b - Isotopic composition and possible genesis of ore leads in north-eastern Queensland, Australia. Econ. Geol., 67, 1168-1179.

BLAKE, D.H., 1970 - Geology and mineral deposits of the Herberton Tinfield, north Queensland. Qd Govt Min. J., 71, 446-454.

BLAKE, D.H., 1972 - Regional and economic geology of the Herberton/Mount Garnet area - Herberton Tinfield, north Queensland. Bur. Miner. Resour. Aust. Bull. 124, 265 pp.

BLAKE, D.H., and SMITH, J.W., 1970 - Mineralogical zoning in the Herberton Tinfield, north Queensland, Australia. Econ. Geol., 65, 993-997.

BLAXLAND, A.B., 1971 - Occurrence of zinc in granitic biotites. Mineral Depos. 6, 313-320.

BOLOTNIKOV, A.F., and KRAVCHENKO, N.S., 1970 - Criteria for recognition of tin-bearing granites. Dokl. (Proc.) Acad. Sci. USSR, Earth Sci. Sec., 191, 186-187.

BRABEC, D., and WHITE, W.H., 1971 - Distribution of copper and zinc in rocks of the Guichon Creek Batholith, British Columbia. Proc. 3rd int. geochem. Expl. Symp., Toronto, 1970. Can. Inst. Min. Metall. spec. Vol. 11, 291-297.

BRADSHAW, P.M.D., 1967 - Distribution of selected elements in feldspar, biotite and muscovite from British granites in relation to mineralization. Trans. Inst. Min. Metall., B, 76, B137-B148.

BRANCH, C.D., 1966 - Volcanic cauldrons, ring complexes, and associated granites of the Georgetown Inlier, Queensland. Bur. Miner. Resour. Aust. Bull. 76, 160 pp.

BROWNLOW, A.H., MOHSEN, L., and AL-HASHIMI, A.R., 1967 - Abundance and distribution of trace metals in the Philipsburg and Boulder Batholiths, Montana (abs). In: Abstracts for 1967. Geol. Soc. Am. spec. Pap. 115, p.26.

COTELO NEIVA, J.M., 1972 - Tin-tungsten deposits and granites from northern Portugal. 24th int. geol. Cong., Sec. 4, 282-288.

ERIKSON, E.H., Jr, 1969 - Petrology of the composite Snoqualmie Batholith, Central Cascade Mountains, Washington. Bull. geol. Soc. Am., 80, 2213-2236.

FAURE, G., and POWELL, J.L., 1972 - Strontium isotope geology. Springer-Verlag, Berlin.

FLINTER, B.H., 1971 - Tin in acid granitoids: the search for a geochemical scheme of mineral exploration. Proc. 3rd int. geochem. Expl. Symp., Toronto, 1970. Can. Inst. Min. Metall. spec. Vol. 11, 323-330.

FLOYD, P.A., 1972 - Geochemistry, origin and tectonic environment of the basic and acidic rocks of Cornubia, England. Proc. Geol. Ass., 83, 385-404.

GILLULY, J., 1971 - Plate tectonics and magmatic evolution. Bull. geol. Soc. Am., 82, 2383-2396.

GOTMAN, Ya. D., and RUB, M.G., 1961 - Comparative characteristics of the tin-bearing granitoids of different ages of the South Primor'ye and certain other tin-bearing areas. Int. geol. Rev., 3, 878-884.

HAMILTON, W., 1969 - Mesozoic California and the underflow of Pacific Mantle. Bull. geol. Soc. Am., 80, 2409-2430.

HESP, W.R., 1971 - Correlations between the tin content of granitic rocks and their chemical and mineralogical composition. Proc. 3rd int. geochem. Expl. Symp., Toronto, 1970. Can. Inst. Min. Metall. spec. Vol. 11, 341-353.

HOSKING, K.F.G., 1967 - The relationship between primary tin deposits and granitic rocks. Tech. Conf. Tin, int. Tin Ccl, pp. 269-306.

HOSKING, K.F.G., 1971 - Problems associated with the application of geochemical methods of exploration in Cornwall, England. Proc. 3rd int. geochem. Expl. Symp., Toronto, 1970. Can. Inst. Min. Metall. spec. Vol. 11, 176-189.

IVANOV, V.S., and NARNOV, G.A., 1970 - On the behaviour of tin in the granitoid intrusives of northeastern USSR. Geochem. Int., 7, 424-431.

IVANOVA, G.F., 1963 - Content of tin, tungsten and molybdenum in granites enclosing tin-tungsten deposits. Geochemistry, 5, 492-500.

JAMES, D.E., 1971 - Plate tectonic model for the evolution of the Central Andes. Bull. geol. Soc. Am. 82, 3325-3346.

DE KEYSER, F., and LUCAS, K.G., 1968 - Geology of the Hodgkinson and Laura Basins, north Queensland. Bur. Miner. Resour. Aust. Bull. 84, 254 pp.

DE KEYSER, F., and WOLFF, K.W., 1964 - The geology and mineral resources of the Chillagoe area. Bur. Miner. Resour. Aust. Bull. 70, 136 pp.

KLOMÍNSKÝ, J., and GROVES, D.I., 1970 - The contrast in granitic rock types associated with tin and gold mineralization in Tasmania. Proc. Australas. Inst. Min. Metall., 234, 71-77.

LARSEN, E.S., Jr., 1948 - Batholith and associated rocks of Corona, Elsinore and San Luis Rey Quadrangles, Southern California. Geol. Soc. Am. Mem. 29, 182 pp.

LOVERING, T.C., COOPER, J.R., DREWES, H., and CONE, G.C., 1970 - Copper in biotite from igneous rocks in Southern Arizona as an ore indicator. U.S. geol.Surv. prof. Pap. 700B, B1-B8.

LYAKHOVICH, V.V., 1965 - Characteristics of distribution of tin and boron in granitoids. Geochem. Int., 2, 10-15.

MITCHELL, A.H.G., and GARSON, M.S., 1972 - Relationship of porphyry copper and circum-Pacific tin deposits to palaeo-Benioff zones. Trans. Inst. Min. Metall., B, 81, B10-B25.

MULLIGAN, R., 1966 - Geology of Canadian tin occurrences. Geol. Surv. Can. Pap. 64-54, 22 pp.

NOBLE, J.A., 1970 - Metal provinces in the Western United States. Bull. geol. Soc. Am., 81, 1607-1624.

PUTMAN, G.W. and BURNHAM, C.W., 1963 - Trace elements in igneous rocks, Northwestern and Central Arizona. Geochim. cosmochim. Acta, 27, 53-106.

RATTIGAN, J.H., 1963 - Geochemical ore guides and techniques in exploration for tin. Proc. Australas. Inst. Min. Metall., 207, 137-151.

RICHARDS, J.R., WHITE, D.A., WEBB, A.W., and BRANCH, C.D., 1966 - Isotopic ages of acid igneous rocks in the Cairns hinterland, north Queensland. Bur. Miner. Resour. Aust. Bull. 88, 41 pp.

RUB, M.G., 1972 - The role of the gaseous phase during the formation of ore-bearing magmatic complexes. Chem. Geol., 10, 89-98.

SCHUILING, R.D., 1967 - Tin belts on the continents round the Atlantic Ocean. Econ. Geol., 62, 540-550.

SHERATON, J.W., and LABONNE, B., in prep - Bur. Miner. Resour. Aust. Bull.

SILLITOE, R.H., 1972 - A plate tectonic model for the origin of porphyry copper deposits. Econ. Geol., 67, 184-197.

T'USON, L.V., 1967 - Geochemistry of rare elements in igneous rocks and metallogenic specialization of magmas. In: A.P. Vinogradov (Ed.), Chemistry of the Earth's crust, Vol. 2 Israel Prog. Sci. Trans., Jerusalem, pp. 248-259.

TAUSON, L.V., KOZLOV, V.D., and KUZ'MIN, M.I., 1968 - Geochemical criteria of potential ore-bearing in granite intrusions. Rep. 23rd int. geol. Cong., 6, 123-129.

TAYLOR, S.R., 1968 - Geochemistry of andesites. In: L.H. Ahrens (Ed.), Origin and distribution of the elements. Int. Ser. Monogr. Earth Sci., 30, 559-583.

TISCHENDORF, G., LÄCHELT, S., LANGE, H., PÄLCHEN, W., and MEINEL, G., 1972 - Geochemical specialization of granitoids in the territory of the German Democratic Republic. 24th int. geol. Cong., Sec. 4, 266-275.

TUREKIAN, K.K., and WEDEPOHL, K.H., 1961 - Distribution of the elements in some major units of the Earth's crust. Bull. geol. Soc. Am, 72, 175-192.

WEBB, A.W., 1971 - Australian Mineral Development Laboratories. Unpubl. Rep. AN5188/71.

WHITE, D.A., 1965 - The geology of the Georgetown/Clarke River area, north Queensland. Bur. Miner. Resour. Aust. Bull. 71, 165 pp.

WRIGHT, J.B., and McCURRY, P., 1973 - Magmas, mineralization and sea-floor spreading. Geol. Rdsch., 62, 116-125.

Figure Captions

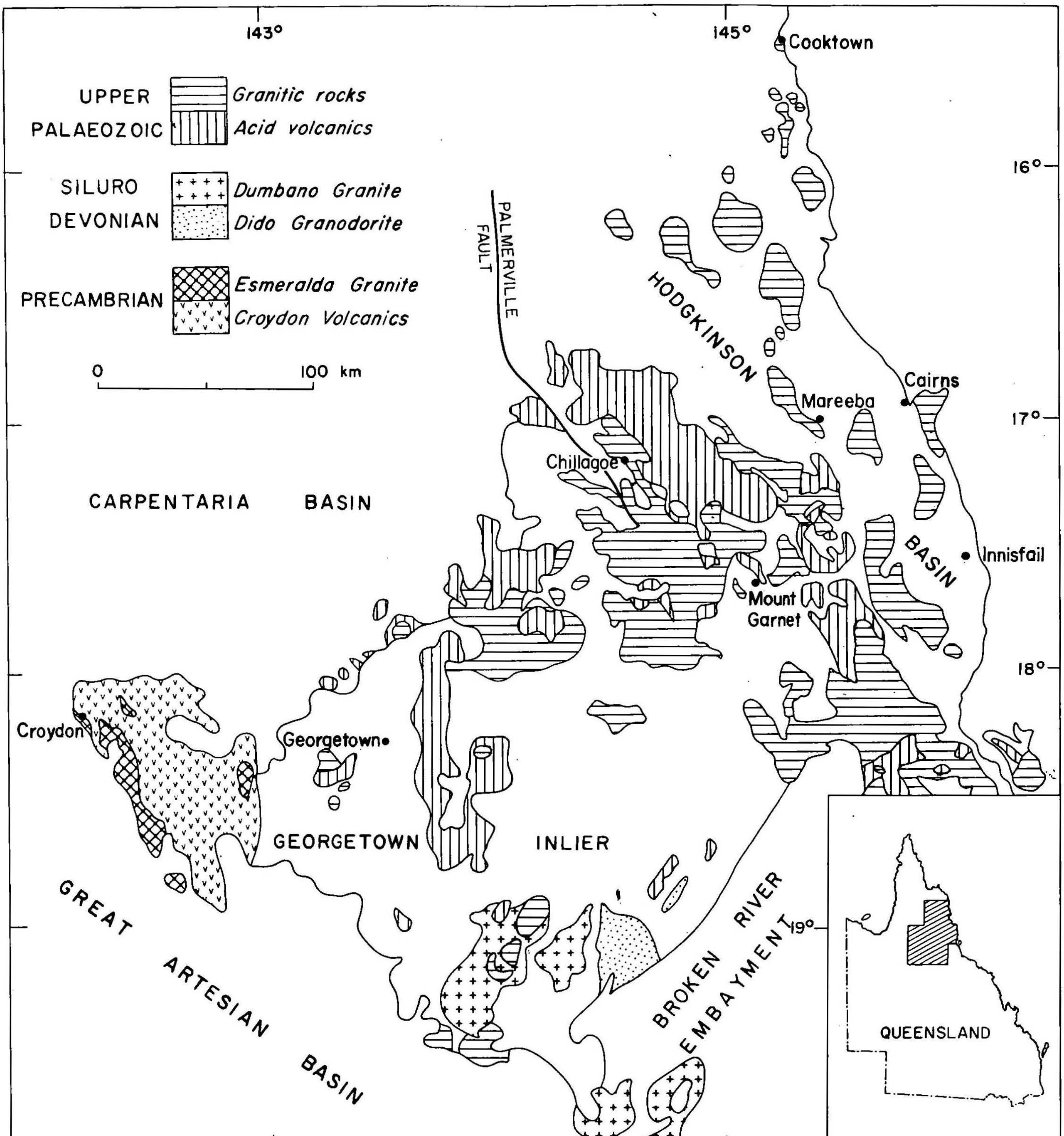
Fig. 1 Locality map, showing distribution of the major groups of acid intrusive rocks, together with their associated extrusives. No distinction could be made between the various Upper Palaeozoic granitic rocks on this scale.

Fig. 2 Plots of Niggli k against mg. (a) Precambrian and Siluro-Devonian granitic rocks, (b) Permo-Carboniferous granitic rocks.

Fig. 3 Frequency distributions of lithium, copper, zinc and lead in the main granitic rocks.

Fig. 4 Frequency distribution of tin in the main granitic rocks.

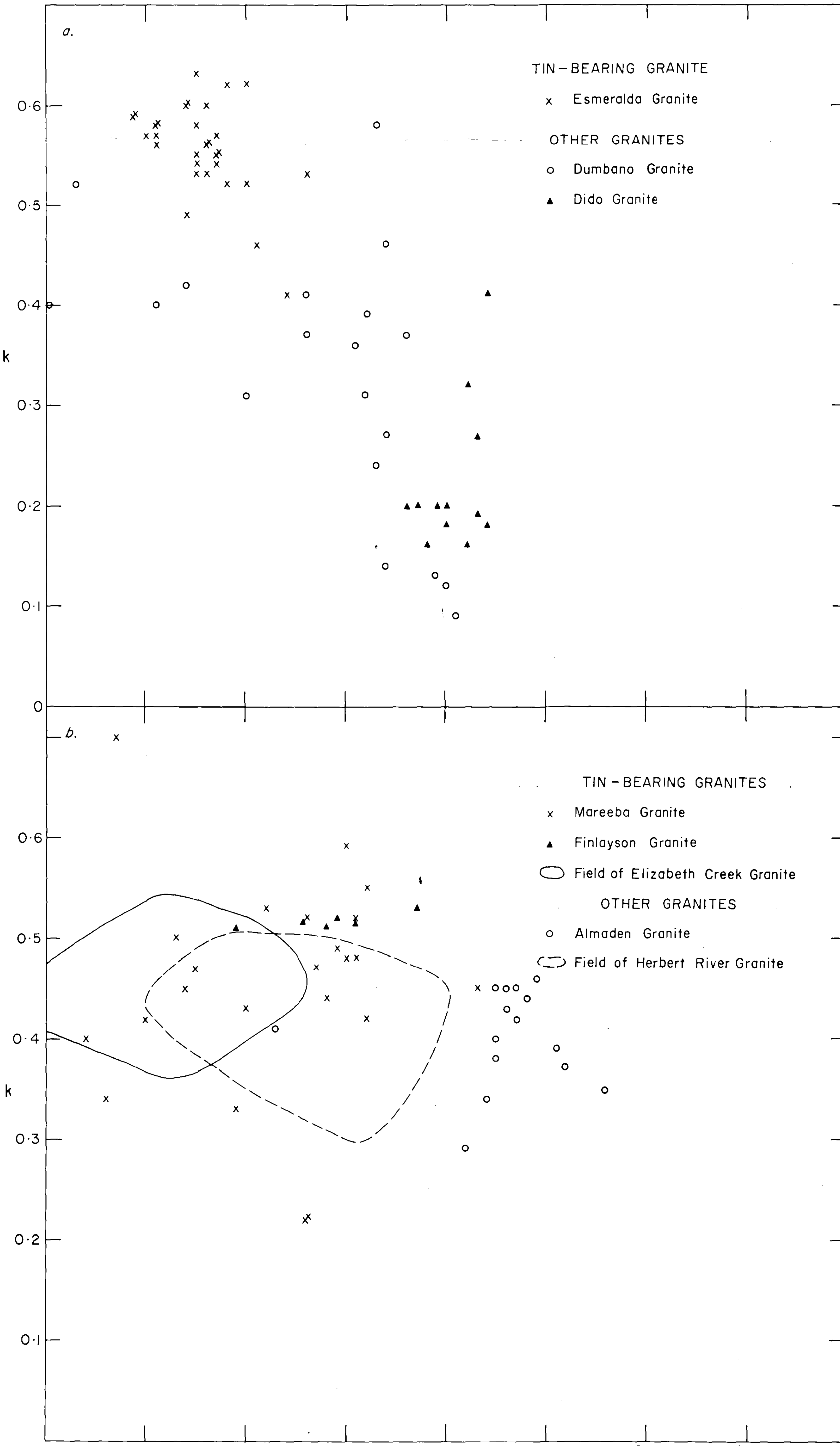
Fig. 1



To accompany Record 1973/110

Q/A 469

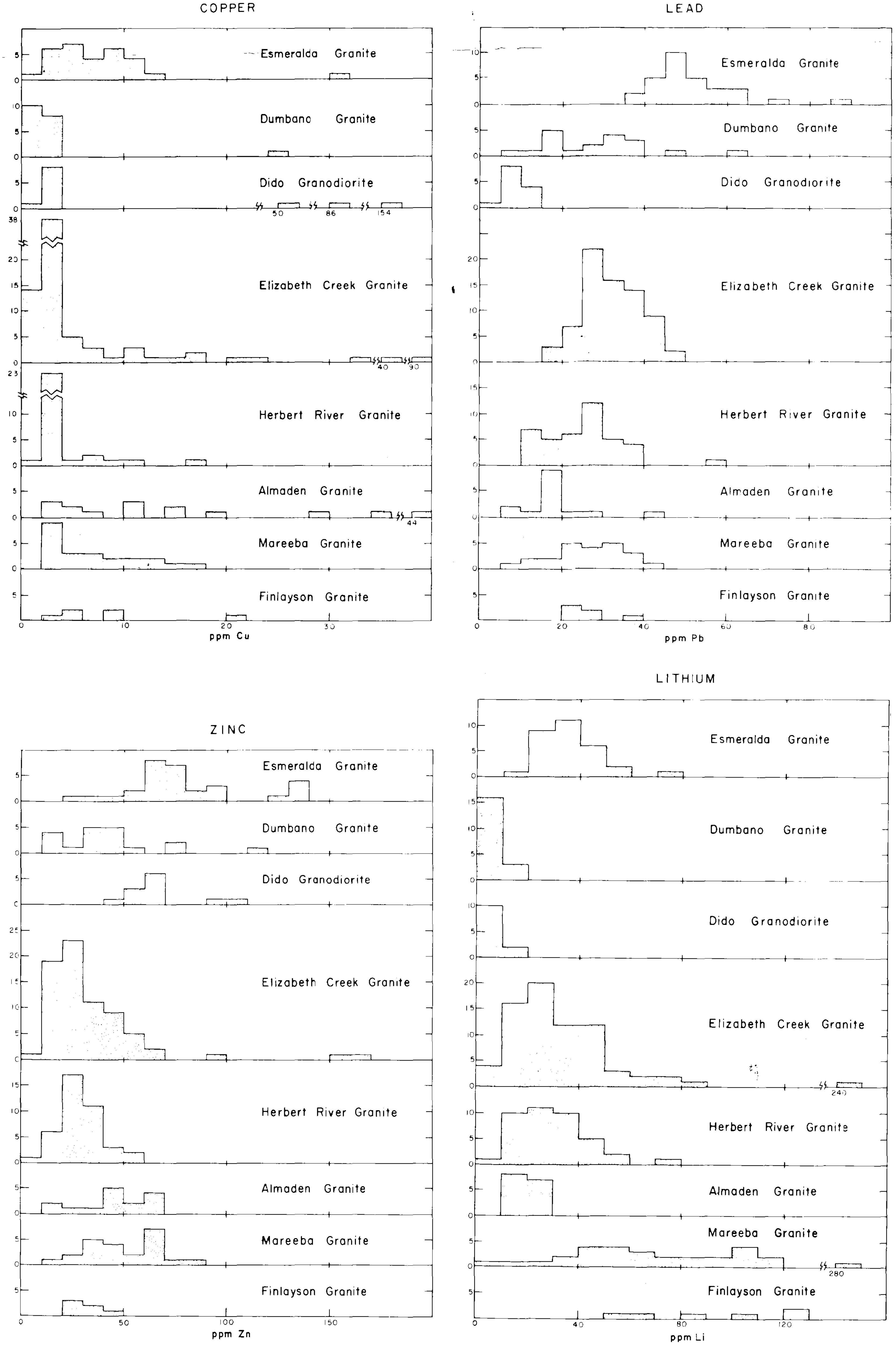
Fig. 2



To accompany Record 1973/110

M(M) 127

Fig. 3

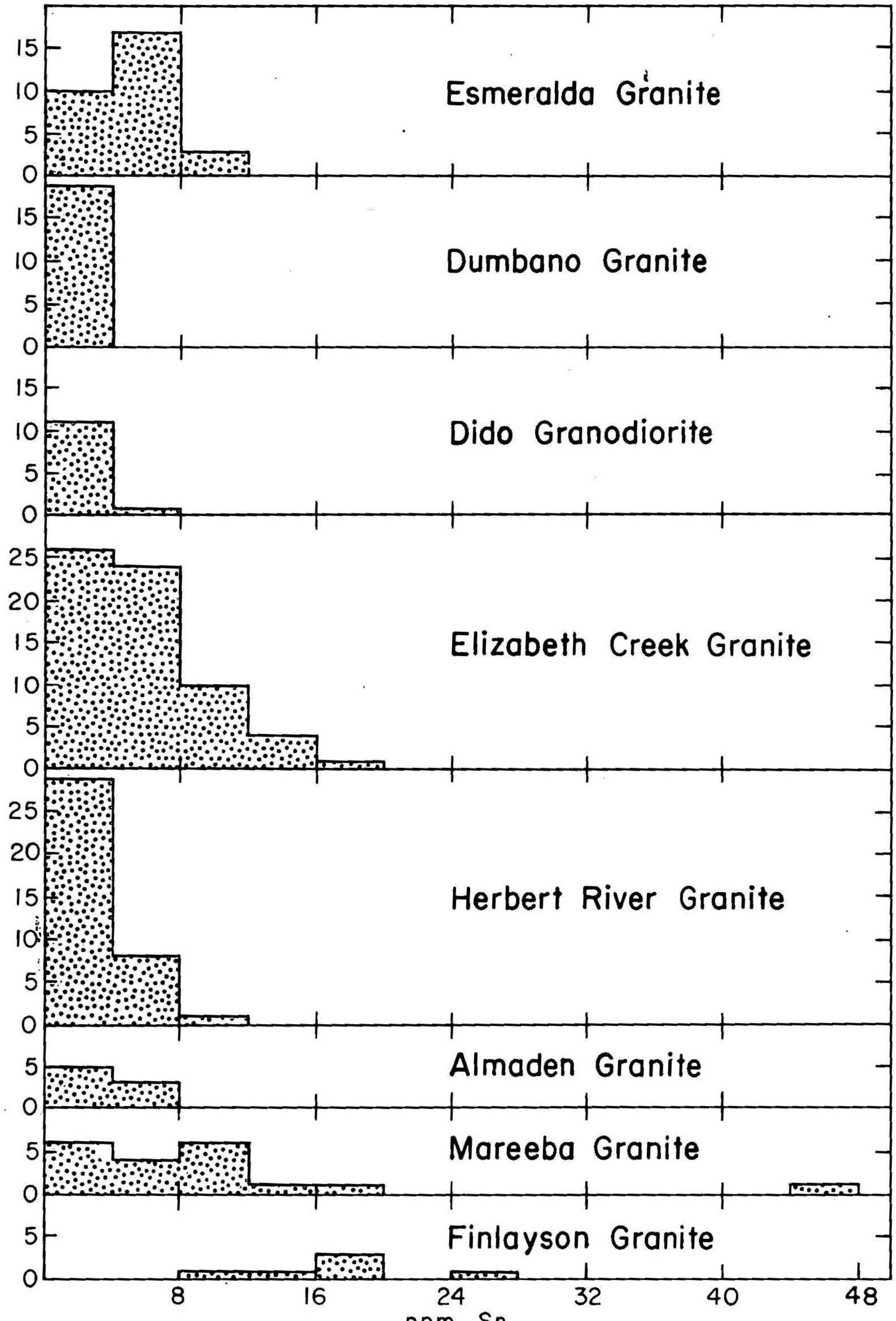


To accompany Record 1973/110

M(M)123

TIN

Fig. 4



To accompany Record 1973/110

M(M) 122