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Some observations upon the tin deposits of Australia

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Abstract: The Australian tin occurrences display a wide diversity in terms of environmental setting and types of deposit. The various provinces are discussed within the framework of a proposed international classification. The relationship between deposit type and broad geological setting is examined in terms of Precambrian-pegmatitic and orogenic-fold belt environments. Most of the Australian provinces fall into the deep volcanic/plutonic category although the plutonic-greisen style, and the volcanic styles are represented. Several exploration models are incorporated within the environmental framework.

GENERAL DISTRIBUTION

The widespread and irregular distribution of tin deposits within Australia was noted by Hills (1953) who plotted all known individual occurrences upon a map of the continent. Although there have been a few new discoveries this map still portrays the main features of tin distribution and is presented as Figure 1.

The major concentrations are located intermittantly along the eastern Phanerozoic orogenic belts, with the majority of the remainder occurring in the western PreCambrian cratonic shield zones. This represents a time range from Archean (Western Australia) to Permian (Queensland).

The distribution pattern (Fig. 1), illustrates some of the problems involved in grouping the occurrences. There are a spectrum of patterns which can be resolved into four main groups.

1) *Isolated individual occurrences*, i.e., a solitary occurrence of tin within an area of several thousand square kilometres. These 'orphaned' occurrences are usually pegmatite deposits in the PreCambrian shield areas, i.e. the tin bearing pegmatite at Mt. Isa (Fig. 2).
2) *Isolated group occurrences*, i.e., a group of tin occurrences which are sufficiently divorced from other occurrences to have a clear identity. In this sense they are similar to the isolated occurrences but occur as a group. They are usually of minor economic significance, and examples are Broken Hill, New South Wales and Crystal Hill, Queensland (Fig. 2).
3) *Diffuse zones*, i.e., occurrences of the single and small group type, spread diffusely over a large area to form an ill-defined tin rich region. This is a larger scale style than the previous groupings and is well illustrated by the Albury-Ardlethan region in New South Wales—Victoria. The Northern Territory, Darwin-Katherine occurrences could be similarly classified.
4) *Concentrated zones*, i.e., occurrences of the single and small group type concentrated within well defined borders to form a distinctive tin rich region. These constitute the major tin rich zones of the continent and good examples are Herberton, Queensland, and New England, New South Wales–Queensland.

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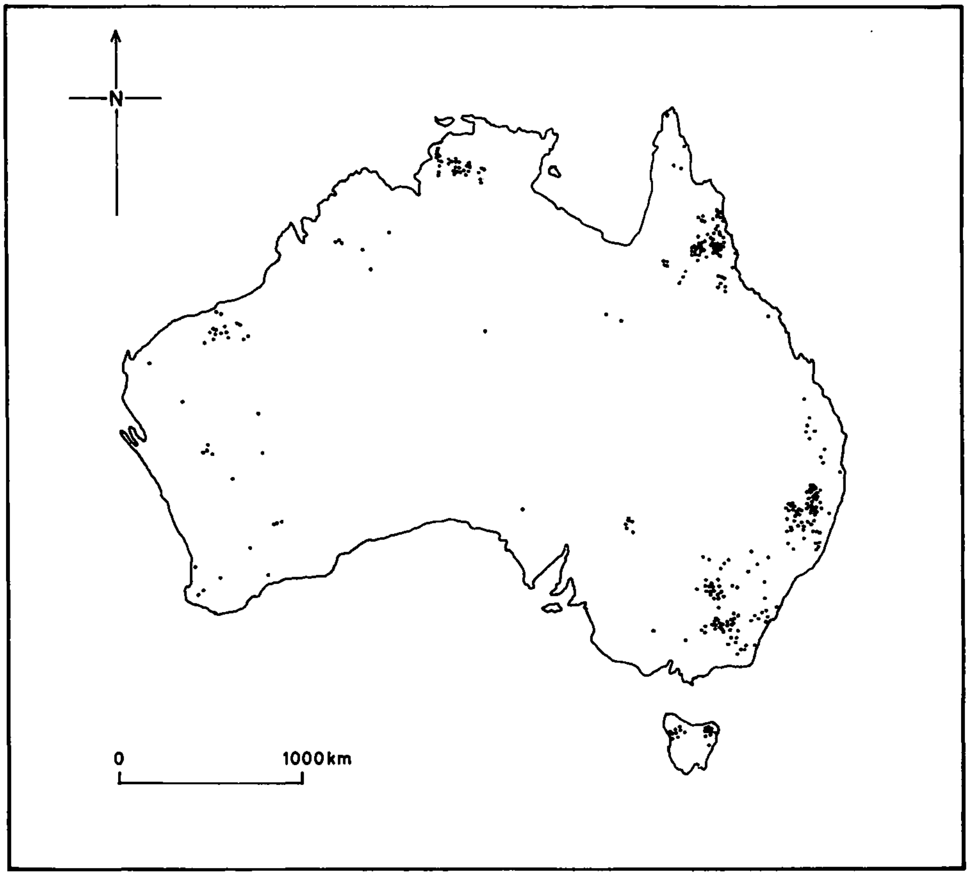


Fig. 1. General distribution of Australian tin occurrences (After Hills, 1953 with minor additions).

This range in style and scale presents problems in terms of defining metallogenic provinces. Regions noted for significant occurrences of metals are generally termed metallogenic provinces. However, this apparently simple concept is difficult to define precisely and eminent authorities have debated the topic without reaching unanimity.

There are many problems of scale, for instance, should groups, 2,3 and 4 above all be regarded equally as metallogenic provinces or should they be further classified? To obtain a full perspective of metal rich areas it is necessary to prepare a series of metallogenic maps at different scales displaying different parameters (Noble, 1970). This exercise has not been fully undertaken for Australian tin occurrences. However, stanniferous zones can be clearly identified from the various metallogenic maps of the Bureau of Mineral resources, and some of these were examined by Taylor 1978 (in press) (Table 1).

CLASSIFICATION

Itsikson (1960) and subsequently Taylor (1974, 1978a) have both favoured classification based upon the environmental characteristics of a tin rich province. Different

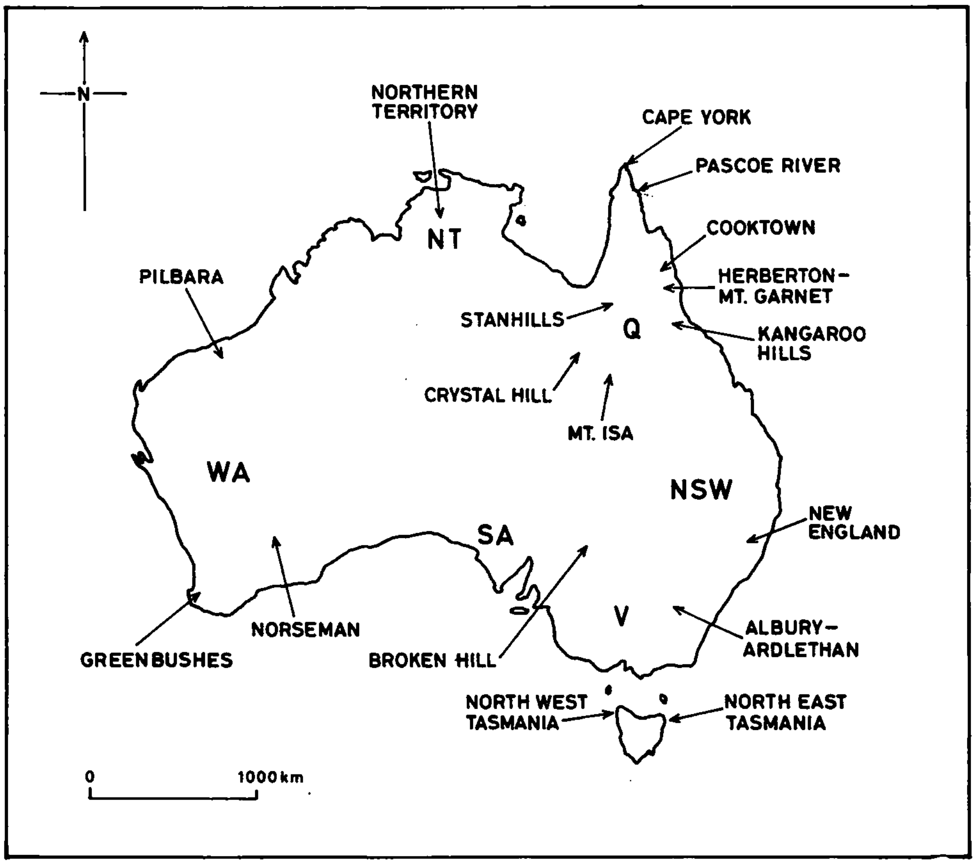


Fig. 2. General locality map (W.A.—Western Australia, S.A.—South Australia, V—Victoria, N.S.W.—New South Wales, Q—Queensland, N.T.—Northern Territory).

provinces have different characteristics which appear to have a strong relationship with the type of associated igneous magmatism and its level of emplacement.

Thus Taylor (1978) considered some 40–50 tin rich zones and attempted to classify them in terms of general environmental setting, together with the nature of the associated intrusives. This is reproduced as Table II and the Australian groupings can be discussed within this context. This concept is a development of the original classification of Itsikson (1960).

THE CRATONIC-METAMORPHIC ENVIRONMENT OR PRECAMBRIAN PEGMATITIC TYPE (ENVIRONMENT 3, TABLE II)

This environment occurs at many points within the cratonic shield areas of central and western Australia, i.e. Broken Hill, Pilbara, Greenbushes, Norseman, etc. These deposits all have many similarities and are best described from the Pilbara tinfield, Western Australia. This tinfield falls within the category of a diffuse collec-

TABLE 1

DATA CONCERNING SOME MAJOR TIN BEARING REGIONS IN AUSTRALIA

Region—Province	Age	Economic Significance (World Basis)	General Environment
North-west Tasmania	Middle-Upper Devonian	Intermediate A	P.O.I.
Herberton—Mt. Garnet, Queensland	Upper Permian	Intermediate A	P.P.O.I.V. Mostly I.
North-east Tasmania	Upper Devonian	Intermediate P	P.O.I.
New England, New South Wales	Upper Permian	Minor—Intermediate A	P.O. IV Mostly I
Cooktown, Queensland	Permian	Minor A	P.O.I.
Albury—Ardlethan, New South Wales	Upper Devonian	Minor A.P.	P.O.I.
Kangaroo Hills, Queensland	Carboniferous-Permian	Minor P	P.O.I. (V?)
Greenbushes, Western Australia	Precambrian	Minor A	C.—G?
Pilbara, Western Australia	Precambrian	Minor A	C.—G.
Northern Territory	Precambrian	Minor P	P.O.?—I?
Broken Hill, New South Wales	Precambrian	Minor P	C.—G.

NOTES FOR TABLE 1

P. — Predominantly Primary
A. — Predominantly Alluvial
P.O. — (Post-orogenic). Deposits associated with granitoids emplaced in close relationship with a major period of orogeny. (i.e. folding, fracturing and uplift). Granitoid emplacement predominantly postdates major folding.
I. — (Intrusive). Deposits associated with granitoids which show no direct evidence of a volcanic association.
V. — (Volcanic). Deposits associated with granitoids which are spatially and temporally linked with acid volcanic extrusives.
C. — (Cratonic). Deposits associated with ancient cratonic shield areas. Geological details concerning connection with major orogeny uncertain. Spatial association with granitoids ranges from close (G) to uncertain (G?).

tion of isolated deposits and groups of deposits occupying an area some 250×150 km. The general environment consists of Precambrian metamorphic rocks intruded by Precambrian granitoids (Figs. 3 and 4) (Blockley, 1973).

The granitoids form extensive batholiths which vary from major gnessic/migmatitic granitoids to younger smaller intrusive stocks. The tin mineralisation is associated with these smaller intrusives in some 8–10 separate centres. The two major types of pegmatite mineralization are,

1) Li, $\pm$ Sn, Nb-Ta, Be in pegmatitic dykes which may be up to 1 km long and 75 m wide. These are frequently zoned and intrude the metamorphics. Localities inlcude, Tabba Tabba, Pilgangoora and Strelloy.

2) Sn, $\pm$ Ta-Cb, Bo in low angle vein swarms of pegmatitic affinities around the margins of the younger granites and within the metamorphics and migmatites. The veins are predominantly quartz and are often associated with a quartz-albite aplitic phase. Localities include Moolyella (Figure 3) Cooglegong, Eley's, Pinga Creek and Coondina.

TABLE 2

ENVIRONMENTS CONTAINING SIGNIFICANT* PRIMARY CONCENTRATIONS OF TIN

General Environment	Subdivisions	Form of associated igneous rocks	Composition of associated igneous rocks	Economic significance of primary (and secondary) ores	Examples
1. Tin deposits associated with granitoids which show a close spatial and temporal relationship with a major period of orogeny. (i.e. folding, fracturing, uplift). Granitoid emplacement predominately post major folding, i.e. late stage and controlled by major fracture/suture zones (FOLD BELT TYPE)	(a) Tin concentrations associated predominantly with extrusives and pyroclastics. Minor related intrusives.	Terrestrial lava flows, tuffs, volcanic breccias. Minor stocks/dykes and intrusive sheets volcanic (non porphyritic) textures.	Predominantly rhyolites with andesites, dacites and latites.	Primary: Very minor Secondary: Very minor	Mexico
	(b) Tin concentrations associated with intrusive complexes of subvolcanic nature occurring in association with terrestrial extrusives.	Small stocks, pipes, and irregularly shaped intrusives. Often steep walled and funnel shaped at depth. Associated dykes, dyke swarms, sills, breccia pipes, etc.	Diverse composition—porphrytic textures predominate. Granite porphyry, quartz porphyry, dacite, quartz latite porphyry. Quartz diorite, granodiorite, granite, etc. Aplites and pegmatites very rare. Volcanics are predominantly rhyolites-andesites.	Primary: Major to minor Secondary: Minor	Bolivia (Southern portion) Southern Maritime Territory, U.S.S.R. Japan Maly Kinghan, U.S.S.R. Mio-Chang, U.S.S.R.,
	(c) Tin concentrations associated	Wide diversity in form ranging from small stocks to large scale	Predominantly granites, granodiorites with minor alaskites, leucogranites and other	Primary: Major to minor Secondary: Intermediate to minor	Herberton, Australia New Eng-

TABLE 2 (*Continued*)

	with intrusive complexes of mixed character, i.e. representing a deep subvolcanic to high plutonic environment. Extrusive rocks mostly absent, but may be present in places.	intrusive complexes. Major massifs/batholiths are often very complex and contain a large number of intrusive phases. Active repeated intrusion prevails over more a passive environment. At upper levels garlands or rosary chains of small granitoids associated with regional fractures reflect the deeper batholith structures. Geochemically specialised granitoids are often present and may form clear end members of a granodiorite-granite differentiation sequence. Dykes, dyke, swarms normally abound although may be irregularly distributed. Aplite and pegmatites uncommon.	specialised intrusives. Plutonic textures prevail. Aplites and pegmatities common.		land, Australia Chukotka, U.S.S.R. Kangeroo Hills, Australia Transbaikal, U.S.S.R. ?Darwin-Katherine region, Australia Yakutia, U.S.S.R. New Brunswick, Canada Cornwall, England Northwest, Tasmania East Kazakstan, U.S.S.R. Albury-Ardlethan, Australia East Coast, Malaysia
(d)	Tin concentrations associated with intrusive complexes of plutonic character.	Intermediate to large scale intrusive complexes. Massifs—batholiths, generally containing a small number of individual plutons. Differentiation sequences are com-	Predominately granites, granodiorites with minor alaskites, leucogranites and other specialised intrusives. Plutonic textures prevail. Aplites and pegmatites common.	Primary: Major to minor Secondary: Major to minor	?Bolivia (Northern portion) Erzgebirge, Czechoslovakia G.D.R.

TABLE 2. (*Continued*)

	Extrusives absent. Dykes, dyke swarms, minor.	monly well established between phases, and a relatively passive intrusion environment suggested. Geochemically specialised granitoids are present and often form minor phase end member differentiates in a granodiorite-granite sequence.				Cooktown, Australia France Spain—Portugal ?Thailand—West Malaysia—Indonesia ?Central Asia Alaska North East Tasmania
2. Tin deposits associated with granitoids emplaced via major in zones of fracturing cratonic shield areas. Granitoids are anorogenic (i.e. not locally associated with major period of fold development). (ANOROGENIC)		Small ovate/circular intrusive ring complexes. Minor stocks, ring dykes are often capped by sheets. Minor volcanics. Groups of complexes show strong linear alignments.	Predominantly granite, microgranite and rhyolite. Alkali granites present in Nigeria. Plutonic and porphyritic textures present.	Primary: Secondary:	Very minor Major	Nigeria Brazil—Rhondonia South West Africa
3. Tin deposits associated with pegmatites in ancient metamorphic cratonic terrains, (PRECAMBRIAN PEGMATITIC)	Subtypes may be present. Present data does not permit subdivision Association with granitoids ranges from well established to uncertain.	Wide range of intrusive forms, e.g. batholiths, domed complexes, stocks, sills etc. Plutonic and gneissic textures. Detailed geology often uncertain.	Predominantly granites, with minor alaskites. Pegmatites, aplites and granophyric phases common.	Primary: Secondary:	Minor Intermediate to minor	Central Africa Pilbara—Australia Greenbushes—Australia Brazil (Shield) Nigeria (Shield) Southern Rhodesia

TABLE 2. (*Continued*)

					East Sayan, U.S.S.R. Swaziland
4. Tin deposits associated with rapakivi granites in ancient metamorphic cratonic areas. (PRECAMBRIAN RAPAKIVI)	May also be considered as a subtype of (3).	Massifs, stocks of polyphase granitoids. Plutonic to porphyrite textures. Late phases of massifs are geochemically specialised for Sn, and associated with deposits.	Predominantly granite, with porphyritic and pegmatitic phases. Pegmatites common.	Primary: Very minor Secondary: Very minor	Ladoga-Karelia, U.S.S.R.
5. Tin deposits associated with granitoid members of layered mafic intrusives in ancient metamorphic cratonic terrains (BUSHVELD)	Unique to Bushveld Complex, South Africa.	Stratiform granitic sheet associated with felsitic extrusions and pyroclastics. Intruded by stocks of granite, and underlain by sheets of gabbro and norite. Wide textural variation (plutonic -granophyric).	Predominantly granite (plutonic, porphyritic, and granophyric).	Primary: Minor Secondary: Very minor	Bushveld, South Africa

*Significant denotes that local production centres occur with tin as a major product. Tin occurs in other environments as a minor or trace element. Whilst rarely of commercial interest the occurrences are of genetic significance, e.g. rare occurrences in association with pyritic base metal ores of probable volcanogenic origin, Sullivan–British Columbia (Swanson & Gunning 1948) Timmins—Ontario (Walker *et al* 1975) Mt Lyell—Tasmania. Trace amounts are recorded in the nickel ores of Sudbury (Hawley, 1962) etc.

†In terms of annual world production, the following first order approximations would apply.

Group 1. a negligible
b, c, d — 90–96% (mostly alluvial, say 65–75%)
Group 2. 2–5% (All from alluvial sources)
Group 3. 2–5% (Mostly from alluvial sources)
Group 4. negligible
Group 5. negligible

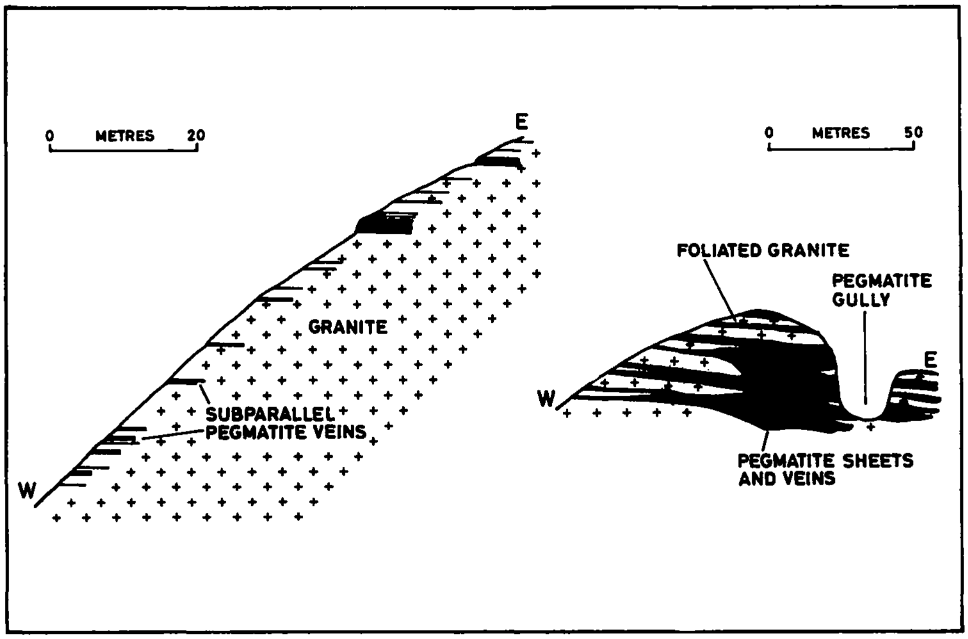


Fig. 3. Selected sections to illustrate the structure of the tin bearing pegmatites at Moolyella tinfield, Pilbara, Australia.

The deposits are all of minor economic significance and in terms of tin are responsible for local alluvial concentrations.

THE OROGENIC (FOLD BELT) ENVIRONMENT—GENERAL STATEMENT (ENVIRONMENT 1, TABLE II)

Situated predominantly along the eastern coastline the deposits of this environment yield the bulk of current Australian production. The major centres are listed in Table III.

VOLCANIC/SUBVOLCANIC PROVINCES (ENVIRONMENTS IA AND IB, TABLE II)

These categories are not well represented in the Australian orogenic groupings (Table III). None of the major provinces fall clearly into this type, although parts of the Herberton field could be regarded as subvolcanic.

The only clear example of these subdivisions is the minor Cape York tin field where the deposits are associated with ignimbrite sheets, (Willmott *et al.*, 1973). Little is known concerning the nature of the primary mineralization which seems to consist of small iron-stained quartzose veins and veinlets associated with sericitic alteration. Willmott et al., 1973, indicate that substantial areas of the ignimbrites have suffered mild clay alteration. The environment and the large alteration zones possibly require closer investigation for breccia pipe and porphyry tin style mineralization. (Ypma and Simons, 1969, Sillitoe *et al.* 1976).

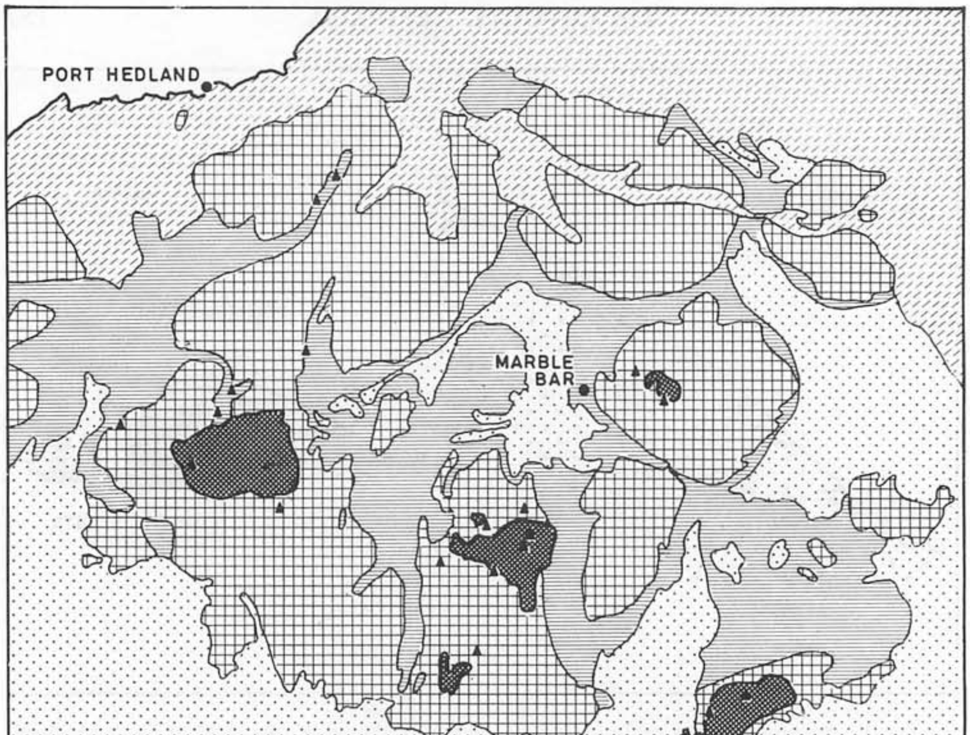


Fig. 4. General geology of the Pilbara district (based on Blockley, 1969). Plan and diagrammatic illustration of deposit settings.

TABLE 3

TIN CENTRES OF THE OROGENIC FOLD BELT TYPE

Name	Type (from Table I)	Classification (from Table II)
Major.		
1. Northern Territory	Diffuse	Deep subvolcanic-plutonic
2. Cooktown-Queensland	Concentrated	Plutonic
3. Herberton–Mt. Garnet, Queensland	Concentrated	Deep subvolcanic-plutonic
4. Kangaroo Hills, Queensland	Concentrated	Deep subvolcanic-plutonic
5. New England, New South Wales–Queensland	Concentrated	Deep subvolcanic-plutonic
6. Albury–Ardlethan, New South Wales	Diffuse	Deep subvolcanic-plutonic
7. North-west Tasmania	Concentrated	Deep subvolcanic-plutonic
8. North-east Tasmania	Concentrated	Plutonic
Minor (Listing incomplete).		
1. Cape York, Queensland	Isolated Group	Volcanic
2. Crystal Hill, Queensland	Isolated Group	Deep subvolcanic-plutonic
3. Pascoe River, Queensland	Isolated Group	
4. Stanhills, Queensland	Isolated Group	

It will immediately be noted that the majority of the Australian provinces fall into the intermediary category, deep subvolcanic-plutonic, i.e., "tin concentrations associated with intrusive complexes of mixed character, representing a deep volcanic to high plutonic environment. Extrusive rocks mostly absent, but may be present in places." (Table II).

This category covers a wide range of environments and although difficult to interpret, some provinces are considered to have greater affinities towards the subvolcanic whilst others seem deeper. Thus, Herberton, New England, and Kangaroo Hills are all considered to represent a higher intrusion level than North-West Tasmania.

DEEP SUBVOLCANIC-PLUTONIC PROVINCES (ENVIRONMENT 1C, TABLE II)

This category embraces the majority of the Australian tin provinces. Herberton, Kangaroo Hills and New England provide clear examples, whilst North-West Tasmania, Albury-Ardlethan and Northern Territory are less well established. Most observers place the North-West Tasmania granitoids in the epizonal category (Klominksy, 1972) whilst few details are known from the Northern Territory region. The wide ranging Albury-Ardlethan zone poses many problems concerning level of granitoid emplacement. The bulk of the intrusives are of the contact aureole type but some of these occur alongside granitoids of similar age with regional aueroles (White et al. 1974). The latter authors caution against utilising aueroles as indicators of emplacement depth and at this stage the general position of the province remains uncertain. The actual Ardlethan region with breccia-pipe style mineralization and mixed plutonic and porphyritic intrusives suggests a deep subvolcanic (or even subvolcanic) category for this particular section of the field.

The Herberton-Mt. Garnet province typifies the general character of this category, with a wide diversity of intrusive types and mineralization types and merits a short description to establish a stereotype.

The Herberton tin province is the most intensively mineralised province in Australia, extending over some 15,000 sq. km.

The province straddles the contact between a Precambrian cratonic block to the west, and sediments of the Hodgkinson orogenic belt to the east. This junction marks the site of extensive granitic emplacement during the Upper Permian/Lower-Carboniferous and is also a region of major lineament and fracture development (Figure 5).

The details of sedimentation during the development of the Hodgkinson belt are uncertain, but in general terms the western portion is predominantly shelf sediments (arenites, shales, limestone), grading into a flysch sequence towards the west (arenites and shales). The sedimentation record extends from Mid-Silurian to Lower-Carboniferous, with major orogeny occurring during the early Carboniferous.

Post tectonic granitic emplacement occurred during Upper-Permian Lower-Carboniferous, intimately associated with the development of extensive acid volcanics of similar age.

The batholith is composite, and contains a large number of separate plutonic and hypabyssal intrusives. Adamellites and granites are the most frequently occurring plutonic rocks, although granodiorites and minor quartz diorites are recorded (de Keyser and Lucas, 1968). The volcanics are predominantly rhyolites, dacites and rhyodacites with ash flow tuffs. The emplacement level is subvolcanic, and the tin deposits are related to one specific intrusive—the Elizabeth Creek Granite. However there is growing evidence to support the concept that mineralization is also related to some of the hypabyssal intrusives. Igneous activity during the Cainozoic is represented by extensive development of alkali basalts. Mineralization occurs at a large number of separate centres (Blake, 1972) and mineralization styles are extremely diverse with a wide variety of ore types (Figure 5). The dominant style is fracture controlled fissure fillings and replacement, forming veins and pipes in the regions of granite sediment contacts. Chlorite types predominate but tourmaline, sericite, and sulphide rich examples are common. Greisen assemblages also occur in the western regions associated with quartz veins, whilst tin bearing skarn assemblages are known to the south and north. Zonal or partial zonal sequences are frequently developed (Blake and Smith, 1970, Taylor and Steveson, 1972).

The intermediary character of this environment between the (Bolivian) subvolcanic style and the quieter (Erzebirge) plutonic style results in a wide diversity of style. Indeed on an international scale, the latter two provinces could be designated end members in a series which runs from provinces more akin to Bolivia to those closer to the Erzgebirge.

In terms of mineralization, brittle fracture and replacement styles predominate, although the quieter greisen styles are often represented. Thus veins and pipes predominate associated with various assemblages of minerals such as quartz, topaz, sericite, clay minerals, chlorite, tourmaline. Other common minerals both within the veins/pipes and the alteration assemblages include adularia, flourite and carbonates.

Very few veins/pipes form major deposits of 2–5 million tonnes, and this factor is well exemplified in the Herberton tinfield where some 2000 prospects have yet to yield a single major hardrock mine.

When carbonate rich rocks are present the possibility of a skarn or carbonate-replacement type deposit exists, and both these types are of considerable interest to current Australian exploration (Taylor, 1978b).

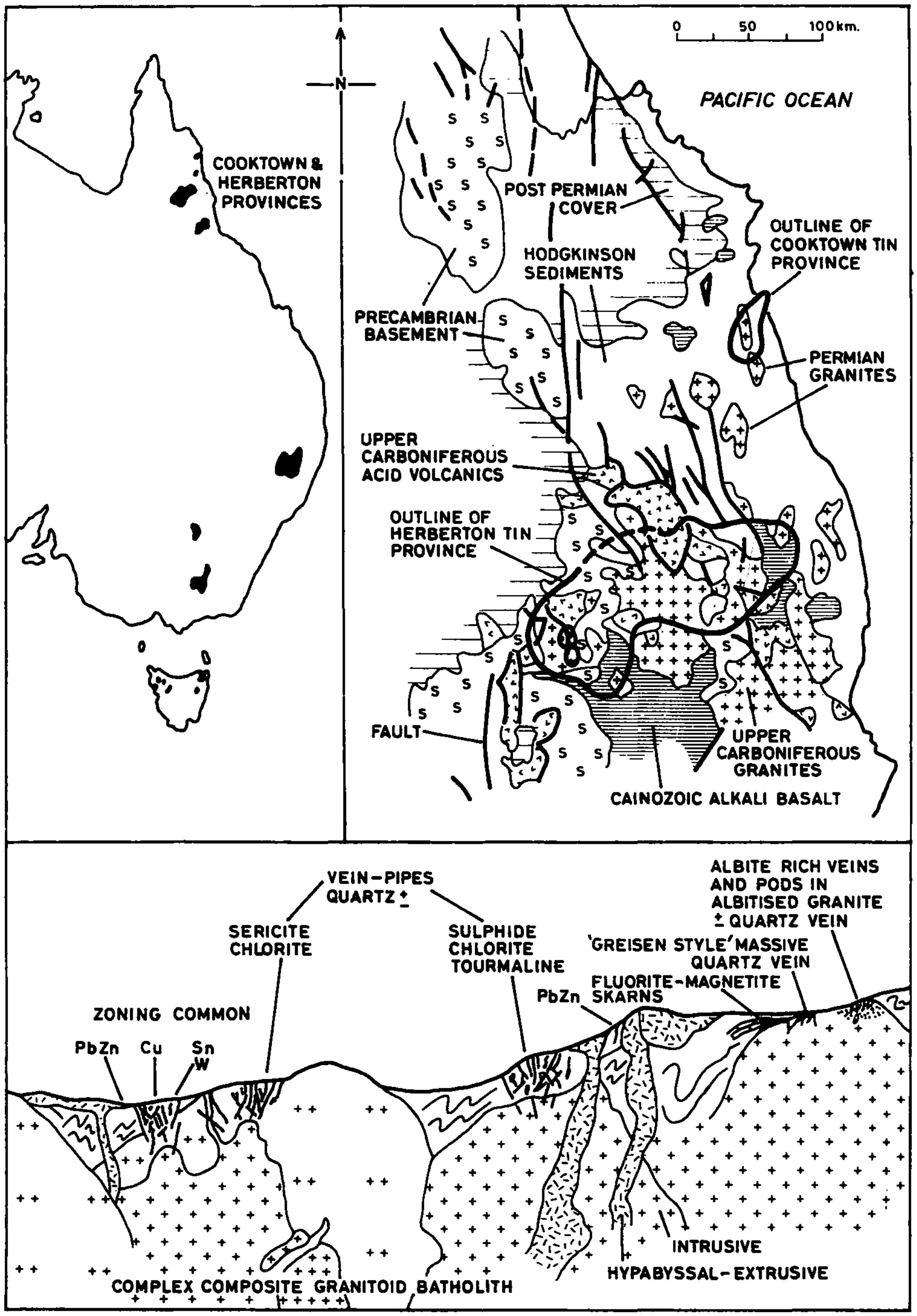


Fig. 5. Herberton—Mt. Garnet Province, Queensland. Location, geology and types of mineralization.

The carbonate replacement style is of prime interest being the generally accepted mode of origin for the major sulphide rich deposits of the North-West Tasmanian province, e.g. Renison Bell, Mt. Bischoff and Cleveland (Newnham, 1975, Ransom and Hunt, 1975, Groves *et al.*, 1972). The reserves at Renison-Bell are of the order of 15–20 million tonnes at around 1.0% Sn, and the general style of mineralization is shown in Figures 6 and 7. To date no direct analogies have been located in the other provinces, although there is a general paucity of carbonate facies in Eastern Australia. Orebodies of the carbonate replacement type are usually sulphide rich. For instance, Renison Bell ores typically contain 60–70% sulphides, predominantly pyrrhotite, with minor pyrite, chalcopyrite and arsenopyrite. This assemblage gives excellent electrical and magnetic response. The limestone replacement style typically occurs some hundreds of metres from the granitic source and with average deposition temperatures of 200–400 C is quite distinct from the skarn styles.

Although the presence of tin in skarn deposits is well established internationally, these deposits have only recently attracted attention in Australia. Several interesting tin bearing skarns have been located and are currently being evaluated, e.g. Mt. Moss-Kangaroo Hills, Redhill-Herberton, Gillian-Herberton, Mt. Lindsey-North West Tasmania, Doradilla-New South Wales. The results of this work have been both intriguing and disappointing. In keeping with overseas experience the Australian skarns have also presented problems in terms of, erratic tin distribution, overall low grades, a tendency for cassiterite to be fine grained, and for tin to be 'tied up' within minerals other than cassiterite such as magnetite, garnet etc. In one example an impression was gained that cassiterite did not appear below a threshold of 0.20% Sn, thus suggesting that tin was taken by the other minerals until a saturation point was achieved. In another case the bulk of the tin within a heavily oxidised skarn proved to be within limonite, and was presumed to have been present within the original minerals as tin rather than as independent cassiterite. Similarly substantial tin values were found to be tied up within malayaite in another example. Most of the above skarns are magnetite rich but many also exhibit pyrrhotite rich facies.

Despite the above problems the Doradilla and Mt. Lindsey tin bearing skarns represent a massive tin reserve and both are still being seriously investigated. The general build up of skarn type reserves in Australia has now reached such proportions that serious metallurgical attention is justified to find new methods for treatment of these complex assemblages. Exploration for tin bearing skarns is a relatively simple task involving careful sampling of known skarns and a search for new occurrences utilising ground or airborne magnetic surveys.

It should be noted that skarn style assemblages can also result from metasomatism of mafic rocks, and although only preliminary investigations have been conducted it seems that an unusual pyroxene-amphibole-magnetite apatite, flourite rock may be an Australian example. This alteration assemblage is associated with significant tin values and occurs at the Magnum Bonham mine, Silver Valley, Queensland (Okonu Obiji, personal communication, James Cook University of North Queensland).

A further skarn style which has also aroused considerable interest is the banded magnetite (pyrrhotite)-flourite type (Figure 8). This usually textured-finely banded rock is known colloquially as wrigglite (Askins, 1975) on account of the extremely "wriggly texture". The banding seems to form as a complex replacement process which can be seen commencing as fine parallel bands developing adjacent to fractures in the parent marble.

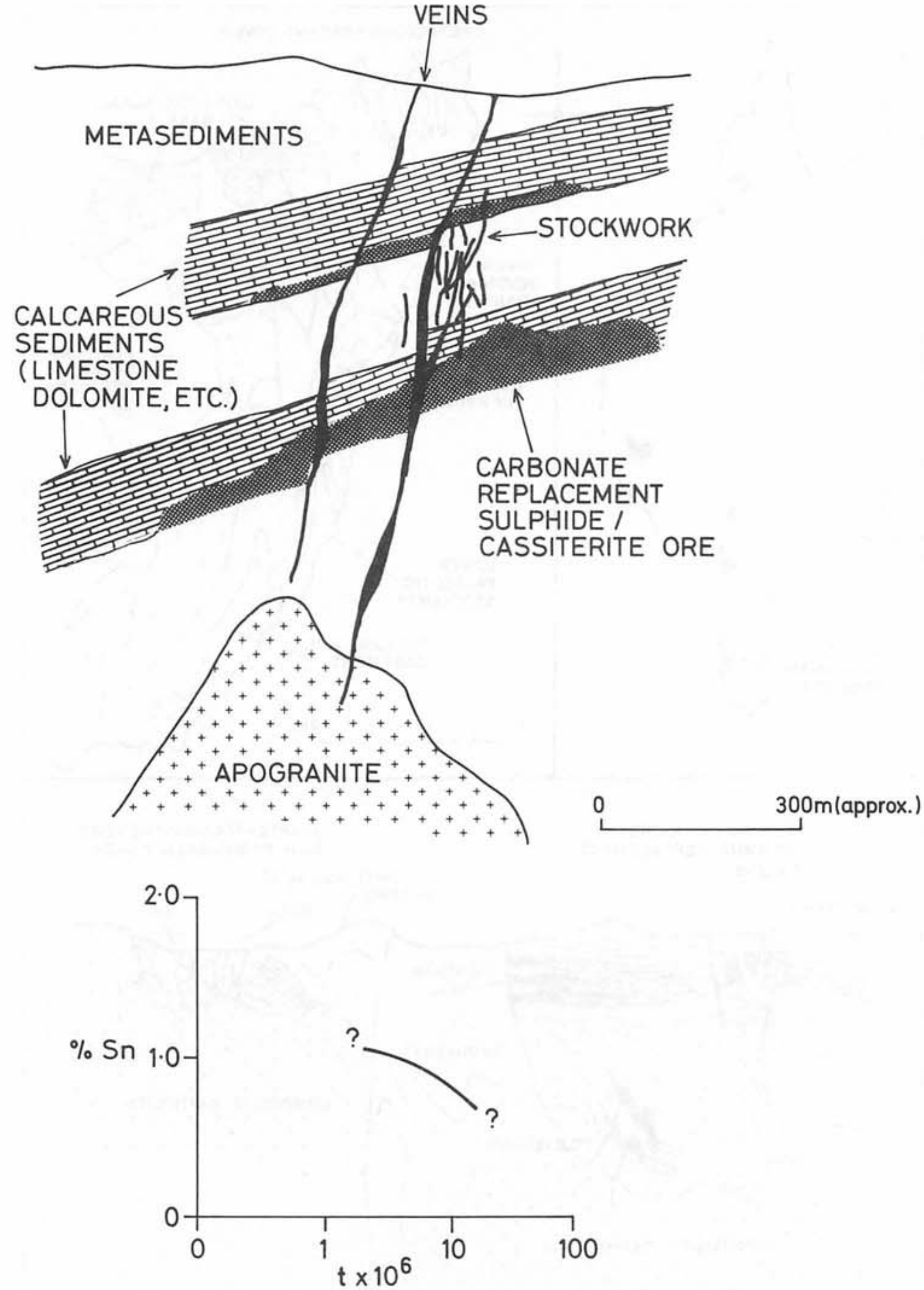


Fig. 6. The limestone replacement model. Diagrammatic transverse section and tonnage-grade curve. The model is based upon Renison Bell mineralization, North-West Tasmania.

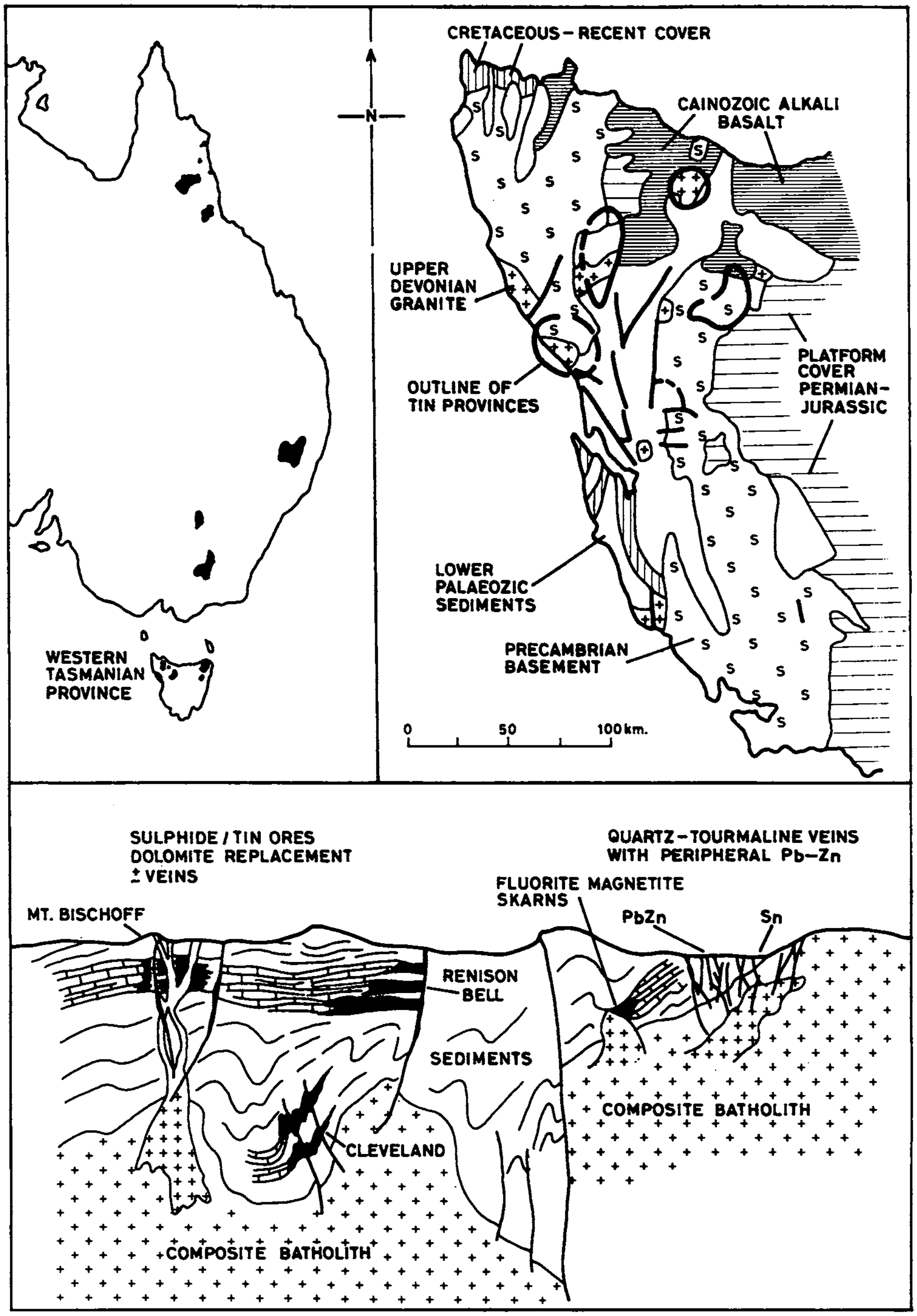


Fig. 7. North-West Tasmania Province. Location geology and types of mineralization.

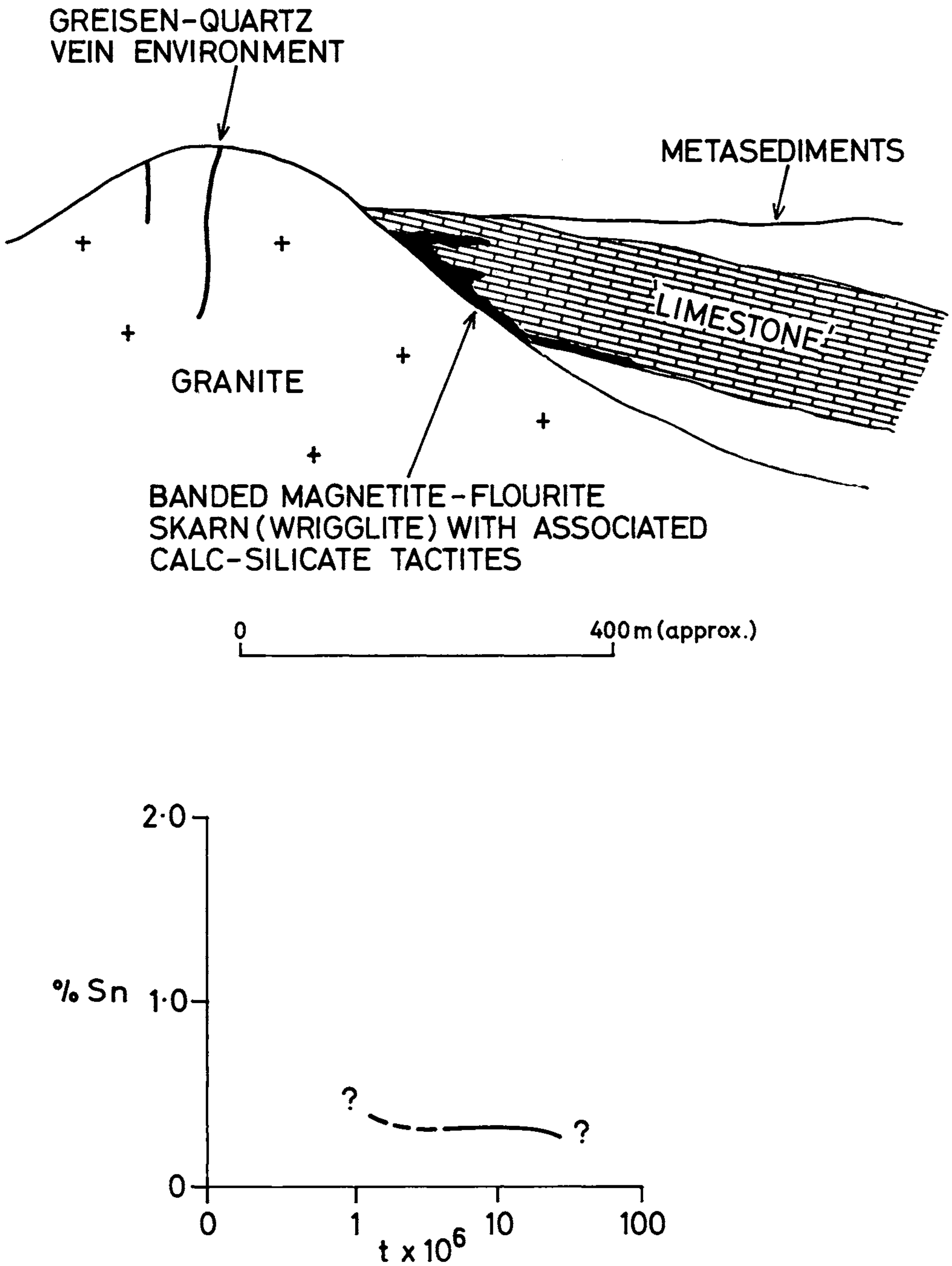


Fig. 8. The banded magnetite-flourite skarn model (wrigglite). Diagrammatic transverse section and tonnage grade curve. The model is based on the Moina mineralization, North-West Tasmania.

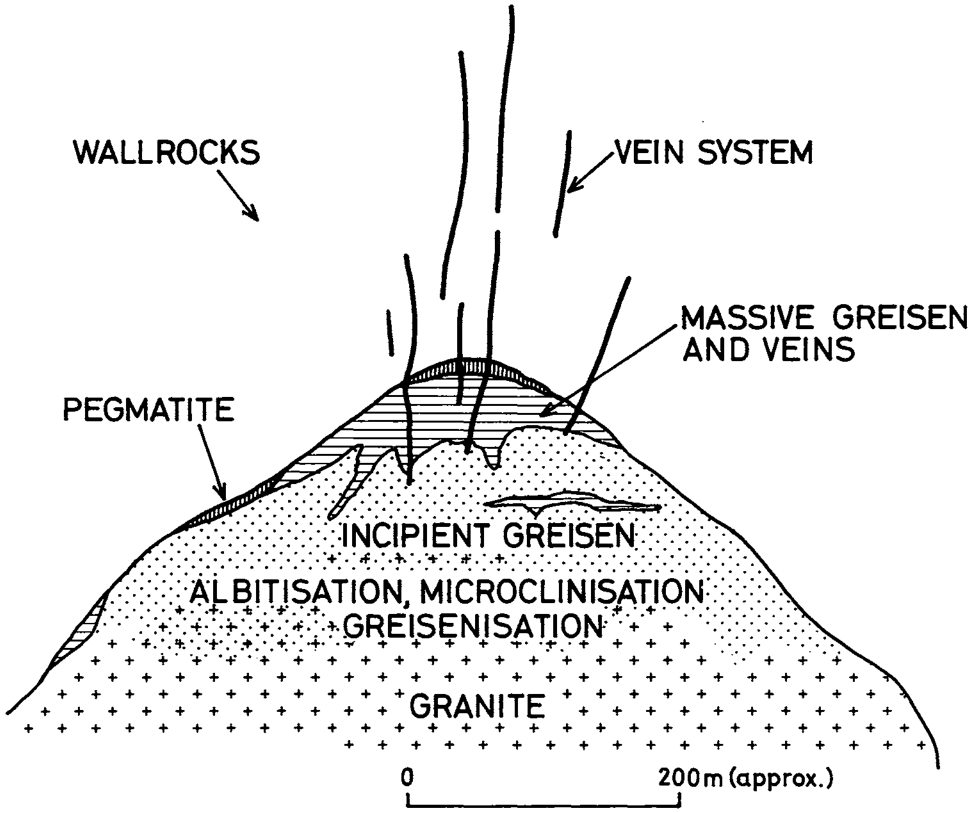
This type of skarn has been located at Moina, North West Tasmania, and Mt. Garnet, Queensland and seems directly analogous to the 33 million tonne ore. body located at Lost River in Alaska (15.0% flourite, 0.27% Sn, 0.0037% WO_3) The Moina occurrence is of a similar scale although the Mt. Garnet examples are relatively smaller (Taylor, 1978b). The latter occurrences are composed of flourite, idocrase, magnetite/hematite, spinel, and biotite with minor feldspar, garnet, chlorite, muscovite, scheelite, cassiterite, ilvaite, epidote, pyrrhotite, pyrite, chalcopyrite, arsenopyrite, sphalerite and galena (Askins, 1975). Both the Tasmian and Queensland occurrences contain sulphide-rich facies, where pyrrhotite occurs in place of magnetite. As in conventional skarns not all the tin is present as cassiterite, but is locked within several of the associated minerals.

Whilst the greisen style is generally poorly represented within this category (Figure 9), numerous examples occur in the western section of the Herberton field. Greisens are also recorded in the New England region and to a lesser extent in the Albury-Ardlethan belt. Large areas of massive greisen are uncommon and the quartz-vein $\pm$ greisen border style is more frequent. Considerable exploration attention directed to these occurrences has shown that whilst these are true greisen systems in the sense of Shcherba (1970) or Bauman (1970) they fail to approach the size or grade of their more illustrious Erzebirge/German Democratic Republic counterparts.

However an interesting variation on the greisen model has been located in the Herberton field which has economic potential (Figure 10). The Mt. Tin prospect at Irvinebank, Herberton consists of a series of albitised patches and lenses within fine medium grained granitic rocks (Handley, 1976). The granitic rocks are all partially albitised, but the heavily albitised patches and leases contain disseminated cassiterite and flourite. The albitisation and presence of cassiterite are difficult to recognise in the field and despite the intensity of local prospecting were not properly identified until 1976. Similar, although smaller concentrations have been recognised in the general Herberton district, and the general setting seems to be an apogranitic environment associated with a weak development of the traditional greisen style model. However, many more examples are required before this unusual? concentration can be viewed in context. Similar albitisation associated with tin-flourite mineralization has recently been noted by the author adjacent to the Mt. Garnet banded flourite-magnetite (wrigglite) skarns and it seems possible that both the deposit types form part of a single system.

The ore deposits at Ardlethan represents a type unique within the Australian environment (Patterson, 1976). The deposits consist of a compact mineralised system, comprised of a series of adjacent disseminated orebodies together with related small pipes and veins. The mineralization history is complex, and the major ore bodies are all associated with zones of brecciation. The nature of the brecciation is diverse and at various points features of collapse, shattering, and intrusion are visible. At least one major hydrothermal intrusion breccia pipe has been identified. The breccias are associated with intense and pervasive zones of alteration of the host granitoid rocks. Major alteration minerals include tourmaline, chlorite, topaz and sericite in varying proportions. Extraction is occurring via two open pits.

This unusual deposit is difficult to categorise. The mineralization is style very reminiscent of a high level porphyry copper or porphyry tin system, whilst the associated rocks are predominantly plutonic. Porphyritic rocks exist adjacent to the mine area, porphyry dykes are present in the main pit and quartz porphyry fragments are present in the intrusion breccia pipe.



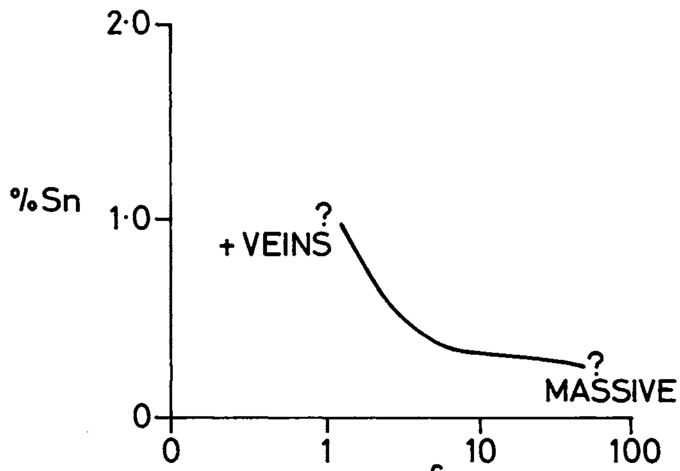


Fig. 9. The greisen style-conventiona model. Diagrammatic transverse section and tonnage-grade curve.

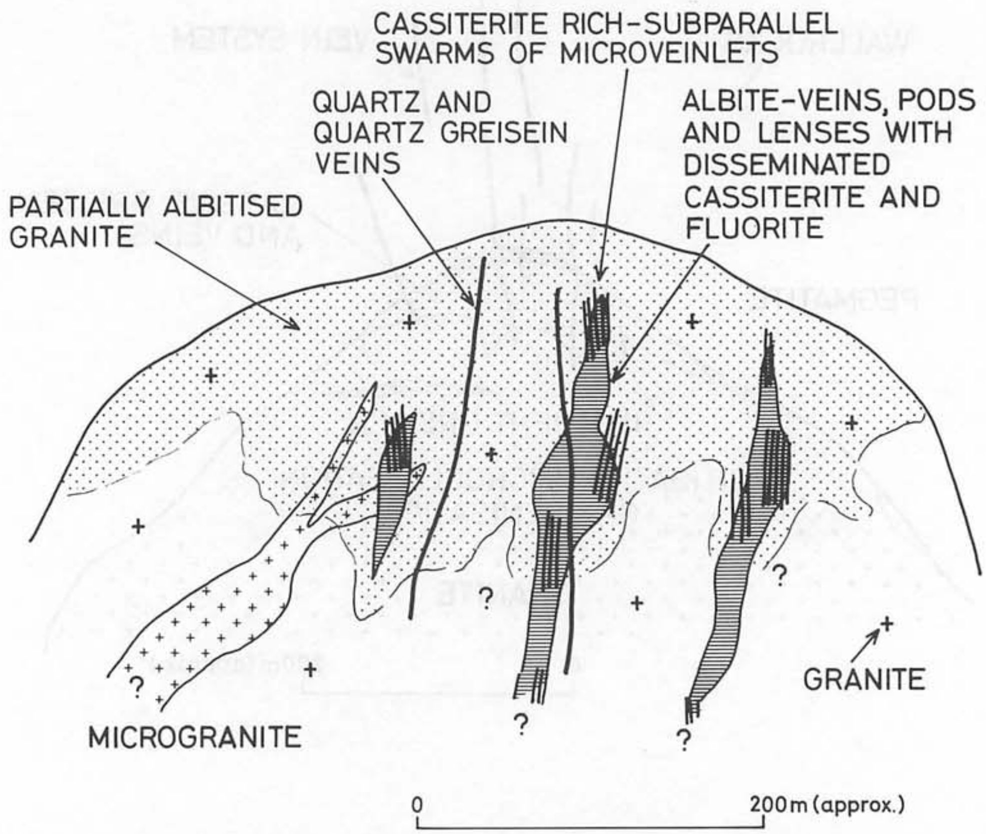


Fig. 10. The greisen style-albite model. (After Handley, 1976) Diagrammatic transverse section based on the Mt. Tin mineralization, Irvinebank, Herberton-Mt. Garnet Province, Queensland. Mineralization occurs within:

1) Subparallel microveinlets of cassiterite which occur in close association with,
2) Lenses and pods of albite rich rocks quartz with disseminated flourite and cassiterite.
3) As late phase cassiterite-quartz greisen bordered veins.

It is possible that the deposit may relate to a hidden porphyritic intrusive of the Bolivian type. However, current thinking at the mine favours a relationship with the plutonic granitoids which are highly anomalous in tin content.

THE PLUTONIC ENVIRONMENT (ENVIRONMENT 1C, TABLE II)

This style of environment with the emphasis upon plutonic character, passive intrusion environment, well established differentiation? sequences, geochemically specialised granitoids, etc., is well represented by the North-East Tasmanian and Cooktown environments.

The North-East Tasmanian region provides many excellent examples of the greisen style (Figure 8) as well as the quartz-vein end member as at Aberfoyle.

The major Blue Tier field displays different mineralization characteristics to the southern Aberfoyle field and they could be considered as separate provinces. However both are of similar age, appear to have formed under similar tectonic regimes relating to Upper Devonian batholiths, and are considered as part of a single province.

The geological setting (Figure 11) consists of a series of N-NNW trending granitoids intruding folded Lower Palaeozoic sediments. The sediments are composed of sandstone, subgreywacke, siltstones and shales and represent a flysch style environment. Major orogeny occurred during the Mid Devonian and produced folding along axes trending NNW-NW. Subsequent to folding the granitoids were emplaced during the Upper Devonian. The western margin of the flysch sequence is concealed beneath platform cover sediments and from limited evidence appears to unconformably overly Precambrian basement. The post orogenic platform cover rocks consist of Permian/Triassic sediments which were intruded by extensive sills of tholeiitic dolorite. Minor Cainozoic alkali olivine basalts unconformably overly both the platform cover and orogenic zone.

The emplacement of the granitoids occurred towards the central region of the orogenic zone, with the main intrusions displaying a general NNW-NW trend. The major Blue Tier Batholith (Gee and Groves, 1971) comprises at least eleven major separate intrusions which are predominantly adamellite-granodiorite with minor amounts of granite. The granitoids are of the contact aureole type with metamorphic aueroles ranging from 500m.–2km. The granitoids have no associated volcanics. Although major lineaments and fracturing is not a feature of the province, Gee and Groves (1971) consider that the intrusion of the granitoids was primarily fracture controlled, involving a wide variety of emplacement mechanisms, i.e. horsting, wedging, permissive, etc.

Tin production is of the order of 70,000 tons, predominantly from alluvial sources. The primary deposits are associated with a scattered series of small bodies of biotite granite which are the latest intrusions of the batholith (Groves, 1972). Many of these late bodies are essentially sheet-like intrusions with feeder dykes.

The style of mineralization is distinctive and all deposits are related to roof zones of the biotite muscovite intrusives.

The main types include:

(1) Greisen-floor deposits and/or disseminated cassiterite in hydrothermally altered granite (Groves and Taylor, 1972).

(2) Vein deposits, i.e. quartz veins with sericite wall rock alteration and quartz veins associated with coarse muscovite (greisen style).

(3) Massive greisen zones associated with argillic alteration quartz veins as at Mt. Paris.

Wolframite is occasionally present and sulphides are rare. The Aberfoyle mineralization displays a differing mineralization style consisting of several small centres of fracture controlled veins often associated with underlying cupolas of aplite (Kingsbury, 1965). This may reflect a slightly higher level granite/sediment contact environment than seen in the more deeply eroded Blue Tier Batholith although the association with a specific granite type is not apparent.

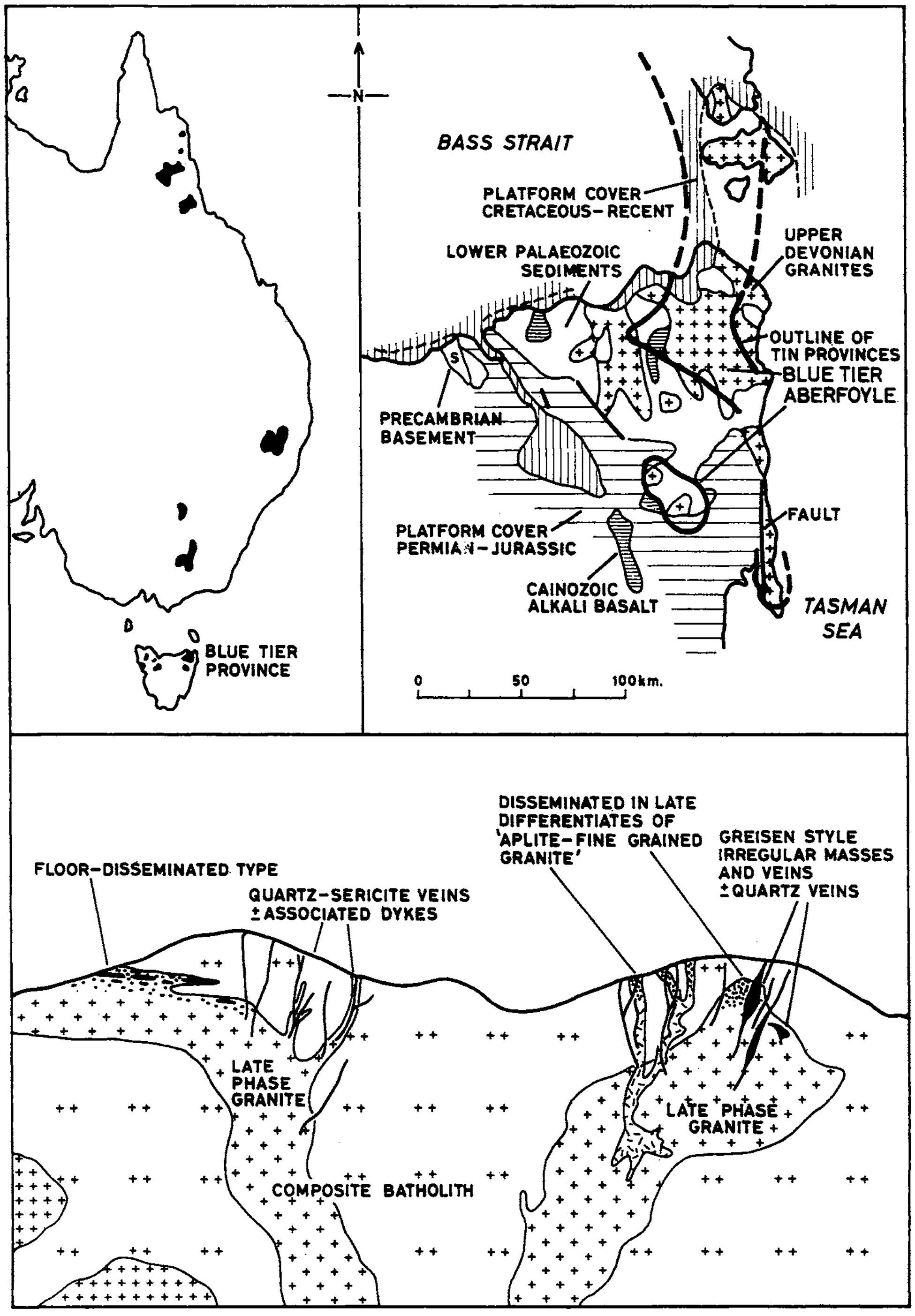


Fig. 11. North-west Tasmania (Blue Tier) Province. Location, geology and types of mineralization.

The main types in the Aberfoyle field include:

(1) Vein deposits in sediments, i.e. quartz veins with muscovite selvedges. Wolframite is the major associated mineral and may be dominant. Minor sulphides are generally present.

(2) Vein deposits in granite, i.e. quartz veins associated with coarse muscovite (greisen style).

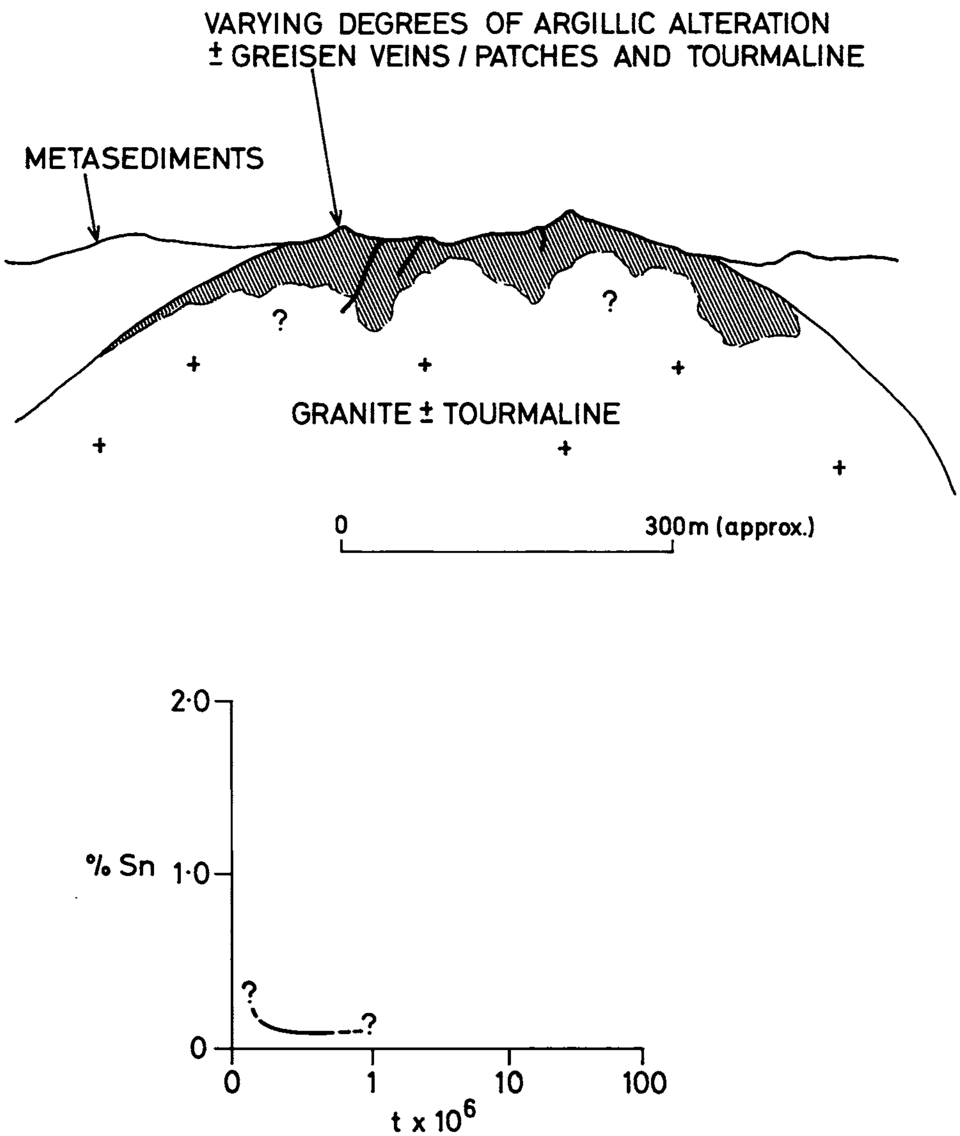


Fig. 12. The greisen style-argillic model. Diagrammatic transverse section and tonnage-grade curve. The model is based upon Dalys Face mineralization and other similar deposits in the Cooktown region, Queensland.

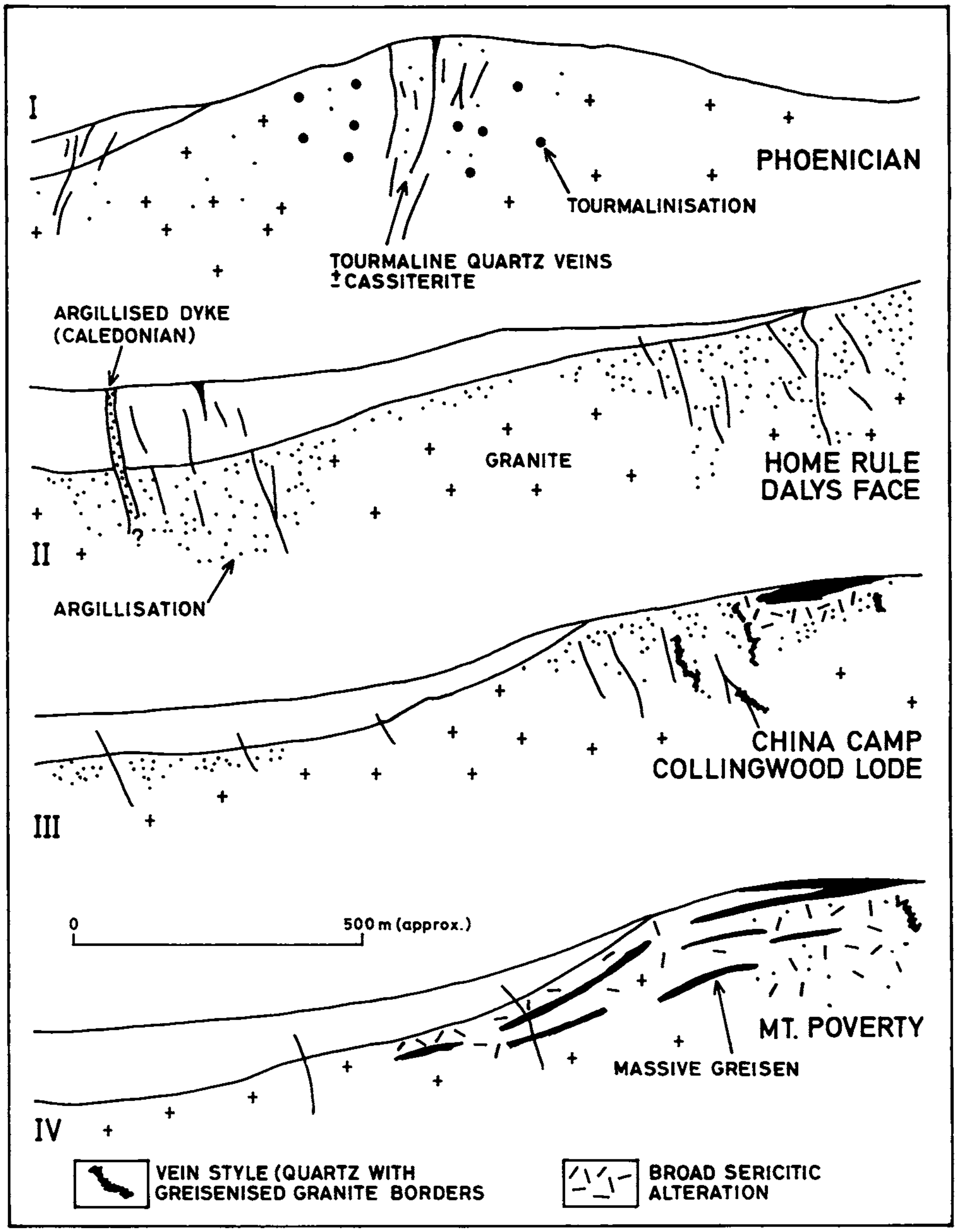


Fig. 13. Deposit types in the Cooktown tinfield. The deposits appear to form an overlapping spectrum and those illustrated are members of a series. (N.B. the models are based upon literature, survey and limited field data).

I Tourmaline-quartz veins, veinlets, patches, $\pm SnO_2$ and/or quartz-SnO_2 veinlets, veins, in tourmalinised granite with minor argillisation.

II Tourmaline quartz and/or quartz veinlets, veins $\pm SnO_2$, associated with pervasive argillic alteration ($\pm$ minor sericitic alteration).

III Tourmaline-quartz, quartz veins, veinlets $\pm SnO_2$ with minor greisen development. Alteration ranges from argillic to sericitic.

IV Similar to types II and III but with significant greisen development and less argillic alteration.

Cooktown differs from the North-East Tasmanian province in that although it contains examples which are close to the classic greisen mode, e.g., Mt. Poverty, the majority of the major occurrences seem to be an end member of the greisen spectrum dominated by argillic alteration. This species is also seen in North-East Tasmania at Mt. Paris, but appears relatively uncommon.Tin values associated with the argillic style of alteration seem an order of magnitude lower than those of the normal greisen environment (Figure 12). Some concept of the range of deposits in the Cooktown province is given by Figure 13.

CONCLUDING

This brief account of the Australian tin settings has attempted to demonstrate the relationship between different environments and deposit types. The nature of deposits within any specific province seems directly related to the nature of the granitoid and environment.

The more passive plutonic environments appear to favour the development of greisen/argillic styles. The more active deep subvolcanic/plutonic settings favour the development of a wide range of brittle fracture-replacement styles although greisen types are not excluded. The role of carbonate rocks in the passive plutonic environment is uncertain as both the North-East Tasmanian and Cooktown provinces are devoid of carbonate rich facies. However, in the deep subvolcanic plutonic regions skarns and carbonate replacement deposits constitute a major tin resource. The Precambrian/pegmatite relationship is well established although the precise reasons for this association are obscure. It should also be noted that other types of Precambrian province exist, e.g. Crystal Hill with greisen affiliations and the Northern Territory with plutonic/deep subvolcanic? features.

When it is realised that many of the deposit types and environmental associations mentioned in this account have been recognised within the last decade, it is clear that understanding of the geology of tin deposits is advancing rapidly with an accompanying sharpening of exploration perceptions. However, much remains to be deciphered and there is a continuing need for international collation, co-operation and synthesis.

ACKNOWLEDGEMENTS

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