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THE BARNARD METAMORPHICS AND THEIR RELATION TO THE BARRON RIVER METAMORPHICS AND THE HODGKINSON FORMATION, NORTH QUEENSLAND.

by

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ABSTRACT

During the Middle Palaeozoic, the Tasman Geosyncline extended to north-eastern Queensland, including the area between Cape York Peninsula and Ingham. The geosyncline was here represented by the Hodgkinson Basin, in which the Hodgkinson Formation forms the main geosynclinal deposit. Metamorphic rocks of doubtful age, exposed along the coast within the geographical limits of the Hodgkinson Basin, are called Barron River Metamorphics (greenschist facies of metamorphism) and Barnard Metamorphics (amphibolite facies). They have hitherto been thought to have formed tectonic land during the Middle Palaeozoic geosynclinal sedimentation - hence to be older than the Hodgkinson Formation - and their ages were estimated to be early Palaeozoic (Barron River Metamorphics) and Precambrian (Barnard Metamorphics). Recent field work suggests that the two units may both be the metamorphic equivalents of the Hodgkinson Formation: it is concluded that they formed an integral part of the Tasman Geosyncline during the Middle Palaeozoic, and were metamorphosed during the late Palaeozoic orogeny under conditions of high temperature and relatively low pressure. This idea is supported by geological examples from other places of the world, and by the latest views on the relationships between metamorphosed and unmetamorphosed rock sequences in orogenic belts. The picture thus obtained appears to harmonize with the circum-Pacific area in general, where this type of metamorphism (andalusite-sillimanite association) is rather common.

INTRODUCTION

The Tasman Geosyncline, a Palaeozoic geosynclinal zone along the eastern edge of Australia (Schuchert, 1916), included north-eastern Queensland during the late Silurian to early Carboniferous. That part of the geosyncline known as the Hodgkinson Basin (or Hodgkinson Trough, Fig.1), is separated from the Precambrian Shield in the west by the Palmerville Fault, 600 miles long, and extending from Princess Charlotte Bay in the north to Halifax Bay, near Ingham, in the south. Rock units exposed within the present geographical limits of the Hodgkinson Basin are dominantly its geosynclinal fillings: the shallow-water sediments of the late Silurian Chillagoe and Mount Garnet Formations along the western shores of the basin, and the deeper-water flysch deposits of the Hodgkinson Formation, the main rock unit in the basin. These formations are tightly folded, but not regionally metamorphosed, and are intruded by late Palaeozoic granites and volcanic rocks (Fig.1).

Less clear are the age and stratigraphic relationships of metamorphosed rocks that crop out in the coastal area within the geographical limits of the Hodgkinson Basin. They are the Barron River Metamorphics and the Barnard Metamorphics, developed in, respectively, low-grade and high-grade facies of metamorphism, and exposed in the coastal area between Mossman and Tully (Fig.1). The high-grade Barnard Metamorphics have, up till now, been regarded as a Precambrian (possibly Archaean) rock unit, and the Barron River Metamorphics generally as Lower Palaeozoic, and hence older than the formations of the Hodgkinson Basin. However, systematic regional mapping since 1960, by combined parties of the Bureau of Mineral Resources and the Geological Survey of Queensland, suggests that both units are part of the Hodgkinson Basin sequence and represent time equivalents of the unmetamorphosed geosynclinal formations.

THE BARNARD METAMORPHICS

Outcrops of high-grade metamorphic rocks along the coast and on the offshore islands between Tully and Cairns were included in 1946 by Bryan & Jones in their 'Coastal Series', and were later re-named Barnard Metamorphics by Jones & Jones (1956), after the Barnard Islands south-east of Innisfail (Fig.1). They are not shown separately on the Geological Map of Queensland (1953), but are stated to occur on many of the islands and coastal stretches from Innisfail south to a latitude of about 26°S. (Jones & Jones, 1960). This paper is concerned only with the occurrences on the Frankland Islands, the Barnard Islands, and in the region east of Tully - that is, with the occurrences in the type area. There the distribution of the Barnard Metamorphics as presented in Figure 1 differs to some extent from that indicated by Jones & Jones (1960).

The Barnard Metamorphics consist of mica schist, gneiss, migmatite, and rare lenses of ultrabasic schist (talc-antigorite-carbonate rock), and include some gneissic granite. Outcrops along the coast comprise coarse-grained migmatite, gneiss, and schist composed of quartz, muscovite, red-brown biotite, some albite and more calcic plagioclase, and masses of sericite probably replacing feldspar. Zircon, apatite, iron oxides, garnet, and tourmaline are the accessory minerals. Quartz is partly replaced by sericite or muscovite along grain boundaries.

Intrusive gneissic granite at South Mission Beach consists of phenocrysts or porphyroblasts of quartz, twinned albite, and potash feldspar (microcline as well as an untwinned variety) in a granular quartz-feldspar mosaic. Brown biotite and a little dark green to blue-green, possibly somewhat sodic, hornblende are the mafic constituents; muscovite is associated with the biotite.

The gneissic structure is due to granulation and recrystallization, and is not a flow-foliation. Schist intruded by the gneissic granite is composed of fine-grained masses of pale green amphibole and pale brown biotite, and contains accessory quartz and pyrrhotite.

The gneiss and migmatite found on High Island and Russell Island (Fig.1) has andalusite, sillimanite, and cordierite, in addition to quartz, orthoclase, microcline, biotite, muscovite, albite, oligoclase, chlorite, and accessory tourmaline, apatite, zircon, epidote, and iron oxides. Although kyanite has been reported by Jones & Jones, none was recognised in our thin sections. Biotite and muscovite are commonly intergrown, biotite being the later mineral. Locally, apatite and iron oxides are concentrated together in thin layers. The thin sections of rocks from High Island generally contain much cordierite and equidimensional andalusite, and the biotite is a green-brown variety; less cordierite is present in the thin sections from Russell Island, the andalusite is commonly intergrown with coarse sillimanite, and the biotite is generally red-brown, as on the mainland. In the thin sections, fibrolitic sillimanite and the coarse andalusite-sillimanite intergrowths appear to have nucleated from the micas, and in the intergrowths rounded remnants of biotite are still present, as well as trails of opaque iron oxide particles and dust that probably were liberated during the destruction of the biotite.

Because oriented specimens were not systematically collected, and only a few thin sections were made, little can be said about the interplay of different phases of deformation and metamorphism. However, it is clear, from a study of the available thin sections, that the tectonic-metamorphic history of the Barnard Metamorphics is complex. Late-metamorphic and post-metamorphic stresses deformed the original fabric by straining and crushing quartz and by bending micas, and evidence of granulation can be seen side by side with evidence of recrystallization. In places, remnants of former S-surfaces, in the form of rows of mineral inclusions in quartz grains, are rotated relative to the latest foliation. Several minerals occur in more than one generation: sillimanite, for example, is present as fibrolite in fine-grained felts, and as coarse idioblastic crystals generally intergrown with andalusite (Figs. 2-5). Andalusite occurs as clear, equidimensional, somewhat rounded porphyroblasts, and intergrown with sillimanite in prismatic porphyroblasts (Figs. 2-4) which tend to be oriented with their longer axes along the plane of foliation though showing some rotation in places, with concomitant attrition of the grain boundaries. The micas, too, were probably developed in more than one episode: besides being normal rock constituents, they also replace cordierite (Fig.6), which in places is almost completely transformed into clusters of decussate, colourless and green micas.

The relative times of formation of the different generations of minerals is not known with certainty. Fibrolite is later than cordierite, andalusite, and probably also andalusite-sillimanite intergrowths, for it either surrounds them in thin rims of fuzzy felt, (Fig.2) or sprouts from the ends of prisms as brush tips of fine needles. In the intergrowths, andalusite probably replaces sillimanite (Figs. 3,4), although this is not completely certain. The clear, equidimensional andalusite and the cordierite, which lack preferred orientation, were formed under stress-free conditions at a certain stage, and were later corroded and altered; whether they are older or younger than the andalusite-sillimanite intergrowths is not known.

That metasomatism has also played a role in the development of the Barnard Metamorphics is suggested by an unusually great abundance of potash-feldspar in a few thin sections.

The Andalusite-sillimanite-(kyanite) Association

This association is of importance in defining the type of metamorphism in Miyashiro's classification (1960), and has recently been discussed by Chinner (1962), Weill & Fyfe (1961), Schuiling (1962), Aramaki & Roy (1963), and others. The association has also been investigated in a series of recent laboratory experiments (Bell, 1963; Khitarov, Pugin, Pin Chao, & Slutskii, 1963).

The general opinion at present (Schuiling, 1962, and others) appears to be that the existence of different modifications of Al_2SiO_5 can no longer be explained in terms of stress or anti-stress conditions. Stress may help to increase hydrostatic pressure, perhaps by 2000 to 3000 bars at the most ('tectonic overpressure'), but is otherwise probably of little significance. Likewise, the notion of stable (sillimanite) and metastable (andalusite) modifications of Al_2SiO_5 (e.g., Weill & Fyfe, 1961) was rejected by Schuiling (1962), who concluded that at a temperature somewhere below 1010°C. andalusite appears to replace sillimanite as the stable modification. This conclusion, which is in much better agreement with petrographic observations, of, for instance, the reversibility of transformations between modifications (Hietanen, 1956), has been confirmed by recent laboratory experiments (Bell, 1963; Khitarov et al., 1963), which show that the three modifications andalusite, sillimanite, and kyanite all have their own stability fields, which join together at a common triple point (Fig.7). On theoretical grounds, the inferred position of this triple point had already been indicated in tentative diagrams by Chinner (1962), Miyashiro (1961), Schuiling (1962), Zwart (1963), and others. Figure 7 shows the diagram as given by Schuiling, supplemented with the triple points as inferred or experimentally obtained by several others.

Although the co-existence of such allotropic forms is theoretically metastable, associations of, for instance, andalusite and sillimanite without evidence of replacement are fairly common. This is regarded by Chinner and Schuiling as an indication that the field boundary lines actually represent 'bands of indifference' within which two modifications - or three, near the triple point - can exist together owing to the sluggishness of the transformation. The width of these 'bands of indifference' would depend on a number of variables such as H_2O content, temperature, duration of metamorphism, and initial composition (Schuiling, 1962).

The temperature-pressure conditions under which Al_2SiO_5 associations are formed may be inferred from the phase diagram (Fig.7). For the andalusite-sillimanite association in the Barnard Metamorphics, which was probably not far removed from the triple point (as kyanite has been reported), the temperature of formation must have been at least 550°C. (or 400°C., if the values of Khitarov et al. are preferred), and the pressure below 7000 bars (or 9000 bars, according to Khitarov et al.).

THE BARRON RIVER METAMORPHICS

Whitehouse (1930) first used the term 'Barron River Series' for low-grade metamorphic arenites and lutites in the Cairns area. They were subsequently designated 'Barron River Metamorphics' on the Geological Map of Queensland (1953), on which they are shown as a strip, about 20 miles wide, extending along the coast from Cape Melville in the north to Ingham in the south. However, the recent mapping has indicated that they do not extend south of Tully, and that their northern boundary may be located near Mossman (Fig.1).

The Barron River Metamorphics consist of slate, phyllite, sericite schist, recrystallized arenites (mainly greywacke and quartz greywacke), thin-bedded weakly metamorphosed siltstone, and subordinate bedded chert and green-schist; rare lenses of recrystallized limestone and ultrabasic rock (talc schist, tremolite-chlorite schist) are also present. The grade of metamorphism is nowhere higher than the quartz-albite-epidote-biotite subfacies of the greenschist facies (Fyfe, Turner, & Verhoogen, 1958), and in places is lower still. The phyllites and schist are composed of quartz, sericite, and small amounts of biotite, chlorite, and feldspar. Accessory minerals include tourmaline, apatite, zircon, iron oxides, and leucoxene. The arenites consist of quartz, potash-feldspar, plagioclase, muscovite, biotite, and rock fragments. Recrystallization of their mostly quartzose-micaceous matrix has caused some corrosion of the clastic grain boundaries, but in hand-specimen the arenites are the least metamorphosed in appearance. The greenschists show the usual combinations of albite, chlorite, epidote, actinolite, sphene, and magnetite.

In the southern part of their outcrop area, the metamorphics are separated from unmetamorphosed Palaeozoic formations farther inland by large tracts of later intrusive and extrusive rocks, so that their boundary relationships with these formations are hidden, and the contrast between rocks east and west of the later igneous belt seems considerable. The eastern, metamorphosed, rocks had therefore previously been interpreted as a distinct unit of doubtful age, but seemingly older than the unmetamorphosed rocks to the west.

In the north, where the contact of Barron River Metamorphics with unmetamorphosed Hodgkinson Formation is not buried, the regional geology was little known because of the difficulties imposed by topography, climate, and dense vegetation. The boundary drawn on the Geological Map of Queensland (1953) is therefore rather artificial, coinciding largely with stretches of alluvium and with the western edge of the tropical rain forest. Rock outcrops in the forested eastern zone are generally deeply weathered and decomposed to a soft clay, very different from the oxidized rock exposures, commonly indurated by surface silification, in the drier inland areas, and this may have contributed to the impression that the eastern and western rock sequences are separate units probably of different age.

THE HODGKINSON FORMATION

The Hodgkinson Formation (Jack's 'Hodgkinson Beds', 1884; see also White, 1961, and Cribb, 1960) incorporates thick, monotonous sequences of massive to thin-bedded arenites (greywacke, quartz greywacke, feldspathic sandstone) and lutites, partly deposited by turbidity currents. Intercalated are bedded cherts, basic volcanics, conglomerate, intraformational breccias, and rare lenses of limestone. Fossils indicate a middle to late Devonian age, perhaps extending into the early Carboniferous.

The formation represents the main infilling of the geosynclinal Hodgkinson Basin or Trough, and has an estimated maximum thickness of at least 40,000 feet. It was virtually not affected by regional metamorphism, although locally the rocks are slightly contact-metamorphosed around granite intrusions, or strongly sheared along zones of deformation. To the east, the Hodgkinson Formation is in contact with the Barron River Metamorphics.

RELATIONSHIPS BETWEEN THE HODGKINSON FORMATION AND THE BARRON RIVER METAMORPHICS.

Our fieldwork since 1960 has shown that there is no fundamental difference between the Hodgkinson and Barron River rocks: both consist mainly of arenites (greywacke and quartz greywacke) and lutites with intercalated bedded chert, basic volcanics, and rare lenses of limestone. No angular unconformity could be detected, nor was an unconformity indicated by any changes in lithology, or by the presence of basal conglomerates, or the like. Furthermore, there appears to be a gradual transition from unmetamorphosed rocks of the Hodgkinson Formation in the west into low-grade Barron River Metamorphics in the east: first, the basic volcanics are transformed into greenschist; then the clastic biotite in siltstone and shale gives place to clear recrystallized biotite, before further changes can be noted in such rocks. The arenites retain their unaltered appearance farthest eastwards, though microscopic examination shows that quartz and biotite in the matrix have recrystallized and migrated, and feldspar has been converted to sericite aggregates. The metamorphic boundary appears to cross the regional trend lines.

For these reasons the Barron River Metamorphics are considered to be the weakly metamorphosed equivalents of the unmetamorphosed Hodgkinson Formation, and hence to be of middle to late Devonian age. However, they may also include late Silurian to early Devonian sediments, time-equivalents of the shelf-type Chillagoe and Mount Garnet Formations, but here belonging to a deeper-water facies which, in the absence of fossils, is indistinguishable from that of the Hodgkinson Formation.

The boundary between the Barron River Metamorphics and the Hodgkinson Formation (Fig.1) is therefore of necessity highly arbitrary, and represents a metamorphic isograd rather than a stratigraphic demarcation. It is drawn where the first signs of regional metamorphism become faintly noticeable in the lutites; isolated patches of weakly metamorphosed rocks may exist north and west of the boundary, and virtually unmetamorphosed rocks may yet be found south and east of the boundary.

This conclusion, that the coastal rocks are the metamorphosed equivalents of those to the west, is by no means new. Jack (1884) considered the possibility, although his personal opinion was that the western sequence 'unquestionably looks newer' than the eastern rocks, and that 'if both existed side by side it is not easy to see how one escaped the metamorphism which the other underwent'. In 1923 Jensen stated that the schists and slates around Cooktown, as well as the rocks around Mount Carbine, Molloy, and at Tinaroo and Herberton (Figure 1), are older than the Hodgkinson 'Series', whereas the outcrops in the Cairns-Innisfail area 'undoubtedly belong to the Devonian belt' of the Hodgkinson deposits. Later, however, (in AGGSNA, 1939), he included the rocks of the Molloy-Tinaroo-Upper Russell River area in his Hodgkinson Series, and said that this formation was laid down in a wide basin between the Featherbed Range (about 60 miles west of Cairns) and 'metamorphosed rocks on the east - the latter are now represented sporadically in places of specially strong uplift in the coastal (Dividing) Range between Cairns and Cooktown'. These changes of opinion may serve to illustrate again the vagueness of the boundary and the slight differences between the metamorphosed eastern and the unmetamorphosed western rocks.

In later years the idea prevailed that the whole region indicated as Barron River Metamorphics on the Geological Map of Queensland (1953) formed a highland during the Devonian sedimentation. Hill (1951) defined the 'North Coastal High' as a structural 'high' or eminence on the eastern side of the Hodgkinson Trough; and White (1961) suggested that the 'Early Palaeozoic' Barron River sediments 'were folded to form a major geanticline and finally emerged as land' before or during the Hodgkinson sedimentation. Finally, Brooks (1960), in a summary of the Barron River Metamorphics, correlated them with the early Palaeozoic Neranleigh-Fernvale Group of south-eastern Queensland, because of lithological similarities and coincidence of regional strike.

RELATIONSHIPS BETWEEN THE BARRON RIVER METAMORPHICS AND THE BARNARD METAMORPHICS

It has been the generally accepted opinion that the Barnard Metamorphics are much older than the surrounding rock sequences, and that they are of Precambrian (possibly Archaean) age because their grade of metamorphism is much higher than that of the Precambrian Mount Isa Shale in north-west Queensland (Jones & Jones, 1956). This opinion seems reasonable enough at first glance, for the contrast between coarse-grained mica schist or gneiss of the Barnard type and fine-grained phyllite or sericitic schist of the Barron River type is striking indeed;

besides, the true relationship between the two units is largely concealed under a cover of dense tropical vegetation in the coastal area, where outcrops are deeply weathered and decomposed.

Nevertheless, we have found no sign of angular unconformity: neither conglomerates, nor any changes in lithology were noticed in either unit in the vicinity of the inferred boundary. It seems that the original lithological constitutions of the Barron River and Barnard Metamorphics were much alike, notwithstanding their strong metamorphic contrast - both units consisted mainly of arenites and lutites with minor intercalations of basic volcanics and rare lenses of ultrabasic rock. A more positive point is the observation of what may be a transition zone between the two units, exposed in a road cutting about 10 miles north-east of Tully; there, a few beds of coarse mica schist (Barnard type) are intercalated in fine-grained sericite schist (Barron River type). In general the Barron River Metamorphics and the Barnard Metamorphics east of Tully, though not exposed on the ground, are distinguishable on air-photographs by a slight difference in photo-texture, and their boundary, thus interpreted, passes through the road cutting. Judging by the photographs, the transition is rather abrupt and must be complete within an interval of less than one quarter of a mile approximately.

DISCUSSION

The probability that the Barnard Metamorphics are the higher-grade metamorphic equivalents of the Barron River Metamorphics is supported by recent papers on metamorphic problems, one of which (Miyashiro, 1961) applies particularly to the conditions found in this part of north-eastern Queensland.

In summary, Miyashiro claims that the well-known metamorphic facies series represents only one of five possible series (or three main types with two transitional groups). Which type of series will prevail in any one orogeny is determined by the reigning pressure/temperature conditions. The five types are, in order of increasing pressure/temperature ratio:

1. andalusite-sillimanite type
2. low-pressure intermediate group
3. kyanite-sillimanite type
4. high-pressure intermediate group
5. jadeite-glaucophane type.

The classical metamorphic facies series is represented by the kyanite-sillimanite type of metamorphism, and can be equated with the 'Barrovian' type of metamorphism of the Scottish Highlands. The andalusite-sillimanite type (more or less equivalent with the 'Buchan' type of metamorphism in Scotland), to which the Barnard Metamorphics belong, is the low-pressure, high-temperature end-member in Miyashiro's classification, and is common in orogenic belts in many parts of the world, including the circum-pacific region.

The mineral assemblage of the Barnard Metamorphics, described on page 3, at first sight abnormal and metastable, is, according to Miyashiro, the normal and typical mineral assemblage for the amphibolite facies in the andalusite-sillimanite type of facies series.

Other features characteristic of rocks metamorphosed under conditions of high temperature and low pressure (andalusite-sillimanite type of metamorphism), and typical for North Queensland, are the co-existence of andalusite and sillimanite, and the common presence of cordierite; the abundance of granites, including synkinematic granites (in the higher-grade parts of metamorphic belts); the widespread extension of granites beyond the limits of the regional metamorphic terrain; the scarcity of basic plutonic rocks (generally somewhat older than the granites); and the complete absence of almandine garnet in the metamorphosed basic igneous rocks.

The rather abrupt transition from low-grade (Barron River) to high-grade (Barnard) metamorphic rocks, too, is characteristic of this type of metamorphism (Miyashiro, 1961; Chinner, 1962). According to Miyashiro, the andalusite-sillimanite facies series has only two metamorphic facies in pelitic rocks: a greenschist facies and an amphibolite facies; and as the intermediate albite-epidote-amphibolite facies is lacking, low-grade and high-grade rocks are in strong and sudden contrast. This may be caused by telescoping of metamorphic zones during strongly progressive metamorphism (den Tex, 1963), or by two superposed episodes of metamorphism, as suggested by Chinner (1962); either way, a situation is created where one finds, in Chinner's words, 'a broad background of rocks of greenschist or lower amphibolite facies punctuated by metamorphic "highs" or nodes of andalusite- and sillimanite-schist, some with gneissic granite or migmatite at the centre'. This is the situation found in North Queensland.

In regions where massive, non-foliated granite as well as gneissic granite are exposed, the gneissic granite is commonly, and almost without question, regarded as the older one. That this need not be so was found by Evernden & Richards (1962), when dating the granites in east and south-east Australia. They concluded that the gneissic granite may have been emplaced before, after, or at the same time as, the massive granites, and at the same depth of burial. Therefore the gneissic granite associated with the Barnard Metamorphics may not be older than the massive granites in the surrounding area. They may be younger if one assumes that the peak of metamorphism, migmatization, and gneiss intrusion coincided with a late phase of intense deformation that on the mainland is confined to a belt, several miles wide, extending from beyond Cairns through the Innisfail coastal area to the Barnard Islands, and has affected the rocks at Etty Bay (Fig.1) as well as the margins of the late-Palaeozoic massive granites between Cairns and Innisfail. The rocks at Etty Bay and farther north were intensely quartz-veined, 'crumpled', and somewhat recrystallized, and have thus acquired a (superficial) appearance of high-grade metamorphism that is, however, belied by their low-grade metamorphic mineral composition of quartz, muscovite, and chlorite, and by their small grain-size. The rocks at Etty Bay and farther north are therefore considered to be (deformed) Barron River Metamorphics, not Barnard Metamorphics as suggested by Jones & Jones. It is assumed that farther south, east of Tully, temperatures and pressures during the late deformation were high enough to permit a thorough reconstitution of the rock, and the intrusion of gneissic granite.

From this point of view, therefore, the peak of metamorphism would have occurred somewhat later than the paroxysmal phase of the Carboniferous orogeny during which the geosynclinal formations were folded: post-orogenic granite was affected by the late phase of localized deformation; and indeed it has been suggested (Schuiling, 1963, referring to Niggli, den Tex, Wenk, and de Roever) that in general the climax of a cycle of metamorphism not only is normally represented by a low-pressure/high-temperature type of facies series, but that 'this climax often postdates the main phase of orogeny'.

COMPARISON WITH THE CIRCUM-PACIFIC BELT

Miyashiro noticed that the andalusite-sillimanite belts of metamorphism, so common in the circum-Pacific regions, are paired with jadeite-glaucophane metamorphic belts, which always occur on the Pacific side of the former.

Jadeite-glaucophane type metamorphic rocks are not known from North Queensland, but, if present, should occur farther east, off the coast, in order to conform with the circum-Pacific 'rule'. It is interesting to note that in Miyashiro's opinion such a belt may possibly be represented farther south by parts of the Brisbane Metamorphics, which contain glaucophane-type amphiboles (the low grade of metamorphism prevents unambiguous recognition of an associated andalusite-sillimanite type series in this part of Queensland). If so, they could be laterally connected with a (hypothetical) submarine jadeite-glaucophane belt off the North Queensland coast. The possibly early Palaeozoic age of part of the Brisbane Metamorphics, and the Middle Palaeozoic age of the Barnard and Barron River Metamorphics, would appear to harmonize with de Roever's findings (in Schuiling, 1963) that 'in a plurifacial metamorphic substratum the normal sequence of metamorphism is from an early high-pressure/low-temperature metamorphic facies (e.g., glaucophane facies) towards a climax of low-pressure/high-temperature metamorphic facies'.

CONCLUSIONS

Earlier theories depicting the Barnard Metamorphics as Precambrian basement rocks, and the Barron River Metamorphics as early Palaeozoic rocks forming tectonic land during the Middle Palaeozoic geosynclinal stage in North Queensland, are largely discounted by recent geological mapping. The Barnard Metamorphics as well as the Barron River Metamorphics were an integral part of the Tasman Geosyncline, and were folded during the Carboniferous orogeny.

The high-grade metamorphic parts of the orogenic belt are represented by the Barnard Metamorphics, the low-grade parts by the Barron River Metamorphics; those rocks in which the grade of metamorphism remained below the biotite isograd constitute the Hodgkinson Formation. The boundary between the Hodgkinson Formation and the Barron River Metamorphics is gradational; that between the Barron River and Barnard Metamorphics is much more abrupt, which is quite normal for the type of metamorphism concerned.

These conclusions are supported by the close similarity to metamorphic terrains in other parts of the circum-Pacific area and elsewhere in the world.

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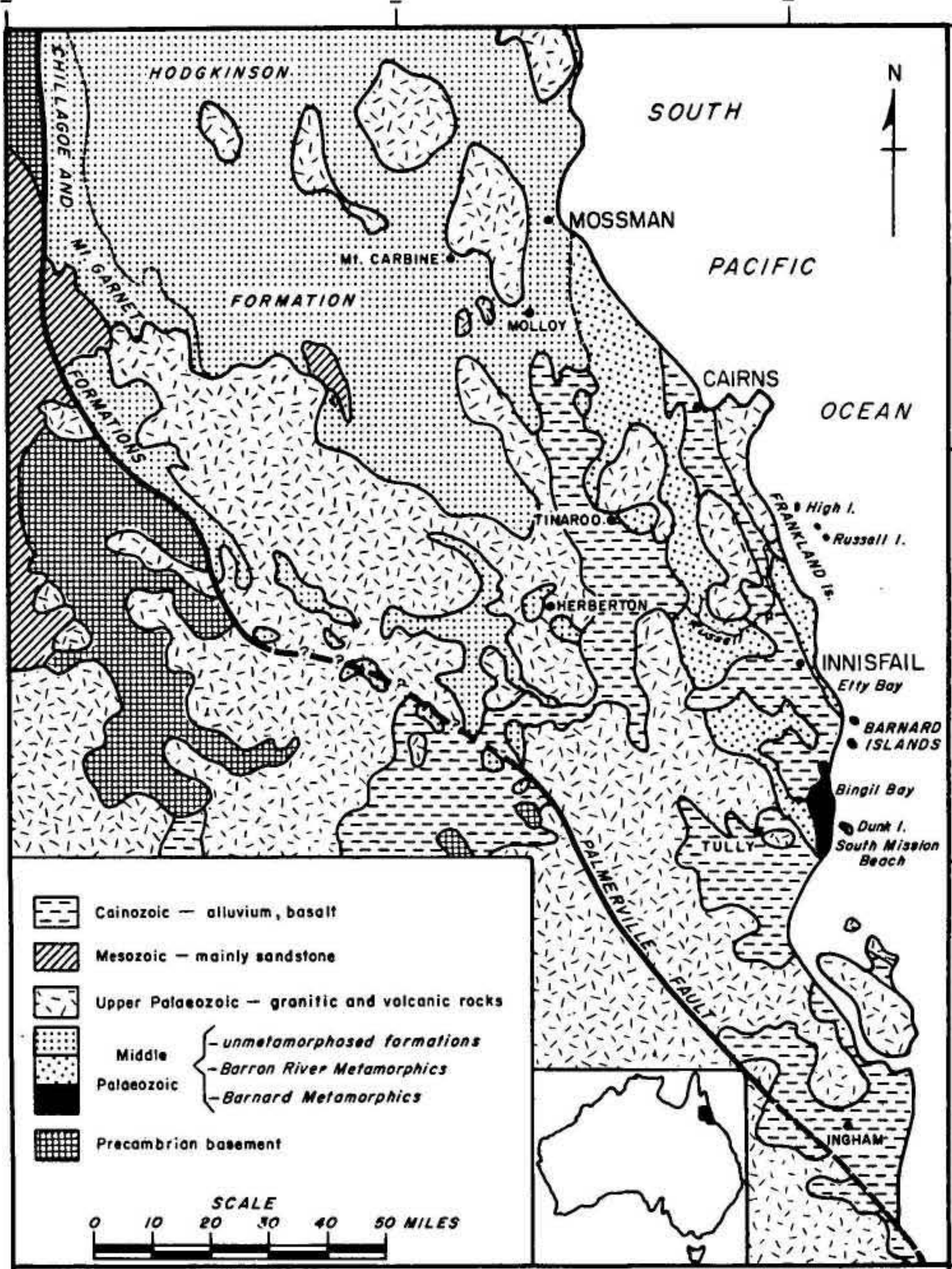

FIGURE 1— Geological sketch map, showing distribution of Barnard and Barron River Metamorphics and unmetamorphosed sedimentary formations of the Hodgkinson Trough, North Queensland.

M.E.N.

Bureau of Mineral Resources, Geology and Geophysics. July 1964.

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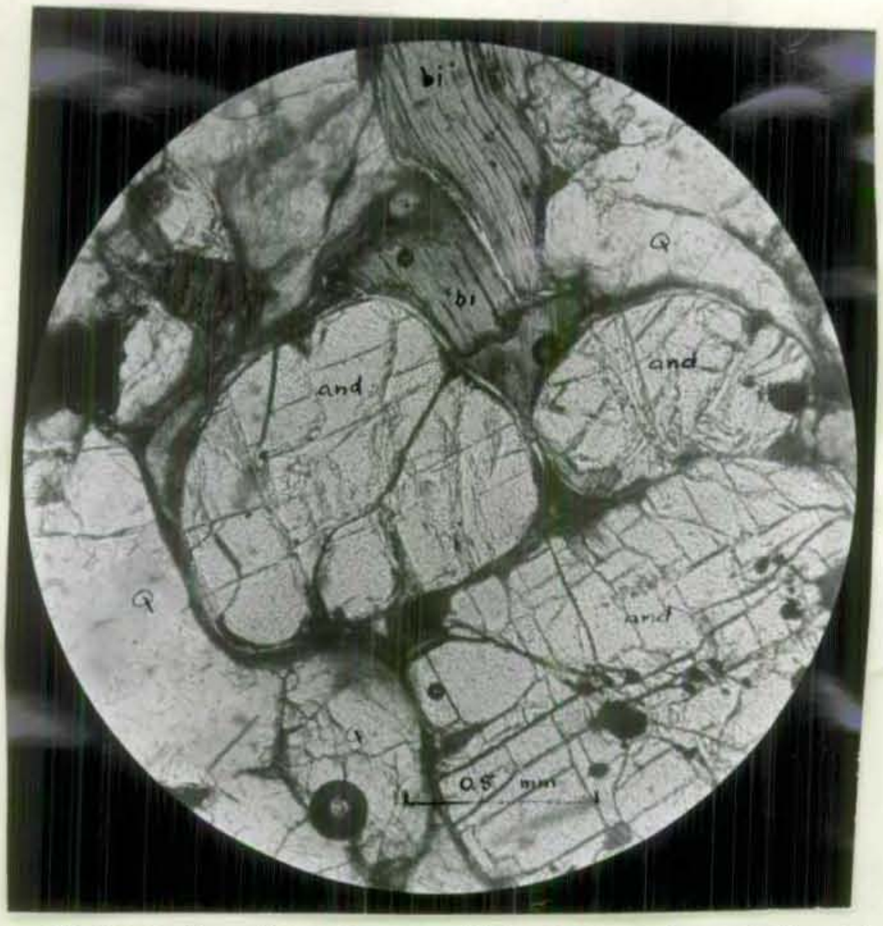

Figure 2 - Clear, equidimensional andalusite porphyroblasts (and) with thin dark rims of fuzzy fibrolite. Other minerals present: biotite (bi) and quartz (Q).

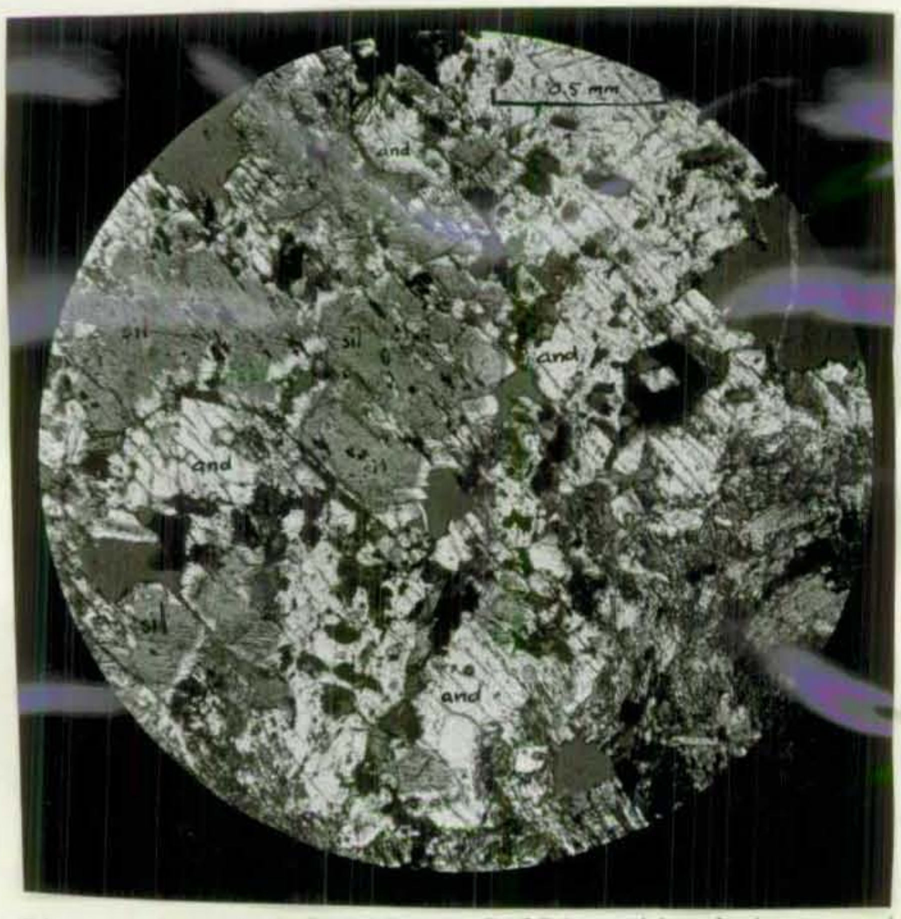

Figure 3 - Andalusite - Sillimanite intergrowths; sillimanite (sil) is possibly partly replaced by andalusite (and.) (x-nicols)

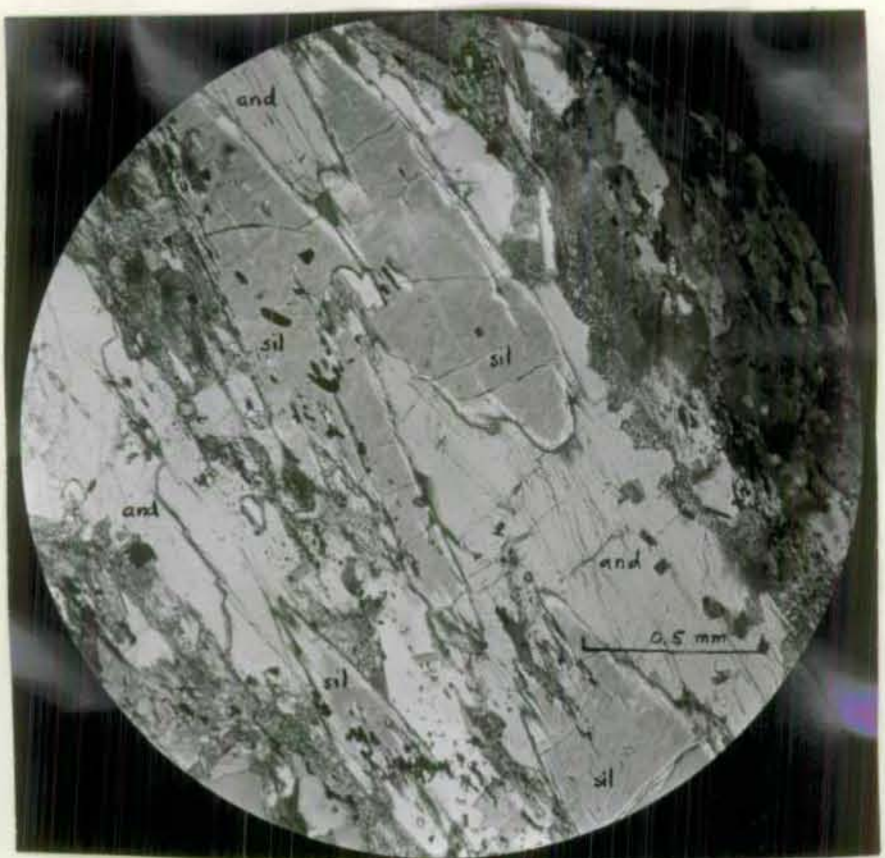

Figure 4 - Andalusite - sillimanite intergrowths.
(X-nicols)

Figure 5 - Idioblastic basal sections of
sillimanite in micaceous aggregate.

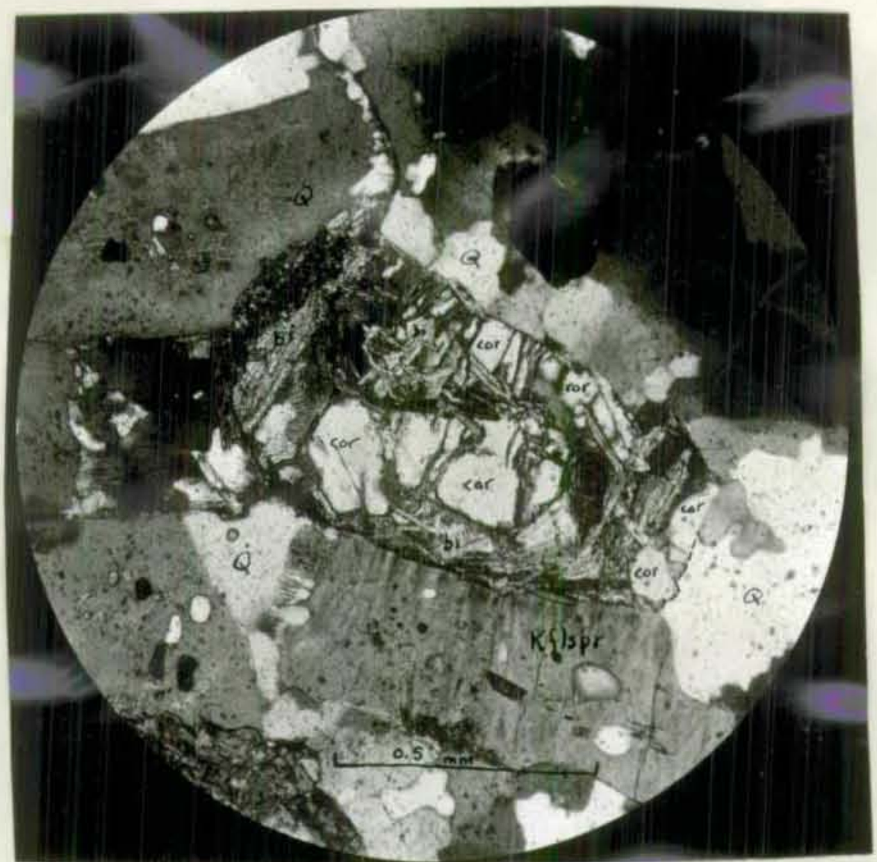

Figure 6 - Cordierite relic intersected by laths of biotite and muscovite.
Cor = cordierite K flspr = potash-feldspar
Q = quartz bi = biotite.
(X-nicols)

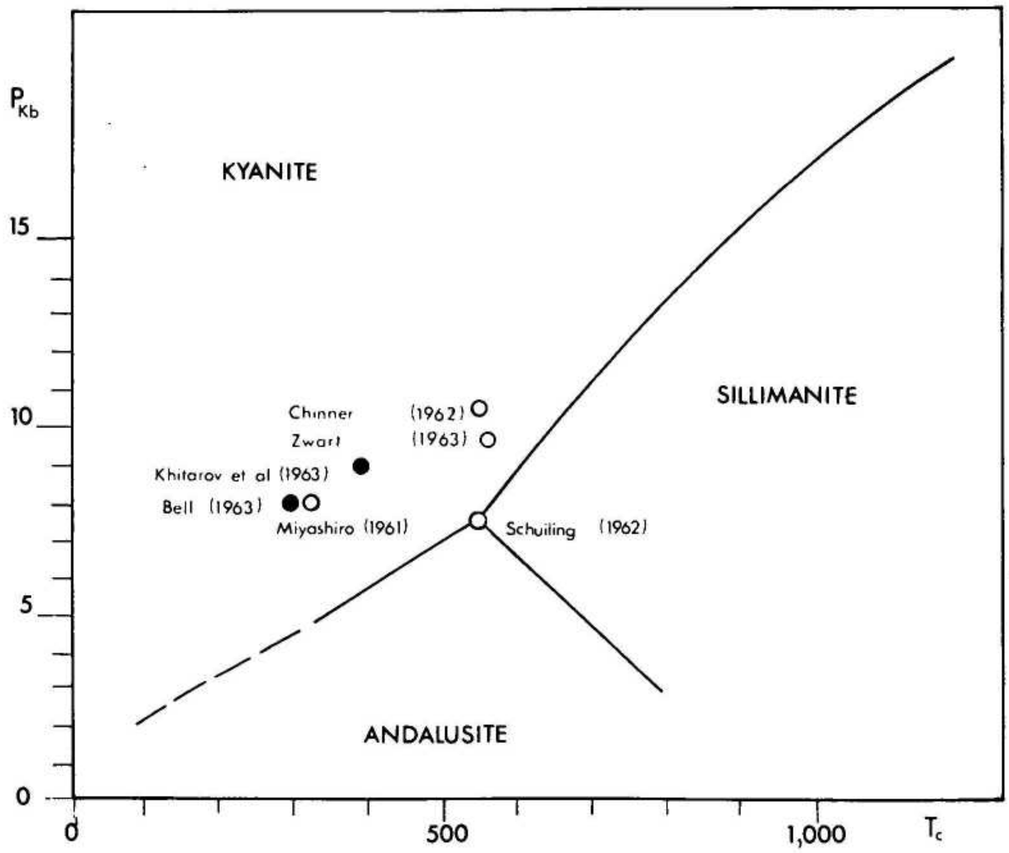

FIGURE 7 — Phase diagram of the polymorphs of Al_2SiO_5, after Schuiling (1962), with the addition of triple point positions as inferred (○) or experimentally obtained (●) by various others. Omitted is the irrelevant mullite–quartz field.