1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

BELELE

WESTERN AUSTRALIA

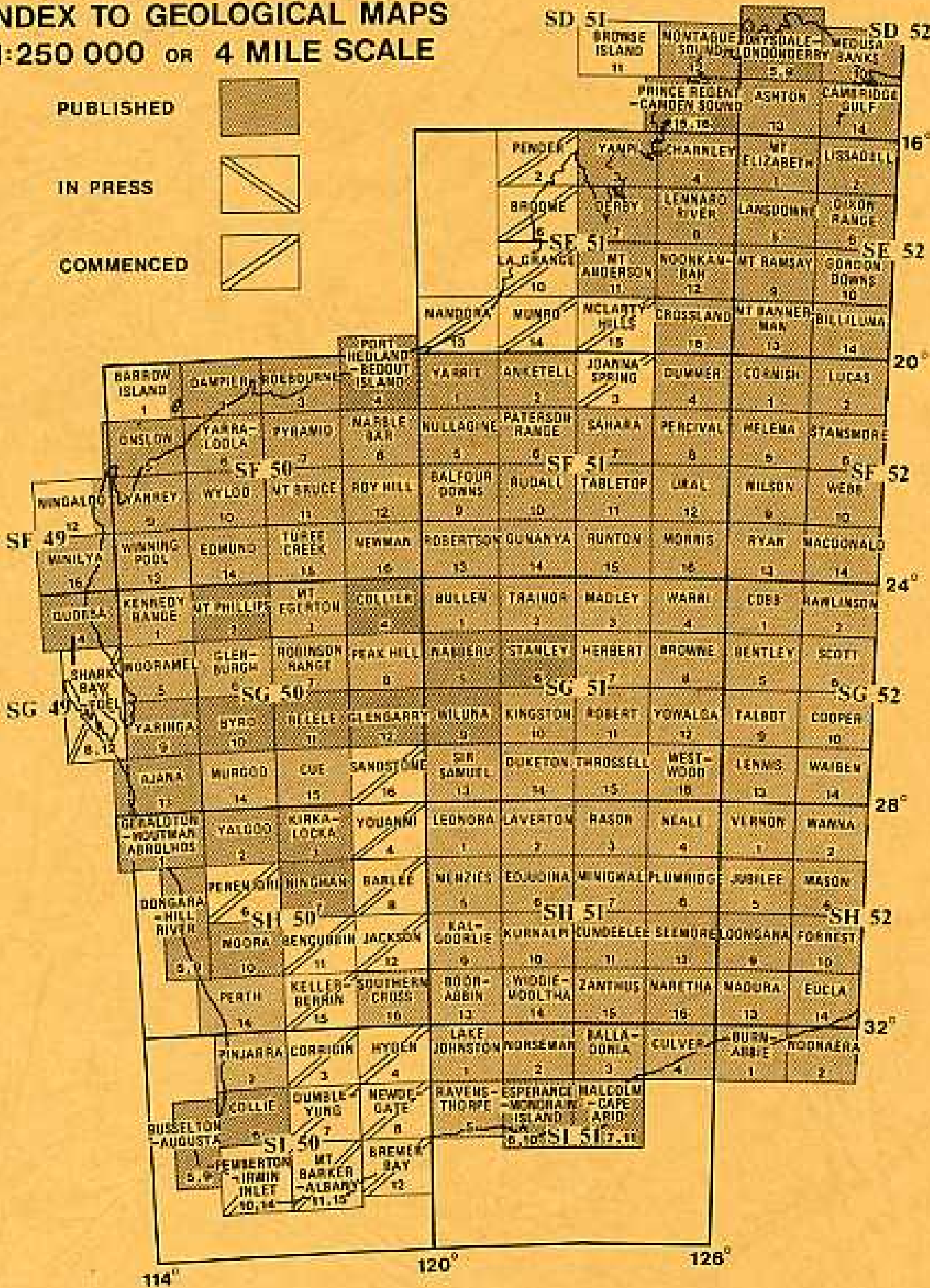
SHEET SG50-11 INTERNATIONAL INDEX

WESTERN AUSTRALIA
INDEX TO GEOLOGICAL MAPS
1:250 000 OR 4 MILE SCALE

PUBLISHED

IN PRESS

COMMENCED



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

1:250 000 GEOLOGICAL SERIES—EXPLANATORY NOTES

BELELE

WESTERN AUSTRALIA

SHEET SG50-11 INTERNATIONAL INDEX

COMPILED BY M. ELIAS

PERTH, WESTERN AUSTRALIA 1982.

23188—1

DEPARTMENT OF MINES, WESTERN AUSTRALIA
Minister: The Hon. P. M. Dowding, M.L.C.
Director General: D. R. Kelly

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Director: A. F. Trendall

ISSN 0729-3720
NATIONAL LIBRARY OF AUSTRALIA CARD NUMBER
AND ISBN 0 7244 8872-3

Explanatory Notes On The BELELE Geological Sheet

Compiled by M. Elias

INTRODUCTION

The BELELE* 1:250 000 Geological Sheet (reference SG50-11 of the International Series) is bounded by latitudes 26°S and 27°S, and longitudes 117°E and 118°30′E.

The area is taken up entirely by pastoral leases, which run predominantly sheep. The town of Meekatharra (population 829, 1976 census), which lies on the eastern margin of BELELE, is a service centre for the pastoral industry, and for mineral exploration. Early in the century, the town supported a strong gold mining industry, which subsequently declined, but is now undergoing a revival.

The sealed Great Northern Highway crosses the southeast corner of the sheet and passes through Meekatharra. A graded road from Cue, 110 km south-southwest of Meekatharra, services pastoral homesteads in the western half of BELELE. Graded roads and station tracks allow access to most other areas.

The climate is semi-arid. Meekatharra has an average annual rainfall of 215 mm, but the usefulness of this is diminished by its irregularity and by the excessive evaporation rate. Winters are cool to mild; summers are hot, and temperatures frequently exceed 40°C.

HISTORY OF GEOLOGICAL INVESTIGATIONS

The discovery of gold at Nannine in 1891, and at Garden Gully and Meekatharra soon afterwards, quickly led to the establishment of thriving mining centres. Consequently, most early geological reports dealt with the gold mines. The most comprehensive studies were by Gibson (1904) on Nannine, Meekatharra and Abbotts; and by Clarke (1916) on Meekatharra, Yaloginda and Garden Gully. These works, as well as providing valuable information on the (now) inaccessible gold mines, contain references to numerous earlier reports. The Mindoolah and Weld Range (Hercules) gold mines were examined by Woodward (1914), who also examined the iron deposits of the Weld Range and gave an informative report on the historical Wilgie Mia ochre deposit. The Abbotts gold mining centre was the subject of an investigation by Ellis (1936).

The first regional study not specifically directed towards mineral deposits was carried out by Johnson (1950); his map, which includes most of BELELE, showed gneissic rocks, only recently confirmed as being part of a regional gneiss terrain, in the northern half of BELELE. BELELE was included in a regional geochemical study of part of the Yilgarn Block by Hallberg (1976), who presented several chemical analyses of mafic and ultramafic volcanics.

Aeromagnetic, radiometric and gravity surveys of BELELE have been carried out by the Bureau of Mineral Resources, and Waller and Beattie (1971) have interpreted the aeromagnetic and radiometric data over a large region that includes BELELE.

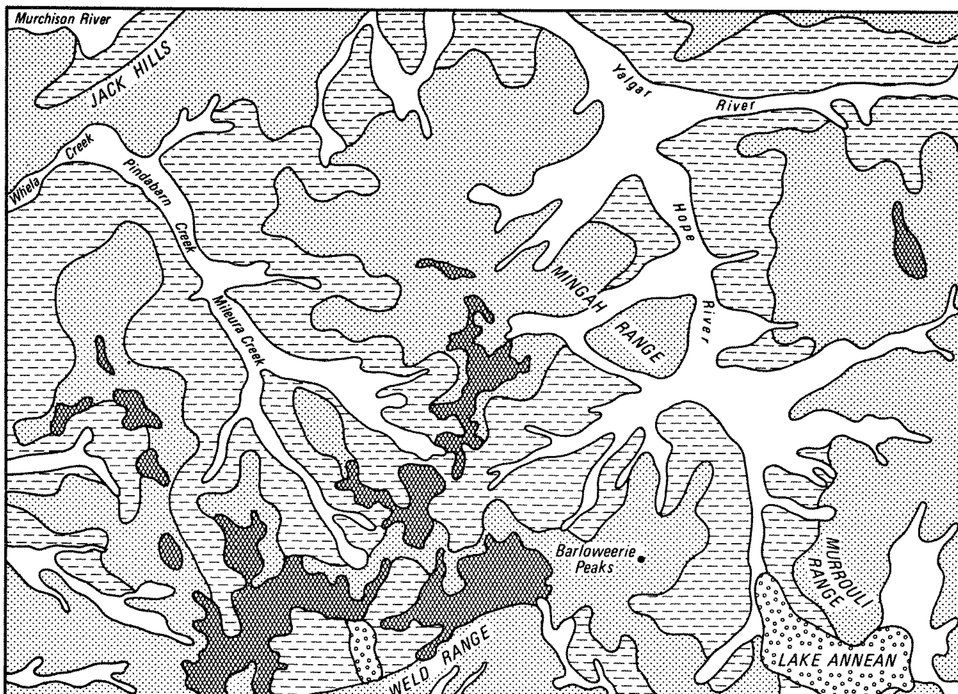
---

*Sheet names are printed in upper case letters to avoid confusion with similar place names.

PHYSIOGRAPHY AND CAINOZOIC GEOLOGY

BELELE lies on the interior plateau of Western Australia, and has elevations ranging from 355 m in the northwest corner to 538 m near Meekatharra. The regional topography is dominated by the northerly flowing Hope-Yalgar River, and Pindabarn—Whela Creek system (Fig. 1), which connect with the externally draining Murchison River.

Plateaux of laterite and silcrete bounded by breakaways occur on the interfluves and at the head of the main drainage systems. These are remnants of a once continuous lateritic duricrust which formed in the Early Tertiary, but which is now almost completely stripped off by headward erosion of the external drainage system. At the eastern end of the Weld Range, the duricrust surface slopes upward to the ridges of iron-formation, indicating that the Weld Range was a topographic feature before the Tertiary. The units *Czl* and *Czs* on the geological map refer to the remnants of lateritic duricrust. Laterite (*Czl*) over greenstone consists of ferruginous clay and indurated limonite pisoliths, and is in places capped by goethitic ironstone. A particular sort of laterite (*Czj*), developed on ultramafic rocks and fine-grained felsic



GSWA 18282

FIGURE 1

DISTRIBUTION OF MAIN PHYSIOGRAPHIC UNITS

BELELE SHEET SG 50-II

0 10 20 30 km

REFERENCE

- Remnants of old lateritic duricrust, mainly covered by sandplain
- Rock outcrop and fringing scree slopes
- Colluvial and alluvial sheet wash plains
- Main drainage and associated flood plains
- Saline lakes

volcanogenic deposits, is a fawn and cream-coloured, siliceous and lightly ferruginous capping. Over granitoids, laterite is pale brown, commonly pisolitic, and consists of angular quartz and opaline silica grains cemented by ferruginous clay. Laterite over granitoids is covered by sheets of pale brown sand (*Czs*) derived from reworking of the exposed duricrust surface. Wind action has accumulated the sand into broad, low banks.

Stripping of the lateritic duricrust in the Quaternary exposed the underlying bedrock. Topography over areas of outcrop varies according to rock type. Granitoids are exposed as large "whalebacks" in the southwestern part of BELELE, and as extensive uplands dissected by incised watercourses in the central and eastern parts. Basalt forms rugged rounded hills such as in the Murrouli Range, iron-formation and metaperidotite form prominent strike ridges (Weld Range, Jack Hills and Mingah Range), and sediments and felsic volcanics are poorly exposed in low-lying flats.

Erosion products of the lateritic duricrust and the underlying bedrock form the Quaternary colluvial and alluvial deposits. These grade downslope from scree slopes and alluvial fans (*Qc*) fringing outcrop, to broad, gently sloping, sand and silt sheetwash plains (*Qw*), to alluvium (*Qa*) deposited along drainage lines and in adjacent floodplains. These units are underlain at shallow depth by a poorly stratified, ferruginous, indurated, poorly sorted colluvial and alluvial deposit, which probably represents the detritus from the erosion of the ferruginous duricrust. The deposit is exposed in the banks of incised creeks; for instance at Koonmarra Pool, where a thickness of 10 m is exposed.

The main drainages are broad flood-plains, which have been discontinuously incised by narrow channels. Elongate sheets of valley calcrete (*Czk*) occupy parts of the trunk drainages, particularly along the Hope and Yalgar Rivers. The calcrete sheets are commonly 1-2 m above the present ground level, indicating that some erosion has taken place since their formation. The calcrete is formed by the replacement of valley-fill sediment by calcium carbonate precipitated from groundwater. The present Hope-Yalgar River trunk drainage follows palaeodrainage lines that developed on the ancient lateritic duricrust during the early Tertiary. Further to the southeast, the palaeodrainage system is represented by salt lakes and saline drainages. North of Lake Annean the drainage becomes less saline. The salt lakes contain bare, saline and gypsiferous mud flats (*Ql*) interspersed with cuneiform banks of eolian calcareous and gypsiferous sand (*Qg*). The lakes are surrounded by eolian sand sheets, alluvial saline flats containing numerous small claypans (both included in the unit *Qg*), and expansive sheets of calcrete (*Czk*).

ARCHAEAN

REGIONAL SETTING

BELELE is situated in the northern part of the Murchison Province (Geological Survey of Western Australia, 1975), in the northwestern part of the Yilgarn Block. The area includes two distinct geological terrains of Archaean age: gneiss and granitoid-greenstone. The gneiss in the northwestern corner of BELELE is part of an extensive terrain that encircles the western Yilgarn Block and contains orthogneiss and paragneiss of high metamorphic grade. Granitoid-greenstone terrain occupies the rest of BELELE, and consists of supracrustal greenstone belts set in expanses of granitoid.

The Jack Hills belt, which occurs in the gneiss terrain, differs from the metavolcanic greenstone belts in the granitoid-greenstone terrain in containing mainly metasedimentary rock, but it is similar to the metavolcanic belts in structural style and metamorphic grade.

Granitoids, which intrude the greenstones and gneiss, generally occur as ovoid or circular bodies; a single body occupies almost the entire western half of BELELE. Although granitoids from BELELE have not been dated, they probably belong to a suite of granitoids dated at about 2 600 m.y. (Muhling and de Laeter, 1971) on adjoining CUE. The age of the gneiss is uncertain but is believed to be older than that of the granitoids; an estimate of 2 900 m.y. is given by Arriens (1971) for rocks from the gneiss terrain to the south near Mullewa.

The southern margin of the Glengarry Sub-basin (Bunting and others, 1977), a major Proterozoic sedimentary basin, crosses the extreme northeast corner of BELELE.

GREENSTONE BELTS

Although all greenstones on BELELE are metamorphosed and, in many cases, deformed, the original rock types are usually identifiable. Accordingly, a system of terminology based on original rock types has been used. Metamorphism is generally of low grade, and the original textures are preserved. Chief metamorphic indicators are mafic rocks, in which pyroxene is altered to pale-green actinolite, and plagioclase is saussuritized. Ultramafic assemblages are serpentine-talc-chlorite-tremolite (-actinolite). Variations to this general pattern are detailed in the relevant sections.

Mafic volcanics

Thick sequences of mafic volcanics occur in all greenstone belts. Two types of volcanics are distinguished by their textural features, which reflect slight mineralogical and chemical differences. Tholeiitic metabasalt (*Abb*) is best seen in the Murrouli Range. It is a dark-green, hard, intergranular-textured rock consisting of amphibole (pseudomorphing pyroxene) and saussuritized plagioclase. Some basalt south of Meekatharra is virtually unmetamorphosed and shows primary mineralogy. Metabasalt from the Murrouli Range forms a featureless succession, but south of Meekatharra abundant pillow structures are seen; and northwest of Beebyn, vesicular flowtops are developed.

Metabasalt with skeletal or spinifex texture (*Abu*) is the other basalt type; the texture is readily identifiable with the unaided eye or a hand lens. Spinifex texture is formed during crystallization by rapid growth of clinopyroxene, or, in some cases, olivine, producing a mesh of interlocking dendritic, acicular, or platy crystals. These phenocrysts, measuring 2 to 10 mm long, are set in a glassy or fine-grained groundmass consisting of mafics, plagioclase, epidote and quartz. With the exception of spinifex-textured basalt near the eastern margin of BELELE, which is part of the upper mafic unit of the Meekatharra belt described by Elias and others (1979), all spinifex-textured basalt has primarily clinopyroxene pseudomorphed by amphibole. Ocellar structures (leucocratic ovoid segregations resembling vesicles) have developed in places, notably between Conroy Bore and a point 2 km northwest of Mount Obal, where they occur over a width of about 75 m, possibly representing a single flow.

On the basis of the spinifex texture, it is thought that these basalts belong to the komatiitic suite of mafic and ultramafic volcanics. This suite, represented in many Archaean greenstone belts, is defined mainly on chemical grounds. However, spinifex texture is highly characteristic of this class of rocks, and serves as a useful field criterion in the absence of chemical data to distinguish komatiitic from tholeiitic basalts (Arndt and others, 1977). The correct identification of spinifex texture may be difficult: at Murromochin Hill, static metamorphism of a magnesium-rich basalt has caused random growth of metamorphic amphibole, producing a texture closely resembling spinifex texture.

Samples analyzed by Hallberg (1976) from areas of spinifex-textured basalt on BELELE show some of the chemical features of the komatiitic suite. The most important of these chemical parameters, according to Arndt and others (1977), are low TiO_2 (generally less than 0.7 per cent), and low $FeO_{total}/(FeO_{total} + Mg)$ compared with tholeiitic basalts of similar Al_2O_3 content. Analyses of thoeliitic basalt from the Meekatharra belt (Hallberg and others, 1976) have been used for comparison.

In areas of dynamic metamorphism, such as near granitoid contacts and major fold closures, tholeiitic and spinifex-textured metabasalt are altered to amphibolite (*Aba*) by the development of a planar or linear fabric resulting from the nucleation and growth in preferred orientations of metamorphic amphibole. Vestiges of spinifex texture can still be discerned in the amphibolite west of Wadda Wadda Bore. Dynamic metamorphism of more ultramafic komatiitic varieties produced amphibole-chlorite schist (*Aur*) which lacks significant feldspar.

Felsic volcanics and intrusives

Felsic volcanics range from clinopyroxene-phyric andesite to quartz-phyric dacite and rhyolite. Rocks without quartz phenocrysts occur only in the eastern greenstone belts, near Abbotts and south of Meekatharra.

South of Meekatharra, andesitic rocks (*Az*) are part of the upper felsic-volcanoclastic unit of the Meekatharra belt (Elias and others, 1979). The andesitic rocks, comprising lava, tuff and subordinate sedimentary rocks, contain unaltered clinopyroxene, saussuritized plagioclase, andesitic lithic fragments, and a chloritic groundmass. Coarse-grained agglomerate (*Azv*) contains angular and rounded clasts of andesitic lava up to 0.3 m across set in a fragmental matrix of similar composition to the clasts. These coarse fragmental rocks occur near the base of the upper felsic-volcanoclastic unit on GLENGARRY and they are believed to represent pyroclastic deposits (Elias and others, 1979).

Andesitic rock also occurs immediately east of the main mafic unit south of Abbotts. Coarse agglomerate (*Azv*) is present, but here amphibole is the mafic mineral. West and south of Garden Gully, quartz-phyric schistose felsic rock (*Af*), probably representing felsic tuff, occurs over a large area.

Other areas of felsic volcanics on BELELE contain generally fine-grained tuff (*Aft*) and lack both lava and coarse-grained agglomerate. These tuffs typically contain 1 mm-sized quartz crystals and lithic clasts. Fine-grained volcanogenic sediments are commonly interbedded in felsic tuff. Drill core provided by Amoco Exploration from an area south of Weebacarry Bore shows predominantly dacitic tuff consisting of medium-grained euhedral clasts of quartz and plagioclase set in a fine-grained groundmass of quartz, plagioclase, muscovite, chlorite and alkali feldspar. Other rocks include meta-andesite and graphite schist. Coarser grained felsic lapilli tuff (*Afx*) containing lithic clasts up to 5 mm across occurs in fine-grained felsic tuff south of Weebacarry Bore and the Mingah Range.

Felsic porphyry (*Ap*) occurs in the Mindoolah area and intrudes dolerite and banded iron-formation in the eastern Weld Range. Near Mindoolah, it is intruded adjacent to the mafic volcanic belt of Mardoonganna Hill and along the northern edge of the Weld Range, and also appears to be associated with rafts of mafic rocks in granitoid. Clasts of felsic porphyry in conglomerate indicate that the porphyry was intruded at a high level, and was probably related to the felsic volcanism in the area. The porphyry contains corroded phenocrysts of quartz and saussuritized feldspar set in a grey-green, quartz-feldspar groundmass.

Sediments

Sediments are common only in the eastern greenstone belts, in the vicinity of Abbotts, and between Meekatharra and Nannine. They are generally fine-grained shale and siltstone (*Ass*), mostly kaolinitic, and containing a volcanogenic component. Because of their grain size and composition, they weather easily and are poorly exposed. Identification of bedding is difficult because of a strong schistosity, but regional bedding trends may be outlined by chert and banded iron-formation marker beds. A good exposure of these sediments may be seen in the road cutting at Nannine.

White, cross-bedded, cleaved quartz-sandstone (*Asq*) occurs in a tight syncline near Jillewarra. The sandstone is underlain by quartz wacke containing quartz grains set in a schistose felsic groundmass, and is overlain by cleaved shale. The sandstone is an unusual rock type for greenstone belts. It requires a stable, near-shore environment and a sialic provenance, and it shows a marked contrast to the surrounding rocks, which are mafic volcanics. Although it was not seen, an unconformity is suspected between the mafic volcanics and the sandstone. The sandstone could be derived from felsic volcanics which overlie mafic volcanics elsewhere in the greenstone belt. If the sandstone were derived from a granitic provenance, it would imply the existence of exposed granitic crust during greenstone belt development.

Minor occurrences of sediment include pelitic schist containing andalusite, garnet and quartz (*Alm*) north of Beebyn, and chlorite, carbonate and quartz (*Alc*) at the Maranoa gold mine. Sediments closely associated with felsic volcanics occur along the north side of the Weld Range, near Mindoolah. The sediments are of felsic composition and range from conglomerate with felsic clasts to finely laminated shale. Graded bedding and load-structures indicate facing to the south.

Banded iron-formation

Some greenstone belts show the development of banded iron-formation (*Ai*) over strike lengths of 40 to 50 km (Weld Range, Meekatharra-Nannine), while other belts (Abbotts belt, Mingah Range belt) are almost devoid of banded iron-formation. This irregular distribution may be partly related to stratigraphic level, although there may also be a sedimentational control on the development of banded iron-formation. Banded iron-formation occurs interbedded with mafic volcanics, felsic volcanic-related sediments, and mafic intrusives. In the Jack Hills, banded iron-formation occurs in pelitic and psammitic metasediments (rocks of the Jack Hills are discussed in a separate section, although the banded iron-formation is similar to that in the other greenstone belts).

Banded iron-formation and related rocks (*Ai*) consist of silica, hematite, magnetite and iron silicates in various proportions. Rocks with the symbol (*Aiw*) contain bands of white chert or very fine-grained quartz alternating with black, fine-grained magnetite. Chert (*Aic*) contains less than 20 per cent magnetite.

Jaspilite (Aij) is characterized by red chert bands in conjunction with either or both white and black bands. The red colouration is due to fine hematite dust. Most of the iron-formations in the Weld Range are of this type. Jaspilites appear to be restricted to areas of low metamorphic grade; towards the northeastern end of the Weld Range, increasing metamorphic grade causes the red colouration to disappear and the grain size to increase. The Weld Range contains three laterally persistent units of jaspilite; from north to south these are informally known as the Madoonga, Lulworth and Wilgie Mia beds. Most of the jaspilites in the Weld Range have a grain size of 10 to 30 μm and contain 20 to 60 per cent magnetite (Jones, 1963).

In the region between Meekatharra and Nannine, banded iron-formation occurs at two levels in the greenstone sequence. Black and white banded iron-formation is interbedded with fine-grained sediments adjacent to the Murrouli Range mafic sequence, and jaspilite occurs to the east near the margin of the sheet. The westernmost banded iron-formation in places contains metamorphic iron silicates.

Aligned rafts of banded iron-formation in granite extending north from the end of the Weld Range to the Mingah Range belt possibly signify a former link between the two greenstone belts. The banded iron-formation in the rafts is recrystallized to a granoblastic mosaic of quartz and magnetite grains up to 0.5 mm across.

Mafic and ultramafic intrusives

Ultramafic (*Au*) and mafic sills (*Ad*) intrude all major rock types in the greenstone belts. The smaller intrusives are unlayered, but larger bodies show differentation. Areas of more abundant mafic and ultramafic intrusions occur in the Abbotts belt at the contact between the mafic volcanic and felsic volcanic sequences; in the Weld Range; and in the felsic volcanic sequence of the Mingah Range Belt. In the Abbotts belt and the Mingah Range, intrusives stand out as prominent ridges and have an outcrop width of 0.1 to 0.3 km. The sills commonly have a basal layer of peridotite (*Aup*) or pyroxenite (*Aux*) underlying mafic gabbro (*Ado*) or dolerite (*Add*). Each of these rock types may also occur alone in a single sill. One sill in the Mingah Range belt southwest of Maranoa has an upper section of granophyre (*Adr*). The layering in the sills of the Mingah Range and Abbotts belts appears to have formed by crystal settling *in situ*, and, therefore, the aspect of the layering has been used to determine facing in the sequences. A thick, undifferentiated dolerite body forms a huge detached fold core at Barloweerie Peaks. This body has an outcrop width of about 1.2 km on the limbs of the fold.

Dolerite and banded iron-formation are the only rocks present in the Weld Range. Dolerite, which intruded the banded iron-formation with minimal disruption to bedding, occurs as multiple sheets which range from less than 50 m to over 150 m in outcrop width. Exactly how this intrusion took place is problematical because dolerite accounts for about 90 per cent of the thickness of the sequence in the Weld Range. There is no evidence to suggest that the mafic rocks are of anything but intrusive origin.

A large, triangular, unexposed ultramafic intrusive occurs to the north of the Weld Range, north of Mount Lulworth. Exploratory drilling has outlined a layered body of variably altered olivine and olivine-clinopyroxene cumulates. Olivine-clinopyroxene cumulates occur to the south of olivine cumulates, implying southward facing if the body is a single intrusive.

Dolerite (*Add*) and gabbro (*Ado*) consist of pale-green amphibole (tremolite-actinolite), either as single large grains or aggregates of small grains replacing original clinopyroxene, and saussuritized and albitized plagioclase. Occasionally, zoning in original pyroxene is reflected in the amphibole pseudomorphs by a core of chlorite or remnant pyroxene. Partially or completely altered orthopyroxene is present in some places, such as in the sill east of Mount Obal. Pyroxenite (*Aux*) consists of amphibole which replaces interlocking clinopyroxene and orthopyroxene prisms, and contains only minor plagioclase. Peridotite (*Aup*) contains serpentine aggregates which replace equant olivine, variable amounts of amphibole which replace pyroxene, and interstitial carbonate, talc, chlorite and opaques.

In most cases, original textures are well preserved. Dolerite and gabbro show sub-ophitic and ophitic textures, and peridotite shows relict cumulus texture. However, in areas of dynamic metamorphism a fabric may be developed by growth of new minerals, forming amphibolite (*Ada*) from dolerite and gabbro. Where peridotite is deformed, but the serpentine-amphibole assemblage essentially retained, the term *Aup* is used. Peridotite may be altered to talc-carbonate schist (*Aue*) by more extreme dynamic metamorphism; an example of this occurs west of the Munarra Gully mine. Penetrative deformation of pyroxenite forms amphibole-chlorite schist (*Aur*).

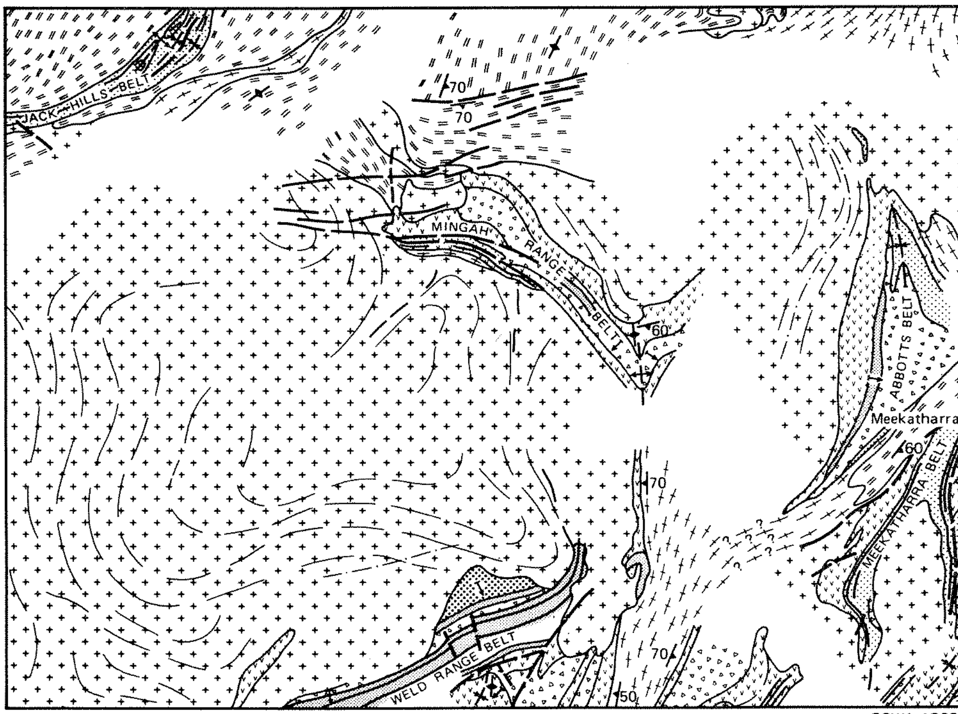
Regional structure of the greenstones

Major structural elements are shown on Figure 2.

A regionally heterogeneous deformation pattern in the greenstones can be related to the distribution of various types of surrounding granitoids. In general, a penetrative tectonite fabric in greenstones near granitoid contacts decreases in intensity away from contacts. The fabric is most widely developed where the granitoid contacts are parallel to lithological layering in the greenstones, and particularly so where those granitoids are syntectonic. Away from the contacts, effects of deformation are non-penetrative, and are marked by jointing in massive rocks such as basalt and dolerite, and as a spaced cleavage in incompetent rocks.

Penetrative fabrics are invariably parallel to granitoid contacts, and where there is a fabric in the adjacent granitoid it is congruent with the greenstone fabric. The marginal greenstone fabrics appear to be unrelated to any major fold structures in the greenstones, a feature common to many other greenstone belts in the Yilgarn Block. On the other hand, the spaced cleavages seen in the interiors of the greenstone belts are commonly axial planar to regional fold structures. Examples of this can be seen in the anticline in the Mingah Range, and in the syncline west of Beebyn. The relationship between the two types of deformation is clearly displayed in the Mingah Range Anticline, where they can be seen to be contemporaneous. Between the Big Ben mine and Wadda Wadda Bore, the mafic volcanics have a penetrative east-west metamorphic schistosity, which, away from the granitoid contact and towards the axial plane of the anticline, becomes a south-plunging lineation, parallel to the axis of that fold. Therefore, the two types of deformation could be responses at different structural levels to a single tectonic event. The penetrative deformation at low structural levels results from the ductility of granitoid-greenstone contacts, during or after granitoid emplacement. Higher structural levels do not show contact effects; instead, fold geometry determines the orientation of structures.

A number of structural and stratigraphic irregularities in the greenstones require the existence of large-scale faults. To explain the discordance of lithological trends, a major strike fault is postulated south of Meekatharra near the extreme eastern margin of BELELE. This fault, when extended northward along strike, passes through the Meekatharra gold deposits. The fault must have existed early in the structural history of the greenstones because it is folded by the intrusion of a granitoid to the west.



GSWA 18283

FIGURE 2

SOLID GEOLOGY AND STRUCTURAL INTERPRETATION

BELELE SHEET SG50-11

0 10 20 30 km

REFERENCE

ARCHAEAN

- Post tectonic granite, mostly unfoliated
- Syn-tectonic granite, foliated to gneissic
- metamorphosed:
  - Sediments
  - Intermediate and felsic volcanics
  - Major mafic inclusives
  - Major ultramafic intrusives
  - Mafic and komatiitic volcanics
  - Banded iron-formation
- Gneiss, contains paragneiss enclaves, includes transitional granitoids

- Fault or shear zone
- Photolineament
- Syncline
- Anticline
- 60 Regional foliation, inclined
- Regional foliation, vertical
- Generalized flow traces in nebulitically banded granitoid
- Facing of sequence

The occurrence of unusual clastic sediments near Jillewarra appears to be related to faulting. The structure could be a synclinal keel infolded into a narrow graben in the basement.

Possible stratigraphy in the greenstones

On BELELE, there is no consistent pattern of regional stratigraphy in the greenstones similar to that described on adjacent GLENGARRY (Elias and others, 1979). However, there are some similar lithological associations, which may be significant in a stratigraphic sense. The most important of these is the association of komatiitic volcanics lacking banded iron-formation. On GLENGARRY, this association forms an upper mafic unit, in contrast to a lower mafic unit at the base of the greenstone sequence which contains banded iron-formation. On BELELE, komatiite-dominated sequences without banded iron-formation occur in the Abbotts Belt, the Mingah Range Belt west of Wadda Wadda Bore and in the area south of the Weld Range. It is possible, therefore, that in the Abbotts and Mingah Range Belts the stratigraphically lower parts have been removed by faulting or granitoid intrusion. Alternatively, they may be isolated basins, in which banded iron-formation did not develop. Both greenstone belts display a mafic-to-felsic development.

The komatiitic mafic volcanics south of the Weld Range are continuous with the Ryansville Formation (de la Hunty, 1973) on adjacent CUE, which is the upper mafic unit of a similar stratigraphic sequence to that described on GLENGARRY.

Jack Hills Metasedimentary Belt

Because of lithological differences between this and the other greenstone belts, it is convenient to describe the Jack Hills Belt separately. These differences, together with the spatial separation of the Jack Hills Belt from the other belts, suggest that the Jack Hills Belt developed independently. However, structural style and metamorphic grade are similar to the other greenstone belts, and therefore it is thought that the Jack Hills Belt formed during the same tectonic phase of crustal evolution.

Pelitic and psammitic metasediments predominate in the sequence. Quartz-mica schist and phyllite (*Alm*) are green in colour, and contain quartz with variable amounts of sericite, muscovite and chlorite. A strong lepidoblastic texture is developed by alignment of mica. Towards the west, biotite and snowball-structured garnet have developed where the schists have reached higher metamorphic grade. Chorite, green muscovite, and iron oxides indicate that the sediments were iron rich. Intercalated in the pelitic schist are beds of orthoquartzite and micaceous quartzite (*Asq*), containing conglomerate bands. The conglomerate has clasts of quartzite, banded iron-formation and chert in a schistose quartz-sericite matrix. Poikiloblastic andalusite has developed in the matrix of pebble conglomerate 5 km east of Mount Hale.

Banded iron-formation and chert form units several centimetres to several hundred metres thick in prominent strike ridges. Banded iron-formation (*Aiw)* contains 1 mm to 10 mm-thick laminae of finely recrystallized quartz and magnetite. Jaspilite is rare. Chert (*Aic*) is generally colour-banded; the dark bands contain iron-oxide dust. Banding in both chert and banded iron-formation may be continuous, wavy, folded or brecciated. Banded iron-formation may be supergene enriched to form lenses of massive hematite or quartz-hematite rock.

Metavolcanic rocks are rare in the Jack Hills, only occurring west of Yarrameedie; some poorly outcropping chloritic schists east of Yarrameedie, however, could be volcanic in origin. Metavolcanics include amphibolite (*Aba*) and tremolite-chlorite schist (*Aur*). Lenses of serpentinized peridotite (*Aup*) intrude the volcanic sequence. Serpentinized peridotite intruding gneiss northeast of Seven Mile Well may be related to these; they lack the high-grade metamorphic textures seen in ultramafics forming part of the gneissic sequence.

Metamorphism in the Jack Hills Belt: Metamorphic grade increases from east to west in the Jack Hills belt. Pelitic schist, containing muscovite, chlorite and quartz in the east gives way to quartz-biotite-garnet assemblages in the west. There is a concomitant slight increase in grain size of banded iron-formation and chert. Andalusite occurs in the groundmass of micaceous quartzite east of Mount Hale, indicating a temperature in excess of 400°C (Winkler, 1976). Garnet forms at slightly higher temperatures and it may require slightly higher pressure. However, its formation may be influenced by composition. What relationship this pattern of increasing metamorphic grade may have to a parallel increase in grade in the gneiss to the south of the Jack Hills (*see: Metamorphism in the gneisses*) is unknown. Metamorphic grade is higher in the gneiss, and the two rock suites are thought to have separately reached their metamorphic peaks. However, the widespread retrograde metamorphism evident in the gneiss could be related to the lower grade, prograde metamorphism in the Jack Hills sequence.

GNEISS TERRAIN

Gneisses (*An*) occur in the northern and northwestern parts of BELELE. Quartz-feldspar-biotite gneiss (*Anb*) is the major rock type; it is a granoblastic to lepidoblastic rock with plagioclase content exceeding alkali feldspar, and with aligned biotite. Continuous compositional banding on a scale of 5 to 50 mm is aligned parallel to the gneissic fabric. Where the banding is isoclinally folded, the gneissic fabric is axial planar to those folds. Leucocratic bands alternate with darker, finer grained bands containing biotite. Banding is thought to result from metamorphic differentiation, but in places the leucocratic bands are discontinuous and vary in thickness; these have probably formed by partial melting during metamorphism.

Occurring as enclaves and lenses within banded quartzofeldspathic gneiss are metamorphic rocks of mainly sedimentary origin. Calc-silicate paragneiss (*Anc*) is a well-layered rock consisting of pale bands of quartz, plagioclase and alkali feldspar, and mafic bands containing clinopyroxene, amphibole, garnet, epidote and sphene. This assemblage suggests a calcareous sedimentary origin, and the layering perhaps reflects bedding, now enhanced by metamorphic differentiation. Calc-silicate gneiss is commonly associated with quartz-magnetite rock, quartzite, and amphibolite. Quartz-magnetite rock (*Ani*) represents metamorphosed banded iron-formation; it contains bands of various proportions of quartz, magnetite and amphibole. Complex flow-folding is common. Quartzite (*Anq*) consists of a granoblastic mosaic of quartz and subordinate amphibole or magnetite, and may represent a clastic sediment or recrystallized chert. Its laminae are folded like those of the quartz-magnetite rock. Amphibolite (*Ana*) is a granoblastic to schistose rock containing hornblende, calcic plagioclase, and, in places, clinopyroxene. Amphibolite may be igneous or sedimentary in origin. A minor rock type is metamorphosed ultramafic rock (*Anu*) containing serpentine, tremolite, chlorite, clinopyroxene. Amphibolite may be igneous or sedimentary in origin. A minor rock type is metamorphosed ultramafic rock (*Anu*) containing serpentine, tremolite, chlorite, clinopyroxene and spinel.

Pelitic schist and granofels (*Any*) form a band about 1 km wide, which extends from north of Mount Hale homestead to the western sheet margin. It is a bluish-grey, medium- to coarse-grained aluminous rock containing quartz, feldspar, muscovite, biotite, garnet, cordierite, andalusite and kyanite. Pegmatitic segregations about 30 mm thick contain coarse garnet. Layers of micaceous quartzite (*Anl*) occur in the pelite. These are strongly foliated and lineated rocks containing coarse muscovite flakes on the foliation. This sequence represents metamorphosed sediments rich in magnesium and aluminium, and the co-existence of kyanite and andalusite can be used to determine metamorphic conditions (*see: Metamorphism in the gneisses*).

The association of quartz-feldspar-biotite gneiss and its metamorphic enclaves is thought to represent a highly metamorphosed sequence of sediments and intrusive granitoids, which formed the basement on which the younger sediments of the Jack Hills were deposited. Quartz-feldspar-biotite gneiss probably includes a significant proportion of paragneiss, but no attempt has been made to distinguish orthogneiss from paragneiss on the map. Compositionally-banded granitoid gneiss (*Ang*) intrudes the gneisses, and lacks metamorphic enclaves; it is thought to represent the precursor of the voluminous granitoids, and is therefore discussed with the granitoids.

Metamorphism in the gneisses

Metamorphic conditions in the gneissic terrain are deduced from mineral assemblages in the igneous and sedimentary enclaves.

In pelitic rocks (*Any* and *Anl*), a metamorphic gradient increasing from east to west is indicated. North of Mount Hale homestead, co-existing andalusite and kyanite in the presence of quartz, muscovite and biotite, indicates a temperature of about 550°C at a pressure of 500 MPa. The presence of cordierite in another sample nearby confirms this estimate. Near the western margin of BELELE, co-existing cordierite and garnet indicate higher temperature and intermediate pressure, near the transition from medium to high metamorphic grade (Winkler, 1976). Further confirmation of high-grade metamorphism is provided by the pegmatite segregations, which suggest the onset of anatexis.

Amphibolite contains hornblende and calcic plagioclase, indicating medium-grade metamorphism. The presence of subidioblastic clinopyroxene suggests middle or upper amphibolite grade in places. No orthopyroxene was noted.

All of the prograde assemblages in the gneiss terrain show the effects of a later, low-grade thermal event. The effects are best seen in calc-silicate gneiss and amphibolite, where clinopyroxene and prograde hornblende are altered to pale-green amphibole. The event is thought to be related to the emplacement of the voluminous granitoid to the south.

GRANITOIDS

To demonstrate the relationship of granitoid to gneiss terrain, it is convenient to discuss the granitoids in terms of their degree of homogeneity.

Rocks that are wholly granitic in character comprise two types. Homogeneous granitoids are, as the term implies, uniform in texture and composition in hand-specimen and at outcrop scale. The other type is banded igneous granitoid with compositional variation on the outcrop scale, but with a granitic texture. Transitional granitoids are heterogeneous, and texturally they are intermediate between granitoid and gneiss. Included in the group of transitional granitoids are mixtures of granitoid and gneiss, on a scale too small to be separately shown on the map, and granitoid gneiss (*Ang*).

Although no definite age relationships are implied between granitoids of different degrees of homogeneity, it appears that the discrete bodies of homogeneous granitoid that occur in banded granitoid are younger than the banded granitoid. Some foliated granitoids of syntectonic character, such as in the strip between the Meekatharra and Abbotts greenstone belts, are probably older than the adjoining unfoliated granitoids.

Homogeneous granitoids

Homogeneous granitoids occur in ovoid- or irregular-shaped bodies of 15 to 50 km^2, generally with well-defined margins. Even-grained biotite granodiorite, adamellite, less commonly tonalite and granite (*Agb*) are allotriomorphic or hypidiomorphic, and contain quartz, oligoclase, microcline, biotite, and accessory sphene and opaques. Porphyritic grantitoid (*Agl*) differs from *Agb* in containing euhedral phenocrysts of microcline. Adjoining bodies of porphyritic granitoid and even-grained granitoid may share a distinctive characteristic. For instance, southwest of Barloweerie Peaks, distinctive even-grained granite, *sensu stricto*, with smoky-grey anhedral quartz grains, is partly surrounded by porphyritic granite of similar appearance. West of Koonmarra, the fine-grained groundmass of a porphyritic adamellite resembles the adjoining fine-grained, even-grained adamellite.

Leucogranite (*Agf*) is a distinctive granitoid type intruding gneiss north of Cunjarrie Bore. It is of adamellite composition and contains altered plagioclase and chloritized biotite, giving the rock pink and green colours. The same granitoid has been dated on ROBINSON RANGE at 2 460 m.y. (Williams and others, 1978).

Muscovite alkali granite (*Agu*) occurs northwest of Barloweerie Peaks and south of Munarra Gully mine. It is quartz-rich, and contains coarse, anhedral books of muscovite commonly intergrown with coarse quartz grains; the plagioclase is albite (An_5) and biotite and fluorite are minor constituents.

Tonalite and granodiorite with hornblende (*Agh*) occur northwest of Barloweerie Peaks (where they are intruded by muscovite alkali granite), and along the western side of the Murrouli Range. The tonalite and granodiorite invariably contain rounded amphibolite xenoliths from 10 to 100 mm across. The rocks are composed of recrystallized quartz, saussuritized plagioclase, hornblende, minor microcline and chloritized biotite.

Homogeneous granitoids rarely contain flow structures or a metamorphic fabric. The porphyritic granite body near Quartzite Hill, however, has a narrow selvage in which mocrocline phenocrysts are aligned and quartz grains flattened. This fabric is regarded as protoclastic, and as resulting from differential flow of the magma before complete solidification. A similar fabric in porphyritic granitoid near Coobina Bore is developed over the entire width of the granitoid body, and suggests that tectonic movement was involved during intrusion. The granitoid could therefore be regarded as syntectonic. Strongly foliated granitoid west of the Chunderloo mine has a metamorphic texture which also indicates tectonism during or after intrusion. A narrow strip of biotite tonalite (*Agt*) occurs along the northwestern edge of the granitoid/gneiss corridor between the Abbotts and Meekatharra greenstone belts. Rectangular micro-porphyroclasts of plagioclase (possibly remnant phenocrysts) are set in a mylonitic, fine-grained, dark-green groundmass of quartz, plagioclase and chloritized biotite. This rock is similar to early tectonic granitoids found marginal to, or within, greenstone belts on GLENGARRY (Elias and others, 1979).

Homogenous granitoids bearing a fabric that is at least partly tectonic in origin, are indicated on the map by an overprint.

Banded igneous granitoids

In contrast to the homogenous granitoids which occur as discrete, well-defined bodies of comparatively small area, banded granitoids occupy vast areas in the western and northern parts of BELELE. The unifying characteristic that sets these granitoids apart from the homogeneous granitoids is the variable development of mineral banding on a scale of 0.1 to 1 m.

These granitoids are invariably biotite granodiorite and adamellite, and two main textural types are recognized: even-grained to seriate, in places containing sparse microcline megacrysts (*Agbn*); and porphyritic (*Agln*). These two types commonly merge, and the distinction is in places arbitrary. Near Kalli, the two types are mixed on a small scale, and the symbol *Agm* is used. In this area, pegmatite and adamellite dykes abound, indicating a concentration of late-stage igneous activity.

Banding in the granitoids is commonly a dark and light, diffuse or nebulitic banding caused by repeated variation in biotite content. Feldspar and quartz are allotriomorphic, and biotite is in randomly oriented individual books and flakes characteristic of igneous crystallization. Biotite is often entrained within and parallel to the banding. Banding is generally continuous and has a persistent trend at outcrop scale.

Another form of banding which occurs in the porphyrtic granitoids is defined by variation in megacryst content. The megacrysts commonly have a planar alignment parallel to the banding.

The banded igneous granitoids contained synplutonic dykes and irregular bodies of fine-grained granitoids. Most common, is a darker, more biotite-rich, banded adamellite and granodiorite that occurs as continuous and boundinaged dykes concordant to banding in the host granitoid. Dykes of fine-grained granodiorite and adamellite containing leucocratic ellipsoids elongated along the dykes (*Ago*) occur in the western part of the area. In the area around Madoonga Outcamp Well, dykes of fine-grained granitoid contain aligned poikiloblasts of microcline. All of these fine-grained granitoid dykes have swirling, irregular margins indicating that they were intruded while the host was still mobile, and at an elevated temperature, possibly in the final stages of crystallization.

Some brief points can be made about the origin and significance of the banding in the banded igneous granitoids. The general concordance of banding with megacryst alignment, and the igneous texture of the rock which shows no evidence of metamorphic differentiation, indicate that banding is of igneous origin, probably the result of flowage in semi-consolidated magma. Generalized trend lines are drawn on Figure 2; these define a single, large cell-like structure. Trend lines are generally concordant with surrounding greenstone belts, although they may be discordant on a local scale. The gradual lithological variations within the banded granitoids, and the local discordance of these variations with flowage trends, suggest that the major granitoid area in the western half of BELELE is a single heterogeneous body intruded in essentially a single event. Another, smaller body may have developed in the area northeast of the Mingah Range greenstone belt.

Transitional and gneissic granitoids

Rocks with textures and fabrics transitional between granitoid and gneiss (*Agn*) occur between the gneiss terrain and the granitoid-greenstone terrain in the northern part of the area. These are quartz-feldspar-biotite rocks of generally adamellitic composition, which are conspicuously banded on a scale of 10 to 50 mm; the banding is commonly flow-folded. The texture varies from lepidoblastic or gneissic with aligned biotite flakes, to granoblastic or allotriomorphic with entrained but non-aligned biotite books. Compositional bands on these transitional granitoids have sharper boundaries than the banded igneous granitoids. Banding defined by grain size variation is also seen. There is some development of flow-folded pegmatite veins. Further evidence of the transitional nature of these rocks is given by the occurrence of euhedral microcline phenocrysts in gneissic-textured rock.

Near the western margin of BELELE, a different sort of transitional rock contains distinct phases of recrystallized gneiss and nebulitic granitoid (*Agx*), the two components occurring as alternating sheets. This is considered to be a marginal facies of the major granitoid body, produced by lit-par-lit injection of granitoid into gneiss, large areas of which occur immediately to the west on BYRO.

Compositionally banded adamellite and granodiorite gneiss (*Ang*) has a better-developed gneissic texture than *Agn*, with schlieren of aligned biotite separating elongate composite grains of granoblastic quartz and feldspar. Augen of deformed microcline are common, such as near Barloweerie Peaks. Compositional banding occurs on both the granular scale, where it results from metamorphic differentiation, and on a 50 mm scale (e.g. variation in biotite content), which may reflect heterogeneity in the parent rock. These rocks are thought to be early syntectonic granitoids, which were affected by the main metamorphism of the greenstone belts. Concordant inclusions of amphibolite occur in granitoid gneiss southwest of Meekatharra, suggesting that the granitoid originally intruded the greenstones.

RELATIONSHIP OF GNEISS AND GRANITOID TERRAINS

Comment on the relationship between gneiss and granitoid terrains is based on an interpretation of the origin of the transitional granitoids, and their spatial relationship with the large body of nebulitically-banded granitoid.

The transitional granitoids show the seemingly paradoxical combination of distinct compositional banding characteristic of gneisses, and granoblastic or allotriomorphic-granular, non-directional fabric characteristic of granitoids. It is suggested that the transitional granitoids were derived from compositionally banded gneiss that has undergone a static annealing process which destroyed the directional fabric on a granular scale by recrystallization, yet preserved the larger scale compositional banding. The parent gneiss is represented by the banded gneiss to the north. In support of this suggestion is the occurrence of metamorphic enclaves similar to those in the banded gneiss terrain, in the transitional granitoid southeast of Mount Hale homestead. Local movement during recrystallization is inferred from the presence of mylonitic, early-healed shears, and, on a much larger scale, the angular discordance of trends at the gneiss-transitional granitoid contact east of Mount Hale homestead. A lepidoblastic, gneissic fabric is developed in transitional granitoid south of the discordance; this fabric is superimposed on the gneissic banding and results from transposition of the banding from a north-northeast to an easterly trend (*see also: Structures in the transition zone*).

The nebulitically-banded granitoids of the main body resemble the transitional granitoids in the development of compositional banding, but there is no evidence to suggest that the banding in both rocks has a common origin. Generalized trends in banded granitoids (Fig. 2) suggest that the orientation of banding is related to the shape of the batholith, and therefore controlled by flowage of crystal mush. The origin of the banding is uncertain, but may also be caused by flowage of a heterogeneous crystal mush during emplacement.

The homogeneous granitoids are uniform in texture and composition over a large area, suggesting that they were derived from a uniform source, or that they underwent complete mixing before emplacement.

The general progression from north to south of gneiss to transitional granitoid to nebulitic granitoid to homogeneous granitoid, is interpreted as representing a sequence of progressively increasing recrystallization and homogenization, with an increase in magmatic character, from a source represented by the gneiss terrain. This interpretation lends support to the posulate, made elsewhere (Gee, 1979), that the granitoids of the Yilgarn Block are remobilized, by anatectic and solid-state processes, from a sialic crust, the remnants of which are represented by the gneiss terrain.

Structures in the transition zone

The transition zone marks an important division between two regional geological terrains. The area of best exposure is north of Koonmarra, where it is accompanied by various minor structures which may assume some significance when considered in the regional context.

In the northern part of the transition zone, the transposition of structural trends from north-northeast to east-west (mentioned earlier) is associated with a zone of shearing, about 4 km wide. Muscovite has developed on the foliation, which is axial planar to folds of compositional banding. In places, lenses of quartz-muscovite schist, and narrow, muscovite-bearing quartz mylonite zones are developed.

Further south, in the zone of transitional granitoids, as far as Quartzite Hill and Koonmarra, shearing has occurred in discrete zones parallel to the regional boundary between gneiss and granitoid terrains. Many of these shear zones are filled with vein quartz and dolerite, which, themselves, show no evidence of shearing. The shears, which acted as loci of weakness in subsequent tensional fracturing and dyke intrusion, are considered to be of Archean age.

PROTEROZOIC

GLENGARRY SUB-BASIN

Basal sediments of the Proterozoic Glengarry Group, a thick sequence of terrigenous sediments and volcanics, which were deposited in the Glengarry Sub-basin, are exposed in the extreme northeast corner of BELELE.

Saccharoidal-textured mature quartz arenite with conglomerate bands (*ƂGf*) forms the base of the sequence. This is correlated with the Finlayson Sandstone, defined on adjacent GLENGARRY (Elias and others, 1979). The arenite is overlain by poorly exposed pelitic phyllite with minor sandstone bands containing magnetite (*ƂGs*).

The contact between the sediments and the underlying Archaean granitoid is a sheared unconformity, which is faulted in places.

MINOR INTRUSIVES

Post-tectonic plugs and dykes of probable Proterozoic age (*Ed*) intrude the Archaean rocks. Two rock types are represented: fine- to coarse-grained black dolerite and gabbro consisting of clinopyroxene, plagioclase, and minor biotite, opaques, and olivine; and pink quartz diorite or tonalite consisting of graphically intergrown quartz, plagioclase, and minor biotite and opaques.

The intrusives are concentrated in two east-west trending zones. One of these is north of Koonmarra in the transition zone between gneiss and granitoid terrain, where there are abundant tonalite and dolerite dykes and quartz veins occupying shear and fault zones in the Archaean bedrock. One of the dykes, south of Coodabubba Bore, has a thickened portion which contains a core of coarse-grained gabbro surrounded by tonalite. Circular plugs of black dolerite about 100 m across occur near Willyoga Bore and at Murdabool Hill; these unusual forms of dolerite coincide with the zone of transposition of gneissic banding from north-northeast to east-west trends.

No obvious structural control is evident in the other zone of minor intrusives, near Barloweerie Peaks. Most of these dykes are of pink tonalite, and trend 080-090°.

ECONOMIC GEOLOGY

GOLD AND SILVER

Total production figures for gold and silver from centres on BELELE are quoted in Table 1.

TABLE 1: SUMMARY OF REPORTED GOLD AND SILVER PRODUCTION—BELELE

Locality or centre	*Alluvial (g)*	*Dollied or specimen (g)*	*Ore treated (t)*	*Gold therefrom (g)*	*Av. grade (g/t)*	*Total gold recovered (g)*	*Silver recovered (g)*
Abbotts	—	987	41 450	1 279 442	30.87	1 280 429	—
Big Ben	—	1 583	311	15 459	49.71	17 042	—
Carwell	—	—	100	1 208	12.08	1 208	—
Chesterfield	903	12 870	13 033	278 483	21.37	292 256	842
Garden Gully	820	2 913	33 831	733 751	21.69	737 484	34 306
Hercules	—	857	8 939	158 745	17.76	159 602	—
Jillewarra	5 382	43 967	2 383	122 278	51.31	171 627	—
Maranoa	—	—	30	1 004	33.47	1 004	—
Mindoolah	95	990	7 621	161 409	21.18	162 494	1 337
Munarra Gully	—	1 065	14 523	215 661	14.85	216 726	—
Nannine	5 793	66 726	136 329	2 503 884	18.37	2 576 403	5 350
Wanganui	—	—	2 146	23 960	11.16	23 960	—
Yaloginda	2 517	81 483	51 384	708 751	13.79	792 751	396
	15 510	213 441	312 080	6 204 035		6 432 986	42 231

Note: Production from BELELE part of Meekatharra centre not included (see Elias and others, 1979, Table 4). Sundry parcels from Meekatharra and Cue districts not considered.

Gold occurs in post-deformational quartz reefs and veins in the greenstones, and, in two cases, in granitoid. Most of the gold has been mined from the oxidized zone where it has undergone supergene enrichment, and a small proportion (probably greater than is shown in Table 1, due to some of it being included as specimen material) has come from 'alluvial' deposits shed from outcropping reefs.

By far the greatest proportion of gold (72 per cent) is associated with sediments, either clastic or chemogenic. The line of banded iron-formation interbedded with fine-grained sediments, extending between Nannine and Yaloginda, accounts for much of this proportion. At Abbotts, the host sequence consists of fine-grained metasedimentary and tuffaceous schist, intruded by metadolite.

Gold associated with mafic metavolcanics and intrusives accounts for 22 per cent of the total production. The most important centres are Garden Gully, where the sequence includes komatiitic basalt and peridotite; Chesterfield; and Munarra Gully. At Munarra Gully and Chunderloo, copper accompanies gold in the quartz reefs. The Hercules mining centre is in a quartz reef cutting across a jaspilite and intrusive dolerite sequence. At both Chesterfield and Hercules, cherty sediments in the sequence may have a bearing on the origin of the gold deposits.

Gold from felsic porphyry at Mindoolah and Jillewarra-Carwell accounts for 5 per cent of the total production.

A small amount of gold has been produced from the hornblende tonalite body which flanks the western edge of the Murrouli Range mafic sequence. At Wanganui gold occurs in quartz veins wholly within the granitoid, and at Nannine a number of gold mines are sited at the contact of the granitoid and the mafic sequence. This unusual occurrence could be related to a relative enrichment of gold in the granitoid due to crustal contamination by basaltic material.

Abundant mafic xenoliths in the granitoid provide independent evidence that contamination has taken place.

COPPER

Copper mineralization occurs at Chunderloo in strongly lineated basaltic amphibolite. The mineralization is associated with reef quartz, and consists of chrysocolla, malachite, azurite and cuprite (Marston, 1979). The ore appears to be stratabound, and the mineralized unit is folded along axes congruent with the mineral lineation which plunges about 20° to the northeast. Total production from Chunderloo was 1 020.39 t of ore containing 27.71 t of copper; however, most of the ore produced in the years 1955-1962 was used for fertilizer manufacture. Gold was also extracted from the ore. Detailed production figures are given by Marston (1979).

North of Abbotts, near Government Well, 118.16 t of cupreous ore has been produced (1964-1965) from a small open pit. Mineralization occurs in a black shale interbed in schistose komatiitic volcanics near the northern 'closure' of the Abbotts greenstone belt.

Copper mineralization is associated with gold at the Munarra Gully gold mine, but there is no reported production. Traces of copper have also been seen in metabasalt about 3 km northeast of the mine.

IRON ORE

Significant reserves of iron ore occur in the Weld Range and the Jack Hills. Although no production has taken place, feasibility studies are continuing on the possibility of developing a mining project, perhaps incorporating the two areas.

Iron ore formed, in both areas, by supergene enrichment of banded iron-formation during the Tertiary lateritization period. The ore is present in a number of small lenses. In the Weld Range, estimated reserves from about 20 ore lenses are 152 Mt (containing 60 per cent iron) (1973) figures). The lenses are restricted to the Madoonga and Wilgie Mia beds. The most recent published information on the ore bodies is given by Jones (1963), but subsequent work by the company holding the deposits (Northern Mining Corporation N.L.) has disclosed more ore lenses.

Ore lenses in the Jack Hills extend from Noonie Hill on BYRO to Mount Taylor and Mount Gould on ROBINSON RANGE. On BELELE, the ore lenses are in the vicinity of Mount Hale and Mount Matthew. Total ore reserves for the whole of the Jack Hills area are estimated to be almost 94 Mt, about half of which is believed to come from the Mount Hale-Mount Matthew area.

OTHER MINERALS

Uranium

Extensive deposits of valley calcrete occupy the trunk drainages of the Hope and Yalgar Rivers in the eastern part of BELELE, and are prospective for Yeelirrie-type uranium mineralization. Traces of carnotite occur in parts of the calcrete bodies; however, despite vigorous exploration by mining companies no prospects have emerged.

Barite

The Chesterfield barite workings are 48 km west-northwest of Meekatharra. The barite occurs as steeply dipping veins in gabbro and basaltic tuff. Although some thin seams and lenses of country rock contaminate the vein, most of the barite is of good white quality. Prior to 1971, when production ceased, a total of 5 845 tonnes had been extracted. Current reserves are not known.

Barite occurs in a quartz vein occupying a shear zone in granitoid 11 km east of Quartzite Hill. Barite occurs over a width of about 40 m; a 'core' containing a number of 1 m thick massive barite veins is surrounded by zones of thinner barite veins and quartz-barite breccia. The deposit extends over a length of no more than 200 m, but its situation in a quartz-filled shear zone that extends for about 25 km from Quartzite Hill to Eanally Bore suggests the possibility of more pockets of barite being present. The barite occurrence does not appear to have been previously investigated.

Ochre

Ochre deposits of historical as well as industrial interest have developed in the jaspilites of the Weld Range. At Wilgie Mia, a deposit of red ochre has been used by Aborigines for over 1 000 years as a source of high quality pigment which was traded as far as eastern Australia. A smaller deposit of red ochre occurs at Little

Wilgie Mia. Production of red ochre by Europeans started in 1945, and up to the end of 1978, 9 131 t was produced. A small deposit of yellow ochre at the western end of the Weld Range, south of Mindoolah, has yielded 403.47 t.

WATER RESOURCES

Because of low rainfall and a high evaporation rate, surface water is non-existent, except for short periods after heavy rainfall. Consequently, domestic and stock-water requirements are met entirely from groundwater*.

Most groundwater is drawn from shallow aquifers of colluvium, valley-fill alluvium and calcrete. The extensive colluvial flats underlain by hardpan on either side of the main drainages (designated *Qw* on the geological map) provide a reliable source of shallow, good quality groundwater. The water table is generally less than 15 m below ground level and salinities are commonly 800-1 200 mg/L. Salinities are slightly higher near the main drainage lines. The yield, although slight, is sufficient for stock requirements. Far greater yields are obtainable from the highly permeable valley calcrete which occurs in the trunk drainages, such as in the Hope and Yalgar Rivers. Salinities increase markedly towards the salt lakes, with values of greater than 3 000 mg/L common around Lake Annean.

Away from the major drainages, limited supplies are obtained from colluvial aquifers marginal to rock outcrop, and in some cases from weathered or fractured bedrock. Depth to water table is greater than in the valleys of the main drainages; however, it rarely exceeds 25 m. Quality varies according to rock type; in greenstone areas, salinities are generally higher than in granitoid areas. Kaolinized granitoid is unreliable as an aquifer, but groundwater salinity may be as low as 200 mg/L. Near Norie, water is obtained from colluvium immediately upstream from outcropping steeply-dipping banded iron-formation, which bars the passage of groundwater and consequently raises the water table.

---

*During this survey, some 420 bores and wells were field-tested for total dissolved solids; the results are obtainable from the Geological Survey hydrogeology division.

APPENDIX 1

CO-ORDINATES OF SOME LOCALITIES MENTIONED IN TEXT

Place Name	Latitude (S)	Longitude (E)
Abbotts	26°19′20″	118°23′10″
Barloweerie Peaks	26°47′15″	117°59′30″
Beebyn	26°58′10″	117°54′20″
Big Ben mine	26°26′45″	118°00′10″
Carwell mine	26°20′40″	117°46′35″
Chesterfield mine	26°30′10″	117°59′20″
Chunderloo mine	26°42′40″	118°21′45″
Coobina Bore	26°51′25″	118°04′00″
Conroy Bore	26°30′35″	118°19′20″
Eanally Bore	26°20′00″	117°40′00″
Garden Gully	26°27′25″	118°28′00″
Government Well (Abbotts)	26°16′50″	118°22′00″
Hercules mine	26°58′10″	117°37′00″
Jillewarra mine	26°19′50″	117°44′30″
Kalli	26°53′40″	117°07′30″
Little Wilgie Mia	26°56′50″	117°40′30″
Maranoa mine	26°22′15″	117°53′40″
Mardoonganna Hill	26°54′40″	117°25′40″
Meekatharra	26°35′30″	118°29′30″
Mingah Range	26°29′30″	117°59′30″
Mindoolah mining centre	26°57′00″	117°28′30″
Mount Hale	26°02′35″	117°15′25″
Mount Hale homestead	26°06′45″	117°30′30″
Mount Matthew	26°03′45″	117°14′30″
Mount Obal	26°34′30″	118°20′00″
Munarra Gully mine	26°59′20″	118°08′20″
Murdabool Hill	26°05′20″	117°53′20″
Murrouli Range	26°51′30″	118°20′00″
Nannine	26°53′30″	118°20′35″
Norie	26°46′30″	118°21′10″
Quartzite Hill	26°18′00″	117°26′00″
Seven Mile Well	26°05′40″	117°01′50″
Wadda Wadda Bore	26°26′25″	118°03′45″
Wanganui mine	26°47′30″	118°18′00″
Weebacarry Bore	26°55′50″	118°04′50″
Willyoga Bore	26°10′20″	117°43′10″
Yaloginda	26°39′45″	118°25′00″
Yarrameedie Cairn	26°06′25″	117°12′05″

REFERENCES

Arndt, N. T., Naldrett, A. J. and Pyke, D. R., 1977 Komatiitic and iron-rich tholeiitic lavas of Munro Township, Northeast Ontario: Jour. Petrology, v. 18, p. 319-369.

Arriens, P. A., 1971, The Archaean geochronology of Australia: Geol. Soc. Australia, Special Publication No. 3, p. 11-23.

Bunting, J. A., Commander, D. P. and Gee, R. D., 1977, Preliminary synthesis of Lower Proterozoic stratigraphy and structure adjacent to the northern margin of the Yilgarn Block: West. Australia Geol. Survey Ann. Rept 1976, p. 43-48.

Clarke, E. de C., 1916, The geology and ore-deposits of Meekatharra, Murchison Goldfield: West. Australia Geol. Suvey Bull. 68.

de la Hunty, L. E., 1973, Cue, W.A.: West Australia Geol. Survey 1:250 000 Geol. Series Explan. Notes.

Elias, M., Bunting, J. A., and Wharton, P. H., 1979, Explanatory notes on the Glengarry 1:250 000 Geological Sheet, Western Australia: West. Australia Geol. Survey Rec. 1979/3.

Ellis, H. A., 1936, The Geology and ore deposits of the Abbotts mining centre (Murchison Goldfield): West. Australia Geol. Survey Bull. 96, p. 1-49 (unpublished).

Gee, R. D., 1979, Structure and tectonic style of the Western Australian Shield: Tectonopyhsics, 58, p. 327-369.

Geological Survey of Western Australia, 1975, Geology of Western Australia: West. Australia Geol. Survey, Mem. 2.

Gibson, C. G., 1904, The geology and mineral resources of a part of the Murchison Goldfield: West Australia Geol. Survey Bull. 14.

Hallberg, J. A., 1976, A petrochemical study of a portion of the western Yilgarn Block: Australia CSIRO Division of Mineralogy, Mineral Research Laboratories Rept FP13.

Hallberg, J. A., Carter, D. N., and West, K. N., 1976, Archean volcanism and sedimentation near Meekatharra, Western Australia: Precambrian Research, v. 3, p. 577-595.

Johnson, W., 1950, A geological reconnaissance survey of part of the area included between the limits lat. 24°0'S and lat. 29°0'S and between long. 115°30'E and long. 118°30'E including parts of the Yalgoo, Murchison, Peak Hill and Gascoyne Goldfields: West. Australia Geol. Survey Bull. 106.

Jones, W. R., 1963, The iron ore deposits of the Weld Range, Murchison Goldfield: West. Australia Geol. Survey Ann. Rept 1962, p. 54-60.

Marston, R. J., 1979, Copper mineralization in Western Australia: West. Australia Geol. Survey Mineral Resources Bull. 13.

Muhling, P. C., and de Laeter, J. R., 1971, Ages of granitic rocks in the Poona-Dalgaranga area of the Yilgarn Block, Western Australia: West Australia Geol. Survey Ann. Rept 1970, p. 68-73.

Waller, D. R., and Beattie, R. D., 1971, Airborne magnetic and radiometric survey of Belele, Cue, Kirkalocka and the eastern parts of Byro, Murgoo and Yalgoo 1:250 000 sheet area, Western Australia, 1969: Australia Bur. Mineral Resources Rec. 1971/28 (unpublished).

Williams, S. J., Elias, M. and de Laeter, J. R., 1978, Geochronology and evolution of the eastern Gascoyne Province and the adjacent Yilgarn Block: West. Australia Geol. Survey Ann. Rept 1977, p. 50-56.

Winkler, H. G. F., 1976, Petrogenesis of Metamorphic Rocks (4th ed.): Springer-Verlag, 334p.

Woodward, H. P., 1914, A geological reconnaissance of a portion of the Murchison Goldfield: West. Australia Geol. Survey Bull. 57.

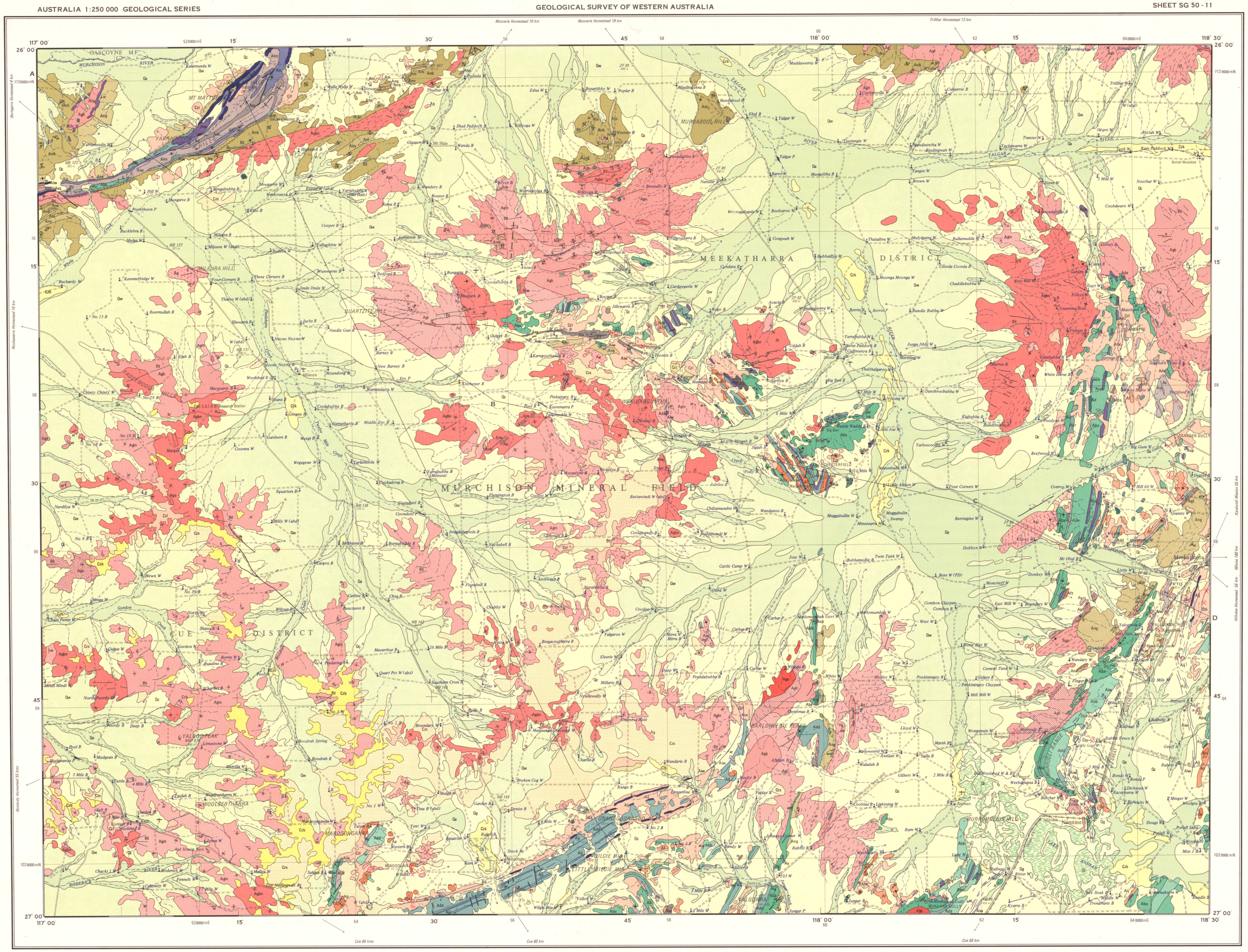
23188/12/82—3 000 Bks—L/3345 WILLIAM C. BROWN, Government Printer, Western Australia

AUSTRALIA 1:250 000 GEOLOGICAL SERIES

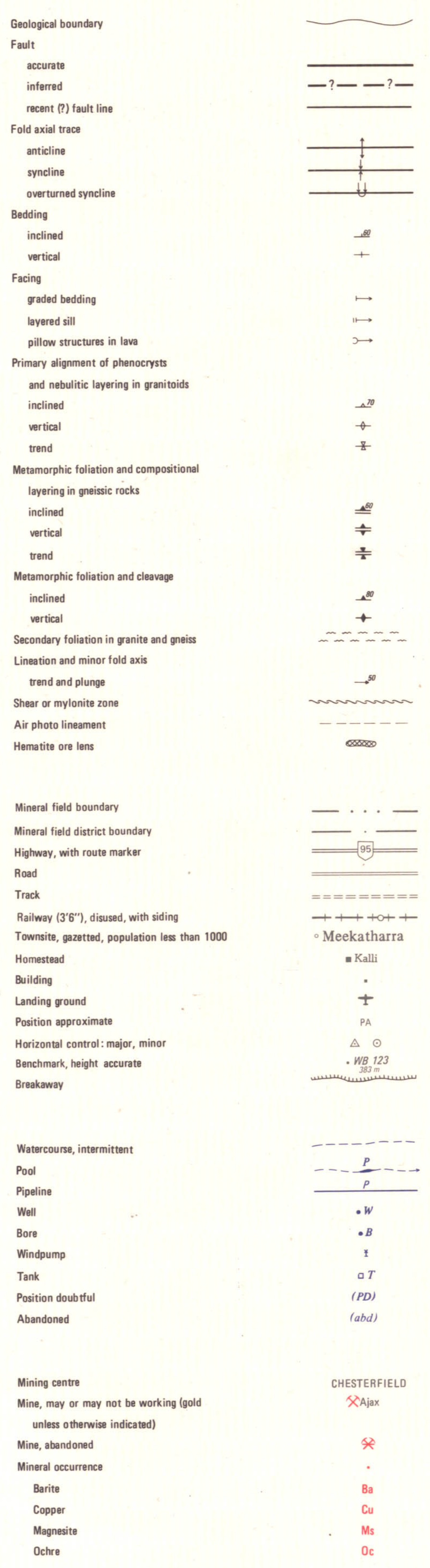
BELELE

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SG 50 - 11



SYMBOLS



REFERENCE

CAINOZOIC — QUATERNARY

Qc Qw Qa Ql Qg

Qc Colluvium – quartz and rock fragments in loam, unconsolidated, forming scree and talus slopes
Qw Colluvium and alluvium – unconsolidated sand and silt in sheetwash plains, mostly with low windblown sand banks
Qa Alluvium – unconsolidated sand, silt and gravel in drainage lines and adjacent floodplains
Ql Lake deposits – clay, silt and grit, saline and gypsiferous
Qg Deposits marginal to salt lakes – mainly eolian quartz sand and gypsum banks, contains numerous small claypans

Czs Czk

Czs Eolian sand in dunes and sheets overlying Czl, contains lateritic gravel in places
Czk Valley calcrete – sheet carbonate formed around lakes and in major drainage lines

TERTIARY

Czl Czj Czb

Czl Laterite, massive and pisolitic ferruginous duricrust, includes silcrete over granitic rocks
Czj Siliceous caprock, brown, fawn and cream in colour, developed on various rocks of greenstone belts
Czb Silcrete, siliceous duricrust with angular quartz grains, over granitoid rock

EARLY PROTEROZOIC — Glengarry Group (ⲢG)

ⲢGs Shale and sandstone, contains detrital magnetite
ⲢGf Mature quartz sandstone, cross-bedded, minor conglomerate (FINLAYSON SANDSTONE)

Ⲣd Diorite, tonalite and dolerite dykes, dolerite plugs
q Quartz vein

ARCHAEAN

Ag Undivided granitoid

Agb Agl Agbn Agln Agm Ago Agx
Agu Agf Agh Agt

Agb Biotite granite, adamellite, granodiorite and tonalite, even-grained
Agl Biotite granite, adamellite and granodiorite, porphyritic with microcline megacrysts
Agbn Biotite adamellite and granodiorite, even-grained, with sparse feldspar megacrysts, commonly has biotite entrainment and nebulitic banding, granitic texture
Agln Biotite adamellite and granodiorite, sparse to abundant feldspar megacrysts, commonly aligned, nebulitic banding defined by megacryst and biotite content, granitic texture
Agm Mixed granitic rocks, Agbn and Agln in approximately equal amounts, net-veined by adamellite and pegmatite dykes
Ago Granodiorite and adamellite dykes containing leucocratic ellipsoids
Agx Mixture of granitoid and recrystallized gneiss, heterogeneous facies marginal to plutonic complex
Agu Muscovite alkali granite, medium and coarse-grained, quartz-rich, contains accessory fluorite
Agf Leuco-adamellite, medium to coarse-grained, sparse biotite altered to chlorite
Agh Hornblende tonalite and granodiorite, unfoliated, contains scattered small mafic xenoliths
Agt Biotite tonalite, mylonitic texture, dark grey in colour

Agn Nebulitic to well-banded gneiss and granofels of adamellite and granodiorite composition, even-grained, mostly recrystallized and migmatized gneiss, grades into Anb

Ang Adamellite and granodiorite gneiss with strong gneissic foliation and lineation, commonly compositional banded, includes augen gneiss

Aiw Aij Aic

Aiw Banded iron-formation, black and white banded, may be recrystallized to a fine granular texture
Aij Jaspilite, red, black and white banded iron-formation
Aic Banded chert, may be recrystallized to a fine granular quartzite

As Ass Asq Alm Alc

As Undivided sediment, generally poorly-exposed, fine-grained, schistose rocks, in part tuffaceous
Ass Shale, mudstone
Asq Quartzite and micaceous quartzite, fine to medium-grained, quartz wacke and conglomerate in places
Alm Quartz-mica schist, contains garnet and andalusite in places, pelitic metasediment
Alc Quartz-chlorite-carbonate schist, chloritic metasediment

Af Aft Afx Az Azv

Af Undivided intermediate and felsic volcanic rock, mainly tuffaceous
Aft Crystal-lithic felsic tuff, fine-grained, generally schistose
Afx Lapilli tuff and agglomerate, medium to coarse-grained, angular and rounded clasts in a felsic matrix
Az Andesitic lava, tuff and minor fine-grained tuffaceous sediments
Azv Agglomerate, coarse-grained, blocks of andesitic lava in fragmental matrix of similar composition

Ap Felsic porphyry, quartz and feldspar phenocrysts

Ad Add Ado Adr Ada

Ad Undivided mafic intrusive rock
Add Dolerite, medium-grained
Ado Gabbro, coarse-grained
Adr Granophyre, medium-grained, has graphically intergrown quartz and feldspar
Ada Amphibolite, medium-grained, dynamically metamorphosed dolerite with foliation and amphibole growth

Ab Abb Abu Aba Aa

Ab Undivided mafic extrusive rock
Abb Basalt, fine-grained, pillowed and/or vesicular in places, intergranular texture
Abu Basalt containing fresh or altered skeletal clinopyroxene, mostly komatiitic
Aba Amphibolite, fine-grained, schistose with growth of amphibolite in foliation; metamorphosed Abb and Abu
Aa Hornblende-plagioclase (-clinopyroxene) amphibolite

Au Aup Aux Aue Aur

Au Undivided ultramafic rock
Aup Serpentinized peridotite, cumulate olivine texture preserved
Aux Metapyroxenite, medium to coarse-grained actinolite after clinopyroxene, original texture preserved
Aue Talc-carbonate schist, altered olivine-rich ultramafic rock
Aur Chlorite-amphibole schist, fine-grained, altered pyroxene-rich rock including ultramafic komatiite

Anb Anc Any Anq Anl Ani Ana Anu

Anb Quartz-feldspar-biotite gneiss and migmatite, compositionally banded
Anc Calc-silicate paragneiss, quartz-feldspar-clinopyroxene-hornblende assemblages, compositionally banded
Any Pelitic schist and granofels, quartz-feldspar-muscovite-biotite-garnet-cordierite-andalusite-kyanite assemblages, compositionally banded
Anq Quartzite, minor amphibole, shows relict bedding
Anl Micaceous quartzite containing green muscovite
Ani Quartz-magnetite-amphibole layered rock, metamorphosed banded iron-formation
Ana Amphibolite, hornblende-calcic plagioclase (-clinopyroxene-garnet), metamorphic texture, may be compositionally banded
Anu Ultramafic rock, metamorphic texture, clinopyroxene-chlorite-serpentine-amphibole assemblage

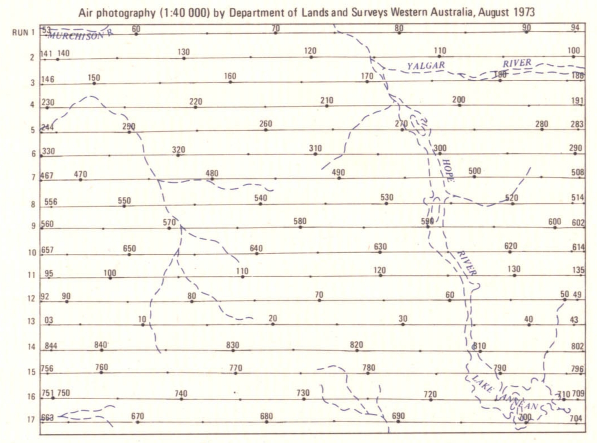
Geology by : M. Elias 1977-78, P.H. Wharton 1977, I.W. Walker 1978, S.J. Williams 1978.

Compiled and published by the Geological Survey of Western Australia. Cartography by the Geological Mapping Section, Department of Mines. Topographic base from compilations by the Department of Lands and Surveys.

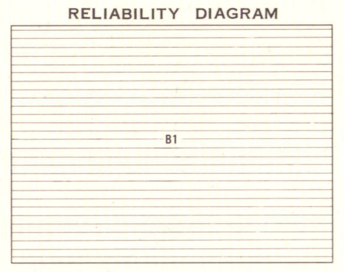
Copies of this map may be obtained from the Geological Survey of Western Australia, 66 Adelaide Tce., Perth.

FLIGHT DIAGRAM

Air photography (1:40 000) by Department of Lands and Surveys Western Australia, August 1973



RELIABILITY DIAGRAM



B1 Numerous traverses with air photo interpretation

HON. P. DOWDING, M.L.C.
MINISTER FOR MINES
A.F. TRENDALL, DIRECTOR, GEOLOGICAL SURVEY

SCALE 1:250 000

5 0 5 10 15 20 25 30 Kilometres

TRANSVERSE MERCATOR PROJECTION
ZONE 1 AUSTRALIA SERIES
Grid represents 10000 metre superimposed Australian Map Grid

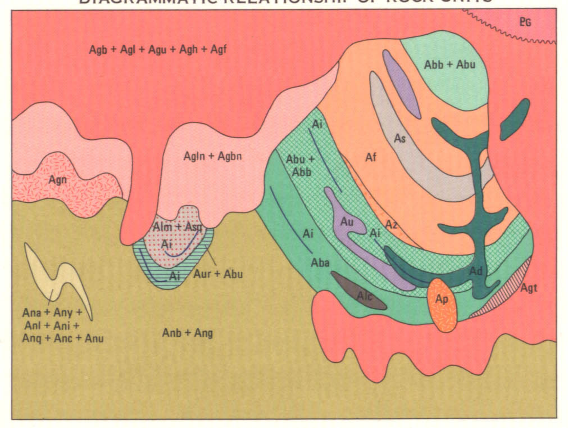
INDEX TO ADJOINING SHEETS

GLENBURGH SG 50 - 6	ROBINSON RANGE SG 50 - 7	PEAK HILL SG 50 - 8
BYRO SG 50 - 10	BELELE SG 50 - 11	GLENGARRY SG 50 - 12
MURGOO SG 50 - 14	CUE SG 50 - 15	SANDSTONE SG 50 - 16

DECLINATION DIAGRAM

The lines indicate magnetic declination, 1980 + means declination is east and correction must be added to compass bearing to give true bearing – means declination is west and correction must be subtracted from compass bearing to give true bearing. Annual change is –1′ westerly

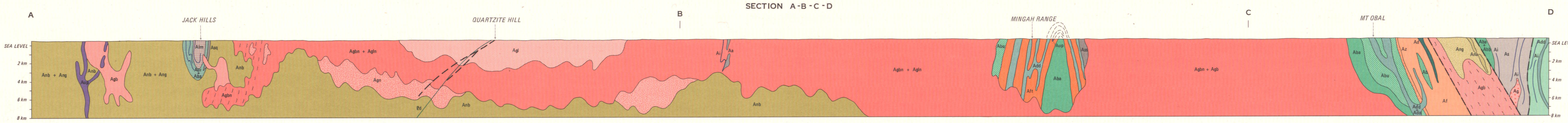
DIAGRAMMATIC RELATIONSHIP OF ROCK UNITS



DIAGRAMMATIC SECTION

NATURAL SCALE

SECTION A - B - C - D



BELELE
SHEET SG 50 -11

FIRST EDITION 1983