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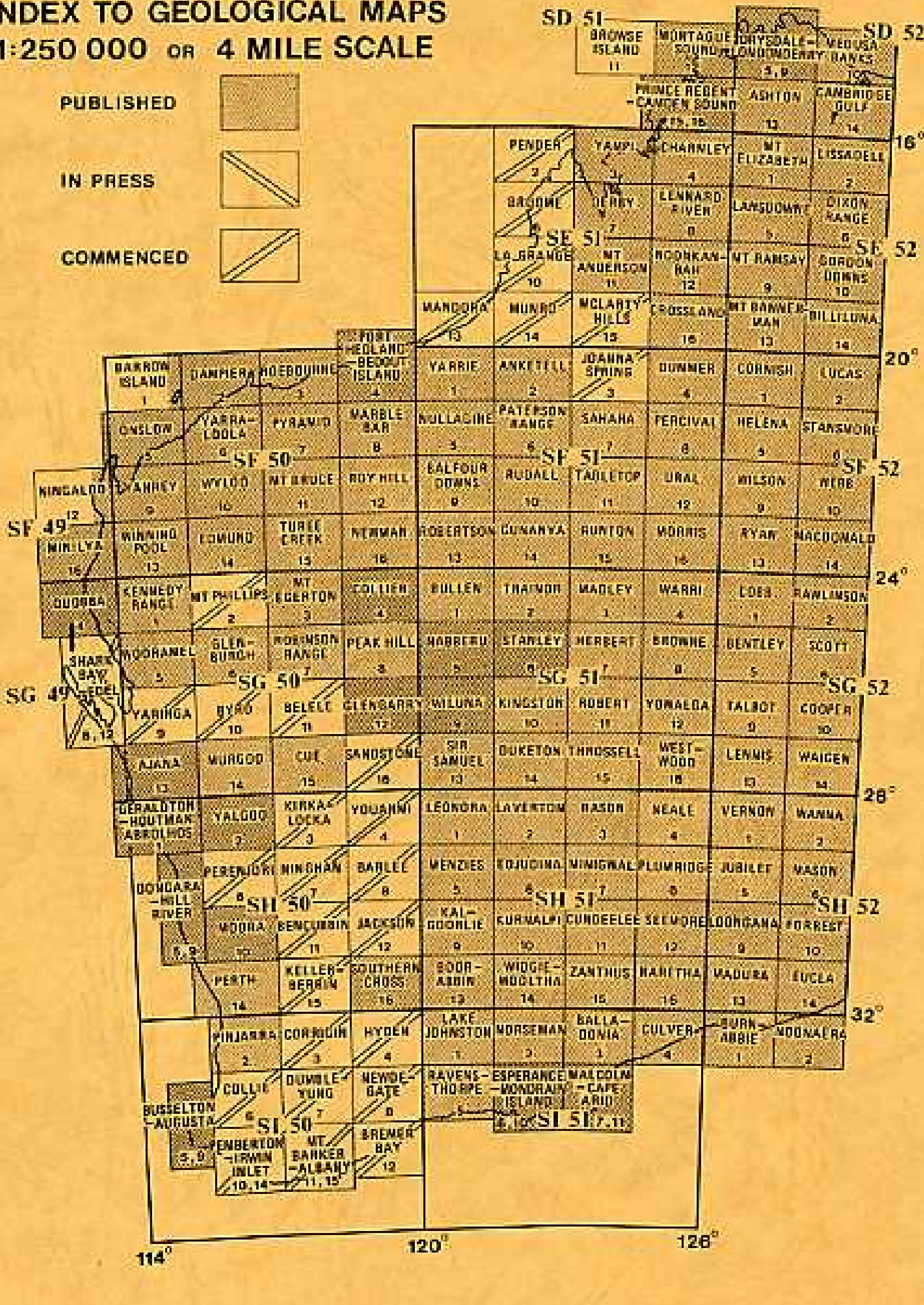

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

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AJANA

WESTERN AUSTRALIA

SHEET SG/50-13 INTERNATIONAL INDEX

COMPILED BY R. M. HOCKING, W. J. E. VAN DE GRAAFF, J. G. BLOCKLEY AND B. P. BUTCHER

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Explanatory Notes on the Ajana Geological Sheet

Compiled by R. M. Hocking, W. J. E. van de Graaff, J. G. Blockley and B. P. Butcher

INTRODUCTION

The AJANA* Geological Sheet, SG/50-13, is bounded by latitudes 27°00′S and 28°00′S, and longitudes 113°45′E and 115°30′E. Parts of the northern Perth Basin, southern Carnarvon Basin, Northampton Block and Yilgarn Block are present within the map sheet. The only settlements are Kalbarri, a holiday resort at the mouth of the Murchison River, and Ajana, a farming hamlet and former railhead. The northern two thirds of the area is either vacant land or under pastoral lease, whereas the southern portion is either mixed farming country or part of Kalbarri National Park. The central-northern part of AJANA is totally undeveloped, but elsewhere the Northwest Coastal Highway, Kalbarri Road, several shire roads, station tracks and some geophysical cut-lines give limited access. The climate is mediterranean, with average annual rainfall increasing from about 200mm in the northeast to 400 mm south of Kalbarri, and potential annual evaporation ranging between 1 800 mm and 2 400 mm. Average daily maximum and minimum temperatures are 30°C and 20°C in January, and 21°C and 11°C in July.

The area is mostly covered by shrub-steppe vegetation (mulga scrub) dominated by *Acacia*, with tall eucalypts lining the Murchison River. On southern AJANA vegetation reflects soil and bedrock distribution, and rich clayey soils in uncleared parts of the Northampton Block are characterized by salmon-gum scrubland. For further details on the flora see Beard (1976).

HISTORICAL REVIEW

The first recorded landing by Europeans on the Western Australian mainland was in 1629 at the mouth of Wittecarra Gully where two mutineers from the Dutch ship "Batavia" were marooned. Subsequently, Dutch, French and English ships landed at the mouth of the Murchison River, and the Dutch ship "Zuytdorp" was wrecked along the Zuytdorp Cliffs to the north in 1712 (Playford, 1959).

In 1848, a party led by A. C. Gregory explored the inland part of AJANA with a view to European settlement. This expedition discovered galena in the bed of the Murchison River, which resulted during 1850 in the opening of the Geraldine mine and the colony's first metallic mineral production and export. This was quickly followed by production of lead and copper ores from other nearby deposits. The Warribanno Chimney is the remains of the earliest smelter in the state, built to process lead ore from this district.

Brief descriptions of the geology of the Northampton Block and its environs appeared in the journals of the Gregory brothers between 1848 and 1858 (Gregory and Gregory, 1884) and in a paper by F. T. Gregory (1861). More detailed accounts of the numerous lead and copper mines in the Northampton Block are given by Brown (1871), Woodward (1895), Maitland (1903), Montgomery (1908), Wilson

* To avoid confusion with place names, sheet names are written in full capitals (AJANA).

(1926) and Blockley (1971). The regional geology of the Northampton Block segment of AJANA is shown in maps by Prider (1958) and Jones and Noldart (1962). In 1968 the Geological Survey of Western Australia issued 1:50 000-scale geological maps of the Ajana and Pencell quarter-degree sheets, covering the south-central part of AJANA.

Detailed petrographic studies of rocks collected along the Murchison River were undertaken by Prider (1958), and Peers (1971) described samples from GERALDTON to the south.

Perry and Dickins (1960) studied Proterozoic sedimentary rocks of the Badgeradda Group and Nilling Formation, which extend on to northeastern AJANA, and Baxter (1974) described Archaean rocks on MURGOO to the east.

The first detailed stratigraphic study of the area west of the Northampton Block was by Clarke and Teichert (1948), who summarized earlier work on the area. Systematic mapping of Phanerozoic sedimentary rocks on AJANA was done by the Bureau of Mineral Resources and West Australian Petroleum Pty. Ltd. in 1954, and 1955, and some results were reported by Condon (1965, 1967, 1968), Johnstone and Playford (1955), Johnstone, Condon and Playford (1958) and, to a lesser extent, Perry and Dickins (1960).

Recent summaries of the geology of the Carnarvon Basin are by Thomas and Smith (1976), Playford and others (1975), and Johnstone and others (1976); and of the Perth Basin by Playford and others (1976). Ozimic (1970) and Raine and Smith (1972) compiled bibliographies of the Carnarvon and Perth Basins.

PHYSIOGRAPHY

Playford and others (1976) differentiated 14 physiographic regions in the Perth Basin, three of which extend onto AJANA. These are divided into ten smaller physiographic regions, shown in Figure 1 and described in Table 1. The regions recognized correspond broadly to those of Finkl and Churchward (1973), who applied the etchplain concept to landscape development in southwestern Australia. However, local names are here proposed, as Finkl and Churchward's practice of using the same name for widely separated regions is confusing.

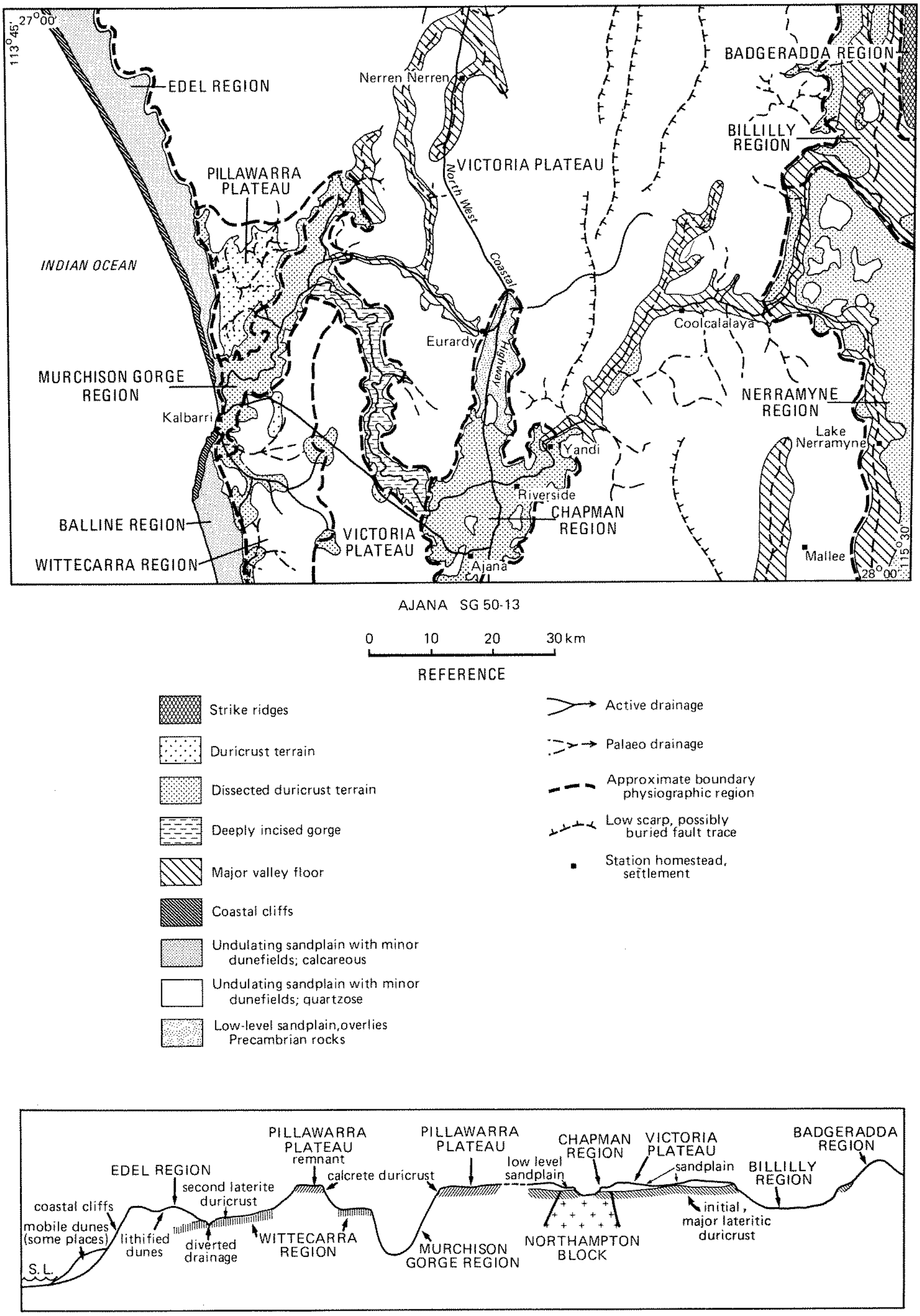
PRECAMBRIAN GEOLOGY.

Precambrian rocks on AJANA are divisible into three groups. In a strip 10 to 15 km wide at the eastern boundary of the sheet, Archaean gneiss and granite of the Yilgarn Block is present, overlain to the north by ?Middle Proterozoic clastic sedimentary rocks, some of which are dynamically metamorphosed. Middle Proterozoic metamorphic rocks, which make up the northern portion of the Northampton Block, are exposed in the central-southern part of AJANA.

All dolerite dykes are grouped in this section although those in the Northampton Block may be of Cambrian age.

YILGARN BLOCK.

The segment of the Yilgarn Block on AJANA forms part of Gee's (1979) western gneiss terrains of older Archaean rocks, i.e. about 3000 m.y. old. It consists mainly of quartz-feldspar-mica gneiss and foliated granite with minor mafic amphibolite and ultramafic rocks.



Spatial relationships of physiographic regions. GSWA 18027

Figure 1 : Physiographic sketch

TABLE 1. PHYSIOGRAPHIC REGIONS ON AJANA

Region	*Age of Development*	*Characteristics, Comments*	*Relationships to Other Regions*
Balline Region (new name)	Pleistocene-Holocene	Calcarenitic coastal dune belts. Holocene mobile dunes overstep Pleistocene dunes (Tamala Limestone). Coastal cliffs bound northern part.	Correlates with Edel Region. Tamala Limestone diverts Wittecarra Region palaeodrainages, therefore Balline Region developed later.
Edel Region ("Edel Province", Logan and others, 1970)	Pleistocene, with Late Pleistocene-Holocene coastal erosion.	Calcarenitic coastal dune belts (Tamala Limestone), bounded by high coastal cliffs.	Correlates with Balline Region. Tamala Limestone blocks Pillawarra Plateau palaeodrainages, therefore Edel Region developed later.
Chapman Region	?Late Pliocene-Pleistocene	Moderately dissected area underlain by Northampton Block. Residual clayey and sandy soils. Minimum age uncertain.	Breaches Victoria Plateau, therefore younger. Contains scattered remnants of Victoria Plateau.
Wittecarra Region (new name)	Late Pliocene to Pleistocene, with later stream incision.	Moderately dissected sand plain with patchily preserved lateritic duricrust. Dissected after lateritization.	Laterite at lower elevation than Pillawarra Plateau remnants in region, therefore Wittecarra Region developed after Pillawarra Plateau.
Pillawarra Plateau (new name)	Middle Pliocene	Calcrete duricrusted plateau developed over Toolonga Calcilutite; well defined palaeodrainages.	Predates full development of Murchison Gorge, postdates lateritization on Victoria Plateau. Correlates with Carbla Plateau (YARINGA).
Murchison Gorge Region (new name)	?Late Miocene-Quaternary	Deeply incised gorge with minor joint-controlled tributaries. Youthful appearance upstream of Mount Curious, marked lateral shift of river course downstream.	Breaches Victoria Plateau, therefore younger. Contains remnants of Wittecarra Region, therefore development continued after formation of Wittecarra Region.
Billilly Region (new name)	?Middle Pliocene	Major depression with valley-fill calcrete and numerous claypans. Marks course of relict tributary of Murchison River.	Breaches Victoria Plateau, therefore younger. Probably predates arid period during which Pillawarra Plateau developed.
Nerramyne Region (new name)	?Middle Pliocene	Major depression marking course of relict, northward-flowing tributary of Murchison River.	Correlates with Billilly Region. Contains remnants of Victoria Plateau, therefore younger.
Victoria Plateau	Late Miocene-Early Pliocene	Gently undulating sandplain underlain by lateritic duricrust; minor dunefields, major and minor palaeodrainages.	Covers most of AJANA, originally more extensive, younger than Badgeradda Region.
Badgeradda Region	?Early-Middle Tertiary	Rugged topographic area bounded by Woodrarrung Range, underlain by Proterozoic sediments.	Higher than Victoria Plateau with no duricrust, therefore older.

Quartz-feldspar-mica gneiss (An)

Strongly foliated, but generally poorly banded gneiss crops out on either side of the Murchison River near Yallalong homestead. It has a general adamellite composition with chloritized biotite as its chief mafic mineral. The rock is probably an orthogneiss.

Medium-grained foliated granite (Agn)

Medium, generally even-grained granite with a weak to moderate cataclastic foliation crops out in the southeastern corner of AJANA. The foliation is of variable trend, suggesting that it has later been folded. Xenoliths, only one of which is large enough to be mapped separately, consist of metagabbro and felsic metavolcanic rocks.

Amphibolite (Aa)

Strongly foliated and lineated amphibolite lenses or bands follow the foliation of the quartz-feldspar biotite gneiss. They consist of hornblende and plagioclase with minor quartz and sphene. Some grade into rock with an ophitic texture suggesting that these bands are metamorphosed dolerite dykes. One xenolith of amphibolite in the medium-grained granite has an augen texture and is probably a metagabbro.

Ultramafic rock (Au)

Generally poorly exposed bands of ultramafic rock occur in the granitic gneiss. They are marked by magnesite and chrysoprase rubble. One band which crops out more prominently consists almost entirely of actinolite with minor veins of silicified tremolite.

NORTHAMPTON BLOCK

On AJANA the Northampton Block consists predominantly of garnet granulite and quartz-feldspar gneiss, with some prominent quartzite horizons and minor amphibolite and megacrystic granite gneiss. The rocks fall into the upper amphibolite to granulite metamorphic facies but the term granulite is used here in the textural sense only. The units used are lithological rather than stratigraphic, and the following descriptions concentrate mainly on megascopic aspects of the rocks to assist field identification, as detailed petrographic descriptions are provided by Prider (1958), Playford and others (1970) and Peers (1971).

Garnet granulite (Ꝑmg)

Garnet granulite is well exposed in the beds of the Murchison River and larger streams, and forms isolated outcrops and extensive rubble areas on the valley slopes. Typically it is a brown-weathering, granular-textured, pale-pink to grey rock with coarse banding due to variation in grain size and composition. This banding is emphasized by concordant segregations of microcline pegmatite, and probably reflects original bedding. Garnet is common, forming from about 5 to 30 per cent of the rock. The finer grained, more arenaceous varieties normally consist of quartz, plagioclase, microcline, garnet, biotite and (locally) sillimanite. Coarser, more pelitic types contain sillimanite and commonly have cordierite in addition to the other minerals. These pelitic varieties may have a gneissic banding parallel to the broader compositional banding. The unit as mapped includes thin bands of quartzite, quartz-feldspar granofels, and schist which are not distinguished separately, except for occurrences of graphitic schist which are denoted by the symbol *Gt*.

Quartz-feldspar gneiss (Ꞓmn)

The northeastern part of the Northampton Block on AJANA consists of an assemblage of mainly garnet-bearing quartz-feldspar gneisses of varying composition. The contact with garnet granulite is conformable and gradational. Generally the gneiss crops out poorly, fresh exposures being present only in the bed of the Murchison River. For this reason no attempt was made to subdivide the various lithologies observed during mapping.

Compositionally the unit ranges from leucocratic quartz-feldspar gneiss through quartz-feldspar-biotite-garnet gneiss to pelitic gneiss and schist containing abundant garnet, biotite, sillimanite and cordierite in addition to the felsic minerals. The unit as mapped includes thin conformable bands of quartzite and amphibolite, some granulite, and in places, abundant pegmatite. Pegmatite-rich gneiss on GERALDTON has been mapped as migmatite.

Quartzite (Ꞓmq)

Ridge-forming quartzite bands are the only useful marker horizons within the metamorphic rocks of the Northampton Block. The quartzite is normally interbanded with leucocratic quartz-feldspar gneiss, which at this scale of mapping cannot be shown separately. In structurally simple exposures the quartzite has a regular grain size and compositional banding which probably reflects original sedimentary bedding. However, in the cores of folds the quartzite is completely recrystallized to coarse, structureless masses resembling vein quartz.

Granitic gneiss (Ꞓmp)

A distinctive megacrystic gneiss of biotite-granite composition forms a prominent bar 100 m wide accross the Murchison River 2.5 km upstream from Riverside farm, and can be traced southeasterly from the river in scattered outcrops.

The rock is grey, strongly foliated and lineated, and contains scattered porphyroblasts of garnet and subhedral to rounded megacrysts of microcline. It differs from the quartz-feldspar gneisses described above in being of uniform composition over considerable thicknesses. Similar rocks on GERALDTON were mapped as granite but because of the pronounced metamorphic texture of the unit and its conformity with other gneisses, the term granitic gneiss is preferred here.

PROTEROZOIC SEDIMENTS

These sediments, exposed marginal to, and overlying, the Yilgarn Block in northeastern AJANA, can be divided into metamorphosed and unmetamorphosed groups. The unmetamorphosed sediments belong to the Badgeradda Group, and a small area of the metamorphosed sediments belongs to the Nilling Formation, but the remainder of the metamorphosed sediments, exposed west of the Woodrarrung Range, cannot be readily assigned.

Nilling Formation (Ꝑn)

South of the Woodrarrung Range, mainly on MURGOO, the Badgeradda Group is underlain by the lithologically similar Nilling Formation ("Nilling Beds" of Perry and Dickins, 1960, amended herein). The latter differs from the Badgeradda Group in that constituent rocks are cleaved and quartz-veined, and consist of poorly bedded, variably recrystallized immature quartzose and feldspathic sandstone. Perry and Dickins (1960) suggested that the greater metamorphic imprint indicated an unconformable contact between the two units, and a period of dynamic metamorphism prior to deposition of the Badgeradda Group.

Badgeradda Group

Recognizable Badgeradda Group rocks on AJANA are assigned to two of the formations defined by Perry and Dickins (1960). The age of the group is assumed to be Middle Proterozoic because of its strong resemblance to the Bangemall Group.

Billilly Formation (Ꝑbb): On AJANA the Billilly Formation consists of a lower member of cross-bedded medium- to coarse-grained sandstone, only developed east of Woodrarrung Well, and an upper member of micaceous sandstone, siltstone and shale extending along the lower slope of the range. The fine-grained sediments part along their bedding planes and, unlike the Nilling Formation, have no superimposed cleavage.

Woodrarrung Sandstone (Ꝑbw): The lower part of the Woodrarrung Sandstone consists of thick-bedded medium- to coarse-grained silica-bonded quartz sandstone. The upper part consists of fine- to medium-grained kaolinitic sandstone which in places is silty and micaceous. Both units are cross-bedded and well sorted.

Metamorphosed sediments

West of the Woodrarrung Range, the Proterozoic sediments consist of well cleaved, quartz-veined siltstone and sandstone, grading to quartzite, with minor basalt horizons and dolerite sills. They were not assigned to either the Nilling Formation or the Badgeradda Group by Perry and Dickins (1960). Isolated outcrops extend southwards from the Woodrarrung Range area to the vicinity of Lake Nerramyne, and the sequence as a whole appears similar to the Wenmillia Formation on GERALDTON (Playford and others, 1970, 1976), but no direct correlation can be established. The well-developed cleavage suggests a correlation with the Nilling Formation, but this may equally have developed in a Late Proterozoic to Early Palaeozoic dynamic metamorphic event related to significant movement on the Darling and Woodrarrung Faults. This would allow the sequence to be correlated with the Badgeradda Group, parts of which resemble some of the sandstone and siltstone.

Because of poor outcrop and suspected structural complexity, the stratigraphic sequence was not determined. The units indicate lithological differences only and have not been assigned to any group or formation.

Siltstone (Ꝑ (s)): Well-bedded purple siltstone with some shale, sandstone and quartzite is the most widely exposed unit. The rocks commonly have an axial cleavage and near the Darling Fault recrystallization of mica along the cleavage has produced phyllite. Cross-bedding is present in many exposures and allows facings to be determined. The rocks consist predominantly of fine-grained quartz and sericite or muscovite, with iron-oxide staining.

Quartzite (Ꝑ(q)): Poorly bedded, variably recrystallized grey and white quartzite is present at several localities. The least recrystallized material consists of poorly sorted, subrounded to rounded quartz grains set in a fine-grained groundmass of quartz and iron oxide. Where the metamorphic grade is higher, the quartzites consist of equigranular amoeboid-textured quartz grains with no relict sedimentary texture. Parts of the quartzite bear a close resemblance both to the Nilling Formation and the Woodrarrung Sandstone.

Silicified metabasalt (Ꝑ(v)): A greenish siliceous rock, occuring mainly as rubble fields covering a small area south of Deep Well, proved on petrographic examination to have a well-defined trachytic texture. The present mineralogy—of quartz and epidote with minor chlorite—appears to be secondary, and the rock is interpreted as silicified metabasalt.

MINOR INTRUSIVES

Prominent swarms of dolerite dykes cut the rocks of the Yilgarn and Northampton Blocks, and sills of metadolerite intrude the metamorphosed sedimentary rocks east of the Woodrarrung Range. No dolerite was noted in the Badgeradda Group, but Baxter (1974) showed a dolerite sill intruding the Coomberarie Formation in the upper part of the group and dykes intrude the group on BYRO.

Dolerite dykes (d)

Some of the dolerite dykes intruding the Yilgarn Block have been converted, at least in part, to amphibolite. A specimen of least altered dolerite (GSWA 40176) consists of uralitized clinopyroxene and dusty ?calcic plagioclase. Dolerites cutting the Northampton Block typically contain both clino- and orthopyroxene and have accessory quartz. One large dyke exposed in the bed of the Murchison River just east of the Northwest Coastal Highway is an olivine gabbro. Intrusion of the dykes was accompanied by chloritization and partial melting of the adjacent granulite or gneiss.

Metadolerite sills (Ꝑd)

Recrystallized dolerite forms a number of sills within the Proterozoic sedimentary rocks. The rocks now typically consist of epidote, clinozoisite, chlorite, actinolite, and minor opaques. Relict ophitic textures are preserved.

PHANEROZOIC

West of the Northampton Block, faulted and heavily jointed Silurian sediments are overlain by flat-lying Mesozoic and Cainozoic sediments. To the east, block-faulted Silurian and Permian sediments are almost totally covered by superficial Cainozoic sediments. Geophysical surveys indicate that the maximum thickness of Phanerozoic sediments exceeds 3 000 m in western AJANA and may exceed 3 000 m in northern AJANA. Table 2 shows the Phanerozoic stratigraphic units on AJANA.

SILURIAN

Tumblagooda Sandstone (St): This formation has its type section along the Murchison River between the Hardabut Fault and Tutula Well. The base of the formation is not exposed on AJANA and has not been penetrated by any oil or water

TABLE 2. PHANEROZOIC STRATIGRAPHIC UNITS ON AJANA

Age			*Symbol and Rock Unit*	*Thickness (m)*	*Lithology and Depositional Environment*	*Stratigraphic Relationships*	*Remarks*
CAINOZOIC	Quaternary	Holocene	*Qs* Coastal dune and beach deposits	50	Well-sorted, calcareous and quartz sand.	Grades into *Qt, Qa, Qc*	In part equivalent to Safety Bay Sand, Perth Basin.
			Qe Dune and sandplain deposits	?30	Red, yellow and white quartz sand.	Grades into *Qa, Qel, Cze, Qt, Qc, Ql*	Eolian, but includes some residual soil and colluvial deposits.
			Qa Alluvium	?25	Poorly sorted clay, silt sand and gravel; partly calcreted on eastern AJANA.	Grades into *Qc, Qe, Qt, Qel, Ql, Qs*	Symbol restricted to water courses with clear drainage pattern.
		Holocene Early Pleistocene	*Qel* Claypan and dune terrain	?25	Poorly sorted clay, silt, sand and gravel intermixed with well-sorted eolian quartz sand; partly calcreted.	Grades into *Qa, Qe, Qc, Ql*	Only present on eastern AJANA, marks course of Tertiary palaeodrainages, may extend into Pliocene at base. Larger claypans mapped as *Ql*.
			Qc Colluvium	?25	Poorly sorted clay; silt and gravel, partly calcreted and variably lithified on eastern AJANA	Grades into *Qa, Qel, Qe, Qt, Cze, Qs*	Includes minor duricrust, sheet-flood deposits, minor areas of other surficial deposits, floors of major palaeodrainages. May extend into Pliocene on eastern AJANA.
		Pleistocene	*Qb* Bibra Limestone	2	Shelly calcarenite to calcirudite. ?Beach to tidal environment.	Localized marine deposit within Tamala Limestone.	
			Qd Dampier Limestone	4	Shelly, quartzose calcarenite. ?Beach to tidal environment.	Localized marine deposit within Tamala Limestone.	
			Qt Tamala Limestone	<300	Variably quartzose calcarenite. Contains landsnails, insect pupal cases. Eolian environment.	Disconformable on older rocks. Grades into *Qc, Qa, Qs, Qe*	Lithified parts mapped as *Qtl*.

TABLE 2. PHANEROZOIC STRATIGRAPHIC UNITS ON AJANA—*continued*

Age			Symbol and Rock Unit	Thickness (m)	Lithology & Depositional Environment	Stratigraphic Relationships	Remarks
CAINOZOIC	Quaternary	Pleistocene ?minor Pliocene	*Cze* Older eolianite	?15	Well-sorted, medium-grained sandstone, ubiquitous soil structures.	Disconformable on older rocks. Grades into *Qe*, *Qc*	Probably equivalent to Peron Sandstone, Shark Bay area. May be partly Pliocene.
CAINOZOIC	Quaternary	Pleistocene possibly minor Pliocene	*Cza* Older alluvium	?5	Poorly sorted, very coarse-grained sandstone, clay rich.	Disconformable on older rocks	Crops out at levels approx. 20m above present river bed. May be partly Pliocene.
CAINOZOIC	Tertiary	Pliocene to Pleistocene	*Czk* Calcrete	?10	Massive to lumpy or nodular, authigenic limestone. Forms in and on pre-existing sediments.	Disconformable on and within older rocks.	Two types: Duricrust on Toolonga Calcilutite (1-2 m thick); valley fill on eastern AJANA (?up to 10 m thick).
CAINOZOIC	Tertiary	Miocene	*Czb* Silcrete	<5	Intensely silicified, poorly sorted sandstone and conglomerate; greybilly soil deposit.	Disconformable on older rocks.	Mostly mapped as Pindilya Formation.
CAINOZOIC	Tertiary	Miocene	*Czl* Laterite	<5	Pisolitic to vermiform massive ironstone, minor ferruginized bedrock soil deposit.	Disconformable on older rocks.	Two phases recognised: Miocene-Pliocene, Pliocene-Pleistocene.
CAINOZOIC	Tertiary	Miocene	*Tp* Pindilya Formation	<10	Poorly sorted sandstone to conglomerate. Fluviatile environment.	Disconformable on older rocks	Equivalent to Victoria Plateau Sandstone, Irwin River area.
MESOZOIC	Cretaceous	Late	*Kt* Toolonga Calcilutite	26	White to pale grey-green-weathering calcilutite to calcisiltite. Marine shelf environment, no terrigenous input.	Conformable on Alinga Formation.	Type section at lat. 27°35′59″S, long. 114°13′33″E. In places mapped with Alinga Formation as *Ku*.
MESOZOIC	Cretaceous	Late	*Ka* Alinga Formation	15	Poorly sorted glauconitic claystone to sandstone. Very poorly consolidated. Marine shelf environment, low terrigenous input.	Conformable on Windalia Radiolarite or Birdrong Sandstone (Alinga Point).	Mostly mapped with Toolonga Calcilutite as *Ku*. Type section at lat. 27°42′30″S, long. 114°9′43″E.

MESOZOIC	Cretaceous	Early	*Kw* Windalia Radiolarite	24	White, yellow, red and black radiolarian siltstone. Contains belemnites. Marine shelf environment, low terrigenous input.	Comformable on Birdrong Sandstone.	In places mapped with Birdrong Sandstone as *Kl*. Thickness measured at Toolonga Point.
			Kb Birdrong Sandstone	33	Very poorly consolidated quartz sand, moderately glauconitic, well-sorted, contains fossilized wood. Shallow marine environment.	Disconformable on Kockatea Shale or Tumblagooda Sandstone.	In places mapped with Windalia Radiolarite as *Kl*.
	Early Jurassic		*Jc* Chapman Group	<10	Coarse-grained, poorly sorted sandstone, commonly heavily lateritized and/or leached. ?Fluviatile environment.	Disconformable on Precambrian in the Northampton Block area.	Identification doubtful; scattered remnants only, on Northampton Block.
	Early Triassic		*Ŧk* Kockatea Shale	<5	Well-bedded clayey siltstone, with scattered quartz grains, occasional conchostracan-bearing beds. ?Brackish environment, conchostracans washed in.	Conformable on Wittecarra Sandstone.	Discontinuous preservation and exposure along cliffs south of Red Bluff. Grouped with *Ŧw* and *Kb* on map face.
			Ŧw Wittecarra Sandstone	12.3	Pebbly, cross-bedded sandstone, grading up into coarse-grained sandstone to granule conglomerate. ?Fluviatile base, ?paralic top.	Disconformable on Tumblagooda Sandstone	Thickness measured at type section 7 km south of Red Bluff. Discontinuous deposition and preservation. Not differentiated from *Ŧk* and *Kb* on map face.
PALAEOZOIC	Early Permian	Artinskian	*Pg* High Cliff Sandstone	<20	Quartzofeldspathic arenite, coarse grained and cross-bedded, unfossiliferous, poorly preserved. ?Shallow marine environment.	Interfingers with, and conformably overlies, Holmwood Shale.	Equivalent to Moogooloo Sandstone, Carnarvon Basin. Top of unit not exposed on AJANA.
		Sakmarian	*Ph* Holmwood Shale	<60	White- to yellow-weathering unfossiliferous siltstone. Marine environment.	Conformable on Nangetty Formation.	Equivalent to Carrandibby and Callytharra Formations, Carnarvon Basin.

TABLE 2. PHANEROZOIC STRATIGRAPHIC UNITS ON AJANA—*continued*

Age			*Symbol and Rock Unit*	*Thickness (m)*	*Lithology & Depositional Environment*	*Stratigraphic Relationships*	*Remarks*
PALAEOZOIC	Early Permian	Sakmarian	*Pn* Nangetty Formation	∽500	Poorly sorted, clayey feldspathic sandstone and siltstone, tillitic siltstone and minor boulder beds. Glacigene environment, continental to ?marine.	Unconformable on Tumblagooda Sandstone or Precambrian.	Equivalent to Lyons Formation, Carnarvon Basin. Thickness estimate is unverified, much thinner near Northampton Block and over Darling Fault.
	Silurian		*St* Tumblagooda Sandstone	>2600	Varicoloured quartz and feldspathic sandstone. Rare conglomerate. Mixed shallow-marine, tidal and braided fluviatile environments, *Skolithos* and *Cruziana* ichnofacies trace fossils common in marine portions.	Base not penetrated on AJANA. Unconformable on Northampton Block to south.	Thickness is maximum drilled offshore. Palaeocurrents indicate southeasterly source. Type section is between Hardabut Anticline and Kalbarri, in Murchison River gorge.

wells. The unit consists of variably red-mottled sandstone and siltstone, and was deposited in braided fluviatile, possibly intertidal, and tidally influenced shallow-marine environments. Trace fossils from the Tumblagooda Sandstone were described by Opik (1959), but no body fossils definitely belonging to the Tumblagooda Sandstone are known from the Murchison area. The formation is dated as Silurian from microfossils found in Wandagee 1 (WINNING POOL), and by its relationship with the Upper Silurian Dirk Hartog Formation, which conformably overlies the Tumblagooda Sandstone in the Shark Bay area (Playford and others, 1975). Further details are available in Hocking (1979).

Dirk Hartog Formation: This formation has not been recognized in any oil or water wells on AJANA but may be present beneath Cretaceous sediments in the northwest corner of AJANA. It is a sequence of dolomite, anhydrite, limestone and salt which is progressively truncated southwards from Shark Bay by pre-Cretaceous erosion, and has been dated as Late Silurian from conodonts and brachiopods (Philip, 1969; Opik, in Glenister and Glenister, 1957).

PERMIAN

A lower Permian glacigene and shallow-marine sequence is poorly and discontinuously exposed on eastern AJANA. Perth Basin terminology is used for this sequence as it lies to the east of the Northampton Block and Ajana-Wandagee Ridge, and therefore within the Coolcalalaya Sub-basin of the Perth Basin as recognized by Playford and others (1976). Equivalent Carnarvon Basin terminology is shown in Table 2.

Nangetty Formation (Pn): This glacigene formation consists of continental and probably marine, poorly sorted clayey sandstone and siltstone, in part tillitic. It is of Sakmarian age, as indicated by plant microfossils (Segroves, 1969, 1970, 1971; Balme, in McWhae and others, 1958) and by comparison with the Lyons Formation of the Carnarvon Basin.

Holmwood Shale (Ph): The shale conformably overlies the Nangetty Formation, and consists of indistinctly bedded, white- to yellow-weathering, unfossiliferous siltstone, probably less than 50 to 60m thick on AJANA. It is dated as Sakmarian (Glenister and Furnish, 1961; Dickins, 1963) and is a marine deposit, transgressive on the Nangetty Formation.

High Cliff Sandstone (Pg): This formation may be present in the core of the broad syncline south of Bompas Well. Here, the Holmwood Shale grades up into, and appears to interfinger with, a coarse-grained, cross-bedded, quartzofeldspathic arenite, which is either the High Cliff Sandstone or a sandy intercalation within the Holmwood Shale. To the north, on YARINGA, the contact between these two units is disconformable, and to the south in the Irwin River area the contact is abrupt though probably conformable, so the latter possibility cannot be dismissed, although on AJANA we consider it more probable that this coarsening-upwards sequence is a transition into the High Cliff Sandstone. The High Cliff Sandstone is of probable early Artinskian age (Playford and others, 1976).

TRIASSIC

Wittecarra Sandstone and the overlying Kockatea Shale are discontinuously exposed in coastal gorges and cliffs south of Kalbarri. The lenticular distribution is due to irregularities in the unconformity surfaces bounding the Triassic sequence.

Wittecarra Sandstone: The sandstone has its type section 7 km south of Red Bluff and consists of pebbly sandstone, grading up into coarse-grained sandstone to granule conglomerate.

Kockatea Shale: The Kockatea Shale conformably overlies the Wittecarra Sandstone. It is a well-bedded clayey siltstone with scattered quartz sand grains, and occasional conchostracan-bearing beds. The two formations form a transgressive sequence of Early Triassic age, with fluviatile to paralic Wittecarra Sandstone infilling irregular topographic lows and grading up into the marine Kockatea Shale.

JURASSIC

Scattered outcrops of poorly sorted, intensely lateritized, unfossiliferous sandstone to granule conglomerate are present on the Northampton Block. These are correlated with the Chapman Group, a lower Jurassic sandy sequence which is preserved in widespread but scattered outcrops on GERALDTON. This correlation is tentative only, and the rocks may instead be a continental equivalent of the lower Winning Group or Wittecarra Sandstone.

CRETACEOUS

The Cretaceous sequence on AJANA is dominated by glaucontic and pelagic sediments, which indicate a low supply of terrigenous detritus and slow rate of deposition.

Winning Group

This group is a siliciclastic sequence which on AJANA consists, in ascending order, of the Birdrong Sandstone, Windalia Radiolarite and Alinga Formation. It was deposited in the Carnarvon Basin during a widespread Neocomian to Turonian transgression, which followed the Jurassic to Neocomian breakup of Gondwanaland.

Birdrong Sandstone (Kb): The Birdrong Sandstone consists of shallow-marine, commonly glauconitic, poorly consolidated sandstone to loose sand. It onlaps over a fairly featureless unconformity cutting across faulted, older Mesozoic and Palaeozoic sediments, and has been dated as late Neocomian to Aptian by Cookson and Eisenack (1958).

Windalia Radiolarite (Kw): The Windalia Radiolarite is a variably porcellanized, radiolarian siltstone to chert. A deep-sea depositional environment, such as is normally suggested for similar pelagic sediments, is less probable than a shallow, marine-shelf environment because of the conformable relationship of the Windalia Radiolarite with the shallow-marine Birdrong Sandstone, and its close proximity to the Cretaceous shoreline further north in the Carnarvon Basin.

Alinga Formation (Ka): The Alinga Formation is present in water bores as far north as Shark Bay, but is rarely exposed *in situ* because of landslides moving on and through it. The unit is a glauconite-rich clayey siltstone to greensand, and has its type section at Alinga Point (lat. 27°42'30" S, long. 114°9'43" E). It is a lateral equivalent of the Gearle Siltstone and therefore is of Albian to Cenomanian, or possibly Turonian, age.

Toolonga Calcilutite (Kt): The Toolonga Calcilutite disconformably overlies the Winning Group, the boundary being a depositional hiatus locally marked by a layer of phosphatic nodules. The formation consists of greenish-grey to white-weathering, slightly clayey calcilutite, and has its type section north of Yalthoo Bore, at lat. 27°35′59″ S, long. 114°13′35″ E. The formation is richly fossiliferous, and has been dated as Santonian to Campanian (Belford, 1958), extending locally into the Maastrichtian (McWhae and others, 1958).

CAINOZOIC

Pindilya Formation (Tp): The Pindilya Formation is an extensively silcreted sandstone and conglomerate of probable fluviatile origin. Original bedding and sedimentary structures have been completely destroyed by soil-forming processes.

The Pindilya Formation was previously thought to correlate with the Eocene Merlinleigh Sandstone (Konecki, Dickins and Quinlan, 1958). However, outcrops of Pindilya Formation on YARINGA appear to grade into the Miocene Lamont Sandstone, a similar unit of probable shallow-marine origin. This may be a better correlation.

Tamala Limestone (Qt): The Tamala Limestone consists of variably quartzose calcarenite, and contains insect pupal cases and land snails (Kendrick, 1978). Most of the unit is of Pleistocene age, but some deposition continued into the Holocene. The formation originated as coastal sand dunes, large parts of which are now lithified (*Qtl*) and variably calcreted. At least two generations of lithified dunes are present in the Balline Region, and a low scarp south of Wagoe Ridge farm may represent an old shoreline cliff similar to the one east of Hutt Lagoon, on GERALDTON. The unit may be over 300 m thick in the northwest of AJANA.

Two outcrops of shelly limestone, too small to show at the map scale, at the mouth of the Murchison River on the north and south banks, are probably equivalent to the Dampier and Bibra Limestones of the Shark Bay area, on the basis of their faunas. They occur about 2 m above high tide level and contain *in situ* fauna, and are localized shallow-marine equivalents of parts of the Tamala Limestone.

Mobile coastal-dune and beach deposits (*Qs*) of Holocene age are extensive south of Kalbarri, where their thickness reaches 50 m, and in smaller areas along the Zuytdorp Cliffs. These are in part derived from Tamala Limestone, and correlate with the Safety Bay Sand of the central Perth Basin.

Superficial Cainozoic deposits cover most of AJANA, and can be divided into three main groups: residual; alluvial and colluvial; and eolian deposits. Most of the eolian sand is derived from the eluvial horizon of the laterite profile, which forms a sandplain covering large areas of AJANA. Alluvial, colluvial and eolian superficial units are mapped largely on differences in morphology, vegetation and photo-pattern, rather than lithological differences.

Laterite (*Czl*) up to a few metres thick covers much of the Precambrian in eastern AJANA, and crops out discontinuously around the edges of the Northampton Block and southwestern sandplain. Silcrete is not widely developed and is grouped with the Pindilya Formation, because the respective photo-patterns of these two units are virtually indistinguishable. On eastern AJANA, there is clear lithological control on the distribution of laterite and silcrete, with the former developed on Precambrian rocks and the latter developed on Permian sediments and Pindilya Formation. The laterite and silcrete of the Victoria Plateau and surrounding the Northampton Block is probably of late Miocene to early Pliocene age, as it overlies the Miocene Pindilya Formation, but predates the calcrete of the Pillawarra Plateau and the dissection of the Northampton Block and Murchison Gorge. Laterite a few kilometres east of Meanarra Hill and at lower elevations, postdates formation of the Pillawarra Plateau and is of late Pliocene to Pleistocene age.

Calcrete (*Czk*) is extensively developed as a duricrust over the Pillawarra Plateau on the Toolonga Calcilutite, and also as valley-fill calcrete in older alluvium in eastern AJANA. Well-developed palaeodrainages in the former are truncated by the Tamala Limestone, and detrital laterite fragments are found within equivalent duricrust calcrete of the Carbla Plateau on YARINGA, thus fixing the time of calcretization as Pliocene to Early Pleistocene. The valley-fill calcrete probably formed in part from ground-water percolation, and may still be forming. Minor superficial calcrete has formed on the Tamala Limestone and is of Late Pleistocene to Holocene age.

Clayey to sandy residual soils (*Qr*) overlie much of the Northampton Block, and are derived from rocks within it.

Conglomeratic to sandy, loose to semi-indurated alluvium (*Qa*) forms extensive deposits along the major rivers and creeks. Although most of this unit is clearly of Holocene age, some parts probably extend into the Pleistocene, e.g. near Bompas Hill. Older high-level alluvium (*Cza*) crops out in breakaways some 20 m above the present-day river bed in the Meebree Well area and is possibly of Pliocene to early Pleistocene age.

Laterally, alluvium grades into colluvium, eolianite and claypan deposits. Colluvium (*Qc*), as mapped, includes slope deposits with no clearly defined drainage patterns, the floors of major palaeodrainages (which are incised in the sandplain), and areas of reworked soil and superficial deposits. Large claypans and playas (*Ql*) are mapped individually, but in much of the area it is impractical at the map scale to separate the innumerable claypans, dunes and small sandplain areas (*Qel*). The claypan and dune unit grades laterally into sandplain and dune deposits (Qe). These eolian quartz sands are reddish-brown or yellow to white, and are typical of the Carnarvon and Perth Basins respectively. Folk (1976) considered that redness of desert sands depended upon their age, and the degree of heat and moisture in the environment. The red-brown sands may owe their colour to earlier periods of lateritization in the Carnarvon Basin, and the drier, hotter climate. North and south of Kalbarri, the quartzose eolian sands grade imperceptibly into the calcareous eolianites of the Tamala Limestone.

Older eolianite (*Cze*) forms low rises on top of some breakaways on the eastern side of AJANA. It consists of moderately indurated, reddish sandstone with ubiquitous soil structures, such as root casts, and probably correlates with early Pleistocene Peron Sandstone of the Shark Bay Area.

STRUCTURE

PRECAMBRIAN

Yilgarn Block

Foliation within the gneiss and amphibolite strikes consistently west-southwest but dips either north or south at moderate angles. Mineral lineations plunge easterly at shallow angles which, considered with the foliation attitudes, suggests that the gneiss is folded about east-plunging axes. There is no obvious pattern to the foliation in the medium-grained granite.

Swarms of narrow dolerite dykes cut the gneiss in several directions.

Proterozoic sedimentary rocks

The unassigned Proterozoic sedimentary and volcanic rocks occurring at the western margin of the Yilgarn Block are folded about north-trending axes whose planes dip west. Folding is more pronounced near the Darling Fault where vertical and overturned limbs were noted. This more pronounced folding corresponds to a general increase in metamorphism and cleavage development towards the fault.

The Nilling Formation is also folded about north-trending axes, although the evidence for this is on MURGOO, to the east of AJANA.

The strike ridge of Badgeradda Group rocks at the eastern edge of the sheet is the west limb of a broad syncline with a northeasterly trending axis. Dips on the limb steepen close to the Woodrarrung Fault.

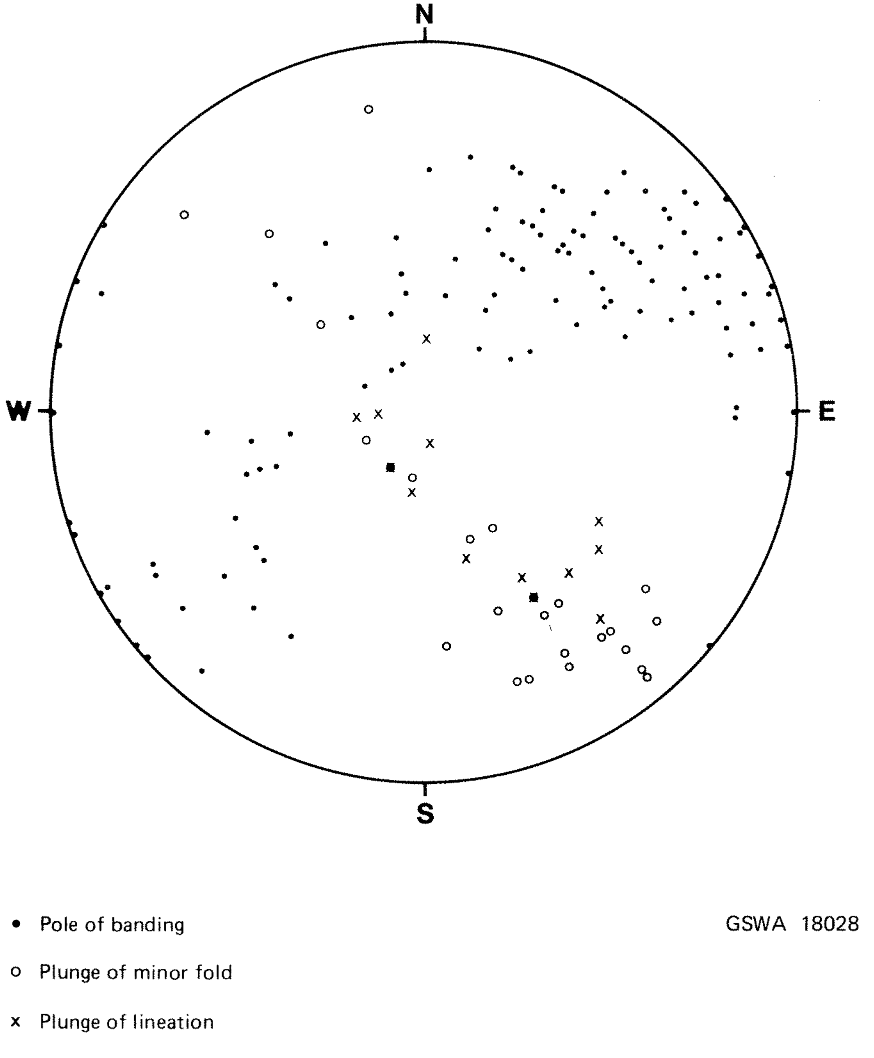


Figure 2 : Lower hemisphere stereographic projection of banding within Northampton Block rocks

Northampton Block

Banding in the gneiss and granulite of the Northampton Block strikes mainly northwest but shows many reversals of dip. Minor folds commonly plunge southeasterly at 10 to 30 degrees but some steeper plunges and north-plunging folds are present. In the bed of the Murchison River upstream from the Northwest Coastal Highway, minor folds in the quartz-feldspar gneiss indicate that the gneiss is on the east limb of an anticline and hence that the gneiss overlies the garnet granulite to the west. Lineations produced by elongated mineral grains are normally parallel to the minor fold axes, but some obvious "a" lineations are at right angles to the fold axes.

Plotted onto a stereographic projection (Fig. 2) the poles of the banding form a broad girdle compatible with folding about southeast-plunging axes. The plots of lineations and minor folds lie close to a plane striking 320 degrees and dupping 70 degrees south-west; an attitude considered to be the axial plane of the folds.

At least three directions of faults cut the Northampton Block. The best developed, and probably oldest, faults strike north-northeast and dip west. They are normal faults which have provided sites for the emplacement of numerous dolerite dykes. The north-northeast dykes are cut by northeasterly-striking tear faults with a general sinistral displacement. One of those faults is also filled with dolerite, and several dykes show minor displacement by the north-northeast faults. Development of these two sets of faults apparently overlapped in time.

The youngest fault mapped strikes east and displaces or terminates faults of the other two sets. It has a dextral displacement.

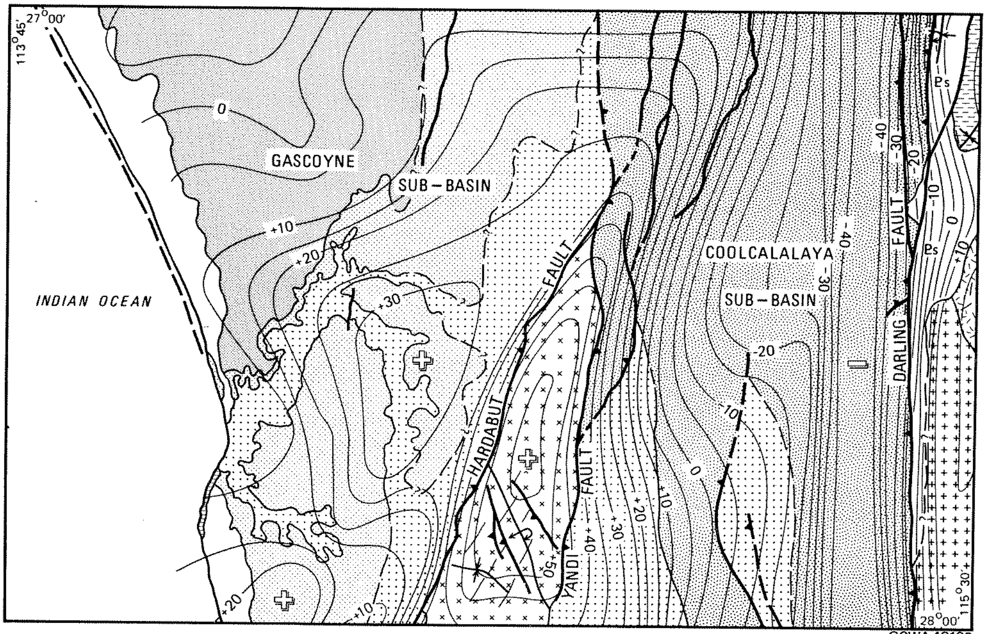
Figure 3 shows the solid geology and structural elements of AJANA. Jurassic sediments, Pindilya Formation and superficial Cainozoic sediments have been removed.

PHANEROZOIC

Parts of the Coolcalalaya and Gascoyne Sub-basins of the Perth and Carnarvon Basins respectively are present on AJANA. The former is bounded by the Yandi Fault and the Darling-Woodrarrung Fault system, and has a Palaeozoic fill possibly 3 000 m thick near the northern margin of AJANA. The Gascoyne Sub-basin is a platform of flat-lying to gently tilted rocks which is uplifted relative to the surrounding sub-basins. On AJANA it is locally downfaulted, by the Hardabut Fault, against the Northampton Block, and has a predominantly Palaeozoic fill over 3 000 m thick in the western part of the sheet area.

The major faults on AJANA are the Darling, "Hardabut", Yandi and Woodrarrung Faults. Of these, the first three are steeply dipping faults with predominantly normal movement. Perry and Dickins (1960) suggested that the Woodrarrung Fault is a high-angle reverse fault, but this has not been substantiated by recent G.S.W.A. mapping. Where the fault is exposed (e.g. Mongolia Well, BYRO), significant transcurrent movement appears to have occurred, affecting Proterozoic sediments.

The Darling Fault is poorly expressed on AJANA, although its total throw may exceed 3 000 m. South of Bompas Well, surface geology and a pronounced air photo lineament correspond well with the gravity trace of the fault (Intergeo Canada Pty Ltd, 1974). North of Bompas Well, no surface lineament is apparent, and the gravity trace extends along the scarp to the west of Billilly claypan. Permian



GSWA 18103

FIGURE 3

STRUCTURAL SKETCH MAP

AJANA SG 50-13

0 10 20 30 km

REFERENCE

- Quaternary – Tamala Limestone
- Upper Cretaceous
- Lower Cretaceous
- Cretaceous, Triassic and Silurian
- Permian
- Silurian
- Proterozoic – Badgeradda Group
- Ꝑs Proterozoic – Metamorphosed sediments (includes Nilling Formation)
- Proterozoic – Granulite and gneiss
- Archaean – Gneiss
- Archaean – Medium grained granite

- Axis of anticline; overturned
- Axis of syncline; normal; overturned
- Direction of dolerite dyke swarm
- Fault, established or probable
- possible and inferred
- Boundary, established
- inferred
- —?— approximate
- —+20— Bouguer anomaly contour
- High anomaly
- Low anomaly

sediments cross this trace without obvious disruption, implying little, if any, post-Permian movement of the Darling Fault in this area. Northeast of Bompas Well, however, Permian rocks show steep anomalous dips, are cut by numerous minor silicified faults, and only crop out west of an unnamed fault between the Darling and Woodrarrung Faults, which also bounds the metamorphosed Proterozoic sediments. This suggests that post-Permian movement was taken up by this fault and possibly also by the Woodrarrung Fault. The Hardabut Fault, as named by Johnstone and Playford (1955) and described by Playford and others (1976), is a small, low-angle thrust fault at the western boundary of the Northampton Block active in late Miocene to Pleistocene times. This fault is apparently a shallow continuation of an older unnamed steep normal fault (indicated by gravity surveys), and the Hardabut Fault is herein redefined to include this normal fault. The total normal movement on AJANA is probably about 1 000 m, as sediments immediately east of the Northampton Block are best matched with those near "The Loop", and the maximum possible throw is 2 300 m. On GERALDTON, no throw occurred on the Hardabut Fault, after deposition of the Tumblagooda Sandstone, as the formation crosses the buried fault trace without disruption of bedding, but on AJANA significant movement is thought to have occurred after deposition. The Yandi Fault has a lesser throw than the Hardabut Fault, increasing northwards, and dying out rapidly to the south. Distorted cross-bedding in the Tumblagooda Sandstone, thought to be due in part to liquefaction during earthquakes, could indicate syndepositional activity of both the Yandi and Hardabut Faults during the Silurian. However, palaeocurrents in the Tumblagooda Sandstone adjacent to the Northampton Block are not deflected around the block, and no trace of garnet from the Northampton Block garnet granulites has been found in the Tumblagooda Sandstone. This indicates that the amount of syndepositional movement on the faults in the Silurian was not sufficient to make the Northampton Block a positive topographic feature which could influence sediment dispersal, although rates of sediment accumulation on the block may have been less than in neighbouring areas.

In the late Tertiary and/or Quaternary, the thrust movement on the Hardabut Fault uplifted western AJANA and formed the Hardabut Anticline, a small anticline developed in the Tumblagooda Sandstone and centred on the Murchison River. A smaller syncline flanks the anticline to the north. The change of direction of the plane of the Hardabut Fault near here may have localized the anticline. The movement also caused the meandering lower reaches of the ancestral Murchison River to become deeply incised into the progressively rising block of Tumblagooda Sandstone west of the fault.

A fault may be present just west of the Zuytdorp Cliffs, and thus be responsible for their straightness, but no geophysical data are available to verify this hypothesis.

A north-south trending fault probably cuts the Tumblagooda Sandstone east of Mount Curious. Its magnitude and sense of movement are unknown.

Four low, indistinct scarps on the Victoria Plateau (Fig. 1) may be traces of buried faults.

PHANEROZOIC GEOLOGICAL HISTORY

Sedimentation on AJANA was intermittent during Phanerozoic time and took place in marine shelf and continental environments. Some Phanerozoic units, such as the Dirk Hartog Formation and the Byro and upper Wooramel Group equivalents, may be present but completely obscured by later sediments.

In the Silurian, deposition took place on a wide coastal plain which was intermittently submerged. The sediment source was a tectonically active predominantly granitic area to the southeast, with sediment input probably controlled by movements on the Darling Fault. In the Late Silurian, terrigenous input lessened, and an evaporitic sequence formed.

Carboniferous or Devonian sediments may have been deposited, but if so they were completely removed before the Early Permian. At that time, there was continental glaciation of the Precambrian Shield areas, and glacigene sediments were deposited throughout the Perth and Carnarvon Basins. A widespread marine transgression took place in the late Sakmarian, possibly caused by post-glacial eustatic sea level rise. Subsequent regressive deposition may reflect isostatic uplift following the melting of most of the ice sheet.

During the Sakmarian the Northampton Block was a positive topographic feature to the south and probably also on AJANA, although there is no evidence on this sheet. The block was uplifted and tilted in the Late Permian and most of the Tumblagooda Sandstone which overlaid the block, together with any Permian sediments which may have been present, were removed, and possibly redeposited to the south in the Wagina Sandstone. Following this, the sea transgressed onto the block in the Early Triassic, and deposited a south- and west-thickening veneer of Kockatea Shale. In the Jurassic, minor faulting may have continued on AJANA around the Northampton Block and along the Wandagee-Yandi Fault system, although there is no positive evidence of this. A thin veneer of Lower to Middle Jurassic sediments onlaps the block on GERALDTON, and there are a few scattered outcrops of possible Jurassic sediments on AJANA. The Jurassic sequence thickens rapidly to the south and west of the Northampton Block. It seems clear that the block must have continued to be a positive structural feature from the Permian through to the present.

By the late Neocomian, all fault movements had ceased. The continental margin foundered, sea levels rose in a major transgression, and a "post-breakup" transgressive sequence was deposited over a peneplained land surface in the west of AJANA. Emergence, erosion and planation of the landscape took place once more in Late Cretaceous-Early Tertiary, and minor but widespread fluviatile deposition occurred in the mid-Tertiary. This was followed by, or was possibly contemporaneous with, lateritization. In the Miocene, the Hardabut Fault moved as a reverse fault forming the Hardabut Anticline and uplifting part of western AJANA. Incision of the Murchison River and dissection of the planated landscape commenced. Calcretization of much of western AJANA took place in the Pliocene, followed by minor lateritization and continued dissection of the landscape, primarily in the lower reaches of the Murchison River.

Low Pleistocene sea-levels are known to have exposed wide expanses of unconsolidated marine carbonate sediments, some of which would have been eroded and transported by wind to contribute to the thick, extensive coastal dune belt which now constitutes the Tamala Limestone. Sea level rose, and some of the Tamala Limestone was removed, forming the Zuytdorp Cliffs. A second factor in the formation of the Zuytdorp Cliffs may have been activity along the postulated fault in front of the cliffs. Parts of the Tamala Limestone eroded from other areas, such as the White Cliffs on GERALDTON, probably acted as a source for much of the Holocene sand belt south of Kalbarri.

ECONOMIC GEOLOGY

LEAD, ZINC AND COPPER

Production of metallic minerals from the Northampton Block commenced in 1850, but systematic records were only begun in 1899. Since then, this mineralized area, now known as the Galena centre of the Northampton Mineral Field, has yielded ore and concentrate containing about 21 700 t of lead, 40 t of copper, 30 t of zinc and 28 kg of silver. Production before 1899 probably amounted to several thousand tonnes of lead ore and several hundred tonnes of copper ore. Since 1899, the principal mines have been the Surprise Group (15 140 t lead), the Mary Springs (2 160 t lead) and the Three Sisters Group (1 390 t lead).

The lead-zinc and copper lodes are in quartz veins and fault breccias developed mainly in the north-northeast trending faults. About one in three are on the contacts of dolerite dykes, the dolerite being older than the mineralization, which is tentatively dated at 500 m.y. (Prider, 1958). The largest mines, those of the Surprise Group, are on a northeast-striking tear fault. Local controls of mineralization are bends or offsets in the faults developed at changes of rock types. A broad regional control is exercised by the stratigraphy; the lodes are confined to the garnet-granulite units.

The principal ore minerals are galena, sphalerite, chalcopyrite, cerussite and malachite. Gangue minerals include quartz and barite. Wall-rock alteration may be pronounced. Details of production and the geology of individual deposits are given by Blockley (1971).

PETROLEUM

The Tumblagooda Sandstone has good porosity and hence hydrocarbon reservoir potential, with Mesozoic sediments as source rocks, but the unit is poorly sealed and apparently lacking in structural traps. On AJANA and elsewhere, wells which penetrated the Tumblagooda Sandstone were dry. Wells drilled for petroleum, and geophysical surveys conducted on AJANA, are shown in Tables 3 and 4.

COAL

There has been no exploration for coal on AJANA. On adjoining GERALDTON, the Irwin River Coal Measures are known only south of and along the bed of the Greenough River, and coal seams within this unit are thin and uneconomic. On GLENBURGH and BYRO, the corresponding Wooramel Group was deposited primarily in a marine environment. It was investigated by Dampier Mining Company (1973, 1976), but only minor detrital coal and thin coaly shales were found. Paralic to continental deposits, transitional between the marine Wooramel Group and the continental Irwin River Coal Measures may subcrop on AJANA beneath the Cainozoic sandplain east of the Yandi Fault. These deposits could be coal-bearing.

The Wagina Sandstone, which contains minor coal on GERALDTON, is unlikely to be present on AJANA.

URANIUM

Valley-fill clastic deposits and calcrete in eastern AJANA may be prospective for uranium, but no exploration has taken place to date.

TABLE 3. WELLS DRILLED FOR PETROLEUM ON AJANA

Name	*Year Completed*	*Type*	*Location*		*Elevation (m.a.s.l.)*	*Total Depth (m)*	*Bottomed In*	*Drilled For*	*Status*
			Lat (S)	*Long (E)*					
Edel 1 (a)	1972	NFW	27°06'46"	113°23'22"	29 (b)	2748	Silurian	Ocean	Dry, p & a
Kalbarri 1	1973	STR	27°16'00"	114°06'26"	129	1539	Silurian	COC	Dry, p & a

TABLE 4. GEOPHYSICAL SURVEYS ON AJANA

Title	*Company*	*Year*	*GSWA S File No.*
1. Bernier Marine S.S. (a)	OCEAN/END	1972	672
2. Coolcalalaya G.S.	SUNG	1973	819
3. Hyde Soak Reconnaissance S.S.	COC	1964	167
4. Murchison-Gascoyne Detailed G.S.	OPPL	1971-72	662
5. Murchison-Gascoyne Helicopter G.S.	WAPET	1970	578
6. WA-7-P Marine S.S. (a)	OPPL	1972	812

Key (both tables)—

NFW New field well

STR Stratigraphic test well

G.S. Gravity survey

S.S. Seismic survey

OCEAN Ocean Ventures Pty Ltd

END Endeavour Oil Co N.L.

COC Continental Oil Co of Australia P/L

SUNG Sunningdale Oils Pty Ltd

OPPL Oceania Petroleum Pty Ltd

WAPET West Australian Petroleum Pty Ltd

(a) Offshore, west of AJANA, all or part.

(b) Rotary table elevation

p & a plugged and abandoned.

FULLERS EARTH

Deposits of attapulgite clay, a variety of "Fullers Earth" with adsorbent properties and a wide range of uses are known from the Lake Nerramyne area. They are of apparently good quality, and development commenced in October, 1978.

MINOR MINERALS

A number of schist bands in the Northampton Block have been tested for their graphite content, but the material is below commercial grade (Simpson 1951, p. 453).

Muscovite capable of yielding blocks 200 cm^2 was mined from pegmatite veins 7 km east of AJANA (Matheson, 1944).

Small amounts of magnesite and long-fibred, silicified tremolite are associated with ultramafic rocks south of Yallalong homestead.

Phosphate occurs in the Alinga Greensand and Toolonga Calcilutite on western AJANA, as nodules and phosphatized wood near the boundary of the two units. These deposits are thin and discontinuous, and have no economic potential (Low, 1960).

CONSTRUCTION MATERIALS

Gravel for road construction and other purposes is obtained from laterite. Road metal is quarried from a dolerite dyke north of Mary Springs farm. Sand is excavated from the bed of the Murchison River, and abundant supplies (quality undetermined) are available from the Cainozoic sandplain.

Building blocks have been prepared from garnet granulite and laterite. Useful flagstones come from the Badgeradda Group.

Limestone and limesand, of undetermined quality, are available from the Tamala Limestone, and the mobile sandbelt south of Kalbarri. Seven samples of Tamala Limestone from the type section on EDEL averaged 32 per cent HCl insoluble residues, with a minimum of 9.5 per cent.

HYDROGEOLOGY

The principal Phanerozoic aquifer is the Tumblagooda Sandstone. This produces large quantities of water in nearly all the wells and bores which produce from it, and is the source of supply for Kalbarri. Salinity decreases with depth in some bores in the Kalbarri area. This is probably related to local permeability and salinity differences in the gently dipping sequence.

The Birdrong Sandstone is a well-known artesian aquifer in the central Carnarvon Basin, and in that area yields good supplies with salinity ranging from about 2 000 mg/L to 8 000 mg/L. However, in northwestern AJANA where the Birdrong Sandstone is present beneath the sandplain there are few bores or wells. Kalbarri No. 1 oil well and Long Thicket Bore, which penetrate Birdrong Sandstone, have salinities of 9 025 and 3 300 mg/L respectively; but in both there is an unknown amount of contamination from the Tumblagooda Sandstone.

Lesser aquifers are the Nangetty Formation, Windalia Radiolarite, Tamala Limestone and older alluvium and colluvium. The first produces limited supplies of variable quality, sandy intervals being the better aquifers. The Windalia Radiolarite contains generally good quality water, but yields are generally low due to poor permeability. Consolidated older colluvium and alluvium in eastern AJANA and along ancient drainage channels produce limited supplies at shallow depths with the salinity mostly less than 5 000 mg/L. Small supplies of generally low-salinity water are also obtained from the Tamala Limestone.

Weathered and fractured rocks in the Northampton Block locally form good, shallow-depth aquifers with, in places, low-salinity water suitable for domestic use. However, in most places supplies are low and the groundwater is saline. The water table is commonly less than a metre deep on the western side of the Northampton Block, but supplies are limited.

Springs and soaks occur in the Tumblagooda Sandstone (notably near Ross Graham Lookout), Birdrong Sandstone, Lamont Sandstone (on Nerren Nerren Station) and Woodrarrung Sandstone; and in the Alinga Formation and some Precambrian rocks of the Northampton Block.

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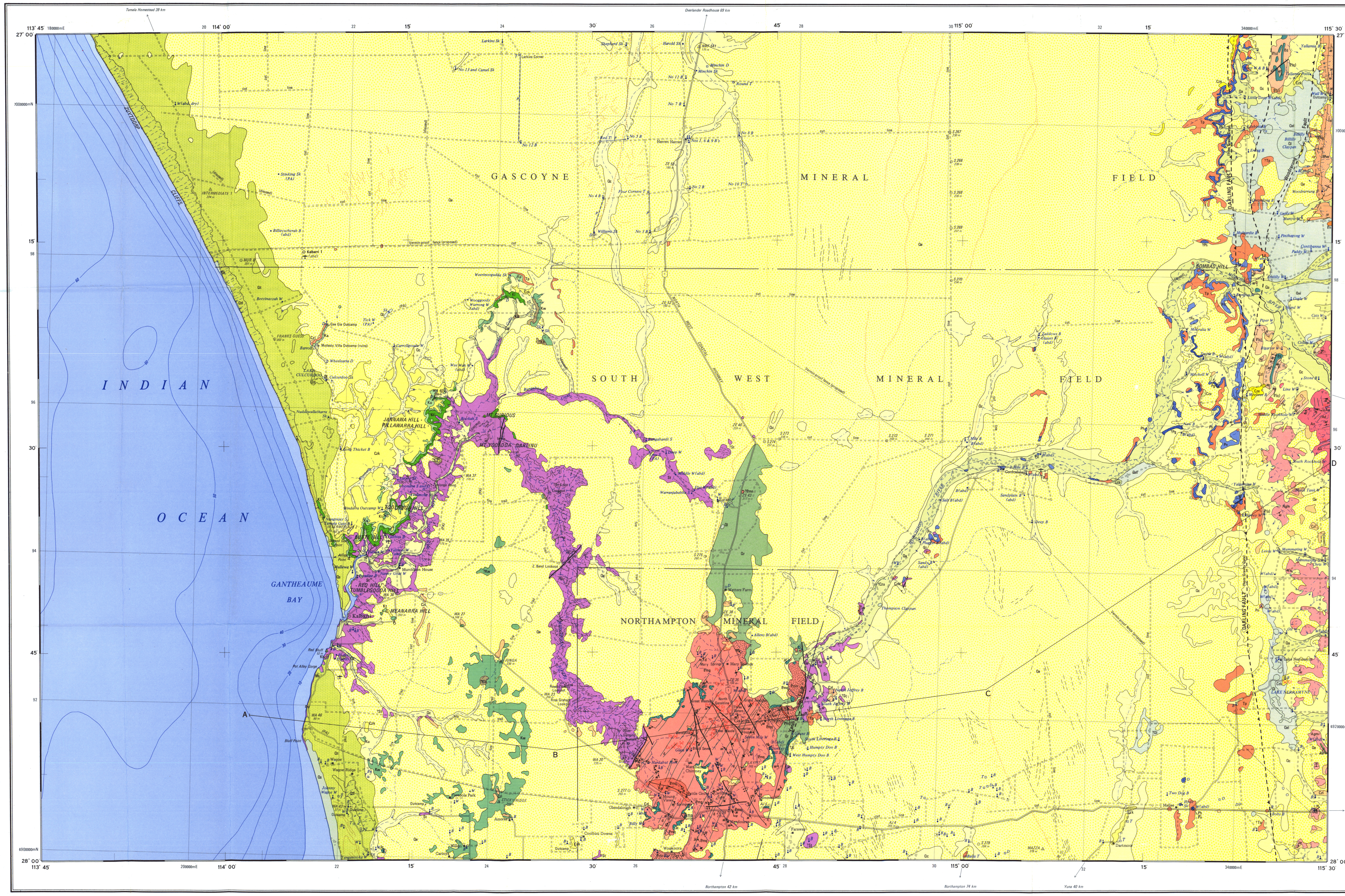
AUSTRALIA 1:250 000 GEOLOGICAL SERIES

AJANA

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

SHEET SG 50-13



SYMBOLS

Geological boundary
Fault
Accurate
Concealed
Normal
Fold
Anticline accurate, showing plunge
Anticline overturned, showing plunge
Syncline accurate, showing plunge
Syncline approximate, showing plunge
Plunge of minor fold
Bedding
Inclined
Vertical
Horizontal
Overturned
Trend
Facing, top of bed (from cross-bedding)
Palaeocurrent, from cross-bedding
Joint pattern, vertical
Cleavage
Inclined
Vertical
Foliation (metamorphic and foliated igneous rocks)
Inclined
Vertical
Plunge of lineation
Type section locality
Fossil locality
Wood fossil locality
Trace fossil locality
Air photo lineament
Reflecting underlying bedding
Uncertain origin
Petroleum exploration well
Dry hole, abandoned

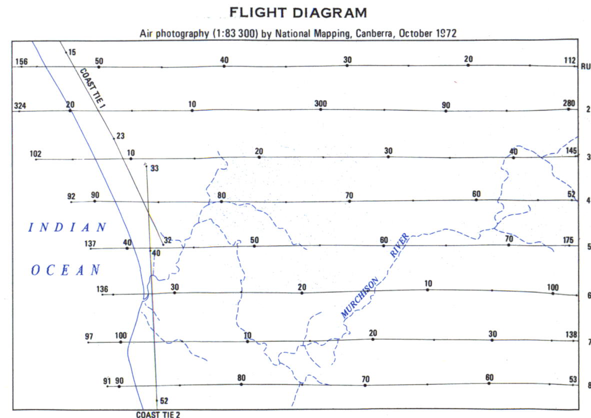
Mineral field boundary
Highway with national route marker
Formed road
Track
Townsite, gazetted (pop. less than 1000) — Kalbarri
Homestead
Building
Landing ground
Horizontal control : major, minor
Bench mark, height accurate
Breakaway
Sand dune

Watercourse, intermittent
Ancient drainage
Pipeline
Bathymetric contour line, depth in metres
Well
Bore
Windpump
Soak
Spring
Tank
Dam
Abandoned
Position approximate

Mine
Mine not being worked
Quarry
Battery abandoned
Mineral occurrence
Tremolite
Antigorite
Copper
Gravel
Graphite
Magnesite
Lead
Road metal
Zinc

FLIGHT DIAGRAM

Air photography (1:83 300) by National Mapping, Canberra, October 1972



REFERENCE

CAINOZOIC

QUATERNARY

HOLOCENE – PLEISTOCENE: Qs, Qe, Qel, Ql, Qa, Qc, Qr

Qs Beaches and mobile coastal dunes – quartzose calcarenite
Qe Eolian and residual sand – red-brown and yellow quartz sand
Qel Mound dune and playa terrain – clay, silt, sand and gravel
Ql Larger playas – poorly sorted clay, silt, sand and gravel
Qa Alluvium – clay, silt, sand and gravel, in places calcreted
Qc Colluvium – clay, silt, sand and gravel; formed by sheet flood and deflation
Qr Residual soil derived from Northampton Block – clay, silt and sand

PLEISTOCENE – EARLY HOLOCENE

Qt TAMALA LIMESTONE : calcarenite with calcrete soils; eolian
Qtl Lithified Tamala Limestone

LATE PLIOCENE – PLEISTOCENE: Czs, Cza, Czk

Czs Older eolian sand – reddish quartz sand with ubiquitous soil structures
Cza Older, high-level alluvium – poorly sorted clay, silt, sand and gravel
Czk Calcrete – lumpy, nodular and massive authigenic limestone; duricrust and valleyfill

TERTIARY

PLIOCENE – MIOCENE: Czl Laterite – pisolitic, vuggy and massive ironstone; minor ferruginized sandstone

MIOCENE: Tp PINDILYA FORMATION : poorly sorted sandstone; conglomerate; ? fluviatile; includes minor authigenic silcrete

MESOZOIC

CRETACEOUS

CAMPANIAN – SANTONIAN: Kt TOOLONGA CALCILUTITE : chalky calcilutite to calcisiltite; shallow marine

TURONIAN – CENOMANIAN: Ka ALINGA FORMATION : glauconitic clayey siltstone to greensand; shallow marine
Ku Toolonga Calcilutite and Alinga Formation undifferentiated

ALBIAN: Kw WINDALIA RADIOLARITE : radiolarian siltstone; commonly porcellanized; marine
Kb BIRDRONG SANDSTONE : well-sorted, friable sandstone; commonly glauconitic; shallow marine

APTIAN: Kl Windalia Radiolarite and Birdrong Sandstone, undifferentiated

JURASSIC: Jc CHAPMAN GROUP : poorly sorted sandstone to conglomerate; ?fluviatile;identification uncertain

CRETACEOUS AND LOWER TRIASSIC: Ms Sequence of Birdrong Sandstone, Kockatea Shale and Wittecarra Sandstone; south of Red Bluff, cliff exposure

PALAEOZOIC

PERMIAN

ARTINSKIAN: Pg HIGH CLIFF SANDSTONE : coarse-grained quartzofeldspathic sandstone; ? marine

SAKMARIAN: Ph HOLMWOOD SHALE : chalky, unfossiliferous siltstone; marine
Pn NANGETTY FORMATION : tillitic clayey siltstone and sandstone; glacigene

SILURIAN: St TUMBLAGOODA SANDSTONE : red-bed sequence; sandstone, siltstone, minor conglomerate; fluviatile,and marginal marine

CAMBRIAN

MARGINAL TO YILGARN BLOCK

NORTHAMPTON BLOCK

d Dolerite or gabbro dyke

MIDDLE–LATE PROTEROZOIC

Ꝑd Meta-dolerite sill

Badgeradda Group

ꝐAw WOODRARRUNG SANDSTONE : medium to coarse-grained sandstone
ꝐAb BILILLY FORMATION : fine-grained sandstone and siltstone

Ꝑn NILLING FORMATION : cleaved quartzose and feldspathic sandstone
Ꝑ(q) Quartz sandstone, locally quartzitic
Ꝑ(s) Siltstone (locally phyllite) with minor quartzose and feldspathic sandstone
Ꝑ(v) Silicified ? basalt

Ꝑmg, Ꝑmn, Ꝑmq, Ꝑmp — 1040 ± 50 my

Ꝑmg Garnet (- sillimanite) granulite, local quartzite, gneiss, pegmatite and graphitic schist
Ꝑmn Quartz-feldspar gneiss, local quartzite, granulite, amphibolite and schist
Ꝑmq Quartzite with associated quartz-feldspar gneiss
Ꝑmp Granitic gneiss with megacrysts

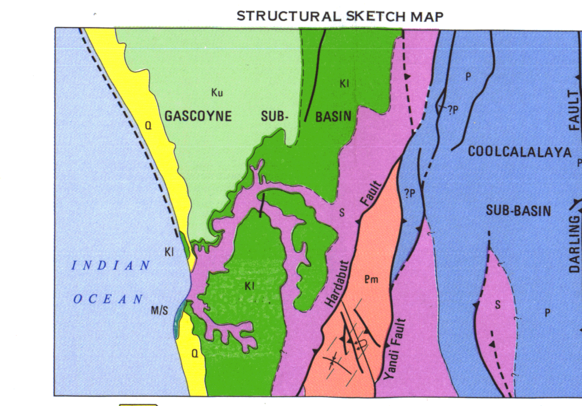
ARCHAEAN (ca 3000 my)

YILGARN BLOCK

Ad Dolerite dyke, locally metamorphosed to amphibolite
Agm Medium-grained, foliated granite

An Quartz-feldspar-mica gneiss
Aa Amphibolite
Au Ultramafic rock

STRUCTURAL SKETCH MAP



Q Quaternary – TAMALA LIMESTONE
Ku Upper Cretaceous
Kl Lower Cretaceous
Cretaceous, Triassic and Silurian
P Permian
S Silurian
Badgeradda Group
Metamorphosed sediments (includes NILLING FORMATION)
Granulite and gneiss
Gneiss
Medium-grained granite

Fault, established or probable
Fault, possible and inferred
Axis of anticline, overturned
Axis of syncline, normal
Axis of syncline, overturned
Inferred boundary
Approximate boundary
Direction of dolerite dyke swarm

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 National Mapping, Canberra, A.C.T.
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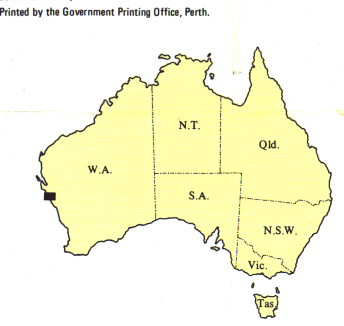
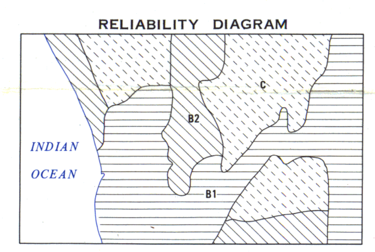


RELIABILITY DIAGRAM



B1 Numerous traverses with air photo interpretation
B2 Air photo interpretation with a few traverses
C Air photo interpretation

HON. P.V. JONES, M.L.A.
MINISTER FOR MINES
A.F. TRENDALL, DIRECTOR, GEOLOGICAL SURVEY

SCALE 1:250 000

TRANSVERSE MERCATOR PROJECTION
ZONE 50 AUSTRALIAN MAP GRID

Geology : Carnarvon Basin—R.M. Hocking, W.J.E. van de Graaff and B.P. Butcher 1977
Precambrian—J.G. Blockley 1977

INDEX TO ADJOINING SHEETS

SHARK BAY – EDEL SG 49 - 8, 12	YARINGA SG 50 - 9	BYRO SG 50 - 10
INDIAN OCEAN	AJANA SG 50 - 13	MURGOO SG 50 - 14
	GERALDTON – HOUTMAN ABROLHOS SH 50 - 1	YALGOO SH 50 - 2

DECLINATION DIAGRAM

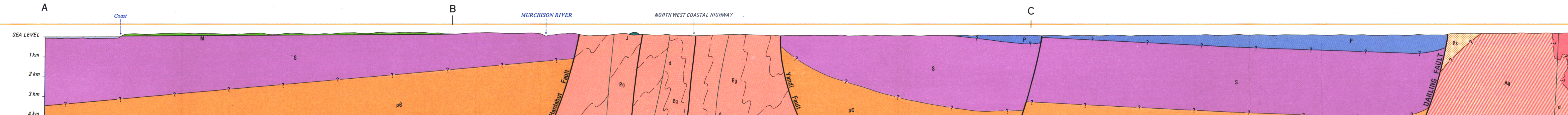
The lines indicate magnetic declination, 1980 + means declination is east and correction must be added to compass bearing to give true bearing – means declination is west and correction must be subtracted from compass bearing to give true bearing.

Annual change is – 2' westerly

DIAGRAMMATIC SECTION

SCALE $\frac{V}{H}$ = 2

SECTION A - B - C - D



M Mesozoic - Triassic and Cretaceous
J Jurassic – Chapman Group
P Permian
S Silurian – Tumblagooda Sandstone
pЄ Precambrian, undifferentiated
Ꝑg NORTHAMPTON BLOCK Granulite and gneiss
Ꝑs Metamorphosed sediments
Ag Granite
An Gneiss
d Dolerite

AJANA
SHEET SG 50 -13

FIRST EDITION 1982