GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

RECORD 1982/4

GEOLOGY OF THE WONGAN HILLS

BY S. L. LIPPLE

1982

Geological Survey of Western Australia

Record 1982/4

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SH50-10 (2236)

National Library of Australia Card No. and

ISBN 00 7244 8856 1

ABSTRACT

The Wongan Hills Belt is a sequence of deformed and metamorphosed Archaean sedimentary rocks intercalated with mafic and felsic volcanic rocks. It occupies a critical position between extensive Archaean greenstone belts of the Murchison Province to the north and the Western Gneiss Terrain (including the Jimperding Metamorphic Belt) along the western margin of the Yilgarn Block. There is consensus that the Wongan Hills Belt is similar to the greenstone belts of the Murchison area, but similarities to the Jimperding Metamorphic Belt (regarded by many authors as being older than the greenstones), such as those at Bolgart, 40 km to the southwest, have not been previously highlighted. The Wongan Hills Belt may thus preserve an intermediate stage of development between the low-grade regional metamorphism (greenschist to low amphibolite facies) of the extensive Archaean greenstone belts, which have open concentric to similar style folding and high-grade metamorphism (amphibolite to granulite facies) of the Jimperding Metamorphic Belt, which has tight to isoclinal style folding. At least some of the earlier metamorphic events recorded in the Jimperding Metamorphic Belt appear to have also been imposed on the Wongan Hills Belt. Geochronology and further petrological studies may clarify the relationship of this strategically preserved belt to the belts of adjoining terrains.

Mineral exploration in the Wongan Hills Belt has located chalcopyrite mineralization within high-grade pelitic and ?volcanogenic metasedimentary rocks. The small gold production was derived from small quartz veins in mafic volcanic rocks. Thick residual laterite deposits were unsuccessfully prospected for bauxite.

Mineral exploration in the Wongan Hills has in recent years aroused some environmental concern, as the hills are an important refuge for native fauna and flora.

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S. L. LIPPLE

INTRODUCTION

The Wongan Hills Belt is 150 km northeast of Perth (Fig. 1), near the eastern margin of the Western Gneiss Terrain (Gee and others, 1980). It strikes north, is 28 km long, and narrows from 10 km at Lake Ninan in the south to 1 km at Little Wogan Hill in the north. The township of Wongan Hills is situated several kilometres to the east of the belt.

The first geological report on Wongan Hills was by Brown (1872) who commented on the north-striking, vertically dipping metamorphic schists, and correlated these (Brown, 1871; 1872; 1873) with similar rocks at Tallering Peak ("Nancarrong") and Koolanooka Hills ("Blue Mountains"). In late 1888, gold was reported from Wongan Hills, and events leading to the discovery were recounted by Fraser (1906). A subsequent visit and brief description of the geology is recorded by Woodward (1895). A more extensive account is that of Maitland (1899; 1900), who referred to metamorphic rocks and copper-bearing quartz reefs. There was no further reference in the literature to this greenstone belt until Williams (1975), in a general summary of metamorphic rocks of the Southwest Province, referred to mafic igneous rocks, banded iron-formation, pelitic schists, and ultramafic intrusions at Wongan Hills; and noted their similarity to rocks of the Jimperding Metamorphic Belt. Carter and others (1979) reported on regional mapping (at 1:250 000 scale) completed in 1975. Results from more detailed mapping undertaken at that time provide the basis for

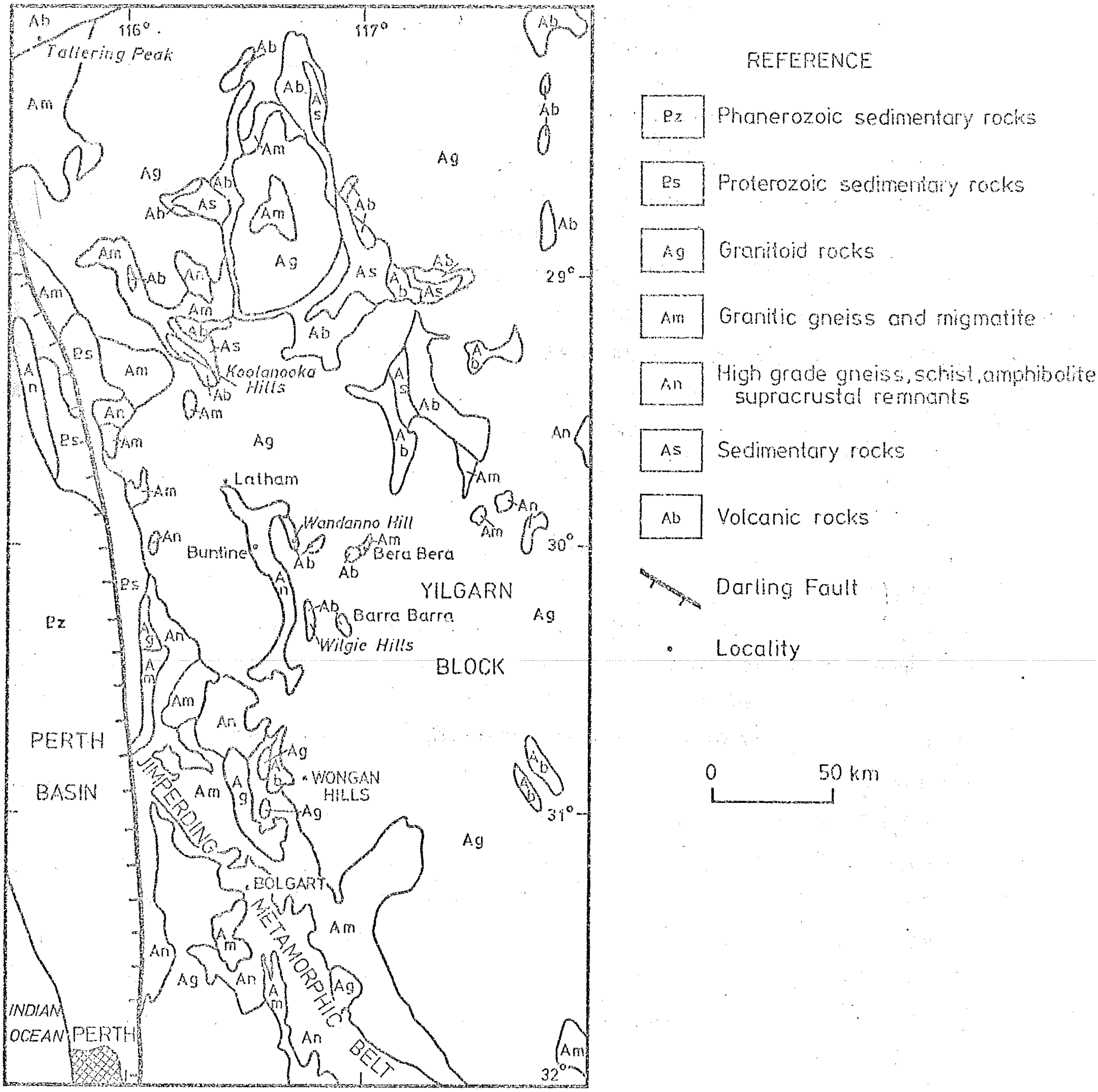

Figure 1: Regional geological setting of the Wongan Hills

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this description. Additional reports also derived from material obtained during this mapping include those by Blight (1978; 1979).

Prospecting for bauxite, including drilling, was undertaken during the late 1960s by Vam Limited, but there were no encouraging results.

Wongan Hills was reported on by the Conservation Through Reserves Committee (1974) under Item 1 of System 4, where the hills are described as "an island of bush surrounded by agriculture". A number of recommendations were made which were endorsed in principle by Government in 1976.

GENERAL GEOLOGY

The Wongan Hills Belt is a comparatively well-exposed tract of Archaean greenstone rocks (Plate 1) which are analogous to some amphibolite-bearing sequences within the Jimperding Metamorphic Belt (Wilde, 1974) and within Archaean greenstone sequences further north (Baxter and Lipple, 1979; Lipple and others, 1980). Exposures are sparse but relatively unweathered, and consist of metamorphosed mafic and felsic volcanic rocks and metasedimentary rocks, principally chert and banded iron-formation. Subordinate quartz-mica-garnet-sillimanite schist, quartz-feldspar gneiss, cordierite rock, and small ultramafic intrusions are also present. The belt is bounded by Archaean migmatite and gneiss, and is intruded by even-grained and porphyritic granitoids.

STRUCTURE

The structure is complex: a triaxial distribution of the sequences is the main structural element (Plate 2). Synforms (overturned to the east) extend north through Mount Rupert, and southwest through Ochre Hill. The Elphin Hills contain several tight, northwest-plunging antiforms and synforms. Structure and lithologies of the three branches are continuous along the periphery of the belt, but their junction is intruded by adamellite west of Elphin Siding. Some later open folding, which may account for the present distribution of the earlier tight folds is suggested at several localities. Faulting is common, and trends mainly northwest; displacements are dextral near Ochre Hill and sinistral at Elphin Hills. Further north, both senses of displacement have been noted. Dolerite dykes of presumed Proterozoic age intrude faults and north-east-trending fractures.

ARCHAEAN ROCKS

Banded iron-formation and chert

Metamorphosed banded iron-formation and chert are widespread and outline the regional structure. Their mineralogy is quartz, magnetite, (grunerite), and subordinate muscovite, chlorite, carbonate, and pyrite. They typically show both grain-size and compositional layering. Relicts of (apparent) graded bedding and cross-bedding are preserved locally. "Ripples" and "pinch-and-swell" features, most of which are of tectonic origin and parallel to a related mineral lineation, have been noted; however, some are unrelated to minor folds, are crossed by the lineation, and are considered to have a sedimentary origin.

Laminated, grunerite-rich amphibolite associated with the banded iron-formation commonly grades into both massive green amphibolite and into banded iron-formation.

Manganiferous and ferruginous gossans are commonly associated with banded iron-formation in the Elphin Hills. Analyses of some gossans are given in Table 1.

Metasedimentary rocks

These rocks range from psammitic to pelitic and occasionally to calc-silicates, and, although metamorphosed, commonly show relict sedimentary structures, which include bedding, graded bedding, and, more rarely, features resembling cross-bedding and micro-scours. Commonly they have a prominent foliation and lineation, which is parallel or subparallel to bedding.

Typical assemblages are:

(a) for psammitic rocks - quartz, plagioclase, biotite, opaques, (K-feldspar), (muscovite), (tourmaline), (sphene), and secondary epidote and chlorite;

(b) for calc-silicate rocks - quartz, hornblende, plagioclase, (oligoclase to andesine), opaques, and subordinate secondary chlorite, epidote and sericite; and

(c) for pelitic rocks - microcline, quartz, fibrolite, muscovite, andalusite, biotite, (garnet), subordinate tourmaline and opaques; or - cordierite, garnet, quartz, biotite, opaques, and spinel.

Similar assemblages in drill-core specimens from the southern end of the Wongan Hills have been described by Godkin (1976).

The unusual assemblage, cordierite, cummingtonite, (tremolite), and minor amounts of quartz, biotite, opaques, garnet and spinel, was noted at a few localities between Little Wongan Hills and Bald Hill. These rocks may be massive or schistose and occur in layers up to 5 m thick within meta-psammitic rocks, characteristically near boundaries of mafic meta-igneous rocks. The unusual chemistry, manifested by the modal assemblage of these rocks, may be the result of non-isochemical metamorphism; or, alternatively, the original rock may have been of unusual composition, possibly having both a tuffaceous and sedimentary component.

It appears from mapping that psammitic rocks are more abundant in the northern areas, whereas pelitic assemblages are more common in the south. The calc-silicate rocks are, flaggy, laminated, and foliated in outcrop. They appear to be confined to a northerly trending belt near Mount Rupert.

Mafic meta-igneous rocks

Mafic igneous rocks are a major component of the belt and occur principally along the western margin of the hills. They are particularly well exposed near Mount Rupert, and commonly contain relict textures that enable the original identity of the rock to be determined. These relict textures include pillows, vesicles, and varioles in metabasalts, and chilled margins and sub-ophitic textures in metadolerites. Near Ochre Hill, a coarse pyroclastic fabric is preserved. The mineral assemblage seen in these rocks is: hornblende, plagioclase, opaques, minor amounts of sphene, biotite, and quartz; and secondary epidote and sericite.

Felsic metavolcanic rocks

Foliated and lineated felsic volcanic rocks, predominantly of metadacite, occur in well-exposed sequences near Bald Hill and Ochre Hill. They display the assemblage quartz, plagioclase, hornblende (phenocrysts), biotite, sphene, opaques, and some secondary epidote and chlorite. Tuffaceous and agglomeratic metadacites are represented by quartz-muscovite rocks, with poorly preserved pyroclastic textures.

Quartzo-feldspathic gneiss

Thin bodies of leucocratic, fine-grained quartzo-feldspathic gneiss are scattered throughout the southern region. They have the modal assemblage, quartz, plagioclase, perthitic microcline (biotite), (muscovite), minor amounts of opaques and a trace of secondary epidote.

Other Archaean rocks

Subordinate ultramafic rocks include thin tremolite dykes that occur near Mount Rupert and west of Bald Hill, and small sill-like bodies of serpentinite and hornblendite in the Elphin Hills. Fine-grained, dark-green amphibolite of uncertain origin, but probably including metasedimentary and volcanogenic components is of small extent. Several muscovite-bearing quartzites occur near the margins of the greenstone belt. They resemble the green muscovite quartzites that are notable in the Jimperding Metamorphic Belt (Wilde, 1974; Carter and others, 1979). Several varieties of both porphyritic and equigranular granitoid rocks border and intrude the belt.

CAINOZOIC DEPOSITS

Of the superficial deposits, indurated pisolitic and nodular laterites are the most common. These form an extensive, gently dipping cover over the Wongan Hills, capping mesas in elevated areas. The laterite profile, together with underlying pallid- and mottled-zone clays, is up to 20 m thick. Downslope from the laterite capping are deposits of colluvial pisolitic gravel which are utilized for road aggregate. Elsewhere, superficial deposits are alluvium, saline lacustrine deposits with adjacent eolian sands, and colluvial debris and sand (Plate 1).

METAMORPHISM

The mineral assemblages are characteristic of the cordierite-amphibolite facies of low-pressure Abukuma-type metamorphism (Winkler, 1975). A weak and sporadic greenschist facies retrogression has affected the rocks of the Wongan

Hills and is responsible for the development of secondary minerals such as chlorite (after biotite), and epidote and sericite (after plagioclase).

Fibrolite, andalusite and fayalite are restricted to the Lake Ninan area. The northern limit of common almandine development appears to be a boundary extending northeast through Ochre Hill (Plate 2). This boundary may be partly controlled by the chemical composition of the rocks, for pelitic assemblages are more abundant in the southern regions. Maitland (1900) reported isolated occurrences of garnet in quartz veins near Mount Matilda and Little Wongan Hill, well north of this boundary. However, the same rock units that exhibit coarse garnet idioblasts in the south, strike northwards across the boundary towards Mount Matilda (Plate 2). indicating that a genuine mineral isograd exists. The presence of cordierite in some schist bands throughout the belt, and the presence of andalusite and fibrolite in the southern portion, indicate that low-pressure conditions of metamorphism prevailed.

Blight (1979) confirmed from the TiO_2 content of hornblende that the metamorphic grade in Wongan Hills increases southward, principally because of temperature increase. Plots of hexavalent aluminium versus silicon show that metamorphic pressures were low (less than 500 MPa), and, although variable between samples in close proximity, suggested only a slight average increase southward. The ratio of hexavalent aluminium to "edenitic" (sodium plus potassium) alkalis decreases with increasing metamorphic grade. Plots of this ratio in nine analysed hornblendes also suggest a trend of increasing metamorphic grade (i.e. temperature) southward. Previously, Blight (1978) demonstrated in a study of drill-core samples of pelitic schist (from Otter Exploration DDH 3 at $30^{\circ}53'19''$S and $116^{\circ}38'25''$E) near Lake Ninan, that these rocks were metamorphosed under estimated pressure-temperature conditions of

140 to 240 MPa and 640–680 °C, and concluded that this implied a high (70 °C/km) geothermal gradient. This finding is consistent with the conclusion that a temperature-controlled metamorphic gradient exists within the belt and that high-grade rocks near Lake Ninan pass to medium-grade rocks in the north.

Formation of the high-grade metamorphic rocks in the Wongan Hills Belt by contact metamorphism adjacent to granitoid intrusions is not favoured. Apart from local effects marginal to contacts, metamorphic facies are independent of the distribution of granitoids, as indicated by the grade being lowest in the north where the greenstone belt is most attenuated and greatest in the south, corresponding with thickest preservation of the belt. Similarly, Wilde (1974, Fig. 1) shows that zones of metamorphic facies are truncated by granitoid intrusions, rather than being concentric around them. It is considered that the metamorphic facies at Wongan Hills result from regional metamorphism.

ECONOMIC GEOLOGY

Mineral production from the Wongan Hills comprises about 250 g of gold obtained from about 84 t of ore. There are also early unconfirmed reports of copper mining. In recent years, the bauxite and base-metal potential of the hills has been examined by various companies, but no commercial deposits have been announced.

GOLD

Gold was first recorded in 1888 (Fraser, 1906), when a small parcel of about 2 t, which was taken from Paynes shaft at Little Wongan Hill, yielded 29 g/t. A further 82 t of ore from the same quartz reef was treated at Paynes Find in 1936 to yield 190.35 g of gold.

The quartz veins near Mount Matilda and Little Wongan Hill are described by Woodward (1895) and Maitland (1899; 1900). The veins are small (up to 2 m wide), lenticular, and have sharp contacts. They generally strike north, parallel to the foliation of the enclosing rock, and dip moderately to steeply west. Most veins consist of white sugary quartz, minor amounts of hematite and limonite, small lenses of altered actinolite, pyrite and garnet. At Little Wongan Hill, the quartz has a glassy appearance. A few large kernels consisting of azurite, malachite, and copper oxide, are present in veins near Mount Matilda. Iron oxides are disseminated through the quartz as irregular grains and veinlets. Different portions of the quartz veins assayed up to 1.5 g/t of gold and 8 to 16% copper; the highest values were returned from the most ferruginous parts. Visible gold was reported by Woodward (1895) in both the quartz vein and the adjoining country rock, but this observation was not confirmed by Maitland (1899; 1900).

COPPER

Several small shafts, up to 10 m deep, reputedly worked for both gold and copper prior to 1898, are shown on Plate 1. Although interest recurred in 1914, no production is recorded.

Exploration for copper mineralization was undertaken by Otter Exploration NL in 1975 (Blackburn, 1975), and by Otter in partnership with Aquitaine (Australia) Minerals Pty Ltd in 1976-77 (Roberts, 1977), and with the Shell Company of Australia Ltd since 1978 (Lee, 1979). Accounts of the prospect are contained in Otter Exploration's Annual Report for 1975, in confidential statutory reports to the Department of Mines, and in Marston (1979). Investigations included percussion and diamond drilling, ground and detailed aeromagnetic surveys, electromagnetic surveys, base-metal analyses of drill, gossan and soil samples, and geological mapping.

Lake Ninan north

The main prospect is located 1.5 km northwest of Lake Ninan on Melbourne Location 2070. Massive hematite gossan (after magnetite), and porous, largely exotic, limonitic gossan (after sulphide) occurs in poorly exposed, ferruginous, weathered, garnet-mica-fibrolite schists. The gossans form a north-trending ridge (350 m long and 25 to 75 m wide), parallel to the pronounced north to north-northwest-plunging (20-40°) lineation of the enclosing schists. The gossans show the foliation and strong lineation noted in the schists. Layering in the gossans at the northern end dips north-northwest and west.

The prospect has been tested by thirteen inclined diamond drillholes (totalling 2 235 m) and 10 percussion drillholes most of which were sited west and north of the gossan ridge. This drilling indicates that the surface gossans do not persist at shallow depth below the ridge and revealed a weakly but variably mineralized zone, about 140 m wide, which averages less than 0.5% chalcopyrite, 1% magnetite, and contains traces of arsenopyrite. Lead, zinc, silver and gold assays are very low. Within this zone, an intersection (9.8 m drilled width DDH 4) of concealed mineralization assayed 0.66% copper and 7.5 g/t of silver. This intersection included two one-metre bands assaying respectively 1.26% copper, 23 g/t silver, and 23 g/t gold; and 1.75% copper, 16 g/t silver, and 19 g/t gold. The mineralization is interpreted to occur at the core of a faulted, moderately (20-40°) north-northwest-plunging antiform with reported dips of 50-60° on the fold limbs. The lack of depth persistence of mineralization could be ascribed (Marston, 1979) to the mineralized layers being folded and rodded, and plunging to the north-northwest as suggested by the surface structure.

The zone of oxidation extends to about 120 m below the surface, and copper minerals in this zone include native copper, malachite, cuprite and chalcocite. The primary mineralized assemblage contains up to 20% by volume chalcopyrite in veinlets and disseminations. These are mostly concentrated in numerous thin (generally less than 15 cm) bands of almandine variously with or lacking fibrolite, magnetite, and biotite. The bands assay 1.5 to 3.5% copper. Subordinate arsenopyrite, cubanite, cobaltiferous pyrite and marcasite are also present. The adjoining rock has only accessory chalcopyrite and generally contains less than 0.3% copper. Identification, using X-ray diffraction, of lollingite, cubanite and marcasite represents a newly reported location for these minerals (Godkin, 1976).

The enclosing schist seen in drill core is highly aluminous. Petrological descriptions of the assemblages are given by Godkin (1976) and Blight (1978). These consist of various associations and varying relative abundances of almandine, quartz, biotite, muscovite, chlorite, microcline, fibrolite and magnetite. The schist locally contains iron-rich (fayalite, grunerite) layers. Almandine and magnetite seem to be preferentially associated with the sulphides. Tourmaline is locally abundant and may indicate a sedimentary origin for some units. Textures include a heterogeneous lensoid appearance, (interpreted by the prospecting companies to represent relict pyroclastic texture) and dendritic features in addition to normal schistosity. Thin, late- or post-tectonic pegmatite and granitoid veins cut the schists.

<u>Bald Hill - Elphin Hills</u>

Near Bald Hill, percussion and core drilling of gossans in garnet-mica(-andalusite) schists, which were anomalously high in lead and zinc, intersected only traces of mineralization. In the Elphin Hills, gossans examined within banded iron-formation and garnet-mica schists are interpreted as forming from massive, banded and disseminated pyrite and/or pyrrhotite, which is commonly associated with banded magnetite and traces of base-metal sulphides. Analyses of gossans sampled during mapping for this report are presented in Table 1.

BAUXITE

Bauxite investigations were conducted by Vam Limited in the late 1960s, when approximately 180 shallow boreholes were sunk in laterite cappings. Of these, some 160 holes failed to return an available alumina content of more than 25% and in only seven holes were alumina grades between 30 and 35% recorded. Best results were from just east of Mount Matilda where nine holes outlined a continuous zone about 1 800 m long which averaged 370 m wide and contained 25-35% available alumina. Bottom samples were analysed for copper, lead, zinc, cobalt, chromium, nickel, and silver. High cobalt, nickel and chromium in eight samples obtained 1-2 km southwest from Elphin Siding indicate probable derivation from underlying ultramafic rocks. Other results were not significant. The prospect was relinquished.

REGIONAL SIGNIFICANCE OF THE WONGAN HILLS BELT

The relationship of the Wongan Hills Belt to the greenstone belts (e.g. Ninghan Fold Belt) lying to the north, and the Jimperding Metamorphic Belt to the west and south is not readily established. The rocks of the Wongan Hills Greenstone Belt resemble those forming the typical greenstone belts of the Murchison region, but have a metamorphic grade closer to that found in rocks of the Jimperding Metamorphic Belt. Their position between the two terrains (Fig. 1) raises the possibility that there may have once existed a connection between low-grade greenstone assemblages in the Murchison and the high-grade metamorphic rocks of the Jimperding Metamorphic Belt, i.e. that the latter represent highly metamorphosed greenstones or their chrono-stratigraphic equivalents.

TABLE 1 GOSSAN ANALYSES

G.S.W.A. NO.	29681	29685	29686	29687	29688R	29688Y
Latitude(S)	30°54'49"	30°56'16"	30°56'16"	30°56'10"	30°56'22"	30°55'22"
Longitude(E)	116°36'45"	116°38'22	116°38'26"	116°38'15"	116°38'23"	116°38'23"
DESCRIPTION	Gossanous BIF	Gsn.next to BIF	Gossanous BIF	Gsn(?) ass.with BIF & gn amph	Gsn.ass.with meta siltstone	Gsn(?)over mafic shst.
ELEMENT (ppm)						
Antimony, Sb	<30	<30	<30	<30	<30	<30
Arsenic, As	1050	750	280	15	20	15
Barium, Ba	400	700	500	500	700	500
Bismuth, Bi	<20	<20	<20	<20	<20	20
Cadmium, Cd	<20	<20	<20	<20	<20	<20
Cerium, Ce	30	30	20	20	25	<20
Chromium, Cr	120	120	40	300	200	60
Cobalt, Co	<10	<10	140	140	85	140
Copper, Cu	95	100	100	80	310	200
Gallium, Ga	<10	15	20	20	15	20
Germanium, Ge	<10	<10	<10	<10	<10	<10
Lanthanum, La	<20	30	20	20	20	<20
Lead, Pb	50	<20	<20	20	20	20
Manganese, Mn	25	28	700	2500	5200	5000
Mercury, Hg	<20	<20	<20	<20	<20	<20
Molybdenum, Mo	<10	<10	<10	<10	<10	<10
Nickel, Ni	30	60	240	280	130	130
Rubidium, Rb	<10	<10	<10	<10	<10	<10
Scandium, Sc	25	50	<10	20	35	65
Silver, Ag	<10	<10	<10	<10	30	<10
Strontium, Sr	<10	<10	<10	<10	40	<10
Tellurium, Te	<20	<20	<20	<20	<20	<20
Thorium, Th	30	<20	20	60	50	40
Tin, Sn	<10	<10	<10	<10	<10	<10
Titanium, Ti	700	350	<100	900	1700	890
Tungsten, W	<20	<20	<20	<20	<20	<20
Vanadium, V	65	160	70	200	750	200
Yttrium, Y	15	10	15	40	25	10
Zinc, Zn	<20	<20	240	320	240	300
Zirconium, Zr	95	<10	20	15	35	<10
Gold, Au	< 0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Table 1 - cont'd

G.S.W.A. NO.	29690C	29690D	29690E	29690F	296690G	29691A
Latitude (S)	30°53'03"	30°53'03"	30°53'03"	30°53'03"	30°53'03"	30°55'09"
Longitude (E)	116°39'15"	116°39'15"	116°39'15"	116°39'15"	116°39'15"	116°37'57"
DESCRIPTION	Banded magnetite rock		Haem gsn in gn mica shst	Chl.sample acrs. gossaneous shst.	Haem gsn.in gn mica shst.	Gsn.next to BIF &gn.amph shst
ELEMENT (ppm)						
Antimony, Sb	<30	<30	<30	<30	<30	<30
Arsenic, As	620	50	950	55	220	65
Barium, Ba	500	500	500	400	500	600
Bismuth, Bi	<20	<20	<20	<20	<20	20
Cadmium, Cd	<20	<20	<20	<20	<20	<20
Cerium, Ce	20	20	20	20	20	20
Chromium, Cr	25	60	70	40	50	130
Cobalt, Co	10	<10	65	45	90	60
Copper, Cu	170	120	400	260	350	130
Gallium, Ga	25	20	20	20	25	20
Germanium, Ge	<10	<10	<10	<10	<10	<10
Lanthanum, La	20	20	20	20	20	20
Lead, Pb	30	<20	<20	<20	50	<20
Manganese, Mn	9000	12500	6500	2300	750	2200
Mercury, Hg	<20	<20	<20	<20	<20	<20
Molybdenum, Mo	<10	<10	190	<10	<10	<10
Nickel, Ni	90	260	90	80	80	110
Rubidium, Rb	<10	<10	<10	<10	<10	<10
Scandium, Sc	30	10	10	15	15	20
Silver, Ag	<10	<10	<10	<10	<10	<10
Strontium, Sr	<10	<10	<10	<10	<10	<10
Tellurium, Te	<20	<20	<20	<20	<20	<20
Thorium, Th	35	30	70	20	20	45
Tin, Sn	<10	<10	<10	<10	<10	<10
Titanium, Ti	<100	170	100	110	720	740
Tungsten, W	25	<20	<20	<20	30	<20
Vanadium, V	55	80	70	80	160	270
Yttrium, Y	150	60	70	15	30	10
Zinc, Zn	30	45	60	40	20	85
Zirconium, Zr	15	30	90	160	40	<10
Gold, Au	<0.2	0.2	<0.2	0.2	<0.2	<0.2

Table 1 - cont'd

G.S.W.A. NO.	29691B	29691C	29692	29693A	29693B	29694
Latitude (S)	30°55'09"	30°55'09"	30°55'15"	30°55'04"	30°55'04"	30°53'22"
Longitude (E)	116°37'57"	116°37'57"	116°37'56"	116°38'02"	116°38'02"	116°40'42"
DESCRIPTION	Gossanous material next to BIF in gn. amph. shst.		Gsns. BIF in gn.amph.shst.	Gossan in garnet amphibole schist		Gossanous amph.shst.
ELEMENT (ppm)						
Antimony, Sb	<30	<30	<30	<30	<30	<30
Arsenic, As	85	70	45	15	10	60
Barium, Ba	400	400	500	600	700	500
Bismuth, Bi	20	<20	<20	<20	<20	<20
Cadmium, Cd	<20	<20	<20	<20	<20	<20
Cerium, Ce	20	20	20	20	30	30
Chromium, Cr	50	40	40	120	140	70
Cobalt, Co	110	200	130	240	140	<10
Copper, Cu	140	110	75	240	190	4000
Gallium, Ga	25	20	25	20	25	20
Germanium, Ge	<10	<10	<10	<10	<10	<10
Lanthanum, La	20	20	20	20	20	20
Lead, Pb	30	25	30	<20	30	<20
Manganese, Mn	500	500	3400	2000	4300	70
Mercury, Hg	<20	<20	<20	<20	<20	<20
Molybdenum, Mo	<10	<10	<10	<10	<10	<10
Nickel, Ni	120	130	170	220	220	85
Rubidium, Rb	<10	<10	<10	<10	<10	<10
Scandium, Sc	15	10	10	50	55	10
Silver, Ag	<10	<10	<10	<10	<10	<10
Strontium, Sr	<10	<10	<10	15	<10	<10
Tellurium, Te	<20	<20	<20	<20	<20	<20
Thorium, Th	60	20	<20	40	40	20
Tin, Sn	<10	<10	<10	<10	<10	<10
Titanium, Ti	320	100	170	220	330	1600
Tungsten, W	<20	<20	<20	<20	<20	30
Vanadium, V	140	130	200	220	210	270
Yttrium, Y	20	20	40	120	160	30
Zinc, Zn	55	100	150	360	320	65
Zirconium, Zr	20	60	60	15	10	55
Gold, Au	< 0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Table 1 - cont'd

G.S.W.A. NO.	29695	29696	29697A	29697B
Latitude (S)	30°55'36"	30°55'48"	30°55'19"	30°55'19"
Longitude (E)	116°38'21	116°38'30"	116°37'53"	116°37'53"
DESCRIPTION	Gossanous BIF	Gossanous BIF	Gossan associated with serpentinite & gn-trem.shst.	
ELEMENT (ppm)				
Antimony, Sb	<30	<30	<30	<30
Arsenic, As	55	45	10	10
Barium, Ba	600	400	800	1000
Bismuth, Bi	<20	<20	<20	20
Cadmium, Cd	<20	<20	<20	<20
Cerium, Ce	20	20	20	20
Chromium, Cr	250	200	180	120
Cobalt, Co	<10	130	180	200
Copper, Cu	180	170	100	120
Gallium, Ga	25	25	20	20
Germanium, Ge	<10	<10	<10	<10
Lanthanum, La	20	20	<20	<20
Lead, Pb	170	25	30	<20
Manganese, Mn	100	120	6400	6000
Mercury, Hg	<20	<20	<20	<20
Molybdenum, Mo	<10	<10	<10	<10
Nickel, Ni	70	110	320	380
Rubidium, Rb	<10	<10	<10	<10
Scandium, Sc	20	35	15	10
Silver, Ag	<10	<10	<10	<10
Strontium, Sr	20	<10	150	170
Tellurium, Te	<20	<20	<20	<20
Thorium, Th	70	45	<20	45
Tin, Sn	<10	<10	<10	<10
Titanium, Ti	7600	170	1000	600
Tungsten, W	<20	<20	<20	<20
Vanadium, V	1200	220	850	630
Yttrium, Y	10	<10	40	25
Zinc, Zn	50	95	580	650
Zirconium, Zr	80	20	25	<10
Gold, Au	<0.2	<0.2	<0.2	<0.2

Abbreviations

Haem = haematite
gn. = garnet
amph = amphibole
Gsn. = gossan
ass. = associated
shst. = schist
chl. = channel

If this should prove to be the case, then one of the commonly stated criteria (de la Hunty, 1975; Williams, 1974) for distinguishing the Southwest Province from the remainder of the Yilgarn Block would be invalid.

A former connection between the Wongan Hills Belt and the greenstone sequences of the Koolanooka Synform (Baxter and Lipple, 1979) through the intervening area of gneiss and granitoid is suggested by a chain of north-trending mafic remnants which link these two areas. Greenstone remnants at Wilgie and Wandano Hills, Barrabarra and Bera Bera are enclosed by granitoid rocks (Carter and others, 1979), whereas remnants between Buntine and Latham, around Neereno Hill (Baxter and Lipple, 1979) and Berkshire Valley (Carter and others, 1979) are enclosed in ortho- and paragneiss revealing a complex history. This northward trend of the gneisses and greenstone remnants is emphasized by connecting aeromagnetic trends, which are inferred to be caused by concealed remnants and/or represent contaminated zones in granitoid rocks marking former continuation of the greenstones. Remnants incorporated in granitoid rocks and infolded with gneissic rocks exhibit similar rock types, and have comparable structures, deformation and metamorphic grades to the Wongan Hills belt. Metamorphic grades are mid- to high-grade for most of the remnants. In the Koolanooka Synform, the grade declines northwards from amphibolite to greenschist facies. The picture that emerges is one of regional metamorphic grade declining northwards from the high grades of the Jimperding Metamorphic Belt (Wilde, 1974) to widespread greenschist-facies metamorphism recorded in the Murchison Province (Lipple, and others, 1980; Baxter and Lipple, 1979); a feature consistent with the northward-declining gradient already noted at Wongan Hills.

Apart from metamorphic grade, the Wongan Hills Belt closely resembles greenstone belts elsewhere in terms of similar rock types and structures. The Wongan Hills Belt is thus regarded as a former extension of these Archaean greenstone belts, a view expressed first by Brown (1872) and recently by Gee (1979), preserved within a terrain of higher metamorphic grade.

The relationship between the Wongan Hills belt and the Jimperding Metamorphic Belt is more difficult to establish. Their proximity and affinity in terms of metamorphic grade implies at least some common history, and Williams (1975) draws comparisons between rocks of the Wongan Hills Belt and the Jimperding Metamorphic Belt (then undefined) within a general discussion on metamorphic rocks of the Southwest Province. In comparing the relative abundances of various rock types, it is obvious from descriptions by Wilde (1974) that the much larger Jimperding Metamorphic Belt is generally poorer in mafic components, and contains much more granitic gneiss than the Wongan Hills Belt. However, in some local areas, the composition of the Jimperding Metamorphic Belt is similar to that of the Wongan Hills Belt. This is demonstrated in Table 2 which compares the proportion of the main rock types (excluding peripheral ortho- and paragneisses) in the Wongan Hills Belt with similar enclave 40 km southwest at Bolgart in the northern Jimperding Metamorphic Belt.

TABLE 2: COMPARISON OF AREAL PROPORTIONS OF PRINCIPAL ROCK TYPES EXPOSED AT BOLGART AND WONGAN HILLS.

Lithology	Bolgart		Wongan Hills	
	Area (km^2)	%	Area (km^2)	%
Amphibolite	13.7	56.4	27.7	45.2
Quartz-garnet-mica and quartz-grunerite schists	5.6	23.0	7.7	12.6
Quartz-mica schist	2.7	11.1	12.0	19.6
Quartzite	1.6	6.6	1.1	1.8
Banded iron-formation	0.6	2.5	12.7	20.7
Ultramafic intrusions	0.1	0.4	0.1	0.1
Total	24.3	100.0	61.3	100.1

The differences between the figures for banded iron-formation and quartzite may be due to the inclusion of meta-chert with banded iron-formation at Wongan Hills, while in the Jimperding Metamorphic Belt any chert has been converted to quartzite. However, the presence of cross-bedding in quartzites of the Jimperding Metamorphic Belt indicates that at least some of these units had a clastic origin. It is nevertheless concluded that portions of the Jimperding Metamorphic Belt are comparable with metamorphosed greenstone at Wongan Hills. Other general comparisons with a zone of quartzite, amphibolite and ultramafic rocks enclosed in gneisses of the Jimperding Metamorphic Belt at Berkshire Valley, and correlated extensions of this Belt, around Neereno Hill and northward from Wongan Hills to Latham can also be made.

The principal and important difference between the Wongan Hills Greenstone Belt and the much larger Jimperding Metamorphic Belt is the predominance of granitic gneiss in the Jimperding Metamorphic Belt, at least partly representing better preservation and exposure. The significance of this difference is uncertain because the relative proportions of paragneiss and subsequently incorporated orthogneiss is not well known. At Wongan Hills, granitoid intrusion has been more widespread, and gneisses to the west are poorly exposed. Possible differences in original depositional regime, akin to notable variations in proportions of sedimentary to volcanic rocks seen in greenstone belts elsewhere (Fig. 1), may also be involved. The problem of whether or not a pre-depositional sialic basement to the metasedimentary rocks is incorporated within the Jimperding Metamorphic Belt (Gee, 1979) remains unresolved.

Folds in the layered rocks of the Wongan Hills Belt and of the larger, better preserved greenstone belts of the Murchison Province, are dominantly of upright, open to tight, similar style, folds that have been superimposed on poorly manifested upright isoclinal folds (Baxter and Lipple, 1979).

In the Jimperding Metamorphic Belt (Wilde, 1974), upright to recumbent isoclinal folds, which have been modified by later similar folds and which commonly have only single limbs preserved, are the main fold type. Subsequent local, weak, open folds have been observed in both terrains.

It is concluded from a comparison of rock types, metamorphic grade, and structural history, that the Jimperding Metamorphic Belt contains units that are similar to the greenstone belts of the transitional Wongan Hills Belt and of the Murchison Province, but that the Jimperding Metamorphic Belt has reached a much higher metamorphic grade than the others. In both situations, widespread disruption by major granitoid intrusions 2 600 - 2 700 m.y. ago (Arriens, 1971; Libby and de Laeter, 1979; Nieuwland and Compston, 1980) has obscured former continuity and transitional relationships.

An alternative view, that the Jimperding Metamorphic Belt is substantially older than the Wongan Hills Belt (and other remnants in the Murchison Province) and thus forms basement to the greenstones (Wilde, 1976; Gee, 1979), is supported by little direct evidence, and is based on an emphasis of the gross differences in lithology between the two belts.

Recent U-Pb geochronology studies on zircons reported by Nieuwland and Compston (1980) date the granulite-facies metamorphism of rocks in the Jimperding Metamorphic Belt near Toodyay at 3 180 m.y., and subsequent amphibolite-facies metamorphism (though probably not retrograde, S.A. Wilde, pers. comm.) at 3 000 m.y. The Wongan Hills Belt is considered to have undergone at least this latter phase of regional amphibolite facies metamorphism. Whether or not it was affected by a zone of earlier amphibolite facies metamorphism, adjoining and contemporaneous with the main granulite facies zone (Wilde, 1974), is unknown.

Other constraints on the nature of the Jimperding-Wongan Hills belts arise from the results of Nieuwland and Compston

(1980), who obtained a U/Pb age of ca. 3 340 m.y. for detrital zircons from Jimperding quartzites, representing the age of source material for the protoquartzite. A younger limit to deposition of the protoquartzite is represented by a zircon age which was obtained on orthogneiss intruding quartzite, of ca. 3 250 m.y.

A study of zircon U-Pb geochronology of Wongan Hills rocks would significantly elucidate the relationship between the Wongan Hills Belt and the Jimperding Metamorphic Belt. Felsic volcanic rocks and metasedimentary rocks may yield suitable zircon samples. Further study of this relationship is warranted not only for its geological significance but also for the implication to mineral exploration in the light of significant base-metal mineralization occurring in the Wongan Hills Belt, and the correlation of this mineralization with volcanogenic base-metal mineralization at Golden Grove in the Murchison Province (Blackburn, 1975; Roberts, 1978; and Lee, 1979).

ENVIRONMENTAL ASPECTS

The Wongan Hills are important for their geological and biological features, and are popular for local and tourist recreation. Recent mineral exploration has caused concern for the conservation of the hills for aesthetic and ecological reasons. However, much of the area has been cleared for agriculture, and most of the remaining virgin bushland is freehold land. A small former Temporary Reserve for minerals around Mount Matilda, which includes the copper occurrences described by Maitland (Plate 1), has been declared a Class A reserve (33530) for conservation of flora and fauna, as recommended by the Conservation Through Reserves Committee in 1974 (Environmental Protection Authority, 1974, 1975).

This reserve is located over metabasaltic rocks along the western margin of the hills, and although its potential for copper mineralization appears to be low, the area and adjacent bushland have not been adequately prospected. The best bauxite results were obtained around Mount Matilda.

Recent exploration for copper mineralization has been on lower ground near Lake Ninan in land extensively cleared for agriculture, away from the main hills, but which retains scenic attraction. Lake Ninan includes recreation and flora and fauna conservation reserves (27025 and 27026, Plate 1) and is on the main road from Perth to Wongan Hills.

As shown by this report, although exposure of Archaean rocks is sporadic, much of the Wongan Hills area has potential for mineralization, and prospecting is still incomplete. The best prospects appear to be in the southern portion, mostly on cleared land, where gossanous outcrops have been investigated. Further north, the area of bushland on laterite and Archaean greenstone rocks, and agricultural land adjacent to the hills and underlain by greenstone rocks have not yet been tested.

The Conservation Through Reserves Committee (Environmental Protection Authority, 1974) recommended that remaining freehold bushland be purchased for addition to the Class A reserve for conservation of flora and fauna. This would conflict with utility for mineral extraction, for which the potential is largely untested. Concern was also expressed by some landowners that they would lose either cleared or virgin freehold land. Subsequently, this recommendation was changed (Environmental Protection Authority, 1975) to encourage conservation management by the landowners concerned.

The third recommendation by the committee for the transfer of natural bushland remaining on the Agricultural Department Experimental Farm (Reserve 18762, Plate 1) will not affect mineral exploration since this area is over unprospective granitoid rocks, east of the hills. Additional bushland areas adjoining the farm are reserves 25808 (for conservation of flora and fauna) and 16418 (for water). These reserves also overlie granitoid rocks.

SUMMARY AND CONCLUSIONS

The Wongan Hills Belt is a metamorphosed and deformed tract of Archaean volcanic and sedimentary rocks, which has similarities rock to parts of the Jimperding Metamorphic Belt and to the Archaean greenstone assemblage in the Murchison Province to the north. Possibly these sequences were originally continuous and have subsequently been isolated by tectonic attenuation and widespread plutonic intrusion. The author concluded from 1975-76 regional mapping on the Moora and Perenjori geological sheets that the boundary between the Murchison and Southwest Provinces of the Yilgarn Block (Williams, 1974) has no real expression on the ground, and believes that the distinction between the provinces reflects differences in preservation of gneissic and supracrustal rocks, the presence of more widespread granitoid emplacement in the north, and differences in metamorphic grades. This view has also been expressed by Gee and others (1980). A revised subdivision based on the relative importance of those features has been prepared by Gee and others (1980).

The Wongan Hills Belt contains copper mineralization with associated low gold, silver and arsenic values. The potential has yet to be fully tested. Possible correlation between greenstone rocks of the Murchison Province and metamorphic rocks of the Jimperding Metamorphic Belt of the Southwestern region through the Wongan Hills Belt has implications for mineral exploration, especially in view of discoveries in the Murchison Province and the relatively scant mineral exploration to date in the Southwest Province.

Some concern has been expressed regarding conflicting land use for conservation, recreational, agricultural and mining purposes. However, the greatest potential for mineralization appears to be in cleared land adjacent to the hills rather than in the smaller areas of native bushland remaining around Mount Rupert and Mount Matilda.

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PLATE 1

GEOLOGY OF THE WONGAN HILLS

GSWA 19736

PLATE 2

GSWA 19737