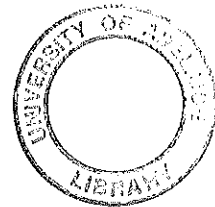THE UNIVERSITY OF ADELAIDE

AN ANALYSIS OF THE SEDIMENTARY
HOST ROCKS TO MINERALISATION
AT THE CATTLEGRID OREBODY, MT. GUNSON

by

M. BUSBRIDGE, B.Sc.

1981

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the requirements of the Honours Degree of
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ABSTRACT

The Cattlegrid Orebody is located at the disconformable contact between the Willouran Pandurra Formation and the overlying Marinoan Whyalla Sandstone. Mineralisation is located on a palaeo high of Pandurra quartzite known as the Pernatty Culmination.

The Pandurra Formation at the Cattlegrid mine is a moderately to moderately well-sorted, cross-bedded quartz arenite. Grainsize analysis and cross-bedding data indicates it to be of fluviatile origin, while packing and compaction of the grains suggests a considerable thickness of quartzite has been removed by erosion. The bimodal Whyalla Sandstone is a texturally-inverted subfelsarenite, with well-rounded and spherical quartz grains in a poorly- to moderately-sorted fabric. Ripple marks, truncation of sandy and clay laminations, and a grain-size analysis suggests the Whyalla Sandstone to be a beach deposit. Syndepositional faulting, thickness of the beach deposit and the textural inversion suggest the sandstone to have been reworked by successive transgressions and regressions.

It is in the fractured and brecciated upper Pandurra Formation that the bulk of the mineralisation (chalcocite, bornite, chalcopyrite) is found in fractures and vughs. Basal Whyalla Sandstone is also richly mineralised.

Throughout the Cattlegrid mine, one, occasionally two, predominant lenticular clay bands shows evidence of acting as a glide plane. Squeezing of the clay into fractures of the overlying quartzite, striations, and sharp transitions from the Upper Cattlegrid Breccia to the underlying mosaic breccia and displacement of sand wedges, all suggest sliding.

The topmost Cattlegrid Breccia is thought to be a bajada breccia underlain by the mosaic breccia, considered to be due to a normal weathering cycle and mild tectonic activity.

Gelifluction or periglacial mass

movement processes is considered to be the mechanism
responsible for the formation of tepee-like anticlines
and sand wedges. Cryostatic pressures resulting from the
melting of the active and talik layers and lateral move-
ment over the permanently-frozen ground and/or clay band
is considered to result in the water-escape anticlinal
structures. Tensional fractures resulting from this move-
ment initiated ice wedges.

Fluid inclusion data suggest a
calcium-rich, highly saline, dense brine precipitated
copper-sulphide mineralisation. Waters of a surface origin
e.g., connate, meteoric, are therefore ruled out due to
the high Ca content and paucity of Na and K salts.

YPMA has suggested that these
dense brines have created instability in the brecciated
quartzite due to excessive pore pressures. This instabi-
lity has caused slumping along a décollement surface and
formation of the anticlinal structures and sand wedges.
Similar structures are observed in Upper Mississippi
Valley Pb-Zn districts.

The mixing of this dense copper-
bearing brine with less saline connate waters of the
Whyalla Sandstone has caused precipitation of copper
sulphides at the disconformable contact.

ACKNOWLEDGEMENTS

INTRODUCTION

The Cattlegrid Orebody at Mt. Gunson lies near the western edge of Pernatty Lagoon on the tectonically-stable Stuart Shelf, 425 km NNW of Adelaide.

The purpose of the thesis was to record and describe the host sediments to the mineralisation and define their depositional environments. Mineralisation occurs in brecciated quartzite in the uppermost Pandurra Formation. A study of the brecciation was essential.

Unusual sedimentary structures, e.g., tepee-like folds, and sand wedges occur within the mineralised breccia. Due to mining operations, it was decided to record and describe these structures adequately and to offer an account of their formation.

Laboratory methods included thin-section work and Scanning Electron Microscope (SEM) analysis. Fluid inclusion studies were also undertaken in order to gain some insight into the nature of the mineralising solutions.

Approximately six weeks was spent by the author at the Cattlegrid open-cut. Work consisted of mapping mine faces, collecting samples and visiting regional areas with emphasis on the two host lithologies. Compilation of drill logs and face maps was undertaken for the preparation of Figures 2, 3 and 4. Volume and tonnage data of the Cattlegrid Orebody was also researched.

CHAPTER I: GEOGRAPHY, HISTORY AND STRATIGRAPHY

1.11   LOCATION DATA

The Mt. Gunson copper deposits are located on and adjacent to the NW margin of Pernatty Lagoon, situated approximately 425 km NNW of Adelaide (see inset map, Fig.1). The area lies within the International Topographic Grid Reference SH53-16 with latitude and longitude co-ordinates of $31^{\circ}25-27^{\circ}S$; $137^{\circ}1C'-13'E$.

1.12   GEOMORPHOLOGY

The copper deposits are situated in an area called the Bookaloo Lowlands. The Arcoona Plateau situated to the north is an extensive tableland elevated some 600-800 feet above sea level, generally capped by a resistant quartzite member.

The Arcoona Plateau represents remnants of a Mesozoic land surface (JOHNS, 1968) and has since been disected and eroded to present-day levels with preferential erosion resulting in the Bookaloo Lowlands.

1.13   CLIMATOLOGY

Temperatures are recorded between $0^{\circ}C$ and $48^{\circ}C$ with a diurnal range of $20^{\circ}C$. Mt. Gunson is located in an arid zone, receiving between 15-20 cm of rainfall per annum (PATTERSON, 1961).

1.14   HISTORY OF MT. GUNSON COPPER DEPOSITS

The copper occurrences of the Mt. Gunson Pernatty Lagoon area were first discovered in 1875 and worked intermittently and unsuccessfully until 1937. In this period, production is reported to have been 3250 tons at 8-16% copper.

The property was worked between 1941-43 as a wartime measure by the Zinc Corporation Ltd. Production was 32400 long tons of ore averaging 3.4% copper and 0.45 oz./ton silver.

In 1966, Austminex was granted

SML No.139 covering 243 sq.miles. In 1969, the joint venture of Pacminex (Exploration and Mining subsidiary of CSR Ltd.) and United Uranium purchased the rights and title to deposits located by Austminex. Upon completion of the mill, mine production commenced in June, 1970. Production figures (1970-1972) were 489000 tonnes @ .85% Cu from the East and West Lagoon orebodies with approximately 1000 tonnes from the Main Open Cut.

Mining operations ceased in late 1971 due to shortages of water, excessive mill stoppages and low LME prices.

1.15 CATTLEGRID OREBODY

The Cattlegrid deposit was discovered in 1972. An area of mineralisation measuring 1600 m x 800 m was outlined with an average intercept of 4.5 m of better than .5% Cu at a depth of 30 m. Using a 1% cut-off, the deposit originally contained 4.5 million tonnes averaging 2.45% Cu, with an overburden to ore ratio of 9.2 : 1. Ore thickness varies from 2 to 20 m and this variability is also accompanied by rapid changes in content of accessory metals such as Zn, Pb, Co, Ag. The ore zone has, in cross-section, a rich central "core", and from this core the metal grade diminishes in both upward and downward directions.

The Cattlegrid deposit is somewhat different from that which existed in the East and West Lagoon deposits in that it contains sulphides of Pb, Zn, Fe and Co in appreciable amounts. Mineralogical studies have shown that the sulphides present are not uniformly distributed and vary from place to place within the mineralised zone.

Contaminants for mining revenues include Pb and As. Bonus elements are Zn, Co and Ag.

1.16 OTHER MINERAL DEPOSITS

Manganese deposits were discovered in 1915 six miles NNE of Woocalla. Total tonnages mined

FIGURE 1

GEOLOGY

Simmens Quartite

Corraberra Sandstone

Tregolana Shale

Whyalla Sandstone

Woocalla Dolomite (outcrop)

Woocalla Dolomite (subcrop)

Pandurra Formation (outcrop)

Pandurra Formation (subcrop)

SCALE

0 1 2 3 KILOMETRES

0 1 2 3 MILES

BONNEY BLUFF

C

CANEGRASS DAM

A

MT GUNSON

MINE

B

D

Extensive Dune Sand

PERNATTY

LAGOON

Extensive Dune Sand

BIRTHDAY

McLEAY

Extensive Dune Sand

WOOCALLA

IRONSTONE LAGOON

Dune Sand

Pernatty Creek

31°45'

MT GUNSON MINES

PERNATTY LAGOON

LAKE TORRENS

PORT AUGUSTA

WHYALLA

PORT PIRIE

SPENCER GULF

were about 34000 tons of Mn ore containing 40-55% Mn.
They are located in the Woocalla Dolomite.

Barite is closely associated
with manganese. 1550 tons were mined between 1917 and
1939 averaging 98% barium sulphate. Fluorite is commonly
found in direct association with massive barite minerali-
sation, but no recorded mining has taken place.

Three miles east of Woocalla,
iron ores were reported by JACK (1922) to include limonite,
goethite and turgite and to occur in a narrow brecciated
zone of quartzite near the margin of Ironstone Lagoon
(see Fig.1).

1.2 TECTONIC SETTING

The area lies within the tectonic
unit known as the Stuart Stable Shelf -- an undeformed
stable platform marginal to the Adelaide Geosyncline to
the east and the Gawler Craton to the west.

The Adelaidean rock sequence of
the Stuart Stable Shelf is typically epicratonic in that
it comprises a series of unaltered and unfolded mature to
supermature quartz arenites with minor shales and carbo-
nate sequences (CREELMAN, 1974). It forms a cover of shal-
low marine sediments marginal to the Gawler Craton.

1.3 STRATIGRAPHIC SEQUENCE

Total thickness of Adelaidean
rocks is probably less than 2000 m.

Roopena Volcanics (1330 Ma -- THOMSON, 1966; THOMSON
et al, 1976).

At the base of the Adelaidean
sequence are the Roopena Volcanics, a unit of spilitic
and trachytic lavas which are only exposed in the southern
part of the Stuart Shelf. The lavas are considered to be
relicts of Early Adelaidean cover deposited on the Stuart
Shelf (MASON et al., 1978).

Pandurra Formation

The Pandurra Formation, a sequence

CATTLE GRID AREA. CROSS SECTIONS.

R.L(m)

A — B

100

0

-100

-200

-300

PERNATTY LAGOON

R.L(m)

C — D

50

0

-50

-100
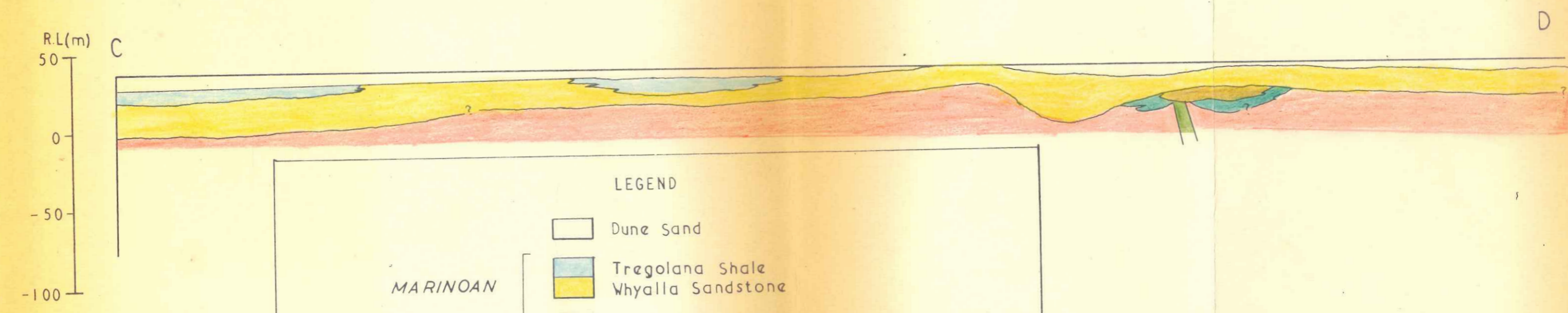
LEGEND

☐	Dune Sand

MARINOAN
- Tregolana Shale
- Whyalla Sandstone
- Yudnapinna Beds

STURTIAN
- Dolomite Member
- Tapley Hill Formation
- Woocalla Dolomite
- McLeay Beds

WILLOURAN
- Pandurra Formation
- Dolerite Dyke

⬛ Cattle Grid Mineralisation

SCALE

0   1   2   3   4 KMS.
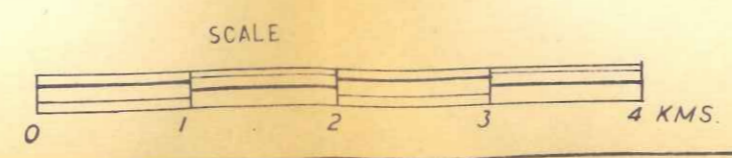
FIGURE 2

of red cross-bedded lithic kaolinitic sandstones and
quartzites and minor siltstone members, is proposed as
the earliest-known widespread cover unit of Adelaidean
age preserved on the Stuart Shelf (MASON et al., 1978)
and forms the basement unit in the Pernatty Lagoon area.
It has largely been derived by erosion of an extensive
terrain of c.1500 Ma Gawler Range Volcanics to the south-
west (BLISSETT, 1975, 1978).

Deposited perhaps at approximately
the beginning of Willouran time, in fluviatile environ-
ments on down-faulted basement blocks (MASON and others,
1978), it attains a maximum thickness over 900 m in the
vicinity of Mt. Gunson and laps out on to crystalline
basement to the west (THOMSON, 1976).

The copper deposit at the Cattle-
grid area lies on a north-south-trending ridge of Pandurra
quartzite and sandstone known as the Pernatty Culmination
and is shown in Fig.2. Contemporaneous faulting is evi-
denced by the relationships of overlying units on the wes-
tern edge of the culmination.

In outcrop and mine faces the
quartzite has an irregular uppermost layer that is jointed,
fractured and finally brecciated in a manner suggestive
of an old erosion surface. It is in this upper part of
the Pandurra Formation that fracturing and brecciation
has provided a favourable environment for the precipitation
of copper sulphides (Fig.3). It is at this same strati-
graphic position, that is, close to the disconformable
contact with the overlying Marinoan Whyalla Sandstone,
that unusual sedimentary structures were observed in the
open-cut mine and regional areas.

Crossbedding of the simple convex
type is present with cross-bed sets up to 1.5 m thick
and fore-set angles averaging 25°. Current directions
from these structures are variable, but there is a pre-
ferred direction from the west. Figure 4 shows these
directions, as measured by company geologists working
at the orebody.

The quartzite shows distinctive grading of beds and in many cases these bedding planes have fractured. Later, mineralising solutions have entered these fractures and deposited their copper and iron sulphides.

Leisegang banding is abundant in the quartzite representing the penetration of iron-rich meteoric fluids flowing through joints and fractures. Leisegang banding pre-dates the brecciation episode and is a relatively older diagenetic phenomenon, where, according to drill logs, it is not seen below 380 metres.

One, sometimes two, clay bands up to 50 cm thick and traceable for often up to 80 metres, shows an unusual habit. The green to brown, sometimes iron-stained, clay consists of angular and rounded quartzite fragments up to 20 cm long of varying dimensions. The poor sorting typifies a debris flow, but its occurrence as a thin band, often lensing out and re-appearing further along strike, is not consistent with this idea (see Fig. 4).

Additional information about the Pandurra Formation was obtained from drill logs. These show a decrease in the frequency of fracturing and jointing with depth until 170 m where it drops off considerably. Sulphides are accommodated within the top 15 m and occur much less abundantly down to 157 m and then fade. Chert clasts are common throughout the depth drilled, while clay bands occur throughout the drilling interval with local concentrations of occurrence. Gawler Range Volcanic fragments, rhyolites to dacites, become obvious from 400 m below the collar and increase in abundance with depth. Conglomerate bands also follow this pattern. Cobbles are mainly rounded conglomerate quartz and Gawler Range pebbles. Silicification is local only below 50 m, but clays, probably largely diagenetic, occur abundantly throughout as interstitial material.

McLeay Beds

These beds have been logged as a distinct stratigraphic unit in the Mt. Gunson area disconformably separated from both the overlying Tapley

Hill Formation and Pandurra Formation below. It is a
discontinuous unit of silt and clay bands, sandstones
and quartzite and conglomerate. Occasional angular
silty quartz erratics, including glacigene rafted "drops",
occur within the clay bands (CURTIS, 1978). He has sug-
gested that the McLeay beds are periglacial sands and
clays formed at the edge of a glacier.

Woocalla Dolomite

Following the Sturtian glacial
phase, there was a widespread marine transgression, lea-
ding to the various facies of the Woocalla Dolomite
(Tapley Hill Fm.). The dolomite is missing at the Cattle-
grid orebody but reaches a maximum thickness in outcrop
of 47 metres east of Pernatty Lagoon (CREELMAN, 1974).

The black manganiferous dolomite
and black shale is the host to the copper mineralisation
seen in other areas around Pernatty Lagoon, e.g., Mystery
Workings, and part of the Main Open Cut workings.

Data from recent stratigraphic
drilling indicate that there are a number of significant
facies changes within the Woocalla Dolomite ranging from
a Black Shale representing deeper water to an oolitic
and sandy dolomite corresponding to shallower water.
High copper values are restricted to two main facies:
the dolomitic mud-and-silt facies and dolomitic shale
facies. In outcrop, the unit may be massive, laminated,
brecciated (intraformational breccias) or stromatolitic,
Collenia and Cryptozoon (CREELMAN, 1974).

Pre-Woocalle erosion of the Pan-
durra Formation produced a surface of low ridges and
stream channels. The sediments of the Woocalla Dolomite,
together with the close association of manganese, iron
and barium (and possibly copper) salts, suggest deposition
in a partially-closed basin or basins. The rims of the
basin (or basins) consisted of Pandurra Formation sand-
stones as topographically high areas.

Whyalla Sandstone

The Whyalla sandstone represents

.the basal Tent Hill Formation in the Stuart Shelf area and records the early Marinoan transgression proposed by COATS (1965) (THOMSON and JOHNSON, 1968). At the Cattlegrid deposit, it lies disconformably on the fractured Pandurra quartzite and in other areas lies disconformably on the Woocalla Dolomite.

It has a thickness of 45 metres in the Cattlegrid open cut.

It is a cream-to-white moderately-soft sandstone with a silty matrix. Its most distinctive feature is a marked sphericity of constituent quartz grains. With an increase in the silt content, the sandstone exhibits alternate laminations of silt-rich layers and sandstone-rich layers. These layers are usually flat and parallel-bedded, but rarely, some truncation of layers is evident. These laminations often lens out and rarely exceed 5 cm in thickness.

Several pebble horizons, first appearing about 10 m above the disconformable contact with the Pandurra quartzite, are present. These layers, concentrated in a zone about 1 m wide, are made up of well-rounded quartzite pebbles, usually less than 1 cm long, and are located in silt-rich horizons about 1-2 cm thick. These horizons extended for a distance of approximately 100 metres before disappearing below rubble. No imbrication of pebbles was observed.

Large-scale cross-bedding was observed at the mine and wave-formed ripples were common in areas surrounding the mine   (Photo 9).

Upper Tent Hill Formations

Overlying the Whyalla sandstone are the upper members of the Tent Hill Formation. These comprise the Tregolana Shale, the Corraberra Sandstone and the Simmens Quartzite. The Simmens Quartzite is correlated with the ABC Range quartzite, and the Corraberra Sandstone-Tregolana shale is correlated with the Brachina Formation. These correlations indicate the widespread transgression of the lower units of the Marinoan

Wilpena Group on to the Stuart Shelf areas during the late Proterozoic (DALGARNO, 1965).

Tertiary and Recent Sediments

Photograph 1 shows the disconformable contact between the Whyalla sandstone and the fluviatile pebble conglomerates of the Tertiary desert sandstones (JOHNS, 1968). These conglomerates are up to 5 m thick and boulders often exceed 20 cm in diameter. They are often duricrusted and can be termed "conglomeratic silcretes".

Red quartz sand forms sub-parallel longitudinal dunes in the region. Their age is uncertain as they have transgressed over all formations. Much of the sand is derived from erosion of underlying Adelaidean sandstones and quartzites and are of probably Recent age, although some may be Tertiary (JOHNS, 1968).

Igneous Rocks

Basaltic dolerite dykes, associated with linear magnetic anomalies, intrude the Pandurra Formation (MASON et al., 1978). At Mt. Gunson, one such dyke is interpreted to have been eroded during the Sturtian interval. It contains trace amounts of pyrite and copper sulphides, especially associated with carbonate veins (GERSTELING and HEAPE, 1975) (Figure 2).

CHAPTER II: PETROGRAPHY

Representative thin-section descriptions are supplied
in Appendix I.

PANDURRA FORMATION

2.11   Mineralogy:

The quartzite of the Pandurra
Formation is a medium- to very-coarse, moderately to
moderately well-sorted, graded, quartz arenite. Grainsize
ranges from 2 mm to .08 mm. Quartz grains are plutonic,
having slight undulatory extinction with occasional com-
posite grains. Kaolinite occupying interstices averages
5% of the rock.

Grains have a sphericity ranging
from .65 to .83, using the scale of BEARD and WEYL (1973).
They are sub-angular to sub-rounded, with an improvement
of roundness with larger-sized grains.

Grainsize and sorting is very
uniform (see later) within single beds, and little vari-
ation in sorting occurs due to changes in grainsize.

Authigenic quartz:

The presence of overgrowths is
suggested by the occurrence of "dust" or iron oxides mar-
king the original grain margin. Overgrowths comprise
2-5% of the rock. They are optically concordant, and do
not attain any crystal form (see Plate 1).

Composite quartz grains exhibit
undulose extinction and may have overgrowths in optical
concordance with individual crystal members of the grain.

Iron oxide:

Iron oxide in the red Pandurra
quartzite coats grains and is responsible for the Leisegang
rings. It forms as coatings around quartz grains and also
silica overgrowths suggesting that iron oxide was contem-
poraneous with overgrowth formation (Plate 1).

Detritals:

These include rounded zircon and

DESCRIPTIONS OF PLATE 1:

a) Iron oxide coating silica overgrowths. Also some iron oxide outlining original grains, suggesting iron-oxide development and silica overgrowths were contemporaneous. Note anhedral shapes of overgrowths (40 X Mag.).

b) Clay Band. Note the large proportion of floating grains and lack of silica overgrowths (10 X Mag.).

c) Sutured contact of detrital grains (40 X Mag.).

PLATE 1

leucoxene grains not exceeding 1%.

Clay (Kaolinite):

Kaolinite is considered to have been derived from the complete alteration of plagioclase grains, i.e., is a diagenetic phenomena, after the deposition of the original grains. Its presence, in thin section, is dependent on the tightness of the quartz fabric and hence the degree of quartz overgrowth abundance.

Potash feldspar:

was identified by staining techniques and never exceeded 2% abundance.

2.12 Framework:

The Pandurra Formation is a grain-supported quartzite in that the interstitual clay forms the discontinuous phase where individual grains touch along one or more contacts and isolate the clay fraction in the pore spaces. By this definition, according to DAPPLES (1972), the quartzite is recognised as an arenite deposited by normal traction processes.

2.13 Packing:

Contact measurements were recorded only on the contacts of detrital grains and excluded overgrowth contacts (Figure 6).

GAITHER'S (1953) study based on artificially packing the well-sorted, moderately-round, medium-grained St. Peter sand into a grain-supported framework provided a measure of compaction.

> "The following conditions can indicate compaction if observed in thin section ... whose texture and composition were similar to those of the sand used in this investigation ... an average number of contacts per grain in excess of .85, less than 46% floating grains, 31% of grains with one contact, 16% with two, 6% with three and 1% with four." (GAITHER, 1953)

Of these contacts, 77% were tangential, 17% long, and 6% concavo-convex contacts. TAYLOR (1950) defines these contacts, which are shown by the photos of Plate 1.
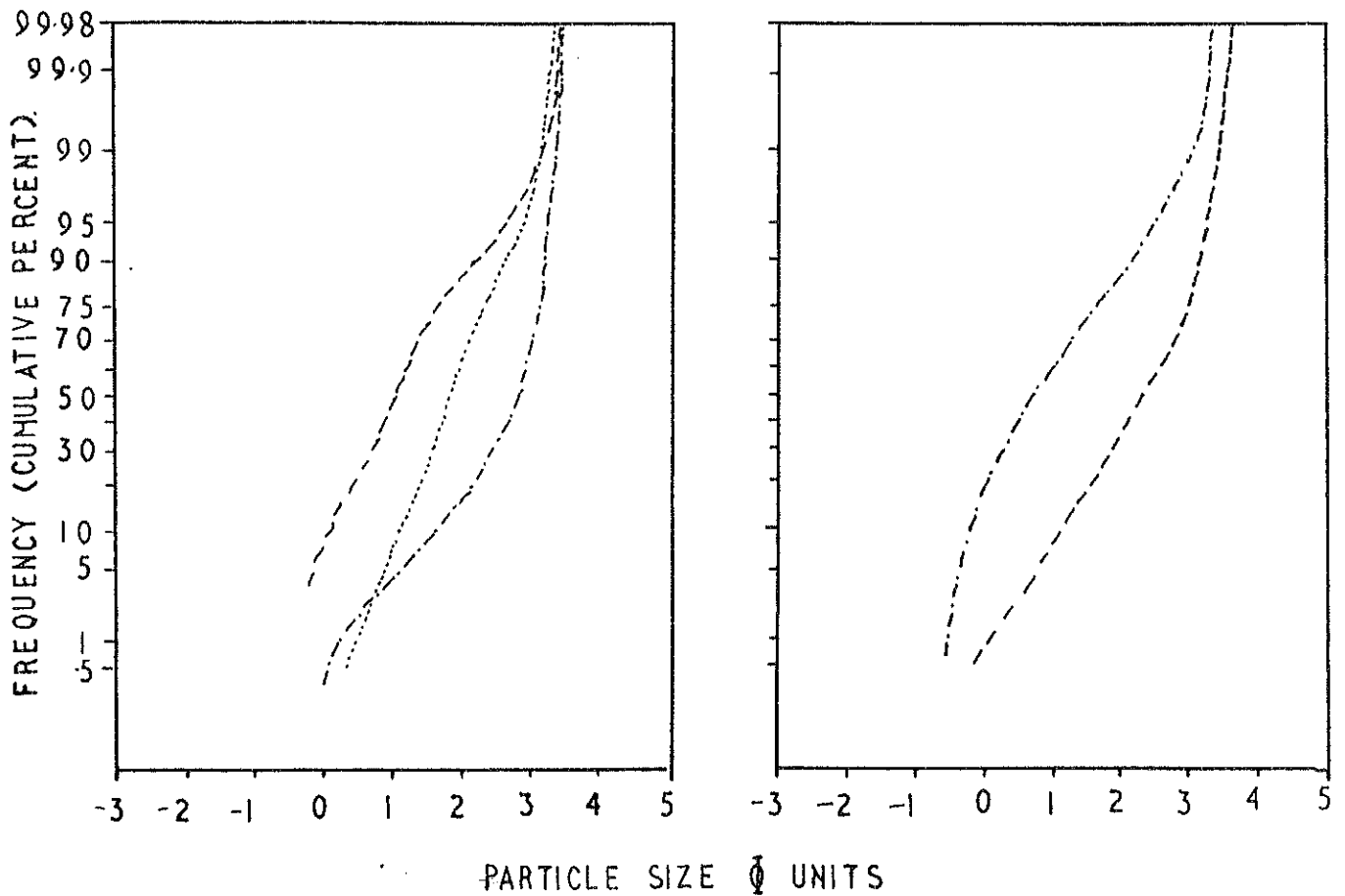
FIGURE 5: GRAINSIZE ANALYSIS

A. NUMBER OF CONTACTS PER GRAIN
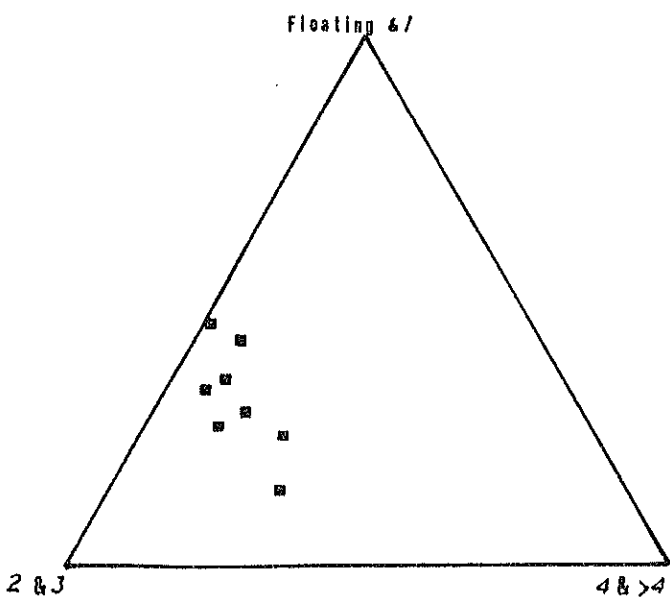
B. TYPE OF GRAIN CONTACTS
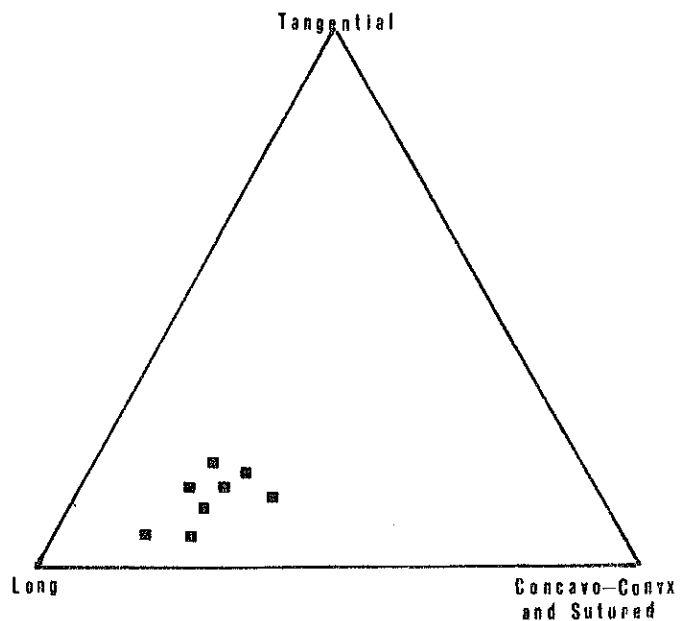
FIGURE 6: PACKING RESULTS

Considering the Pandurra Formation
is a moderately well-sorted, medium-grained quartzite,
parameters obtained, after studying eight thin sections,
are depicted in Table A1. Percentages are given in Appen-
dix IV. Samples were obtained within 6 m of the discon-
formity.

Results show that 9.9% of grains
were floating and 14% had greater than three contacts.
Of these, 19% were either concavo-convex or sutured con-
tacts.

Comparing GAITHER'S study and
the results obtained for the Pandurra Formation, it is ap-
parent that the latter has suffered a noticeable degree of
compaction. Hence, considerable thickness of the Pandurra
Formation is envisaged to have been eroded down to the
present level of the disconformity.

Considerable pore filling has oc-
cured by secondary quartz cement described above. However,
due to the presence of concavo-convex contacts, the small
percentage of floating grains and the large number of long
contacts, simple pore filling as defined by TAYLOR (1950)
is not the only process causing the reduction of pore space

A large number of long, concavo-
convex and sutured contacts, approximately 88% of all
contacts and pressure fracturing of grains, reflect the
effect of pressure and its effect in reducing porosity.

Pressure solution contacts (viz.
sutured and concavo-convex) have not accounted for the
amount of silica overgrowth. Certainly some of the silica
has been derived from pressure solution. The source or
sources of silica most probably have come from the silica-
rich waters of the Gawler Range volcanics lying in the
south-west. These waters were probably channelled up into
the topographic high of the Pernatty culmination.

2.14   Grain size Analysis:

MASON et al. (1978) suggested the
Pandurra Formation was deposited in a fluviatile environ-
ment. FRIEDMAN (1961), in his study of modern-day dune,

beach and river sands using sieving techniques, demonstrated that river sands have positive skewness (although exceptions occur) and are not as well sorted as dune sands standard deviation values averaged approximately 0.8 for river sands. Mean grain sizes ranged from 1.6φ to 3.6φ (.33 to .08 mm).

In the author's study, a grain size analysis of eight thin sections of the Pandurra Formation was undertaken, using $\frac{1}{4}φ$ calibrated intervals on a micrometer (Figure 5). For a conversion of the data obtained by thin-section techniques, to data obtained by sieving, the reader is referred to FRIEDMAN (1958) who found a linear relationship between the two methods.

Results obtained (table A) using Folk's graphic statistical parameters (Appendix V), showed that the standard deviation ranged from 0.6 to 0.94. Mean grain size averaged 2φ (0.25 mm). In addition, with such great thicknesses of Pandurra Formation, in excess of 900 metres in certain areas, and the nature and prevalence of crossbeds, a braided stream environment is suggested.

Skewness values, although not totally convincing using thin-section methods, showed coarser than expected readings. Possibly a greater carrying capacity of the stream's load can be invoked. Alternatively a winnowing effect, such as in a tidal environment, to remove the finer fraction, could be envisaged. However, the absence of tidal facies and structures refutes this suggestion.

2.15 Clay Bands:

In thin section, it is a poorly- to moderately-sorted angular to sub-rounded, quartz wacke. The matrix, kaolinite, comprises 40% of the thin section. It does not show any foliation or compaction around quartz grains (Plate 1).

According to DAPPLES (1972), sand grains forming the discontinuous phase are identified

as wackes. Accordingly, quartz grains of sand size are angular, of low sphericity, and show very limited development of overgrowths. Such is the case with the clay band observed, with only larger grains (> 1.5 mm) showing some degree of rounding. No concavo-convex or sutured contacts were observed, and 68% of the grains were "floating", indicating a much less degree of compaction than that observed for the underlying and overlying quartzite. Iron staining does occur, and mineralization is extremely poor, with only rare scattered grains of pyrite occurring.

In the mine faces, the clay band exhibits angular tabular clasts, sometimes rounded and randomly orientated. These clasts are themselves fractured or show signs of breaking up (Photo 3). Grading, both normal or inverse, was not observed, although clast size and abundance did tend to increase towards the upper and lower margins of the band.

Three alternatives are proposed for the formation of the clay band:
1) Sedimentary Origin: It could represent a waning of the water current to quieter periods. Certainly, the immediately underlying quartzite layer decreases in grain-size. However, the presence of rounded pebbles is difficult to understand, especially as these are absent from adjacent sands.

2) Mud-flow: A clay-supported mud or debris flow seems unlikely. It occurs as a traceable lenticular band never greater than 40 cm thick, and often only 10 cm thick. Fig.4 shows its prevalence and disappearance among mine faces.

3) Slip-plane origin: Here the original clay band of a sedimentary origin acted as a slip-plane to the overlying quartzite. During lateral movement, fragments were lodged into the clay band and rounded by continued movement.

Alternative 3) seems the most likely in the light of structures observed:
    a) squeezing of clay into fractures and vughs in quartzite (Photos 3 and 4);

PHOTO 1: Whyalla Sandstone — Tertiary Conglomerate
          Disconformable Contact. 10 km South of Mine.

PHOTO 2: Pebble layer in Whyalla Sandstone. Mine Face.
          Note Lack of Imbrication.

PHOTO 3: Intruding of a Clay Band into overlying
          Fractured Quartzite. (Pandurra Formation)

PHOTO 4:   Intruding of clay into quartzite. Note rounded
           lath-shaped fragments in clay band.

PHOTO 5:   Lateral displacement of clastic wedge. Basal
           tail is located to the left of the main wedge
           itself.

PHOTO 6:   Sharp transition from overlying Cattlegrid
           breccia to underlying mosaic breccia. Note
           rectangular-shaped cavity between blocks
           at bottom of Photo and sand wedge in upper
           left-hand corner.

b) striations on the underside of a section of the clay band, possibly slickensides (GOSTIN, pers.comm

c) clastic wedges (discussed later) usually exhibit a basal tail. One such wedge was laterally displaced from its tail by a distance of 1.4 metres, suggesting slip along the intervening clay band (Photo 5);

d) a sharp transition from the mosaic breccia to the Cattlegrid breccia (see later) is only marked by the clay band (Photo 6);

e) degree of compaction of the band is markedly less than the adjacent quartzite. Lateral movement along the band has probably destroyed any indications of compaction.

2.2 Whyalla Sandstone:

Basal Tent Hill Formation, and stratigraphically equated with the glacial Elatina Formation (PREISS, 1979).

The Whyalla sandstone is a creamy-coloured, soft, poorly- to moderately-sorted, medium-to-coarse feldspathic sublitharenite or a subfelsarenite. It is a very clean sandstone with no micas or heavy minerals present. Close to the disconformable contact with the Pandurra Formation, bedding is made up of horizontal layers of silt (up to 1 cm thick) and coarser sand-size layers usually thicker (greater than 1 cm). Occasional truncation of these layers occurs, but usually they inter-tongue with each other. No clear grading from sand to silt occurs, although some intruding of overlying sands does occur into the underlying clay seams. Higher up the sequence, banding disappears, and a more homogeneous mixture of silt and sand occurs in large-scale cross-beds.

The most distinguishing feature of the Whyalla sandstone is a marked rounding and high degree of sphericity of the grains. This, together with a poor-to-moderate sorting, implies a textural inversion. Therefore, the sandstone has been through more than one period of erosion.

DESCRIPTION OF PLATE 2:

SEM WORK AND PETROGRAPHY OF WHYALLA SANDSTONE

SEM Photomicrographs (a-f). Thin Sections (g-j)

a) Solution Cavity. Former grain (now removed) dissolved away the silica at the point of contact with this grain (70 X Mag.).

b) Similarly formed solution cavities (70 X Mag.).

c) Striations of unknown origin (70 X Mag.).

d) Euhedral Chalcocite crystals growing on grain (200 X Mag.).

e) Typical spherical sand grain (30 X Mag.).

f) Clay joining two rounded grains together. Some parting has already begun to occur (300 X Mag.).

g) Rounded Plagioclase grain (sericitised) (40 X Mag.).

h) Rounded composite grains and devitrified volcanic grain (almost black) (10 X Mag.).

i) Bimodal grainsize population with the smaller sizes filling pores between larger grains. Note the high number of contacts per grain due to this distribution (10 X Mag.).

j) Long contacts in Whyalla Sandstone. The grains exhibit a high degree of sphericity (10 X Mag.).

PLATE 2
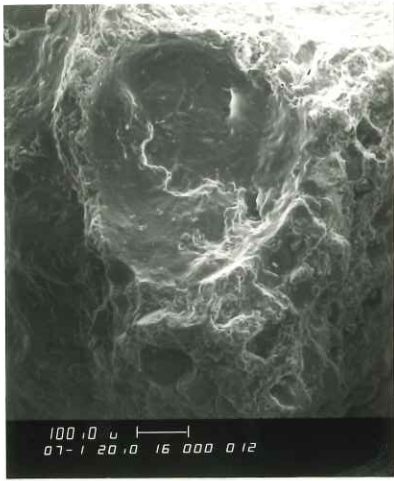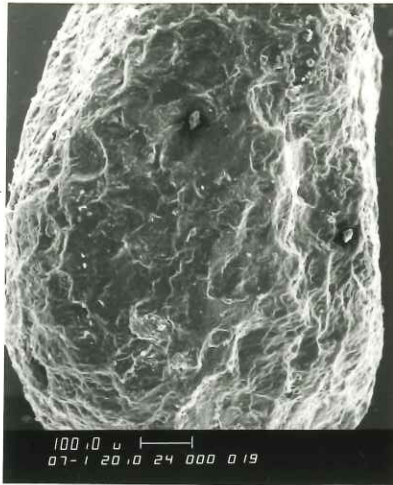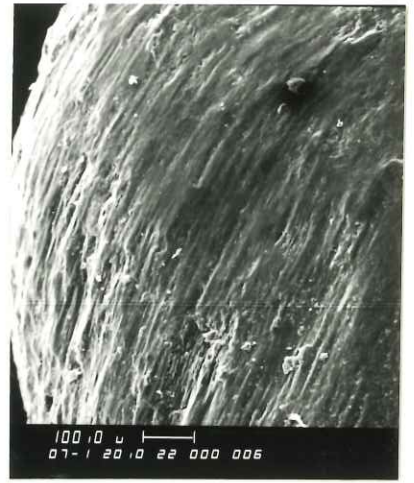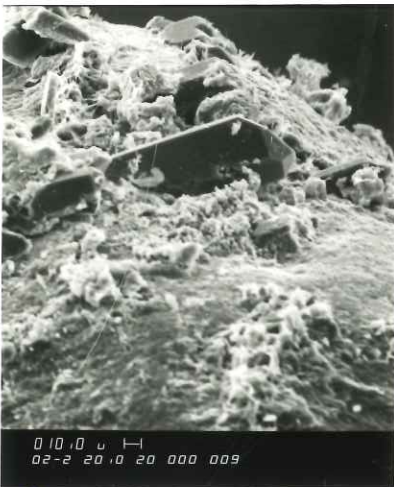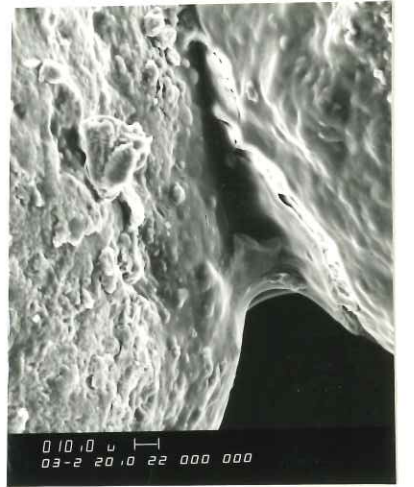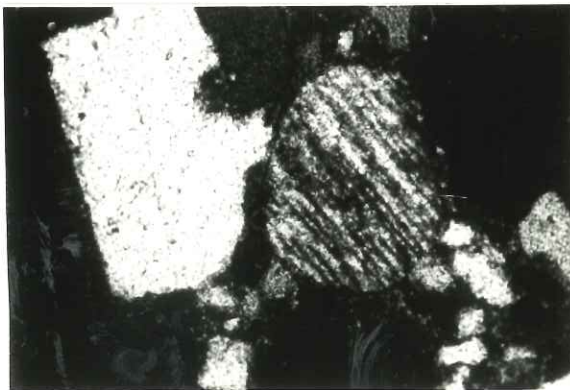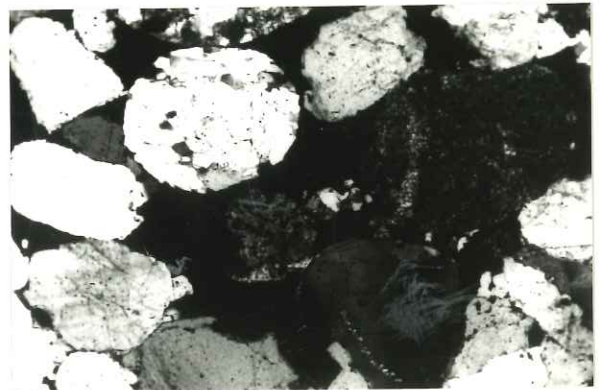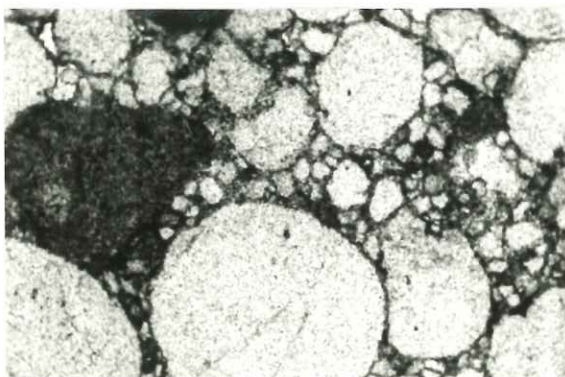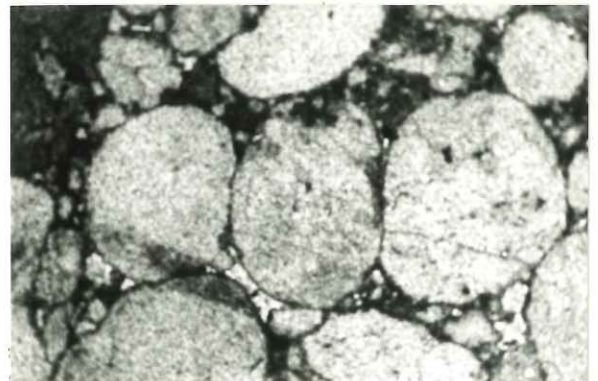
A distinctive traceable pebble horizon occurs 4 to 7 metres above the disconformity in the open-cut mine. Pebbles, well rounded, up to 1 cm long, occur in a narrow zone, among several silty horizons. They have no imbrication and lie suggesting that they were deposited from suspension, perhaps with the sand-size fraction. Professor R. WALKER (pers.comm.) suggested that the pebbles were deposited during storm activity, after the removal of the pebbles from the beach zone (Photo 2).

Closer to the disconformity, the sandstone may be cemented by chalcocite, bornite and pyrite. In sand wedges and clastic dykes (described later) bedding, marked by silty and sandy layers, is often vertical (Plate 3). These structures are therefore seen to have been filled by a single slumping event and not by a gradual filling of sand and silt.

Structures observed away from the mine included wave-formed ripples. These ripples are symmetrical in cross-section and have a wavelength of 3-4 cm. Some bifurcation of ripples represents a sand flat zone where wind-driven waves create similar ripples (Photo 9).

2.2 | Mineralogy

The mineralogy is predominantly quartz, showing two size populations (Plate 2). They show little or no development of overgrowths. Some quartz-composite grains are often ferruginised, and probably have been derived from the Pandurra Formation. Rock fragments, including devitrified volcanic grains, are present (5%) (Plate 2). The devitrified volcanics suggest an acid volcanic source for these grains, as basic volcanics would tend to decompose to clay (J. FODEN, pers.comm.). The Gawler Range Volcanics lying to the south west are considered the most probable source of these volcanic grains.

Potash feldspar, confirmed by staining methods, and plagioclase (An_{67-60}), usually about 1.5ϕ (0.4 mm) in diameter, make up 10% of the rock. Plagioclase grains are usually highly sericitised (Plate 2) The presence of plagioclase in such a mature sediment

suggests an arid or cold climate, which reduces chemical
weathering (GOSTIN, pers.comm.).

2.22 Grainsize Analysis:

Fig.7 shows a bimodal grain-size
distribution of the Whyalla sandstone, being deficient in
the 2ϕ-3ϕ size-range ($\frac{1}{4}$ - $\frac{1}{8}$ mm). The coarser mode, from
2 mm to $\frac{1}{4}$ mm, median of .75 mm, is very well rounded and
occupies 20-65% of the sediment, commonly 60%. The finer
fraction, median diameter of .08 mm, occupies 35-80% of
the sediment, usually about 40%.

Because this size-range is at a
minimum, it is possible that this grade was not produced
by the same rocks. However, it is present in the Pandurra
Formation (Fig.5), and, assuming the Whyalla sandstone was
derived from a number of sources, viz. Pandurra Formation,
volcanic and metamorphic terraines (by the presence of
these grains in the Pandurra thin section), this seems
unlikely.

Analysis of recent beach and near-
shore sands off the South African coast by FULLER (1961
and 1962) showed a similar bimodal distribution with grains
in the region 2ϕ - 3ϕ at a minimum. In discounting several
possible causes, e.g., differential abrasion rate or a
greater susceptibility to erosion for this fraction, he
favoured a two-stage fractionation process:
1) Firstly, the grains approximating and coarser than the
    2ϕ size would remain on the beach;
2) Fractionation would occur when the finer beach componen
    (i.e., around 2ϕ - 3ϕ) was carried inland by on-shore
    wind action.
Subsequent redistribution of depleted grains on the shallow
sea-floor would result in a bimodal size distribution.

The depletion of the 2ϕ-3ϕ size
fraction is not restricted to modern-day beaches. GOSTIN
noticed a similar depletion in Tertiary sands in his study
of the Mt. Martha Sand Beds on Mornington Peninsula (1964)

The 2ϕ - 3ϕ (.25-.125 mm) size-
fraction should be located in other areas, although subse-
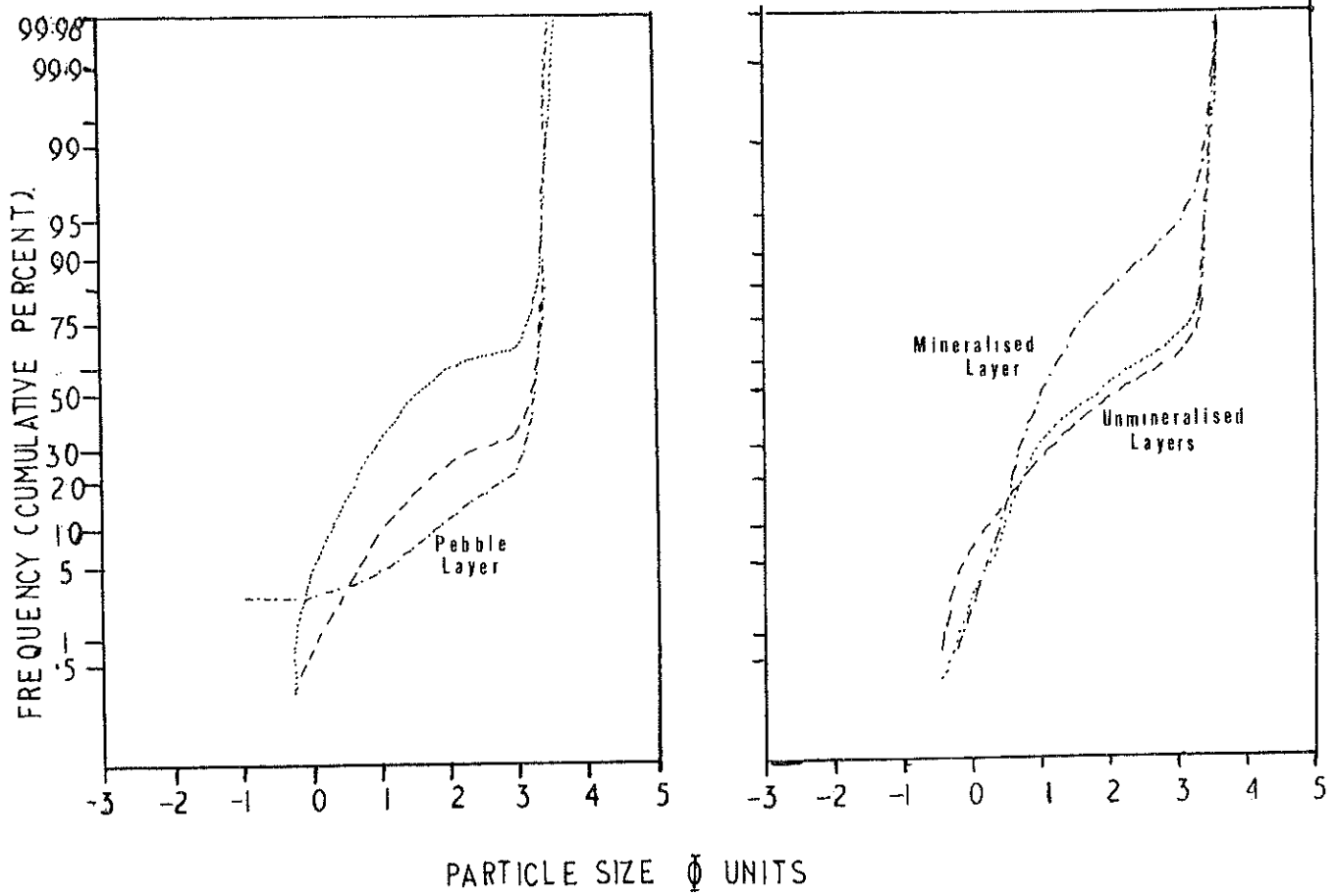
FIGURE 7 GRAINSIZE ANALYSIS

A. NUMBER OF CONTACTS PER GRAIN
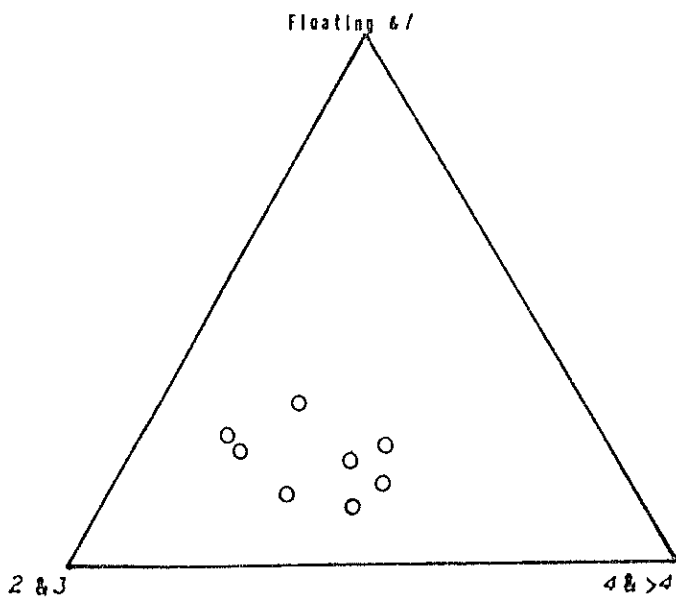
B. TYPE OF GRAIN CONTACTS
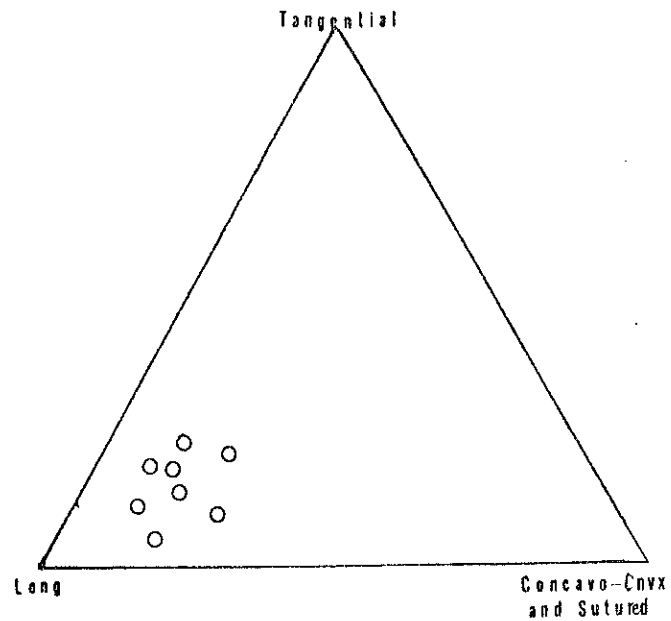
FIGURE 8 PACKING RESULTS

quent erosion may have removed it. It is noticeable that
the Tregolana Shale, which conformably overlies the
Whyalla Sandstone, is a green and purple-to-red, laminated
mudrock containing sandy layers. Grainsize ranges from
0.7 to 0.15 mm (CREELMAN, 1974). He also notes a high
degree of rounding and sphericity of the sand grains. It
is possible, therefore, that the wind-blown component of
the Whyalla sandstone was concentrated into the quieter
waters of the Tregolana Shale.

Another theory to explain this
deficiency of the 2ϕ - 3ϕ sand fraction was provided by
P. YPMA. He suggested that the packing of the well-
rounded, larger sand-sized population (it can represent
65% of the total range in sand sizes) could not accommodate
the 2ϕ - 3ϕ-sized particles. However, this coarser popu-
lation often represents only 30-40% of the constituent
grains, especially in silty layers. Why then, wasn't the
2ϕ - 3ϕ sand fraction accommodated in these layers?

The Whyalla sandstone, after a
grain-size analysis of eight thin sections (Table A2)
was found to be a poorly- to moderately well-sorted, near-
symmetrical to coarse-skewed sandstone. Mineralised
layers were strongly finely-skewed, however.

FRIEDMAN (1961) demonstrated that
ocean beach sands are negatively (coarse) skewed, while
MASON and FOLK (1958) concluded that beach sands at Mustang
Island were near-symmetrical but coarser-skewed than dune
and aeolian sediments. Sorting was found to be good for
all three environments, which is in contrast to those
results obtained for the Whyalla Sandstone. Mean size
ranges from 2.6ϕ to 2.96ϕ for the Mustang Island study,
while those for the Whyalla Sandstone have an average of
2.14ϕ.

Apart from the pebble horizon,
the mineralised layers of the Whyalla Sandstone are the
best sorted (Fig.7). It is assumed that the better porosity
and permeability associated with these horizons provided
the most favourable environment for the precipitation of
copper sulphides.

The Whyalla Sandstone is seen to represent a reworked beach environment. Syndepositional faulting during Whyalla sandstone time (cross-section, Fig.2A) is seen to be representative of the rising Pernatty Culmination. The Whyalla Sandstone sea therefore transgressed and regressed several times according to the rate of elevation of the culmination and the transgressing sea. In times of rapid elevation, the sea regressed and erosion of the culmination removed intervening lithologies, i.e., McIeay Beds and the Tapley Hill Formation. During periods of slower elevation, the marine transgression reworked beaches, creating the texturally-inverted Whyalla Sandstone. After elevation had ceased, the transgression proceeded further and the Tregolana Shale was deposited on flanks of the culmination.

Plate 3 depicts a sandstone tongue with a possible erosional interval in the Whyalla Sandstone. Here, horizontal bedding overlies the tongue, which is infilled with subvertical bedding.

WALKER (pers.comm.) commented on the lack of thickness (usually less than 1 metre) of transgressive beaches, while regressive beaches are noticeably thicker. The beach environment at the Cattlegrid open-cut is up to 10 m thick, before the sands form large-scale crossbeds probably representing aeolian sands. This thickness is therefore considered to represent several periods of transgressions and regressions.

2.23 Packing (see Plate 2):

Results are given in Appendix IV and are diagrammatically represented in Fig.8.

The noticeable difference between the packing in the Whyalla Sandstone and the Pandurra Formation is the amount of pressure contacts. Only 10% of all contacts in the Whyalla Sandstone are concavo-convex or sutured, while the Pandurra Formation contains 19%. Hence, although compaction has occurred, it was not as intense as that described for the quartzite.

Little importance is placed upon the number of contacts per grain in the Whyalla sandstone. The large percentage of smaller-sized grains has infilled pores between larger grains and has increased the number of contacts.

2.24 SEM analysis on Whyalla Sandstone grains (Plate 2)

This work proved to be of little help in confirming or refuting any single depositional environment. Structures such as chatter marks, upturned plates (indicative of aeolian sands), glacial features (high relief, angular sheeting and conchoidal fractures), V-shaped pits and grooves (turbulent subsqueous environments), were not found.

Solution hollows were abundant, and striations of unknown origin were also observed (Photo (C)). The cementing of rounded grains by clay is shown in Photomicrograph (F). The well-formed chalcocite crystals were also seen growing upon quartz grains (D).

CHAPTER III: GENESIS OF BRECCIATION

3.1 BRECCIATION

HEAPE (1978) described three main breccia types at the Cattlegrid Open-Cut:

1) Cattlegrid Breccia: Angular to sub-rounded, often tabular or lath-shaped quartzite fragments randomly orientated in a clay matrix and grading upwards into a Whyalla sandstone matrix. The former is usually only locally mineralised, while the latter can contain a richly-mineralised sandstone matrix.

2) Mosaic or Tensional Breccia: An "in situ" breccia, in which crossbedded or flatlying quartzite is broken up along bedding planes and preferred orientations of quartz grains (Photo 7). Vughs and cavities are created in between fracture blocks (Photo 6). Sulphide mineralisation is prolific in these zones, occupying fractures and joints, vughs and cavities in between clasts. Sulphides include chalcocite (Cu_2S) and bornite (Cu_5FeS_4), with minor amounts of chalcopyrite ($CuFeS_2$) and pyrite (FeS_2).

3) Crush Breccia: Not as common as the above two. Tectonic breccias developed in fault zones and within shale bands.

3.11 CATTLEGRID BRECCIA

According to the classification of NORTON (1917), the breccia ranges from a mosaic breccia in which fragments can still be matched along adjacent surfaces to a rubble breccia in which fragments, although close-set and in touch, cannot be matched together. Less frequently, single clasts of quartzite are floating in a sandstone matrix with no other clasts within 5-10 cm, e.g., in clastic dykes and wedges and immediately above the clay filling breccia. Rarely a "crackle breccia" occurs, i.e., fragments have suffered little displacement (Photo 8).

In all cases, clasts are usually angular, elongated in one dimension with size ranging

PHOTO 7:   Typical Mosaic breccia with cross-beds defined
           by breccias lying along the foresets.   Good
           mineralisation coats quartzite blocks.

PHOTO 8:   Crackle Breccia when fragments can be matched
           together again.   Mineralisation lines
           fractures.

PHOTO 9:   Ripple marks in Whyalla Sandstone.   12 km
           south of the Mine.

from tiny chips (less than 3 mm in length) to fragments
up to 40 cm long. Some rounding of tabular clasts does
occur, indicating transport or abrasion of blocks.

Breccia with clay matrix:

The clay has identical mineralogy
to the quartzite clasts. It consists of quartz grains
and a kaolinite ground mass. Quartz grains are not parti-
cularly rounded, have occasional overgrowths and are
derived from the quartzite. Mineralisation is irregular
and can occur as a rich matrix cementing clasts together.

Breccia with Whyalla Sandstone matrix:

This is NORTON'S residual breccia
corresponding in position to a basal conglomerate. Often
cementing the rounded grains is sulphide mineralisation
of chalcocite with lesser amounts of bornite, covellite
and pyrite. Where mineralisation is absent, the cementing
medium is the silt that occurs on horizontal laminations
characteristic of the Whyalla sandstone at the Cattlegrid
deposit.

3.111   NATURE OF BRECCIATION

Considerable debate has arisen
as to the cause of layers of broken rock called breccia.
More importantly, mineralisation is often associated with
structurally-complex geology of which brecciated sequences
form a major part. Some workers, e.g., BRYNER (1961),
have even suggested that the breccias were produced as a
result of mineralisation.

The theories for the formation
of the brecciated upper Pandurra Formation quartzite can
be grouped under three headings:
1)   Sedimentary Brecciation, formed by lithification of
     scree or talus, by desiccation during sedimentation
     and by slumping during lithification;
2)   Endolithic Brecciation, brecciated due to forces
     within the lithosphere due to introduction of fluids;
3)   Tectonic Brecciation, formed by folding, faulting and
     forceful intrusion.

Those relevant to Mt. Gunson
include:

SEDIMENTARY 1) Talus Breccia   i) Derived from a fault
                                     scarp or cliff where
                                     clasts accumulated
                                     as a scree;
                                 ii) Landslide Breccia;
            2) Brecciation due to Geocryology, i.e., the
               break-up of the quartzite by the action
               of ice as in a permafrost region;
            3) Bajada Breccia -- rock waste due to mecha-
               nical erosion and aggregated by inter-
               mittent streams;
            4) Regolith Breccia -- that produced through
               a normal weathering cycle;
ENDOLITHIC 5) Chemical Brecciation;
            6) Solution Brecciation;
TECTONIC   7) Bedding fault brecciation

3.112 SEDIMENTARY

It is unlikely that the Cattlegrid
Breccia is a Talus Breccia. Unlike talus breccias, the
Cattlegrid Breccia occurs as a predominant covering
throughout the open-cut and was also observed 10 km south
of the mine. It is rarely greater than 3 m thick (Fig.3),
being quite uniform thickness at about 1.9-2.5 m. No
stratification was observed, and although faults occur in
the mine, the breccia is often spatially unrelated to
faulting (Fig.4). No relationships were observed that
suggested a talus deposit adjacent to a hill slope
(Fig.3).

Accumulations of coarse detritus
on level surfaces have been termed "blockfields", and the
processes producing them are connected with the freeze-
thaw environment (EMBLETON and KING, 1975). They are
characterised by coarse angular blocks of local material
or rock debris from more distant sources brought in by
glacial ice. The Cattlegrid Breccia includes both angular
to sub-rounded quartzite fragments not usually greater
than 30 cm long, and averaging 15 cm. The association of

angular and sub-rounded forms is not unusual in freeze-thaw environments. DERBYSHIRE (1972) argues that the conjunction of the two is explained by local differences in the micro-climate. Some rounding may be due to wind abrasion, chemical weathering, or even transport during times of stream-flow. In the case of the Pandurra quartzite, the blockfield could have resulted from the frost shattering of the well-jointed and well-bedded rock. However, the presence of an abundant clay matrix and the presence of the fine-grained fragments and chips causes a problem as these properties are not present in today's blockfields.

Wide slopes of rock waste are not restricted to the cold climates. Arid, warm regions commonly produce areas of angular to sub-rounded fragments called "bajada", or, more recently, gibber plains. The fragments have been detached by mechanical weathering, but unlike other sub-aerial breccias, the bajada has been aggregated by intermittent streams and some degree of rounding is present. The matrix of the bajada consists of the finer stream wash and of dust and sand contributed by the wind. It is imperfectly stratified, with bedding often local and ill-defined with unsorted beds passing vertically and horizontally into those well-sorted. Ancient breccias, as with other types discussed, are not necessarily associated with the buried uplands which supplied their waste. Such elevations may have been destroyed by later denudation

Most reported ancient bajadas, e.g., Permian breccias of the Midlands, England, are wedge-shaped though of a much larger scale than the talus breccia Some, being more than 200' thick at one end, thin out within four to eight miles.

One of the reasons Figure 3 was constructed was to observe any change in the thickness of the breccia, and whether this change was related to the topography of the Pandurra palaeo-surface. If the Cattle-grid Breccia was a product of weathering, it was hoped to show an increase of breccia thickness in troughs of the palaeo-surface where weathering would be strongest and breccias would have concentrated, after moving downhill.

However, no such relationship was observed although breccia thickness did rarely decrease on topographic highs of the Pandurra palaeo-surface (Fig.3). Presumably the marine transgression represented by the Whyalla Sandstone eroded away much of the loose breccias.

The Cattlegrid breccia is also considered to be due to a normal weathering cycle. The quartzite blocks are now cemented by a silt-and-clay matrix derived from the weathering of the fragments themselves.

3.113 ENDOLITHIC

SAWKINS (1969) suggested a Chemical mode as a means of breccia formation. He concluded that brecciation is thought to be related to "expansive cracking of chert during emplacement of mineralisation", resulting in crackle brecciation (mentioned above). At the Cattlegrid, the quartzite is the possible expansive phase as the presence of chert is only trace. However, in areas spatially separated from the open-cut, both types of breccia, i.e., Cattlegrid and mosaic breccia were observed, unmineralised. Crackle breccia was present in the open cut (Photo 8), but several instances portrayed the fractures lined with clay and silt.

RIDGE (1968) suggested a collapse mechanism for brecciation in Mississippi Valley-type deposits. He considered that forces generated during down-setting of beds accompanied solution-thinning of underlying units. However, at the Cattlegrid, the host lithology to any solution-thinning is quartzite and not carbonate as in Ridge's examples, and the brecciation does not occur as in a cave-in habit. Secondly, the fine-grained texture of some of the fragments is hard to explain by a collapse mechanism. Thirdly, the isometric diagram constructed from drill logs does not support solution-thinning as a means to brecciation (Fig.3).

3.114 TECTONIC

The Cattlegrid Breccia could have been developed by the lateral movement of the quartzite

mass along bedding faults or decollément surfaces.
YPMA (pers.comm.) has suggested that the disorientated and
sometimes rounded Cattlegrid Breccia is the result of
movement along such a surface. Evidence for movement
along the clay band has already been mentioned.

According to YPMA, movement along
the clay band and possibly other surfaces was initiated
by very dense brines (their presence has been confirmed
by a fluid-inclusion analysis, discussed later), creating
a buoyancy effect. Upcoming dense brines were channelled
into the Pernatty Culmination, and pore and fracture pres-
sures began to rise. Confinement of the fluids to the
fractured and permeable quartzite by the overlying poorly-
sorted Whyalla Sandstone enabled pore pressures to appro-
ximate lithostatic pressures. Instability of the quartzite
mass was initiated, followed by sliding and slumping along
decollément surfaces, for example, the clay band. Brec-
ciation of the quartzite resulted and the grinding of
fragments together enabled the rounding of blocks to occur.
Attrition of quartzite fragments together created the
clay and silt which now cements fragments together.

Extension effects were observed
(Photo 10) suggesting tensional phenomena, in accordance
with sliding. Compressional features, e.g., anticlines
and neighbouring synclines and crushing, were not seen.
However, such compressional effects are not necessarily
strong when referring to slides or movement along a decol-
lément surface. Faulting is common (Fig.4) with some rare
low-angle reverse faults recorded, while mapping of faces
at the mine revealed inexplicable disappearances of the
clay band.

3.12   MOSAIC BRECCIA

The Mosaic breccia is considered
to be the result of a normal chemical weathering cycle
such as that associated with a regolith. Upon mild tec-
tonic activity, the quartzite fractured along planes of
weakness emphasised by the weathering cycle, e.g., bedding
and preferred orientations of grains along bedding planes.

The breccia is not considered to be the result of geo-cryology, as the "in situ" blocks are not irregularly broken up and shattered, as might be suggested with the successive freezing and thawing of ice.

CHAPTER IV: DESCRIPTION AND GENESIS OF STRUCTURES

4.1   TEPEE-LIKE STRUCTURES

Anticlinal structures up to 4 m high were observed. Mineralisation was very good in the flanks and axis of the structures. They were always observed in the mosaic breccia in the uppermost Pandurra Formation. They varied from 55 cm to 4 metres high and from 35 cm to 3 m wide. A typical structure lies on flat-bedded quartzite, and in the basal central area of the structure a small anticline may be visible. This fold gradually increases in amplitude in successively overlying beds until the quartzite clasts have brittlely fractured or become wedged apart. Bedding can be traced across the structure, indicating no displacement by fault movements. Bedding continues to incline upwards, resulting in an anticline resembling an Indian tent, or tepee. Occasionally, bedding becomes overturned. The structures are always symmetric with equal dips on either side of the anticlinal structure. One example did show some degree of asymmetry where one side had been pushed over to one side (Plate 4).

The bedding of the anticlinal structures is always brecciated in a manner typical of the mosaic breccia. Spaces between clasts in limbs of anticlines are abundant. Brecciation has preceded anticlinal development. If it had post-dated the folding episode, blocks would tend to lie flush against each other.

Lying immediately above anticlinal structures was the Cattlegrid Breccia. Due to the chaotic nature of this breccia, it was not possible to determine if any disturbance had affected its deposition, e.g., upward injections of water from the anticlines. However, TONKIN (pers.comm.) has noted the presence of quartzite breccias "splaying out" above the tepees and now "floating" in a Whyalla sandstone. Others were truncated by the disconformity with the overlying sandstone removed by mine equipment, as the disconformity represents "top of ore". In one example (Plate 3), the tepee was "breached" and was filled with vertically-bedded Whyalla Sandstone, mineralised along several bedding planes. Anticlinal

PHOTO 10:   Extension effects in breccias, perhaps due
to tensional forces associated with lateral
movement.

PHOTO 11:   Folds in Landslide. Note large quartzite
blocks floating in chaotic mixture of
sandstone and quartzite. Location: Mine.

PHOTO 12:   Tepee-like anticline located 12 km south
of mine site.

from tiny chips (less than 3 mm in length) to fragments up to 40 cm long. Some rounding of tabular clasts does occur, indicating transport or abrasion of blocks.

Breccia with clay matrix:

The clay has identical mineralogy to the quartzite clasts. It consists of quartz grains and a kaolinite ground mass. Quartz grains are not particularly rounded, have occasional overgrowths and are derived from the quartzite. Mineralisation is irregular and can occur as a rich matrix cementing clasts together.

Breccia with Whyalla Sandstone matrix:

This is NORTON'S residual breccia corresponding in position to a basal conglomerate. Often cementing the rounded grains is sulphide mineralisation of chalcocite with lesser amounts of bornite, covellite and pyrite. Where mineralisation is absent, the cementing medium is the silt that occurs on horizontal laminations characteristic of the Whyalla sandstone at the Cattlegrid deposit.

3.111   NATURE OF BRECCIATION

Considerable debate has arisen as to the cause of layers of broken rock called breccia. More importantly, mineralisation is often associated with structurally-complex geology of which brecciated sequences form a major part. Some workers, e.g., BRYNER (1961), have even suggested that the breccias were produced as a result of mineralisation.

The theories for the formation of the brecciated upper Pandurra Formation quartzite can be grouped under three headings:
1) Sedimentary Brecciation, formed by lithification of scree or talus, by desiccation during sedimentation and by slumping during lithification;
2) Endolithic Brecciation, brecciated due to forces within the lithosphere due to introduction of fluids;
3) Tectonic Brecciation, formed by folding, faulting and forceful intrusion.

Those relevant to Mt. Gunson
include:

SEDIMENTARY 1) Talus Breccia   i) Derived from a fault
scarp or cliff where
clasts accumulated
as a scree;
ii) Landslide Breccia;

2) Brecciation due to Geocryology, i.e., the
break-up of the quartzite by the action
of ice as in a permafrost region;

3) Bajada Breccia -- rock waste due to mecha-
nical erosion and aggregated by inter-
mittent streams;

4) Regolith Breccia -- that produced through
a normal weathering cycle;

ENDOLITHIC 5) Chemical Brecciation;

6) Solution Brecciation;

TECTONIC 7) Bedding fault brecciation

3.112   SEDIMENTARY

It is unlikely that the Cattlegrid
Breccia is a Talus Breccia. Unlike talus breccias, the
Cattlegrid Breccia occurs as a predominant covering
throughout the open-cut and was also observed 10 km south
of the mine. It is rarely greater than 3 m thick (Fig.3),
being quite uniform thickness at about 1.9-2.5 m. No
stratification was observed, and although faults occur in
the mine, the breccia is often spatially unrelated to
faulting (Fig.4). No relationships were observed that
suggested a talus deposit adjacent to a hill slope
(Fig.3).

Accumulations of coarse detritus
on level surfaces have been termed "blockfields", and the
processes producing them are connected with the freeze-
thaw environment (EMBLETON and KING, 1975). They are
characterised by coarse angular blocks of local material
or rock debris from more distant sources brought in by
glacial ice. The Cattlegrid Breccia includes both angular
to sub-rounded quartzite fragments not usually greater
than 30 cm long, and averaging 15 cm. The association of

angular and sub-rounded forms is not unusual in freeze-thaw
environments. DERBYSHIRE (1972) argues that the conjunc-
tion of the two is explained by local differences in the
micro-climate. Some rounding may be due to wind abrasion,
chemical weathering, or even transport during times of
stream-flow. In the case of the Pandurra quartzite, the
blockfield could have resulted from the frost shattering
of the well-jointed and well-bedded rock. However, the
presence of an abundant clay matrix and the presence of
the fine-grained fragments and chips causes a problem as
these properties are not present in today's blockfields.

Wide slopes of rock waste are not
restricted to the cold climates. Arid, warm regions com-
monly produce areas of angular to sub-rounded fragments
called "bajada", or, more recently, gibber plains. The
fragments have been detached by mechanical weathering,
but unlike other sub-aerial breccias, the bajada has been
aggregated by intermittent streams and some degree of roun-
ding is present. The matrix of the bajada consists of the
finer stream wash and of dust and sand contributed by the
wind. It is imperfectly stratified, with bedding often
local and ill-defined with unsorted beds passing vertically
and horizontally into those well-sorted. Ancient breccias,
as with other types discussed, are not necessarily associ-
ated with the buried uplands which supplied their waste.
Such elevations may have been destroyed by later denudation

Most reported ancient bajadas,
e.g., Permian breccias of the Midlands, England, are wedge-
shaped though of a much larger scale than the talus breccia
Some, being more than 200' thick at one end, thin out with-
in four to eight miles.

One of the reasons Figure 3 was
constructed was to observe any change in the thickness of
the breccia, and whether this change was related to the
topography of the Pandurra palaeo-surface. If the Cattle-
grid Breccia was a product of weathering, it was hoped to
show an increase of breccia thickness in troughs of the
palaeo-surface where weathering would be strongest and
breccias would have concentrated, after moving downhill.

However, no such relationship was observed although breccia thickness did rarely decrease on topographic highs of the Pandurra palaeo-surface (Fig.3). Presumably the marine transgression represented by the Whyalla Sandstone eroded away much of the loose breccias.

The Cattlegrid breccia is also considered to be due to a normal weathering cycle. The quartzite blocks are now cemented by a silt-and-clay matrix derived from the weathering of the fragments themselves.

3.113 ENDOLITHIC

SAWKINS (1969) suggested a Chemical mode as a means of breccia formation. He concluded that brecciation is thought to be related to "expansive cracking of chert during emplacement of mineralisation", resulting in crackle brecciation (mentioned above). At the Cattlegrid, the quartzite is the possible expansive phase as the presence of chert is only trace. However, in areas spatially separated from the open-cut, both types of breccia, i.e., Cattlegrid and mosaic breccia were observed, unmineralised. Crackle breccia was present in the open cut (Photo 8), but several instances portrayed the fractures lined with clay and silt.

RIDGE (1968) suggested a collapse mechanism for brecciation in Mississippi Valley-type deposits. He considered that forces generated during down-setting of beds accompanied solution-thinning of underlying units. However, at the Cattlegrid, the host lithology to any solution-thinning is quartzite and not carbonate as in Ridge's examples, and the brecciation does not occur as in a cave-in habit. Secondly, the fine-grained texture of some of the fragments is hard to explain by a collapse mechanism. Thirdly, the isometric diagram constructed from drill logs does not support solution-thinning as a means to brecciation (Fig.3).

3.114 TECTONIC

The Cattlegrid Breccia could have been developed by the lateral movement of the quartzite

mass along bedding faults or decollément surfaces.
YPMA (pers.comm.) has suggested that the disorientated and
sometimes rounded Cattlegrid Breccia is the result of
movement along such a surface. Evidence for movement
along the clay band has already been mentioned.

According to YPMA, movement along
the clay band and possibly other surfaces was initiated
by very dense brines (their presence has been confirmed
by a fluid-inclusion analysis, discussed later), creating
a buoyancy effect. Upcoming dense brines were channelled
into the Pernatty Culmination, and pore and fracture pres-
sures began to rise. Confinement of the fluids to the
fractured and permeable quartzite by the overlying poorly-
sorted Whyalla Sandstone enabled pore pressures to appro-
ximate lithostatic pressures. Instability of the quartzite
mass was initiated, followed by sliding and slumping along
decollément surfaces, for example, the clay band. Brec-
ciation of the quartzite resulted and the grinding of
fragments together enabled the rounding of blocks to occur.
Attrition of quartzite fragments together created the
clay and silt which now cements fragments together.

Extension effects were observed
(Photo 10) suggesting tensional phenomena, in accordance
with sliding. Compressional features, e.g., anticlines
and neighbouring synclines and crushing, were not seen.
However, such compressional effects are not necessarily
strong when referring to slides or movement along a decol-
lément surface. Faulting is common (Fig.4) with some rare
low-angle reverse faults recorded, while mapping of faces
at the mine revealed inexplicable disappearances of the
clay band.

3.12   MOSAIC BRECCIA

The Mosaic breccia is considered
to be the result of a normal chemical weathering cycle
such as that associated with a regolith. Upon mild tec-
tonic activity, the quartzite fractured along planes of
weakness emphasised by the weathering cycle, e.g., bedding
and preferred orientations of grains along bedding planes.

The breccia is not considered to be the result of geo-
cryology, as the "in situ" blocks are not irregularly
broken up and shattered, as might be suggested with the
successive freezing and thawing of ice.

CHAPTER IV: DESCRIPTION AND GENESIS OF STRUCTURES

4.1   TEPEE-LIKE STRUCTURES

Anticlinal structures up to 4 m high were observed. Mineralisation was very good in the flanks and axis of the structures. They were always observed in the mosaic breccia in the uppermost Pandurra Formation. They varied from 55 cm to 4 metres high and from 35 cm to 3 m wide. A typical structure lies on flat-bedded quartzite, and in the basal central area of the structure a small anticline may be visible. This fold gradually increases in amplitude in successively overlying beds until the quartzite clasts have brittlely fractured or become wedged apart. Bedding can be traced across the structure, indicating no displacement by fault movements. Bedding continues to incline upwards, resulting in an anticline resembling an Indian tent, or tepee. Occasionally, bedding becomes overturned. The structures are always symmetric with equal dips on either side of the anticlinal structure. One example did show some degree of asymmetry where one side had been pushed over to one side (Plate 4).

The bedding of the anticlinal structures is always brecciated in a manner typical of the mosaic breccia. Spaces between clasts in limbs of anticlines are abundant. Brecciation has preceded anticlinal development. If it had post-dated the folding episode, blocks would tend to lie flush against each other.

Lying immediately above anticlinal structures was the Cattlegrid Breccia. Due to the chaotic nature of this breccia, it was not possible to determine if any disturbance had affected its deposition, e.g., upward injections of water from the anticlines. However, TONKIN (pers.comm.) has noted the presence of quartzite breccias "splaying out" above the tepees and now "floating" in a Whyalla sandstone. Others were truncated by the disconformity with the overlying sandstone removed by mine equipment, as the disconformity represents "top of ore". In one example (Plate 3), the tepee was "breached" and was filled with vertically-bedded Whyalla Sandstone, mineralised along several bedding planes. Anticlinal

PHOTO 10: Extension effects in breccias, perhaps due
to tensional forces associated with lateral
movement.

PHOTO 11: Folds in Landslide. Note large quartzite
blocks floating in chaotic mixture of
sandstone and quartzite. Location: Mine.

PHOTO 12: Tepee-like anticline located 12 km south
of mine site.

DESCRIPTION OF PLATE 3:

a) Whyalla Sandstone tongue in Cattlegrid Breccia. The flat undisturbed bedding above the tongue could reflect an erosional interval.

b) Large sandstone wedge bounded by upturned and overturned breccias. Later lateral movement has probably increased the angle of bedding to near vertical within the wedge.

c) Injection of quartzite blocks along the clay band. Note contortions in upper left of drawing.

d) Tepee-like anticline to the left of sandstone wedge.

cms

MetreS

Metres.

Metre
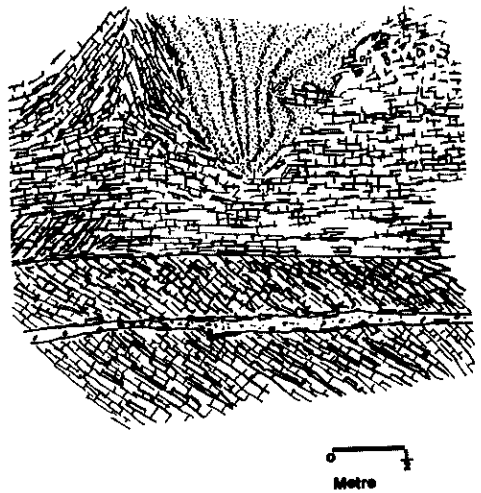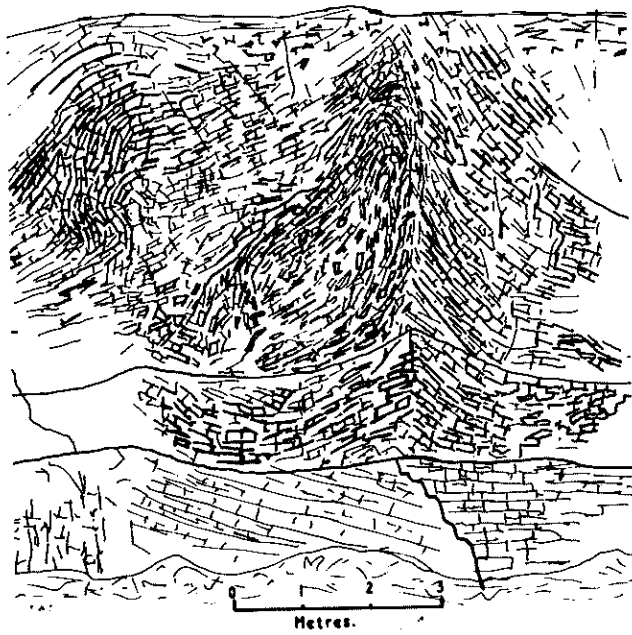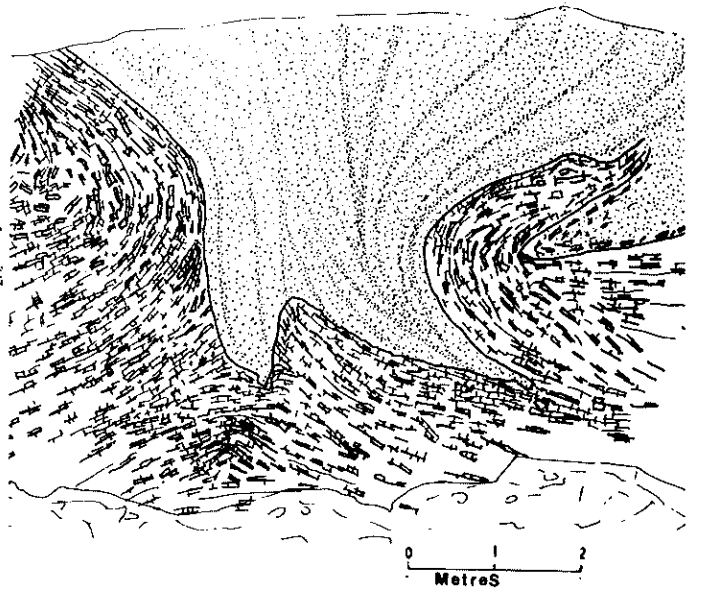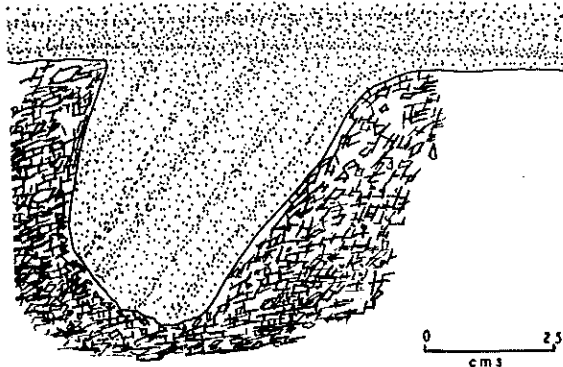
structures are not restricted to the mineralised ore body (Photo 12). Here, approximately 10 km south of the mine, along strike of the Pernatty Culmination, the structures (three were found within an area of 50 m^2) were filled with a clay matrix, similar to that described for the Cattlegrid breccia. Their dimensions were less, never greater than 1.5 m high.

4.2   SANDSTONE WEDGES

These were seen at the Pandurra Formation--Whyalla Sandstone disconformity and intruding downwards into the Cattlegrid Breccia or Tensional Breccia. They were always wedge-shaped (Plate 4). They ranged in width from 40 cm to 2.2 metres at the top and between 85 cm to 1.9 m long. They were infilled by vertically-bedded Whyalla Sandstone, occasionally mineralised, and containing the well-rounded spherical quartz grains. This fact probably assisted the sandstone's ability to flow into the wedges.

Quartzite clasts have been incorporated into the wedges and are lying parallel to bedding within the wedges, viz., sub-vertically. Diverging of bedding around quartzite obstacles within the wedge walls occurs (Plate 3), while some infiltration of sand grains occurred through the quartzite fractures (Photo A3).

All wedges, in becoming narrower at the bottom, possessed a basal tail. In this tail, the percentage of silt markedly increased at the expense of sand grains.

4.3   OTHER STRUCTURES

Other structures observed included several anticlines resembling those seen at the base of many tepee-like structures. They were only anticlines and not accompanying synclines, amplitudes of 40-60 cm and half wavelengths of up to 1 metre. Bedding above anticlines returned to horizontal. A palaeolandslide was observed, with large quartzite blocks "floating" in a chaotic mixture of breccia and Whyalla Sandstone. Parts of the slide were contorted into recumbent folds reflecting

the slide colliding and piling up into the valley (Photo 11). Bordering the slide was the original hillside in which the slide moved down.

(Plate 3c) shows an unusual injection of breccia along a clay band, while contortions of bedding in the left-hand corner of the diagram suggest pushing up of the block against the discontinuity in the centre of the diagram.

A slump of sandstone into the Cattlegrid breccia is shown in (Plate 3). This structure reflects two periods of deposition for the Whyalla Sandstone separated by an erosional interval. Bedding in the slump is sub-vertical and overlain by horizontal bedding showing no signs of slumping downwards. If this is the case, mineralised bedding is also vertical and horizontal, suggesting two periods of mineralisation, one before and one after the erosional interval.

Sand dykes, with parallel sides, also intrude down through the Cattlegrid Breccia from the overlying Whyalla Sandstone. This structure, 2 m long, is not vertical but curves around, as it intrudes deeper into the Breccia. Bedding made up of Whyalla sandstone is vertical and quartzite fragments have been removed from the bordering breccia and now "float" in the sandstone dyke. Mineralised bedding is also vertical while the mineralisation in the surrounding breccia is poor (Photo A2)

4.41   INTERPRETATION

Tepees have been well documented in the literature. Many theories have been suggested for their formation. ASSERETO and KENDALL (1977) listed six theories for their formation, of which three can be disregarded because they explain tepee formation in carbonate lithologies or caliche soil.

Those theories relevant to tepees observed at the Cattlegrid are:

1) Tectonic thrusting and compression of beds of unconsolidated sediment displaced by differential loading or movement due to gravity. In this case, the clay

DESCRIPTION OF PLATE 4:

a) Asymmetrical tepee-like anticline with disturbed bedding. The disturbed bedding on the right (containing Whyalla Sandstone grains) is assumed to have resulted from slump movements along the clay band, causing water to be ejected upwards into the cohesionless quartzite, resulting in the formation of the anticline. Lateral movement to the right has possibly caused overturning of breccias. Another possibility is that lateral movement caused the tepee-like anticline itself where two colliding blocks have deformed the breccias into the anticline. This reflects those ideas proposed by YP?A and HEYL et al. (1959)

b) Nature of breccias in axis of anticline. The open framework and abundant cavities and vughs (now filled by mineralisation) does not suggest any compressional movements, although in lateral sliding, no such features need to be abundant.

c) Typical Ice or Sand Wedges. Note vertical and sub-vertical bedding. They bear a strong resemblance to those reported by BLACK (1976).

PLATE 4

Metres
0   1   2

0   30
CMS.

0   1   2   3
Metres
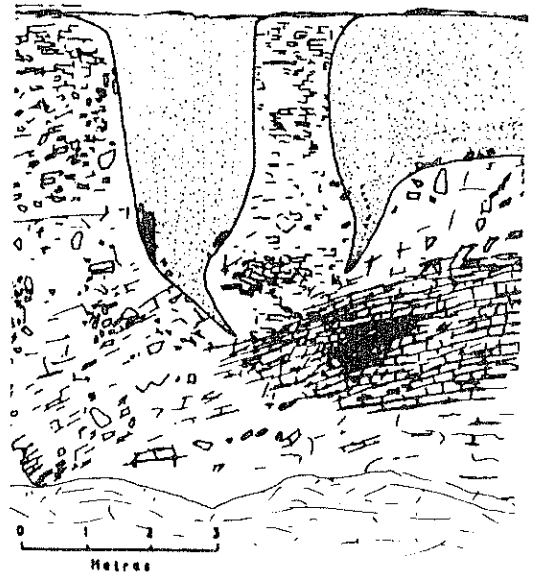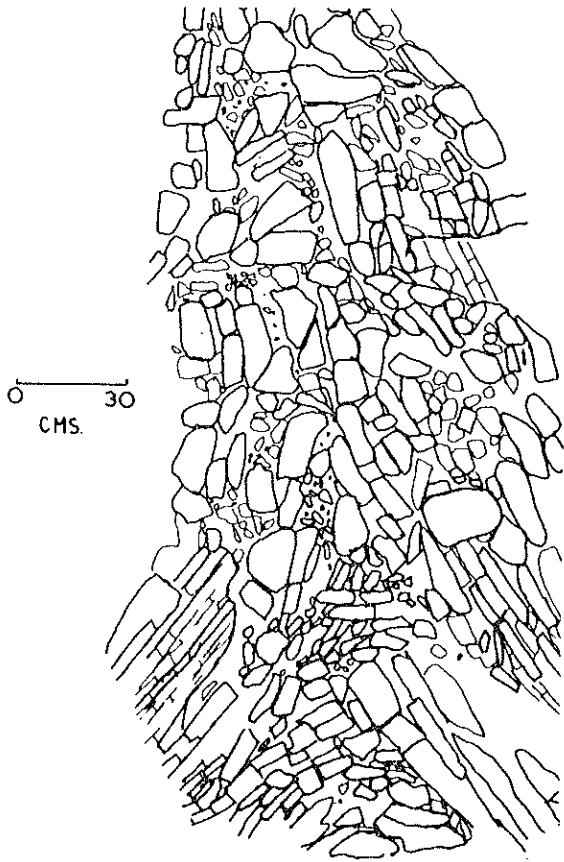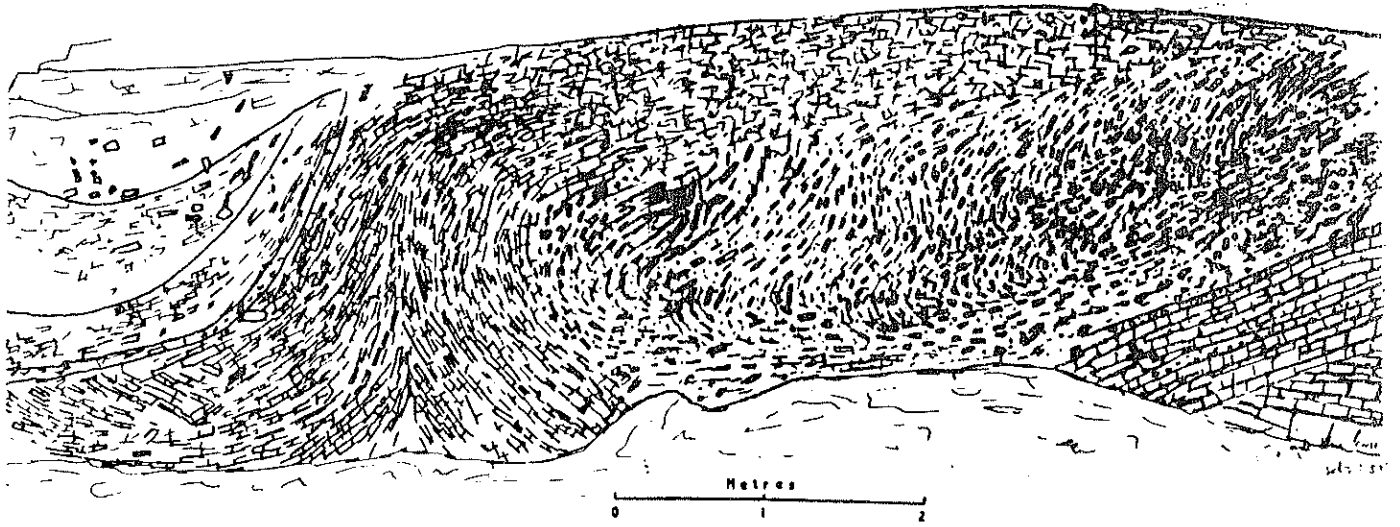
band at the Cattlegrid deposit acted as the slip plane;

2) Tepees were caused by the lateral and vertical movement of evaporites which have since been dissolved;

3) ASSERETO and KENDALL suggest they form by the expansion of crystallising cements in the internal pores, joints and fractures. When the crests of the buckled sediment were traced in plan, they intersected each other to form an irregular polygonal plan;

4) DALGARNO (pers.comm.) suggests tepees are due to water-escape mechanisms;

5) Frozen-ground phenomena. When the ice melts, the quartzite is fluidised and, according to differential pressures of frozen and thawed ground and the differential loading of overlying sediment, the brecciated beds are forced upwards. Similar mechanisms produce involution seen in cold climates today.

Theories 2) and 3) are discounted because the author believes that the presence of the silty clay, of similar composition to the quartzite breccias seen in the unmineralised tepees, was incorporated soon after deposition of the quartzite due to weathering and that the later formation of evaporites or an expansive cement that has since been removed, is considered very unlikely. Also, some tepees are over 3 m in height, and even show overturning. ASSERETO and KENDALL'S examples rarely exceed 1.5 m in height, while those of SMITH (1974) are measured in inches.

T. HAMMOND (Grade Control Officer Cattlegrid Mine; pers.comm.) is of the opinion that the tepees are of a generally point source, i.e., in plan, they are circular. TONKIN and DALGARNO(pers.comm.) have noted the presence of trails of quartzite fragments in Whyalla Sandstone above some tepees. This would support fluid escape via the axis of the tepees. In one structure (Plate 4), the slump, assumed to be due to sliding along the slipping clay band, caused water ejection and the formation of the bordering tepee. However, overlying strata is undisturbed and splaying out of the top of the tepee was not observed. The slump contained well-rounded

quartz grains showing a lack of overgrowths in thin
section and are probably Whyalla sand grains. If the
above hypothesis is true, tepee formation probably occurred
in Whyalla Sandstone times.

According to STEARNS (1966),
permafrost is defined as a thickness of soil or bedrock
at a variable depth beneath the surface of the earth in
which temperature below freezing has continually existed
for a long time.

Above the permafrost there may be
a zone in which temperature conditions vary seasonally.
This is the "active layer" and thaws out when temperatures
rise sufficiently and refreeze in winter or in cold spells
(or even partly at night) to depths of above 3 m depending
on climate.

Unfrozen layers are known within
permafrost, and are termed "taliks". They may reflect
former climatic changes or they may represent aquifers
containing water highly mineralised or under pressure, for
instance.

The anticlinal structures descri-
bed above are considered due to periglacial mass movement
processes. Frozen ground usually contains ice to a volume
much greater than the volume of pore space. On melting,
the grains or blocks are separated from each other by
films of water, and the mass lacks cohesion. The perma-
nently-frozen ground prevents percolation of the water
downward and may even act as a slip plane. The term "geli-
fluction" is used to define the flow of a water-soaked
mass over the permafrost or seasonally-frozen sub-surface
layers. Gravity is assumed to be the motivating force.
Movement is extremely slow, around 2 cm per year due to
the low gradients. Gradients of the Pandurra palaeosurface
are up to 3.5°, calculated from the isometric diagram,
Figure 3. Considering the lack of cohesion of the sediment
during times of thawing, these gradients are sufficient
to initiate movement.

BENEDICT (1970) showed a decreasing
of velocity of such movements with depth. Although such

movement could have caused brecciation and rounding, brecciation is considered to be primarily the result of pre-permafrost activity — a bajada breccia (Cattlegrid Breccia) grading down to a jointed and well-bedded mosaic bedrock, subjected to weathering conditions. Later, the permafrost environment, upon melting, perhaps at the time of the Whyalla Sandstone overall transgressions, created slippage movements and gelifluction. Removal by erosion of the breccia and structures by the incoming sea was only minor. Movement by gelifluction and the associated decreasing of velocity with depth caused the spaces and vughs within the bedrock leading to the disjointed mosaic breccia (Photo 6) and the curved clastic dyke mentioned above.

The Pandurra quartzite is considered to have silicified before the onset of weathering and brecciation. Silicification formed a closed system that would promote pressure effects within the brecciated quartzite upon melting of the active and talik layers. Unsilicified Pandurra Formation, for example, away from the Pernatty Culmination, would not be able to build up pressures necessary for movement. Water would escape via pore-water expulsions. Hence, areas of unsilicified Pandurra Formation would probably be devoid of these structures.

The movement of the cohesionless mass over the clay band and/or permafrost zone (gelifluction) initiated hydrostatic pressures that were set up in layers and pockets of unfrozen material trapped between the frozen talik and permafrost layers. An impermeable and resistant surface, for example, the clay band or massive unbrecciated quartzite, could have the same effect as the permafrost or talik layers. These hydrostatic pressures (termed cryostatic pressures in frozen ground regions) force water to be injected upwards, and, in so doing, deform the brecciated quartzite into tepee-like anticlinal structures. In the example, in Plate 4, later movement along the glide plane caused an asymmetrical anticlinal structure after the initial formation by water injection.

The thickness of the overlying
Whyalla Sandstone is considered to be minimal in order
to allow water to be injected upwards and for pore and
fracture pressures to approximate lithostatic pressures.

YPMA has suggested the anticlinal
structures are due to gravitational sliding along a decol-
lément surface after the initial instability was created
by dense brines causing excessive pore pressures (mentio-
ned earlier). In this case, the structures represent the
piling up of sliding masses against each other. TONKIN
(pers.comm.) has noted the presence of the Cattlegrid ore-
body in a depression of the Permatty Culmination. Hence,
such downhill movement is plausible.

Similar processes have been pro-
posed for the structures that control the main zinc-ore
bodies in the Upper Mississippi Valley zinc-lead district
(HEYL et al., 1959). In these mines, the structures are
due to tectonic lateral compression, rather than gravity-
initiated movements, along a lubricating layer (Spechts
Ferry Shale member). Structures occur in synclinal areas
and result from compression directed primarily normal to
the synclinal axis. By the continued compression of in-
competent beds, the formation of inclined faults origina-
ting from bedding-plane faults is induced. After continued
compression, reverse fault pairs dipping toward the anti-
clinal areas of the syncline create "ramp-type grabens"
and the eventual arching up of incompetent beds into small
anticlines.

In the case of the structures
observed at the Cattlegrid Mine, slumping (according to
YPMA) has resulted in similarly-formed structures.

Problems associated with this
hypothesis include the lack of low-angle reverse faults
observed at the mine (Fig.4) and associated drag syn-
clines, as in the account given by HEYL et al.

This idea can explain many of
the structures observed. For example, the asymmetrical
anticline in Plate 4 could have occurred by movements
along a glide plane without invoking a periglacial climate.

Similarly, the sand wedges (Plate 4), extension of brec-
cias (Photo 10) and structures in Plate 3 could be ex-
plained by these movements. Most clastic dykes in the
literature, due to lateral or fault movements, are dyke-
shaped, i.e., parallel vertical sides and not wedge-
shaped. Those at the Cattlegrid show a striking simila-
rity to ice wedges reported by BLACK (1976); WASHBURN
(1980).

4.42   SANDSTONE WEDGES

Most of the wedges in the litera-
ture are initiated by thermal contraction of the permafrost
and active layers which open vertical cracks, polygonal
in plan, to which ice or sand are added (EMBLETON and
KING, 1975) (BLACK, 1976). Continual contraction leads
to the deposition of more ice and the lateral growth of
the wedge.

Ice and sand wedges refer to the
formation in different environments. In the former, the
wedge, upon contraction of the ground and a crack deve-
loping, is infilled by ice and developed by the ice expan-
ding. Upon melting, sand is infilled. In sand wedges,
however, no ice is invoked. In fact, sand wedges form
today in cold, dry climates. BLACK (1976) lists criteria
for differentiating between the two. The wedges at the
Cattlegrid, due to upturning and downturning of adjacent
walls bordering the wedges, the inference that water was
available and the assumption that other permafrost feature:
were present (anticlinal structures), are thought to be
ice wedges.

From Figure 9 it was hoped to
observe any pattern in the plan of wedges. In the litera-
ture they form polygonal networks, but the distance
between mapped faces due to mining methods, has made this
exercise inconclusive.

These wedges are considered to
have resulted from tensional fractures upon movement by
gelifluction. Tensional fractures, once initiated, would
subsequently have been expanded by ice accumulation in
times of sub-zero temperatures. Upon melting, infilling

by the overlying Whyalla Sandstone occurred. Later,
continued gelifluction along slip planes would tend to
increase the angle of bedding in the wedges. Due to
requirements of gravity, bedding planes cannot exceed 30°
from the horizontal in these wedges, assuming a gradual
filling of the wedge. Such is the case in Plate 3B.
Later movement of the brecciated mass has pushed bedding
to very high angles. In Plate 3D the neighbouring tepee
structure has increased the bedding angle to near vertical.

4.5   COPPER GRADES AND STRUCTURES

Figure 9 shows the spatial dis-
tribution of faults, tepee-like anticlines and sand
wedges, for most of the mine. Due to space requirements,
face correlations and hence, location of structures, was
not attempted west of line 703250 E.

As already mentioned, ice wedges
today form polygonal networks in plan view. Similarly,
many tepees described (ASSERETO and KENDALL, 1977; SMITH,
1974; DIONNE, 1975) form polygonal networks. Unfortunately
due to mining methods, such observations are not possible
due to the distance between successive faces of the mine.

Although only a few faults could
be recognised, those drawn do form possible conjugate
pairs, striking in North-westerly and North-easterly di-
rections. The overlying Copper Grades Contour map, which
was compiled by contouring Grade-control Block diagrams,
also shows this preferred orientation in the two directions.
Mineralisation, therefore, has been influenced by these
directions, although whether the mineralising fluids moved
via these faults is uncertain.

COPPER GRADE
CONTOUR INTERVAL
0.5% COPPER

CATTLE GRID OREBODY
DISTRIBUTION OF STRUCTURES

LEGEND

FAULT

TEPEE LIKE ANTICLINES

SAND WEDGE, DEPRESSION

METRES
0   25   50

6518 500N

600N

700N

800N

FIGURE 9
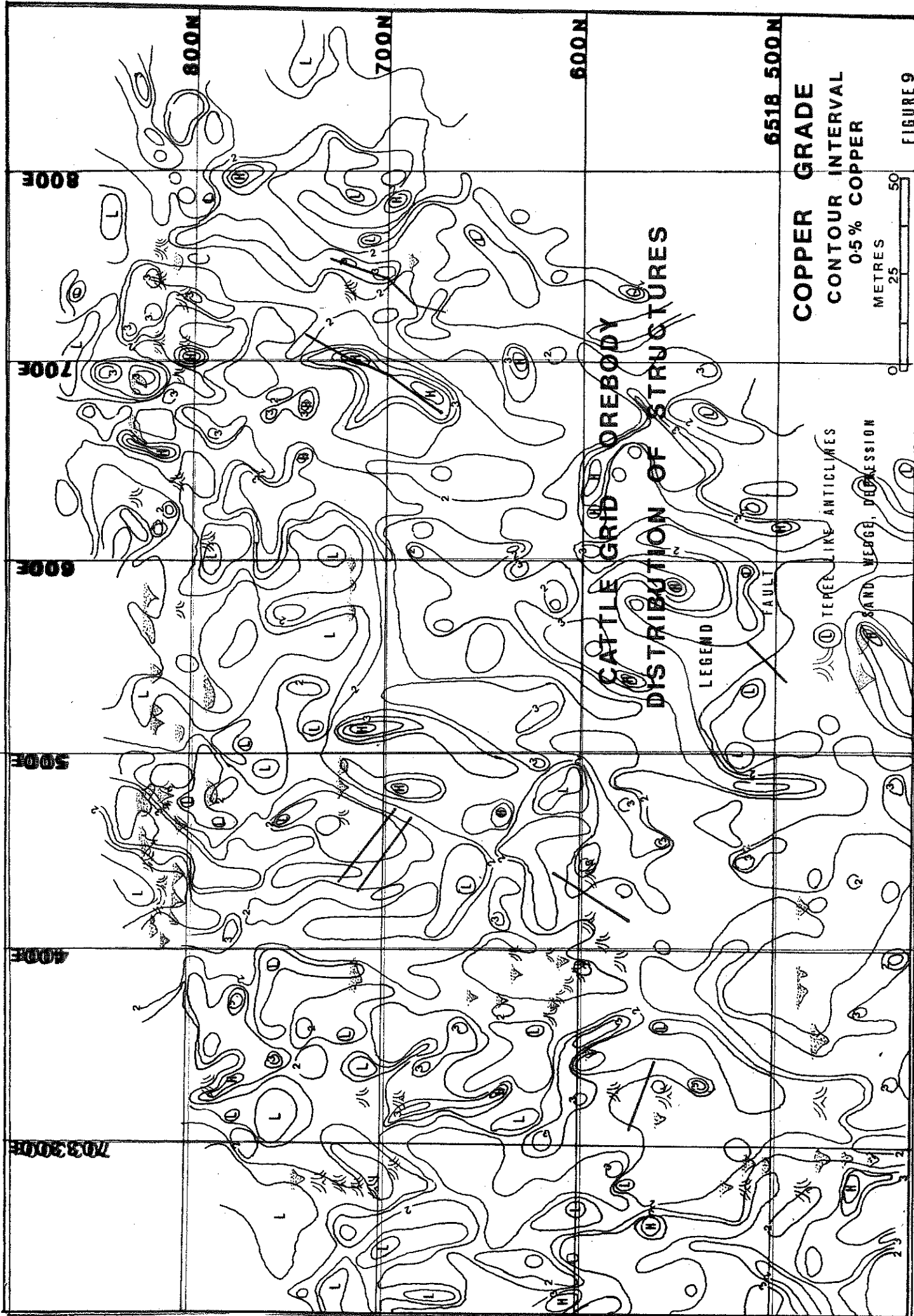
CHAPTER V: FLUID INCLUSION STUDIES

Fluid-inclusion studies were attempted on quartz crystals obtained from mineralised vughs and fractures within the tensional and Cattlegrid breccias at the Cattlegrid Mine.

The inclusions, being quite minute, were filled with a colourless liquid and a gasphase. Solid phases were not observed.

The crystals were subjected to freezing and homogenization temperatures. Graph 1 shows the results obtained.

Final Melts approximated $-31^{\circ}C$, while first melts peaked at $-54^{\circ}C$. Upon freezing hydrohalite ($NaCl2H_2O$), euhedral crystals formed (Photo 13). They all disappeared before $+9^{\circ}C$. The presence of hydrohalite indicates salinity of NaCl of at least 2%.

The first melts indicate that additional salts are required besides NaCl-KCl. The temperature of the lowest eutectic is $-22.3^{\circ}C$ for this system. In the system CaCl and NaCl, for a minimum of 2% NaCl, the minimum temperature of $-52^{\circ}C$ is achieved, corresponding to 30 wt.% CaCl.

The addition of Mg will decrease the eutectic still. (SIEDAII, 1940) quotes the eutectic temperature for the system $CaCl_2-NaCl-H_2O$ at $-52^{\circ}C$, and for the system $CaCl_2-NaCl-MgCl_2-H_2O$ at $-58^{\circ}C$. Hence, salts should include predominantly $CaCl_2$ at the most 5 wt.% NaCl + KCl and a little $MgCl_2$.

Homogenization temperatures ranged from $121^{\circ}C$ to $148^{\circ}C$. CREELMAN (1974) noted the presence of "X bornite" ores from the Lagoon orebodies. It has about one-half of one percent excess sulphur, and is formed only at low temperatures (YUND, 1965).

The salinity of these brines (at least 30 wt.% $CaCl_2$ and 2% NaCl) indicates concentrations much higher than anything now found at the earth's surface. The density of such brines is also extremely high, approxi-
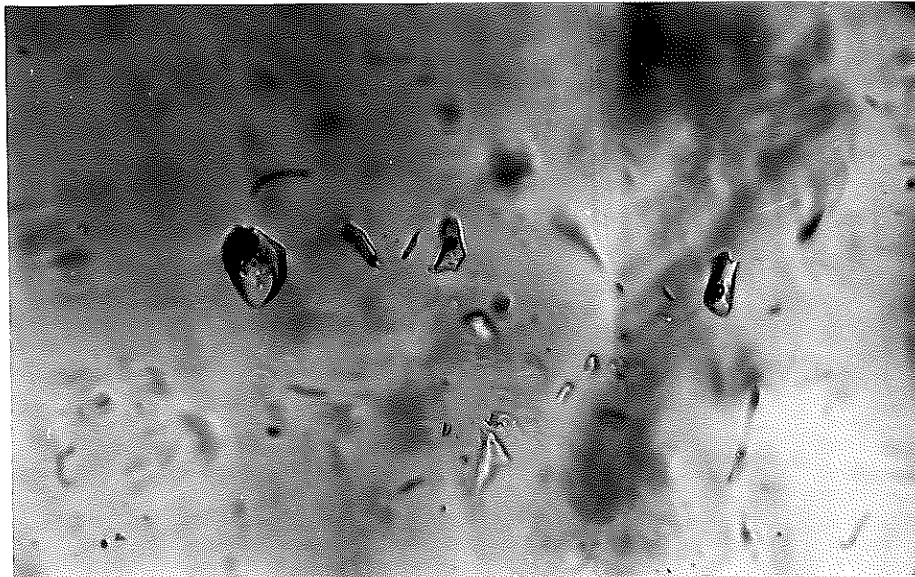
Photo J3: Hydrohalite crystals in fluid inclusions. Temp.=-20°C

GRAPH : I

Number of Inclusions

Homogenization Temperatures °C

Number of Inclusions

Final Melts °C

First Melts °C
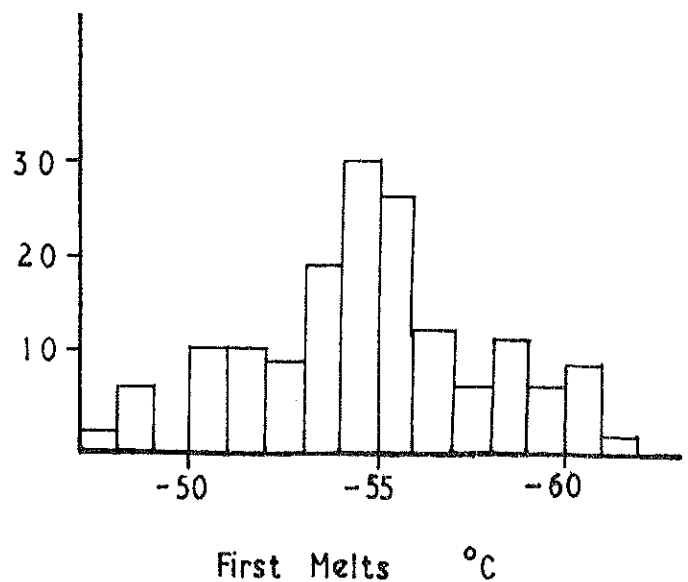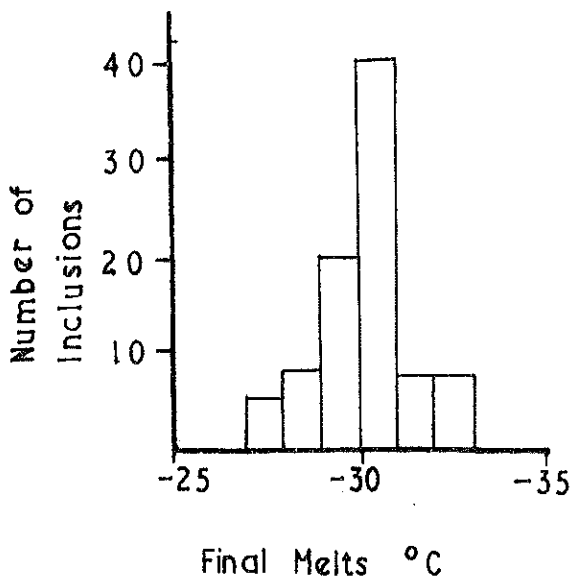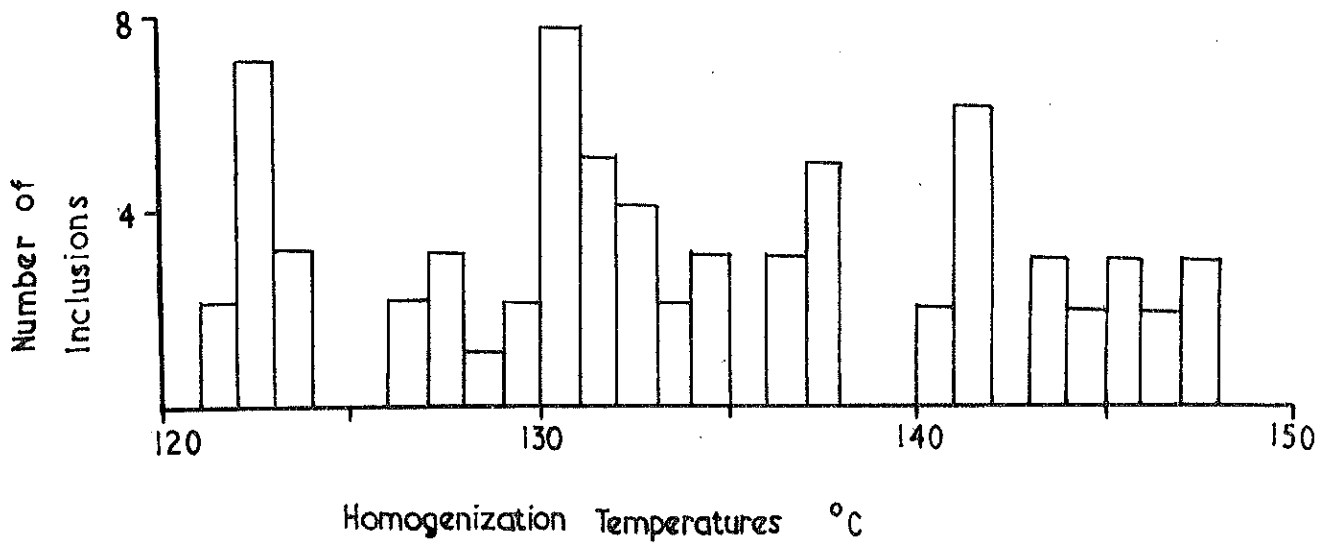
mately 1.5 gm/cc.

LEACH ANALYSIS

Fluid inclusions were crushed
and opened by ball-milling. The procedure is described
in Appendix II. Five leaches were completed, and samples
measured by flame photometry. Table AI summarises re-
sults obtained. Calcium obtained from the first crushing
greatly exceeded other ions, viz., Na, K.

ROEDDER (1963) noticed that flui
inclusions in a hornblende schist wall rock in New Mexico
showed exceedingly strong brines with the lowest first
melting temperatures ($-58^{\circ}C \mp 2^{\circ}$), and he believed the
deposit to be genetically related to a pegmatite.

HALL and FRIEDMAN (1963), on the
change in compositions of fluid inclusions in later quartz
and sulphide minerals from Cave-in-Rock, a Mississippi
Valley-type deposit, suggested waters coming from a
different origin, possibly magmatic, from that which for-
med the earlier crystals assumed to be of connate waters.
The later inclusions had higher Ca/Na, K/Na, Mg/Na,
Cl/Na ratios than the earlier crystals.

The homogenisation temperatures
of around $130^{\circ}C$ require either deep circulation of ori-
ginally cold surface waters or a contribution of heat by
the addition of magmatic waters. Under a normal geo-
thermal gradient (with no flow of water) depths of 4000 m
would be required for temperatures in the range of $130^{\circ}C$.
However, fluids may be related to faults (see Fig.9 and
previous section). Cu grade does not seem to be related
to faults at all!!

Comparable compositions of fluid
inclusions are known in natural waters of only two types:

1) brines and connate waters which have derived their
   content of salt by diagenesis or leaching of evaporite
   deposits -- hypersaline formation waters. However,
   the presence of excess Ca seems a problem.

2) some deep oil-field brines (DAVIDSON, 1966). However,
   these brines exhibit higher Mg:Ca ratios.

The amount of Ca recorded from leach analysis' suggests that the mineralising solutions are not connate in origin. In fact, any waters that have been derived from the surface of the earth are considered unlikely sources of the copper sulphides, as these fluids have high Na and K ion content.

YPMA has suggested that dense brines derived from areas of high heat flow have risen from within the earth's crust to be channelled into the Pernatty Culmination. Such dense brines caused instability at the interface between the fractured quartzite and the overlying Whyalla Sandstone, and the formation of slump structures described earlier.

The connate water associated with Whyalla Sandstone was still present in the pore space. The mixing of the dense and less dense brines caused the precipitation of copper sulphides (present in the upcoming dense brines) at the Pandurra Formation-Whyalla Sandstone disconformity. The presence of breccias and associated structures without mineralisation indicates no contact between the connate brines and dense copper-bearing brines.

SUMMARY AND CONCLUSIONS

Copper mineralisation at the Cattlegrid Orebody is located at the disconformable contact between the Pandurra Formation and the Whyalla Sandstone.

The Pandurra Formation, a moderately well-sorted quartz arenite, was deposited in a braided stream environment. Packing measurements suggest that erosion has removed a considerable thickness of the Pandurra Formation. Silicification of the grains, accompanied by Leisegang ring formation, occurred relatively soon after deposition of the sediments within the upper zones of the Pernatty Culmination.

Throughout the open-cut mine in the uppermost Pandurra Formation, one or two thin lenticular clay bands are present. It is a moderately-sorted clay of a sedimentary origin, but the presence of rounded and fractured quartzite pebbles and fragments together with other lines of evidence, e.g., clay intrusives into fractures of overlying and underlying quartzite, displacement of sand wedges, a notable decrease in compaction and the presence of striations, suggest that lateral movement along this layer has occurred . To create such movements, a high degree of instability must have been present within the upper Pandurra Formation. Gradients of up to 3.5° at the mine do not suggest that movements due to steep slopes could have been responsible. Rather, cohesion of the quartzite mass has possibly been reduced by the introduction of fluids to initiate such sliding.

The upper Pandurra Formation is highly jointed, fractured and finally, brecciated. The Cattlegrid Breccia, a thin layer of disorientated and sometimes rounded quartzite blocks, is considered to have resulted from the breaking up and disintegration by a normal weathering cycle of the Pandurra Formation bedrock. The underlying bedrock or the mosaic breccia has also been developed through weathering. Later mild tectonic activity has fractured the quartzite along bedding planes and other planes of weakness emphasized by this weathering cycle.

The Whyalla Sandstone is a well-rounded, often spherical, moderately-sorted subfels-arenite. The presence of plagioclase in such a mature sediment indicates a dry or cold climate to reduce chemical weathering. A grainsize analysis shows a bimodal distribution of sand grains. The presence of wave ripples, truncation of silty and sandy layers, together with a comparison of South African beaches, suggest it also is a beach sand. The textural inversion present in the Whyalla sandstone, together with syndepositional faulting associated with the rising Pernatty Culmination, suggest that the Whyalla sandstone has been reworked by transgressions and regressions of the Whyalla Sandstone sea. Periods of emergence of the Culmination resulted in the erosion of intervening lithologies. The thickness of the proposed beach sequence of the Whyalla Sandstone, before large-scale cross-beds come into prominence, suggests several transgressions and regressions make up the sequence.

Gelifluction (mass movement in permafrost terrains) is considered to be responsible for the formation of tepee-like anticlines and ice wedges. Cryostatic pressures (hydrostatic pressures set up by frozen and thawed layers) initiated by lateral movement along the clay band or permafrost layer created water injections into the cohesionless quartzite to produce tepee-like anticlines. Lateral movement also caused tensional fractures. Later, expansion by ice and, upon melting, infilling by the Whyalla-Sandstone, formed ice wedges. The Whyalla Sandstone is considered to have been of a minor thickness to allow cryostatic pressures to approximate lithostatic pressures, and for infilling of ice wedges to occur.

Gelifluction movements initiated by the melting of perennially frozen ground (permafrost) is considered to have formed during the cold climatic conditions of the Marinoan glaciation at times of emergence of the Pernatty Culmination. During a transgressive phase of the Whyalla Sandstone sea, cohesion of the originally frozen upper Pandurra Formation and Whyalla Sandstone was

lost and movement along slip planes caused water-escape tepee-like anticlines and sand wedges.

Two problems with this hypothesis are evident:

1) The presence of a notable disconformity within the Whyalla sandstone;

2) The preservation of the upper Pandurra Formation (and structures). A later marine transgression would be expected to remove much of the upper Pandurra Formation breccias and associated structures.

YPMA suggested instability was created by the introduction of dense saline brines (confirmed by fluid inclusion analysis). These brines created buoyancy effects in the fractured quartzite. Pore pressures were allowed to approximate lithostatic pressures due to confinement by the Tregolana Shale. Movements were initiated along a decollément layer. Brecciation of the quartzite by this lateral movement (already weakened by an earlier weathering cycle) resulted in the formation of the Cattlegrid Breccia. Sliding and slumping also produced structures in a manner similar to those mechanisms proposed for the development of structures seen in the Upper Mississippi Valley deposits. Here compressional tectonic movements along the Specht Ferry Shale Member initiated reverse faults across incompetent beds in synclinal areas leading to the formation of anticlinal structures.

Fluid-Inclusion data suggest a calcium-rich brine with minor amounts of Na and K was responsible for copper mineralisation. This omits connate and surficial waters as a carrier of copper sulphides because these waters have considerably higher Na and K contents.

Fluids, heated by deep-seated sources, were channelled up into the Pernatty Culmination during Whyalla Sandstone times. Upon the mixing of less saline connate waters of the Sandstone with these dense brines, copper sulphides were precipitated at the Pandurra

Formation and Whyalla Sandstone disconformity. Sulphides
were not precipitated when the two brines did not come
into contact.

APPENDIX I: DESCRIPTIONS OF THIN SECTIONS

WHYALLA SANDSTONE

792-46 Hand Specimen:

Cream-coloured, coarse, moderately-sorted sandstone. Specimen made up of less than 1 cm thick sandy and silty alternate layers often merging into one another or truncated by the overlying layer. However, layers are often flat-bedded and parallel to each other.

Pebble horizon is also flat and parallel to these layers. Pebbles are up to 1 cm long, very well rounded, and lying with no imbrication. The pebbles are situated in one of several silty layers, and in outcrop can be traced for up to 100 metres before disappearing beneath rubble.

Quartz grains, very well rounded, sometimes spherical, make up 80% of the rock. The silty matrix surrounding them and forming the layers makes up 20% of the specimen. The rock is friable as grains can be removed by rubbing of fingers along rock's surface.

Thin Section:
Texture:

A bimodal distribution of grain sizes is evident. Sizes range from 1.5 mm to 0.03 mm in diameter. The coarser population, from 1.5 mm to .25 mm, with a median grain size of .75 mm, occupies 65% of the slide, while the finer sizes, median diameter .08 mm, represent 35% of the slide.

Coarser quartz grains, rock fragments and feldspar grains are very well rounded and showing a high degree of sphericity. Finer fractions are angular to sub-angular. Sorting is moderate.

The Pebble horizon (see text) is also bimodal, with the coarser population extending to pebbles up to 3 mm in diameter. It is well sorted with coarser grains and pebbles well rounded. Pebbles are usually composite grains and probably derived from the

underlying quartzite, as they are rimmed by iron-oxide staining.

A texturally-inverted sandstone is therefore implied, with well-rounded grains in a poorly- to moderately-sorted sandstone.

Fabric:

The matrix is made up of small (< .125 mm) angular to sub-angular quartz grains with very minor (< 2%) clay (probably illite).

The number and types of contacts has been discussed in the text. The average number of contacts per grain averages 2.78 and that over 15% of the grains have 4 or more contacts per grain. Of these, over 75% are either floating, tangential or long. Grains do not show any degree of deformation by bending or fracturing

No orientation of long axes or crystallographic axes was observed.

Mineral Composition:

The Quartz-type (90%) is mainly plutonic, but 10% of these are composite grains, well rounded and sometimes spherical. The plutonic-type quartz shows straight extinction, and rarely, slightly undulose extinction.

Potash Feldspar (2%) (confirmed by staining) is also well rounded.

Plagioclase (3%) An_{67} (labradorite) is sericitised and well rounded. Both feldspar types are of the smaller population grain size.

Rock Fragments (5%) include devitrified volcanics containing capillary structures.

Hence, coupled with the above-mentioned texturally-inverted sandstone, it is also a sandstone with a high degree of mineralogical maturity.

Orthochemical Minerals:

Quartz occurring as overgrowths is almost absent and, when present, is often rimmed by iron-oxide staining suggestive of derivation from the

underlying Pandurra quartzite. The overgrowths occur
as a thin-rim cement suggestive of having been worn
down during transport of the originally angular quartzite
grain.

PANDURRA FORMATION

792-36 Hand Specimen:

A pink to red, coarse-grained, well-sorted ortho quartzite. Cementing material, quartz overgrowths, are recognisable, while a creamy-coloured clay cement occupies 10% of the rock, filling interstices between larger quartz grains. The amount of FeO staining varies across bedding. Grading of quartz grains, despite overgrowths, is recognisable. The specimen has broken along one of these bedding planes.

The rock has previously fractured and copper sulphides have infilled the available spaces -- chalcopyrite and surrounding bornite.

Thin Section:

Texture:

Detrital grains range in size from .8 mm to .09 mm long, with a median size of .6 mm. It is a moderately-sorted, angular to sub-rounded, quartz arenite.

Fabric:

Clay, kaolinite, occupies about 10% of the rock, filling interstices between grains. Rare, smaller quartz grains (less than .1 mm) make up the rest of the matrix, and together they form a silty matrix of 15% of the slide.

The average number of contacts per grain is 2.27, and over 20% of the grains have more than three contacts. Of the types of grain contacts, over 15% are either concavo-convex or sutured. Some sections showed up to 30% of grains had either concavo-convex or sutured contacts.

Orientation of crystallographic axis was observed (by addition of tint plate) in this slide which was cut perpendicular to bedding. Other slides cut parallel to bedding showed no such alignment.

Mineral Composition:

Quartz (90%). Mainly plutonic quartz grains showing straight or slightly undulose extinc-

tion. 5% are composite grains. Large quartz grains contain inclusions of sericite flakes (approximately 0.01 x 0.01 mm).

Kaolinite (8%). Occurs in voids and as coatings to longer grains.

Zircon (2%). Is present as euhedral grains with edges rounded. Grains are up to 0.4 mr long.

No plagioclase or potash feldspar (as indicated by staining procedure) was seen.

The slide therefore shows a high degree of mineralogical maturity.

Orthochemical minerals:

Quartz overgrowths have caused sub-rounded quartz grains to become somewhat angular. Original outlines of grains are marked by trains of fine inclusions, clay and iron-oxide staining. Occasionally, smaller grains have become fused together to form single larger grains. Overgrowths occur in optical continuity.

CLAY BAND

Hand Specimen:

Poorly-sorted, red quartzite pebbles and grains (60%) cemented by a cream-coloured matrix. Pebbles up to 8 cm long and often lath-shaped are sub-rounded to rounded with smaller fragments having a decreasing degree of rounding. Pebbles show a high degree of shattering, and when removed from the matrix, the pebbles easily break up along these fractures. No foliation of clay is evident, while the quartzite fragments are randomly orientated with no grading visible. Single quartz grains are sub-rounded. Pyrite (5%) occurs as euhedral grains (1 mm long) scattered throughout.

The hand specimen is very friable and easily broken up. Upon the addition of water, the clay becomes very sticky. With more water, the specimen easily breaks up and becomes slippery.

Thin Section:

Texture:

Quartz grains vary from 2.9 mm to .02 mm, are moderately sorted, from the grainsize analysis, with a median size of 0.3 mm. Smaller grains ($<$ 1 mm) are angular while the 10% of grains that are longer than 1 mm show some degree of rounding.

Fabric:

Matrix (kaolinite and minute quartz grains) make up 40% of the slide, and isolated larger quartz grains create a large proportion of floating grains (85%). The remaining 15% of grains have less than four contacts, and of these, no concavo-convex or sutured grains were seen. The degree of packing is irregularly distributed, with contacts occurring in two or three areas of the slide.

Mineral Composition:

Quartz (50%) is similar to that described in the massive quartzite, i.e., sub-rounded,

except that overgrowths are almost absent. They are plutonic and exhibit straight or slightly undulose extinction. Larger grains also contain sericite inclusions.

Kaolinite (45%). This clay is abundant as filling of interstices and surrounding grains.

FeO (2%). Coats quartz grains in certain areas of the slide.

Quartz Overgrowths (2%). Not as common as in the quartzite. Where they do occur, they are irregularly shaped and are in optical continuity with detrital grains.

Pyrite (1%). Both anhedral and euhedral hexagonally-shaped grains occur irregularly distributed.

APPENDIX II

PREPARATION OF SAMPLES AND MILLS FOR CHEMICAL ANALYSIS

Only those quartz crystals found in mineralised fractures and vighs were selected for chemical analysis of their fluid inclusions. Crystals weighing 0.5 grams were immersed in 5N Nitric Acid for three hours, filtered off, and allowed to stand.

In analysing for small amounts of Na, K, Ca, in solution, contamination must be kept to a minimum. The agate mill and zirconium ball used for lea-ching were therefore immersed in 5N Nitric Acid also. After three hours, the acid was drained away and the mills and ball were carefully washed in distilled water. Before commencing leaching, a blank reading of water and sample and ball mill was obtained.

LEACH METHOD

To the 0.5 gram sample in the mill was added 5 ml of distilled water. The mill and sample and ball was then vibrated for 60 secs. The resultant brine was then extracted (using a syringe) and Na, Ca, K were measured using the Atomic Absorption machine. 1 ml was extracted and diluted to 10 ml for more accurate ana-lysis on the AA. The remaining liquid was then extracted and collected in a small flask. Another 5 ml of distilled water was added to the sample in the mill and the process was repeated. In all, five leaches were carried out in this way. Leaching continued until it was considered that crushing the quartz crystals was not releasing any more fluid from inclusions.

Table A1 summarises the results obtained.

TABLE AI

Leach	ppm (In leachate)			
No.	Na_2O	CaO	K_2O	Cl
1	2·9	36·0	5·1	23·0
2	1·5	21·4	2·2	25·1
3	2·1	2·9	2·4	10·0
4	2·9	4·3	4·4	7·1
5	5·2	5·6	2·6	7·2
Blank	·02	·01	·02	

APPENDIX III

GRAINSIZE ANALYSIS, WHYALLA SANDSTONE

DIAMETER (mm)	AVERAGE PER CENT			
	792-46B	MINERALISED LAYER	PEBBLE HORIZON	792-26
Greater than 1.3	.63	--	2.8	--
1.3 -- 1.1	3.22	.85	--	.36
1.1 -- .92	3.84	1.62	--	3.97
.92 -- .775	4.02	5.74	.3	4.26
.775 -- .64	5.74	11.3	.27	7.25
.64 -- .53	4.63	13.57	.57	8.64
.53 -- .455	4.08	14.3	.6	10.16
.455 -- .375	6.38	14.4	1.7	6.9
.375 -- .31	7.57	12.48	.83	8.83
.31 -- .27	5.92	5.31	1.6	5.33
.27 -- .23	4.92	4.04	2.47	2.51
.23 -- .195	3.17	3.17	3.27	2.34
.195 -- .165	3.48	3.08	4.3	1.81
.165 -- .135	2.26	3.03	1.15	1.76
.135 -- .105	3.77	.98	1.7	1.06
.105 -- .07	11.17	4.4	33.03	18.04
.07 -- .035	27.6	2.1	45.26	17.6
less than .035	.53	--	--	.11
	100.5	100.4	99.92	101.3

GRAINSIZE ANALYSIS, WHYALLA SANDSTONE (CONT.)

DIAMETER (mm)			AVERAGE 792-06	PER 792-06A	CENT 792-46A
Greater than 1.3			--	---	.19
1.3	--	1.1	.19	.27	.41
1.1	--	.92	.53	.61	.51
.92	--	.775	1.28	2.3	.64
.775	--	.64	1.21	2.79	1.79
.64	--	.53	2.81	7.82	4.05
.53	--	.455	3.29	9.69	2.45
.455	--	.375	4.57	9.06	5.48
.375	--	.31	5.15	9.26	4.28
.31	--	.27	3.78	6.22	3.40
.27	--	.23	3.55	5.93	4.19
.23	--	.195	1.97	3.41	2.95
.195	--	.165	1.33	3.96	2.67
.165	--	.135	1.57	4.1	2.82
.135	--	.105	1.22	2.75	3.41
.105	--	.07	22.4	11.7	28.61
.07	--	.035	45.6	20.8	33.52
less than .035			--	--	--
			100.35	100.9	100.1

GRAINSIZE ANALYSIS, PANDURRA FORMATION

DIAMETER (mm)	AVERAGE	PER	CENT
	792-44	792-36	792-49
Greater than 1.3	.46	--	1.6
1.3 -- 1.1	7.23	.42	.71
1.1 -- .92	5.64	.84	3.4
.92 -- .775	11.75	3.05	2.72
.775 -- .64	10.97	3.34	5.44
.64 -- .53	8.7	4.7	6.35
.53 -- .455	13.6	4.8	5.85
.455 -- .375	8.9	4.8	7.97
.375 -- .31	4.7	9.7	8.41
.31 -- .27	7.96	5.65	8.34
.27 -- .23	5.74	9.52	6.64
.23 -- .195	3.34	9.39	6.87
.195 -- .165	3.42	9.83	5.81
.165 -- .135	4.02	8.71	8.01
.135 -- .105	2.75	5.53	8.15
.105 -- .07	1.34	16.6	7.75
.07 -- .035	--	3.08	6.10
less than .035	.1	--	.21
	101.6	100.3	100.2

GRAINSIZE ANALYSIS, PANDURRA FORMATION (CONT."A")

DIAMETER (mm)			AVERAGE PER CENT 792-34(b)	792-36A	792-54
Greater than 1.3			--	--	--
1.3	--	1.1	--	.39	--
1.1	--	.92	.3	.50	--
.92	--	.775	.82	.36	.4
.775	--	.64	.46	1.05	.74
.64	--	.53	1.78	1.9	1.49
.53	--	.455	.94	5.01	4.06
.455	--	.375	1.86	3.14	5.67
.375	--	.31	3.19	4.39	8.50
.31	--	.27	3.57	7.3	18.64
.27	--	.23	2.39	12.83	20.94
.23	--	.195	9.07	8.83	14.73
.195	--	.165	7.37	12.97	10.79
.165	--	.135	11.84	14.83	5.13
.135	--	.105	21.4	16.94	4.58
.105	--	.07	20.5	6.5	3.69
.07	--	.035	14.4	3.0	1.11
less than .035			--	--	--
			100.0	100.0	100.2

GRAINSIZE ANALYSIS, PANDURRA FORMATION (CONT."B")

DIAMETER (mm)			AVERAGE PER CENT 792-36B	792-36C	CLAY BAND
Greater than 1.3			3.3	--	9.15
1.3	--	1.1	.34	--	.63
1.1	--	.92	2.17	--	1.03
.92	--	.775	2.09	.58	.42
.775	--	.64	1.65	1.17	1.67
.64	--	.53	1.5	4.09	.62
.53	--	.455	4.84	3.51	2.9
.455	--	.375	2.75	1.75	5.19
.375	--	.31	5.82	3.51	8.89
.31	--	.27	7.49	6.43	10.72
.27	--	.23	8.15	9.94	4.98
.23	--	.195	9.74	9.36	8.52
.195	--	.165	12.42	10.53	9.34
.165	--	.135	13.3	14.03	7.27
.135	--	.105	8.74	13.45	10.14
.105	--	.07	9.40	13.34	9.5
.07	--	.035	6.15	8.30	9.4
less than .035			--	--	--
			99.85	100.9	100.37

APPENDIX IV

PACKING ANALYSIS. PANDURRA FORMATION

SAMPLE	% NO. OF CONTACTS							% TYPE OF CONTACTS				CONTACTS/GRAIN
	0	1	2	3	4	5	6	Tangential	Long	Concavo-Convex	Sutured	
792-36A	7.1	21.4	34.2	25.7	7.1	4.3	.9	5.8	75.5	5.8	12.9	2.2
792-36	12.7	12.7	27.3	27.3	12.7	5.4	--	5.6	82.4	9.6	1.6	2.27
792-09	20.4	25.9	35.2	18.5	--	--	--	18.8	67.0	8.2	5.8	1.57
792-71	8.8	32.3	29.4	20.6	8.8	--	--	13.8	69.2	6.1	10.7	1.91
792-49	--	10.5	22.0	37.1	22.8	7.7	1.9	7.2	57.7	14.4	20.6	2.77
792-09	19.6	17.6	37.3	19.6	5.8	--	--	15.0	68.0	11.0	6.0	1.74
AVERAGE	9.9	20.1	30.9	24.3	8.8	4.5	0.6	11.03	70.0	9.2	9.6	AVERAGE 1.94

PACKING   ANALYSIS.   WHYALLA   SANDSTONE

SAMPLE	% NO. OF CONTACTS							% TYPE OF CONTACTS				CONTACTS/GRAIN
	0	1	2	3	4	5	6	Tangential	Long	Concavo-Convex	Sutured	
792-46A	5	15	26	39	9.4	5.6		14.9	73	8.2	3.9	2.53
792-26	1	17.5	36.3	35.9	5.1	5.1		15.5	69	10.3	3.3	2.31
792-46	1.8	18.5	22	26	20.4	3.7	7.4	5.8	87.8	3.8	1.6	2.89
792-46B	3.7	6.4	27	29.7	21.6	8.1	3.7	16.1	76.7	5.3	1.7	3.02
792-15	--	6.7	22.9	26.7	30.0	10.0	--	6.4	81.3	7.2	5.2	3.13
AVERAGE	2.3	12.8	26.8	31.5	17.3	6.5	2.2	11.7	77.6	6.9	3.1	AVERAGE 2.78

APPENDIX V

GRAINSIZE GRAPHIC STATISTICAL PARAMETERS AFTER FOLK 1961

A. Graphic Mean

$$M_z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

B. Inclusive Graphic Standard Deviation (Sigma 1)

$$\sigma_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

C. Inclusive Graphic Skewness

$$Sk_I = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

D. Graphic Kurtosis

$$K_G = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

RESULTS OF GRAIN SIZE ANALYSIS : TABLE A2

SAMPLE	STANDARD DEVIATION (SORTING)	SKEWNESS	KURTOSIS
Whyalla Sst. 792-06a	Poorly Sorted	Near Symmetrical	Very Platykurtic
Mineralised Layer	Mod. Sorted	Strongly Finely Skewed	Mesokurtic
Pebble Layer	Mod. Well Sorted	Strongly Coarse Skewed	Extremely Lepto-kurtic
792-06b	Poorly Sorted	Coarse Skewed	Very Platykurtic
792-06	Mod. Sorted	Coarse Skewed	—
792-46b	Mod. Sorted	Coarse Skewed	—
792-26	Mod. Sorted	Near Symmetrical	Platykurtic
792-51	Mod. Sorted	Coarse Skewed	Platykurtic
Pandurra Ftm. 792-44	Mod. Sorted	Finely Skewed	Platykurtic
792-54	Mod. Well Sorted	Near Symmetrical	Leptokurtic
792-34b	Mod. Well Sorted	Strongly Coarse Skewed	Leptokurtic
792-36	Mod. Sorted	Coarse Skewed	Platykurtic
Clayband	Mod, Sorted	—	—
792-36b	Mod. Sorted	Coarse Skewed	Mosokurtic
792-36a	Mod. Sorted	Coarse Skewed	Platykurtic

Photo A1 : Sandstone Wedge. Bedding is subvertical.

Photo A2 : Curved sandstone dyke, within Cattle-Grid Breccia

Photo A3 : Edge of sandstone wedge. Note vertical bedding and quartzite
clasts at edge of wedge. Also mineralised layers parrallel
to bedding are present.
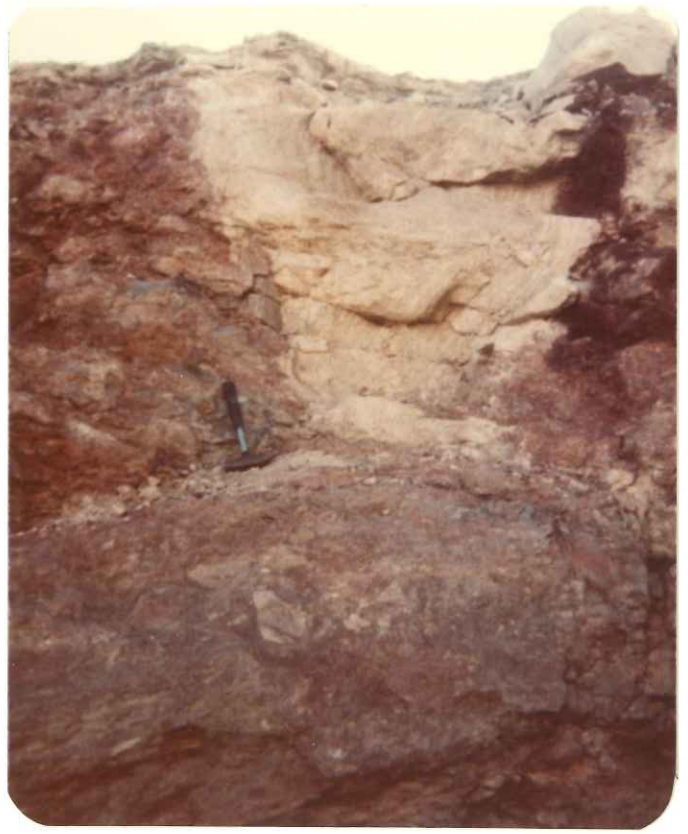
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