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THE GEOCHEMISTRY OF THE TAPLEY HILL
FORMATION AND STURT TILLITE, NEAR
DARLINGTON, SOUTH AUSTRALIA

by

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1972

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A B S T R A C T

Late Pre-combrian sediments, in the vicinity of Sturt Gorge, have been mapped and investigated geochemically. The sequence consists of 112 metres of tillite and interbedded arenites (Sturt Tillite) overlain by about 2000 metres of finely laminated shales (Tapley Hill Formation).

A combination of geochemical and stratigraphic observations suggested that silts derived from the till matrix were transported into a shallow marine basin by the process of glacial outwash.

INTRODUCTION

Siltstones form the largest group in the sedimentary sequence (Wedepohl, 1966), therefore any method which could aid in their interpretation would be valuable. This is possibly even more true when fossil evidence is absent. The project attempted to solve such a situation for the Tapley Hill Formation and Sturt Tillite, in their type area. This consisted of eleven square kilometres, twelve kilometres south of Adelaide, South Australia. (Fig. 1). Mapping was carried out on the Sturt Tillite with approximate limits being recent housing developments around Sturt Gorge. Sampling of the overlying Tapley Hill Formation extended from Sturt Gorge in the east to Brighton Quarry in the west. (Appendix III, Map 2).

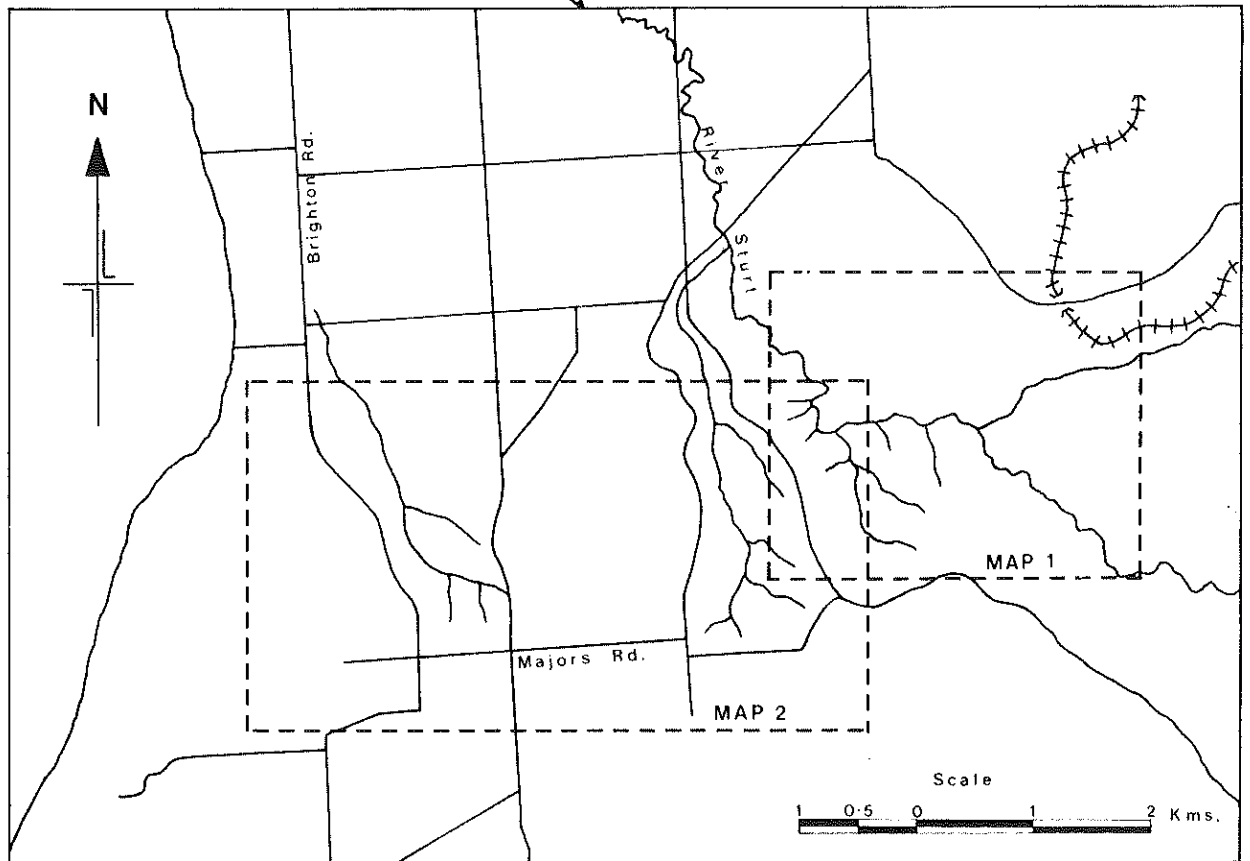
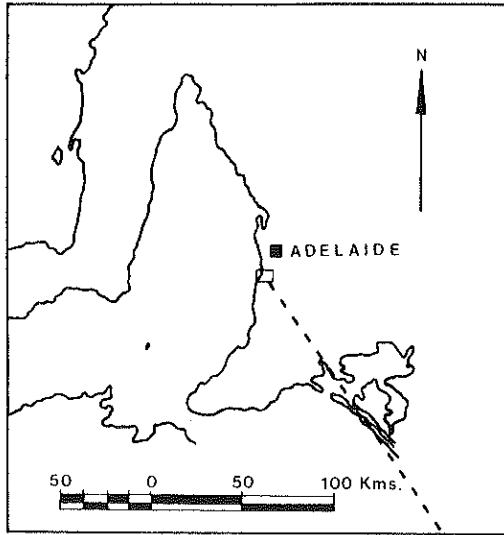
Investigations were carried out with two main aims. Firstly to interpret the environment of deposition of the Tapley Hill Formation by the use of geochemical parameters. Secondly to quantify any geochemical relationship which might exist between the Tapley Hill Formation and Sturt Tillite and hence deduce their sedimentological relations.

Previous discussion of the area has been carried out by Howchin (1918, 1927), Sprigg (1942, 1946) and Hosking (1962). However, these dealt mainly with mapping and stratigraphy. Age determinations by Compston et al (1966) have shown the period of sedimentation to be from 750 m.y. to 670 m.y. ago.

Mapping was done on the tillite using an enlargement of the Department of Lands air-photo 1273/20 (scale: 13.3 cm. = 1 Km). while an enlargement of 1273/22 (scale: 9.5 cm = 1 Km) was used for the Tapley Hill Formation. The larger photo was required for the tillite since smaller airphotos proved inadequate for the detail required. Field difficulties included lack of continuous outcrop and lateratization.

FIG 1

LOCALITY MAP
TAPLEYS HILL AND
STURT GORGE AREAS
S.A.



All analytical work was carried out in the Mawson Laboratories except for Boron analyses which were completed at A.M.D.E.L.

STRATIGRAPHY

STURT TILLITE

Tillite, in the Sturt Gorge area, consists of a poorly sorted medium sand to cobble framework in a dark grey silty to sandy matrix (Plate 1A. TS 380/2, 380/32D). Leucogneiss and granite greiss form the largest proportion of clasts over pebble size. However tillite is not the only lithology represented in the Sturt Tillite, as there are interbeds of sub-feldsarenites, sub-litharenites and shales (Fig. 2). Total stratigraphic thickness has been variously reported to be at least 300 metres (Coates 1967, Sprigg 1946) yet if folding near the base is taken into account the figure is reduced to 112 metres.

The underlying unit is the Burra Group of interbedded siltstones and quartz arenites. The contact is overfolded and not overthrust, as interpreted by Sprigg (1942). Field relationships in the area of the Adelaide to Melbourne railway line suggest the contact is merely disconformable. Within the tillite lithological changes are minor while the interbedded units provide good marker beds and have been extensively traced over the mapped area. (Map 1).

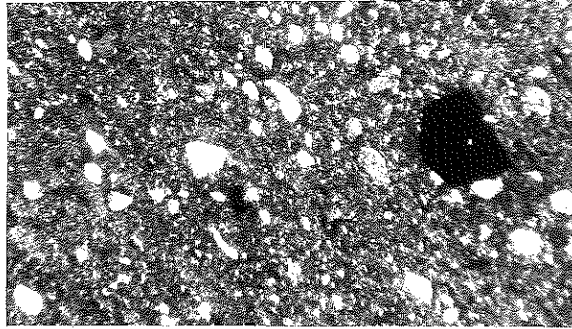
Basal interbeds consist of a cross laminated buff green shale with a cross bedded subfeldsarenite immediately overlying it. The shale formerly contained crystals of pyrite now evidenced in the form of vugs. Both units show variations in thickness over their extent with differences in the shale being more difficult to discern due to lack of outcrop.

PLATE 1

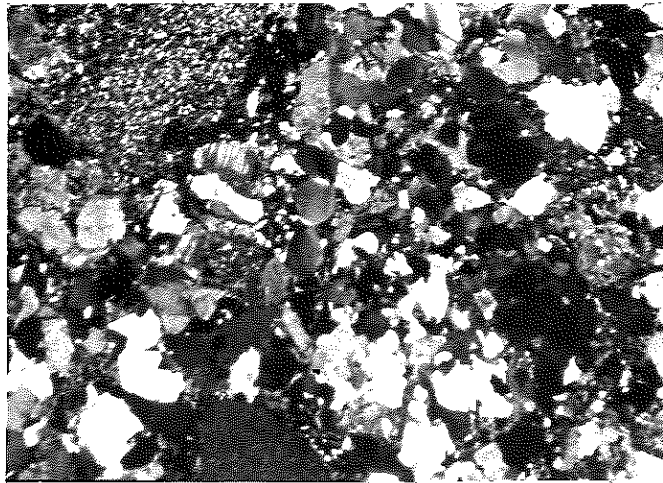
(Crossed Nicols)

- A. Bimodal grain size distribution and pyrite pseudomorph in the Sturt Tillite (TS 380/2).
- B. Fluvioglacial litharenite containing feldspar grains and composite quartz rock fragments, Sturt Tillite (TS 380/59A).
- C. Finely laminated shale, Tapley Hill Formation (TS 380/417).

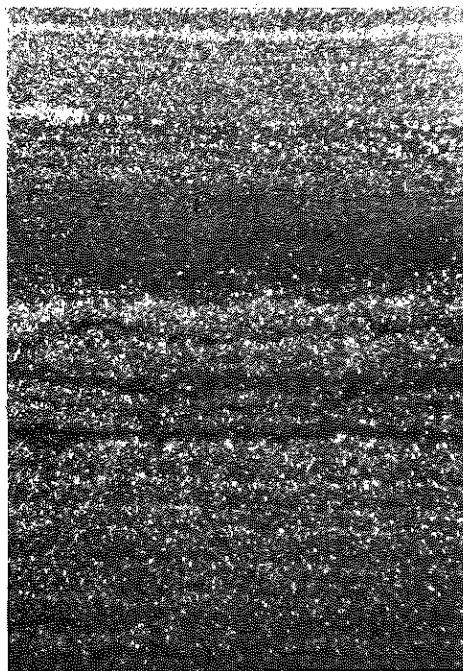
PLATE 1



A.



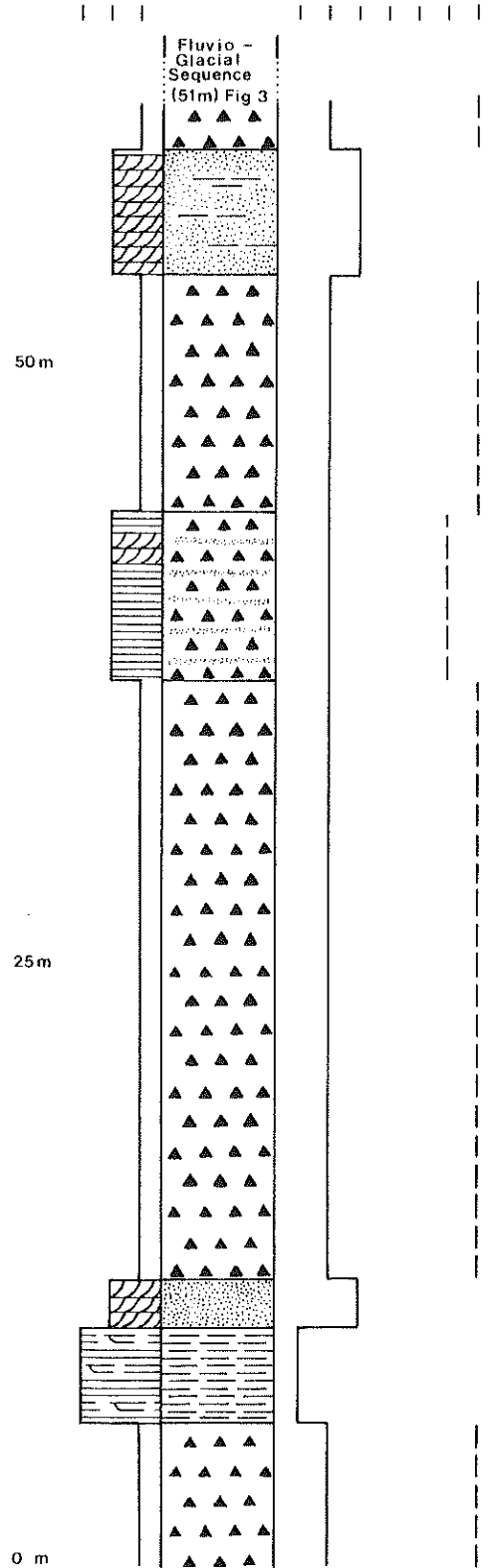
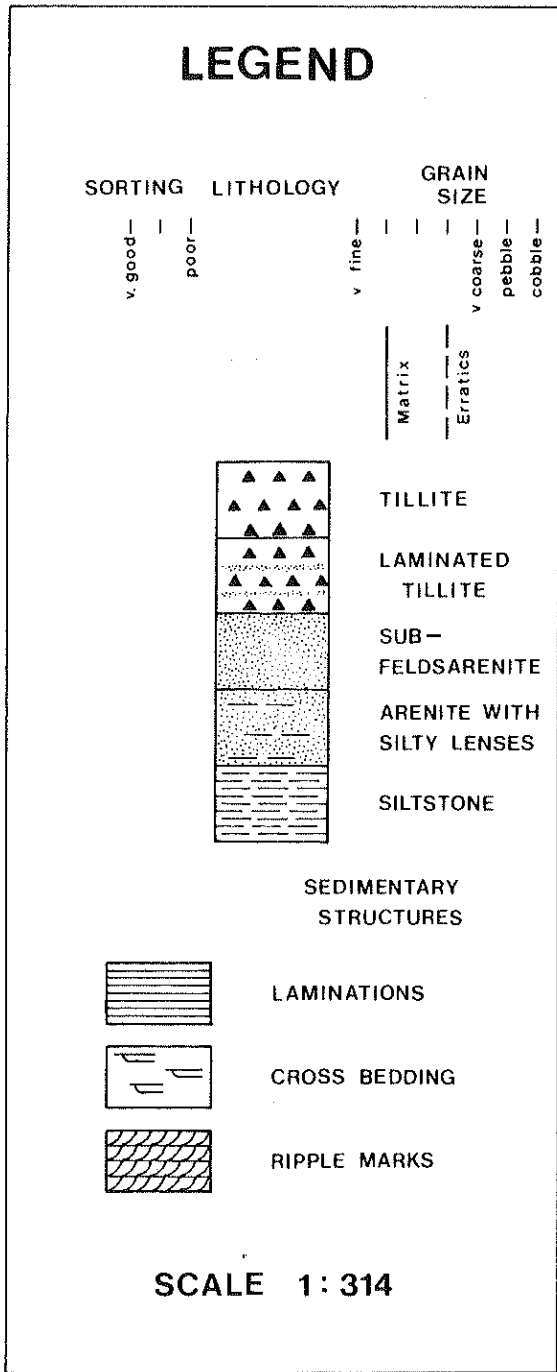
B.



C.

FIG 2

STURT TILLITE : Generalized Stratigraphic Column, Type Area.



The dip rapidly shallows toward the west and this combined with low amplitude folding has resulted in a younger subfeldsarenite being repeated in outcrop. This arenite is similar to the basal arenite but contains lenses of siltstone on a macroscopic, as well as microscopic, scale (TS 380/141). The base of this unit shows an intertonguing relationship with the tillite near Sturt Gorge. Approximately 10 metres below the arenite is a laminated tillite with laminations of coarse sand and silt in a silty matrix (Plate 2B, C). Pebble clasts are common in the coarse laminations while in the finer laminations clasts are almost absent. Other sedimentary features observed were ripple marks (TS 380/1C) and high angle cross cutting (Plate 2A).

Near the top of the Sturt Tillite there are a series of interbedded arenites, tillites and limeston^es which have been collectively referred to by Sprigg (op cit) as fluvioglacial (Fig. 3). Lateral variations in thickness and grain size of these interbeds is common, many lensing out completely. The base is defined by a cobble tillite overlain by a coarse felsic litharenite (Plate 2D. TS 380/59A, 380/30). Locally the arenite shows large scale cross bedding. All coarse arenites found within the fluvioglacial sequence contained relatively large proportions of plagioclase and microcline perthite with calcite as the cement (Plate 1B. TS 380/59B, 380/13, 380/9). The tillite is capped by a black dolomite which lenses out to the east. Both upper and lower contacts were sharp but it was included with the Sturt Tillite because of its similarities with the underlying carbonate beds.

TAPLEY HILL FORMATION

The Tapley Hill Formation consists of a monotonous sequence of dark coloured finely laminated shale. Total thickness is approximately 2,000 metres.

PLATE 2

STURT TILLITE

- A. High angle cross bedding overlying a laminated tillite.
- B. Tillite with fine silt laminations overlying a typically poorly sorted tillite.
- C. Medium to fine sand size grains forming laminations in a tillite with a silty matrix.
- D. Section of the base of the fluvioglacial sequence displaying a cobble tillite zone overlain by a trough cross bedded "gritty" arenite.

PLATE 2



A.



C.

B.



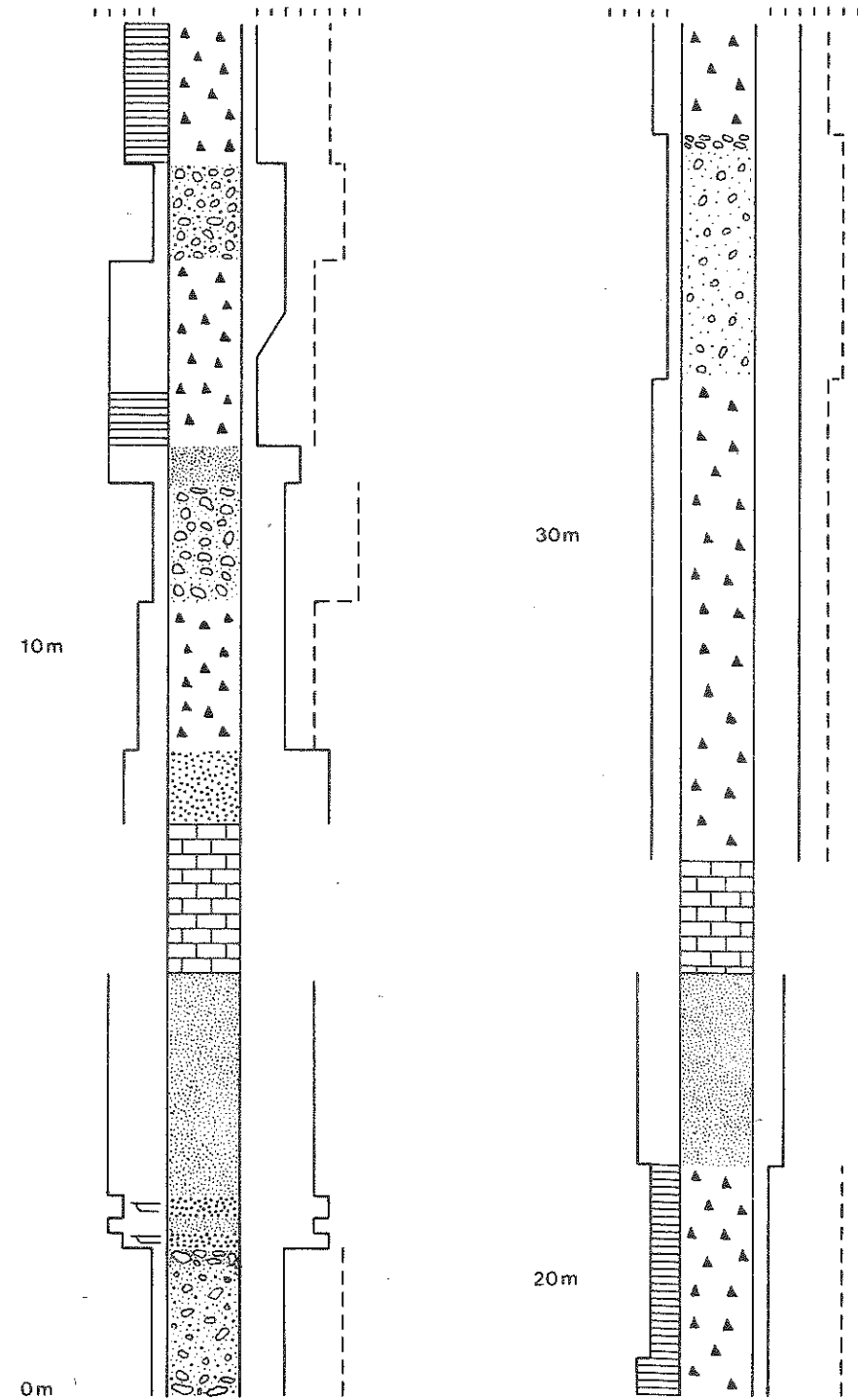
D.

FIG 3

LEGEND

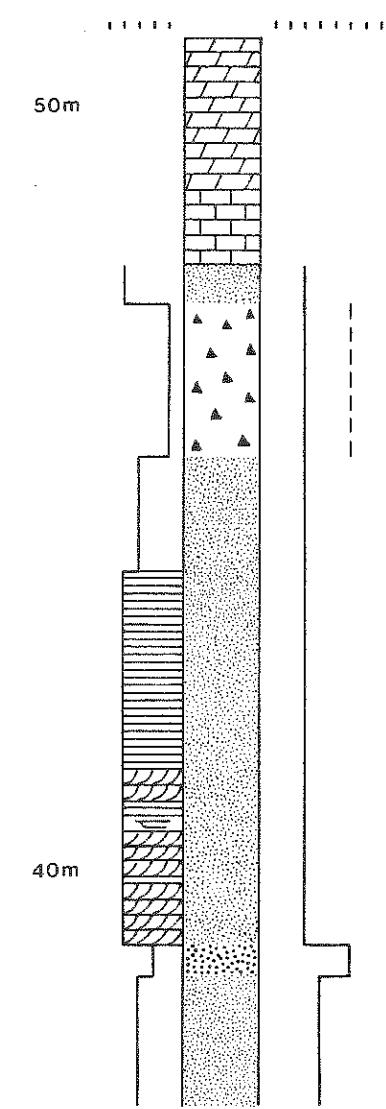
| | | | | | |
|------------------------|-----|----------------|--|------------|-----|
| SORTING | | LITHOLOGY | | GRAIN SIZE | |
| v good | --- | | | v fine | --- |
| v poor | --- | | | matrix | --- |
| | | | | erratics | --- |
| | | | | cobble | --- |
| | | TILLITE | | | |
| | | ARENITE | | | |
| | | GRITTY ARENITE | | | |
| | | COBBLY TILLITE | | | |
| | | LIMESTONE | | | |
| | | DOLOMITE | | | |
| SEDIMENTARY STRUCTURES | | | | | |
| | | LAMINATIONS | | | |
| | | RIPPLE MARKED | | | |
| | | CROSS BEDDING | | | |

SCALE 1:100



FLUVIO - GLACIAL SEQUENCE

Type Area Sturt Gorge
Section A - A'



The basal horizon is rarely exposed in Sturt Gorge due to soil development over the shale. The best exposure is in Flinders University which shows the slate conformably overlies the Sturt Tillite. Coates (1969) termed this part of the formation the Tindelpina Shale Member. The only differences noted between the shale at the base and that higher in the sequence were minor petrological features. (Plate 1C. TS 380/117, 380/153) and colour, when weathered.

Approximately 300 metres above the base ripple marks become common (Plate 3B, C). These are outlined by a light coloured arenaceous material which also forms two minor interbeds (Plate 3A). Bedding within these is contorted but contacts with the shale are very sharp. A very limited number of current directions obtained from the ripple marks indicated movement of sediment had been toward the east. Further up the sequence slumping of a set of laminations was observed (Plate 3D) while ripple marks were absent. Interbeds of intramicrite occur at 1250 metres. The inter^{ra}clasts consist of flakes of black shale. Approximately 300 metres from the top of the formation, also the beginning of the Brighton Quarry, the shale becomes light grey to mauve in colour. Fine laminations are less frequent and interbedded limestone more common. The top of the formation is signified by the beginning of the Brighton Limestone (Mawson and Sprigg, 1950) which, in the quarry, was taken to be an intramicrite.

STRUCTURE

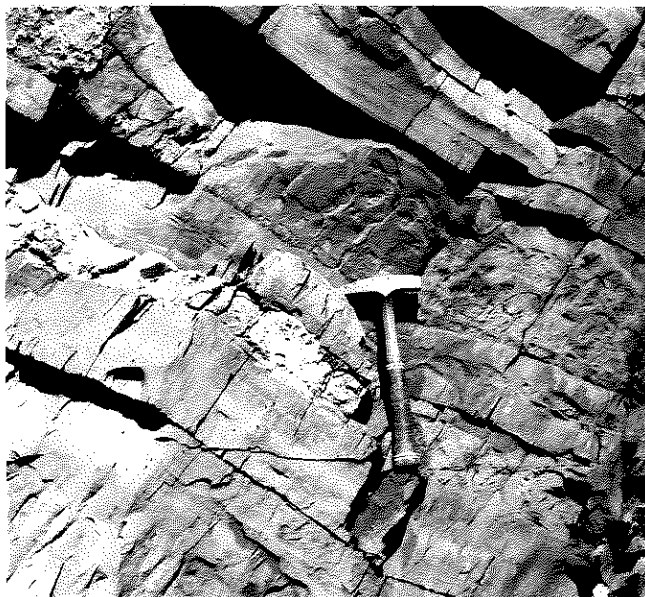
Regionally both units are part of a monocline with the beds dipping toward the west. Plots of poles to bedding and bedding - cleavage intersection, for the Tapley Hill Formation, (Appendix II) gave an approximate plunge of the monocline of 10° towards 200° . Cleavage is strongly developed in the tillite where deformation has also caused fractures, in large clasts, at a high angle to cleavage.

PLATE 3

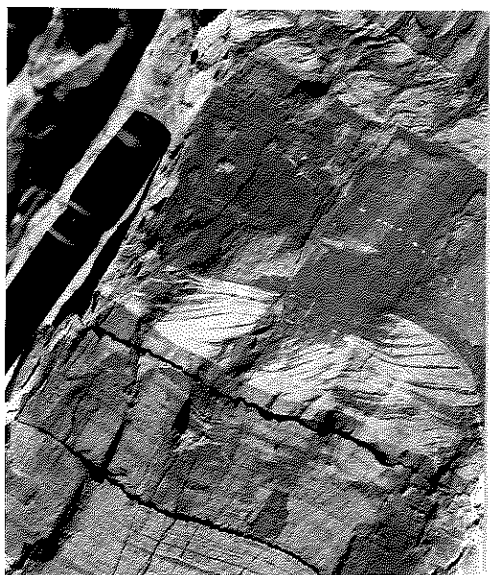
TAPLEY HILL FORMATION

- A. Interbedded arenites (near head and bottom of hammer) showing contorted bedding. Surrounding rock is laminated shale.
- B. Ripple marks composed of fine sand and silt size grains. Pen to the east.
- C. Cross bedding in a laminated shale.
- D. Slumping of laminations in a laminated shale.

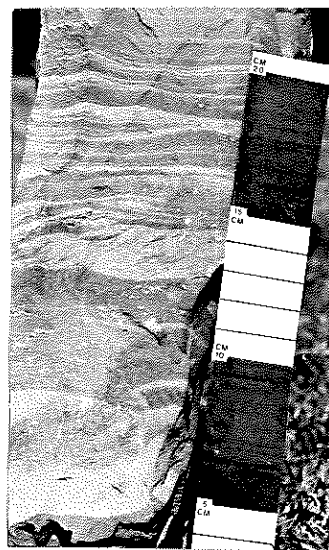
PLATE 3



A.



B.



C.



D.

GEOCHEMISTRY

SAMPLING

A total of sixty two samples of unweathered material, from both the Tapley Hill Formation (46 samples) and the Sturt Tillite (16 samples), were used in analytical work. In the former unit an approximate sampling interval of 50 metres was adopted although this was altered to show lateral variation (380/109,104) and small vertical variations, (380/120 A, B, C, D, E, F, G) and (380/165 A, B, C), in composition. An arenite and an intramicrite were also included. Of those collected in the Sturt Tillite nine were of tillite matrix, and interbedded siltstone, while a further seven were of interbedded arenites.

Analytical work was also carried out on eleven samples of Tindelpina Shale and Sturtian Tillite, collected by J. Sumartojo (from^{of} this department) from other localities in the Adelaide Geosyncline.

MINERALOGY

Semi-quantitative values of mineralogy were obtained by the application of a technique described by Bayliss et. al. (1970), (Appendix III). This involved material, less than 2 microns in size, orientated on a glass slide and analysed by an X-Ray Diffractometer. Within the limits of detection of this technique (5%) samples were found to consist of chlorite, illite, quartz, feldspar and calcite. Distinction between chlorite and kaolinite was made by treatment of three separate samples with 6N HCl (Biscaye, 1964). Chlorite, if present, will dissolve in this solution, and in fact this was the case.

Since percentages for mineralogy essentially represented peak heights recalculated to 100%, it was felt that these values could only be used within a sample. However, inter-sample comparison was

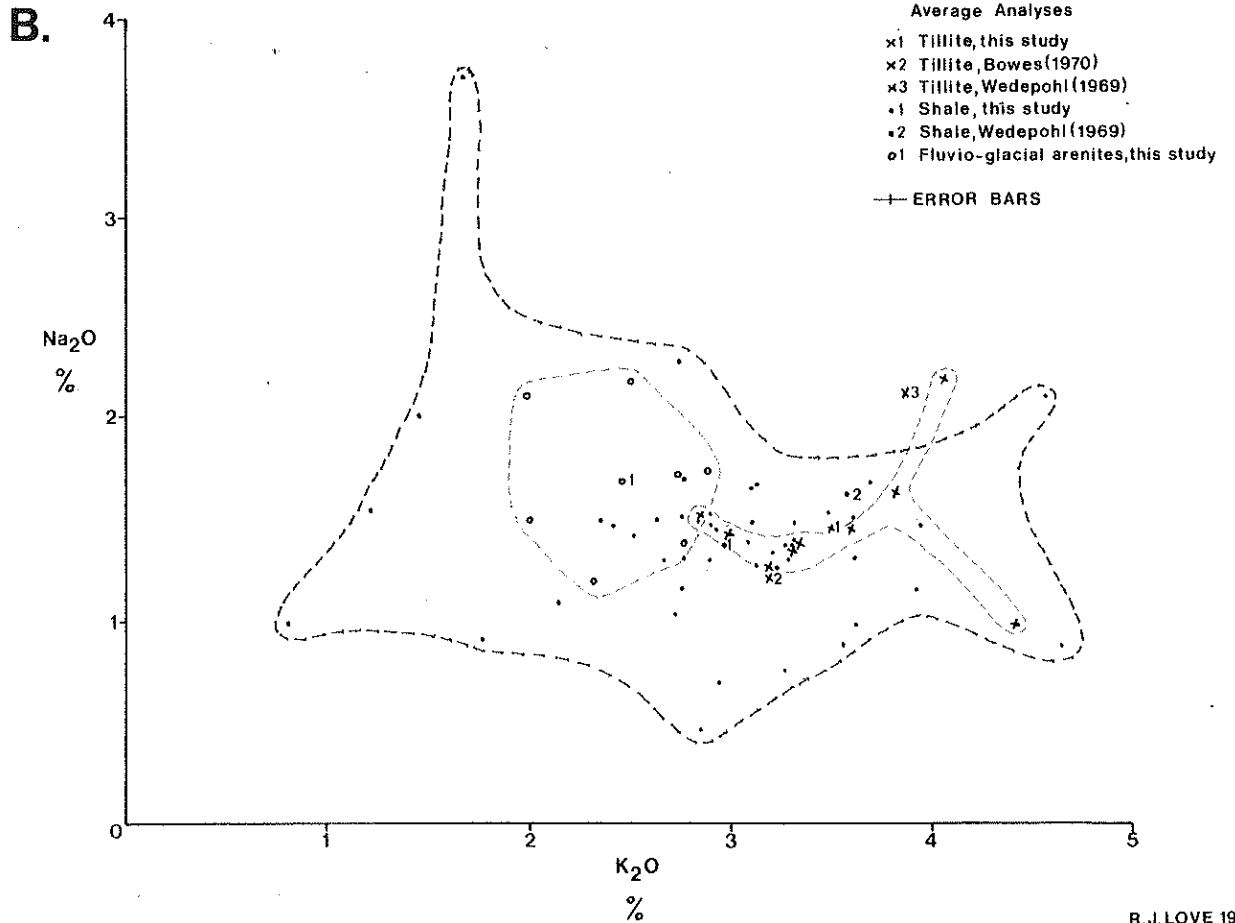
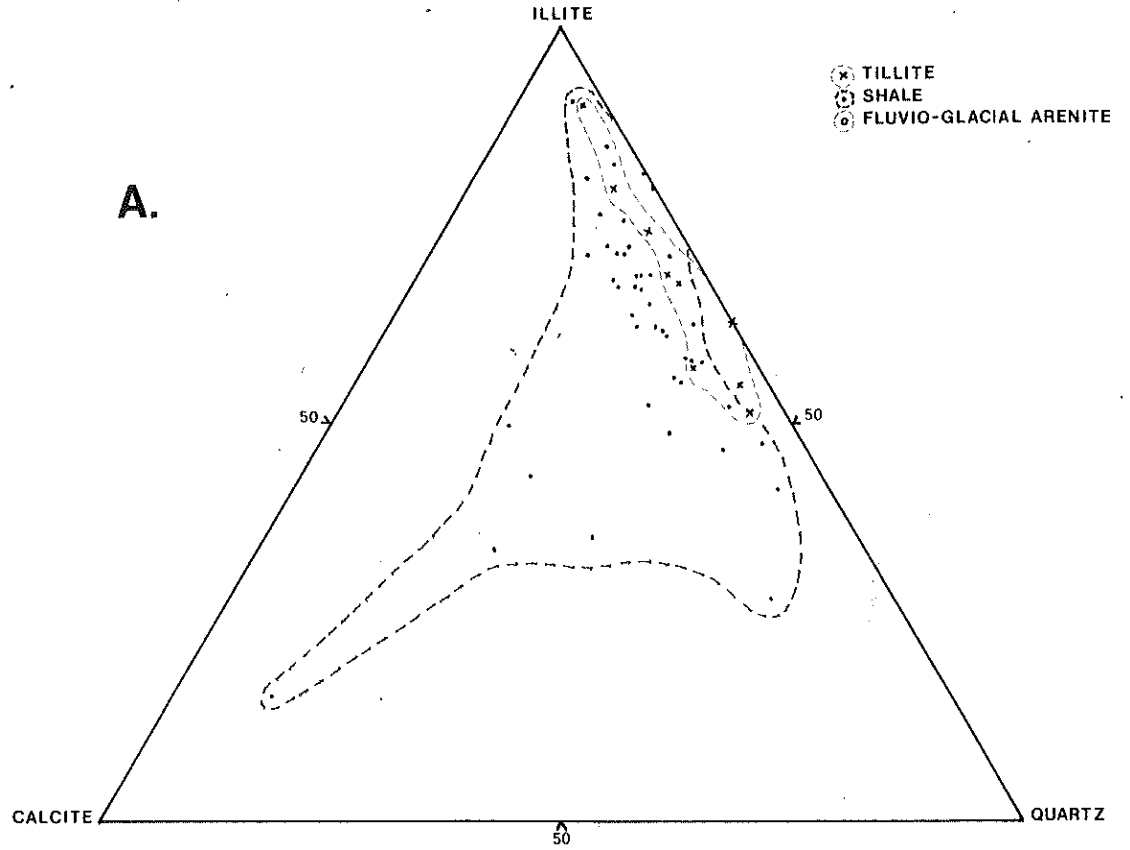
made since calcite, and total carbonate values obtained by a much more rigorous approach (Appendix III), agreed closely.

Calcite, illite and quartz show the largest variations in the Tapley Hill Formation with chlorite and feldspar remaining relatively constant. Consequently, a triangular diagram was chosen on which to plot all values which had as its apices calcite, illite and quartz (Fig. 4A). The tillite is poorer in calcite than is the shale but has approximately the same range of illite: quartz values. Few samples of either group exceed more than 50% quartz. Anomalous shales are represented by greater calcite percentages. In general the units may be distinguished on calcite content since the shale samples cluster around values from 6% to 10% while the tillite is almost uniformly 3.5%.

Although clay mineralogy has been used, in a qualitative sense, as a paleoclimatic indicator (Naidu^{et al}, 1971) its application to this study was omitted. This was due to the unknown effect metamorphism had on the original clay composition. For example muscovite may have converted to illite (Krauskopf, 1967).

Total carbonate content was established by a weight loss technique (Appendix III). Resulting values were slightly greater than calcite percentages ^{which} but was probably caused by other forms of carbonate being present. While absolute amounts were not the same, correlation was very good with both graphs reflecting a peak in carbonates at about 1,300 metres in the shale. This is the only peak for total carbonate but there are three positions at which values are very low. The peak to background ratio is very high in this unit for carbonate, the highest values being greater than two standard deviations above the mean. It has been reported by Sprigg (1942) that the shale becomes more calcareous going up the sequence, however, this is not the case for those samples collected (Fig. 6). Therefore, although the formation, as a whole, may show an increase in the uppermost 100 metres, due to interbedded limestones, there

FIG 4



are no such trends for the rest of the unit. Carbonate content is generally lower in the tillite matrix but reaches 12% five metres above the basal arenite and 9% five metres below the fluvioglaciols.

MAJOR ELEMENT ANALYSIS

Major element concentrations were determined by a combination of two methods. Sodium and potassium contents of all the samples were established using a Flame Photometer (Appendix III) while silicate analyses were only carried out on twenty-six samples using a method described by Norrish and Hutton (1968). Fused buttons were made from all the tillite samples, but only enough to give adequate representation of the shale were used since major element variation was not considered to be significant in this unit. Total percentages for silicate analyses were slightly high (Appendix IV) but no explanation could be given. Those which were completely unacceptable were discarded from further appraisal (380/74, 380/150B). Presentation of data in the form of two component and three component diagrams was selected in place of profile representation since an objective was comparison of bulk geochemistry and not stratigraphic variation.

There is a large spread of points on a Na-K diagram (Fig. 4B) although the majority cluster between 2% to 4% potassium and 0.8% to 1.8% sodium. The trend for more potassium in the tillite is illustrated by plotting the tillite and shale means. These also indicate that the sodium content remains relatively constant. Comparison of a tillite average from equivalent sediments near Broken Hill (Bowes, 1969) and the Sturt Tillite average^(this study) shows that their alkali metal contents are very similar. World average tillite (Wedepohl, 1969), although outside the main cluster, is still close to the other values. The same is true for the two shale averages.

When the alkalis are plotted against Al_2O_3 (Fig. 5 A, B) different relationships are shown. Potassium is positively correlated with aluminium oxide but sodium remains relatively constant with increasing alumina. The fluvioglacial arenites are well separated from the tillite and shale, having a higher ratio of alkalis to alumina than the fine grained rocks.

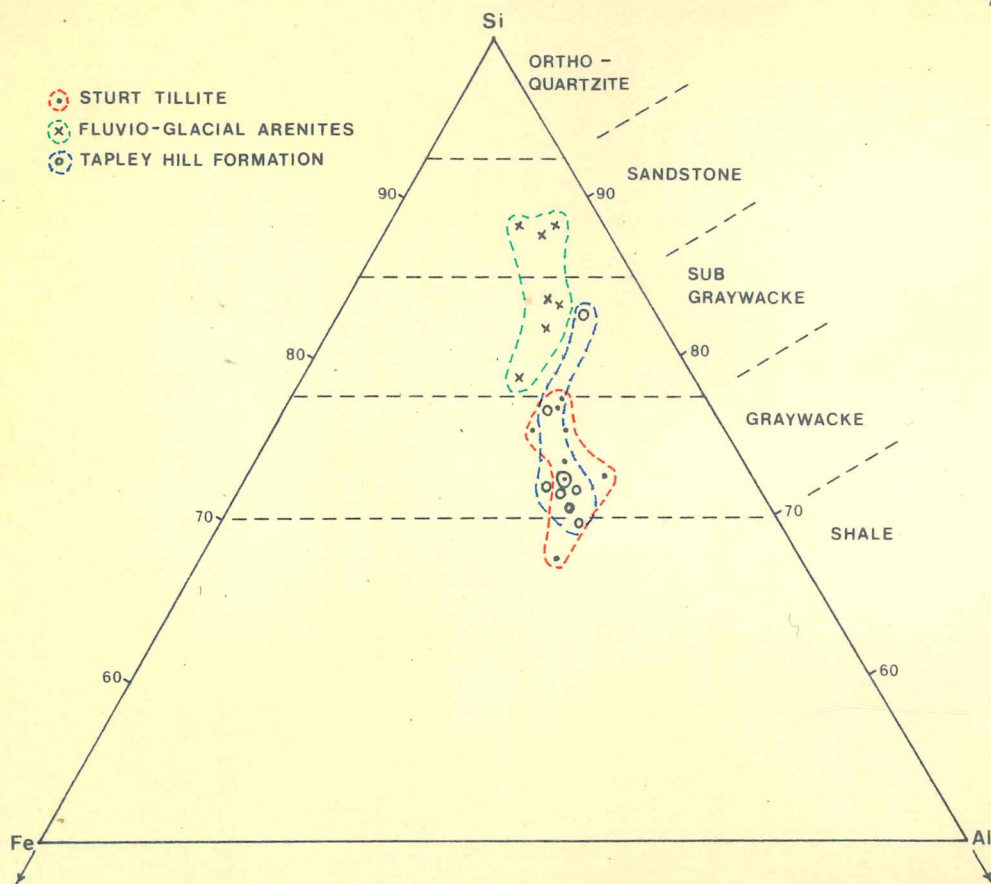
Besides morphological classification of the units, chemical classification was also attempted using major elements (Moore and Dennon, 1970). The samples from this study plotted into two groups (Fig. 5C). The arenites formed a silica rich group (sub-greywacke to sandstone) while the tillite and shale are superimposed in a lower silica, sub-greywacke, field. Hence, in this plot, as in other diagrams, variations between the two units were slight when based on chemistry.

PALEOTHERMOMETRY

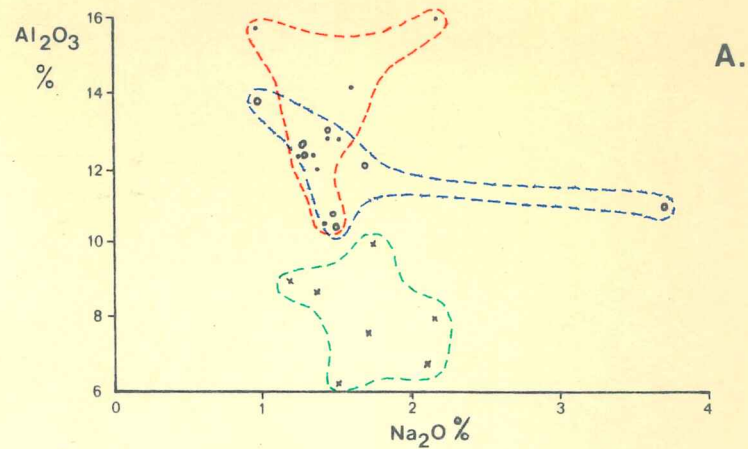
The basis of paleothermometry is that elements will behave differently in different temperature environments. Inherent in this assumption is the concept of uniformitarianism.

One of the methods used depended^s on the degree of weathering of the original sediments. That is low concentrations of highly mobile, easily weathered, elements should reflect a warm paleoclimate and high concentrations, cold paleoclimates. The method adopted was based on a weathering index proposed by Parker (1970) who used Na, K, Ca and Mg for silicate rocks. However, since clays and carbonate were main components in the shale and tillite Ca and Mg were omitted and untreated values of Na and K were used (Fig. 6). Variation in the shale mainly occurred within the potassium concentrations. Approximately in the middle of this unit values for potassium were substantially reduced below the mean value. This region also corresponded with peaks for other analyses. Comparison of values for the tillite and the shale show that, in general, the latter has a lower index of weathering.

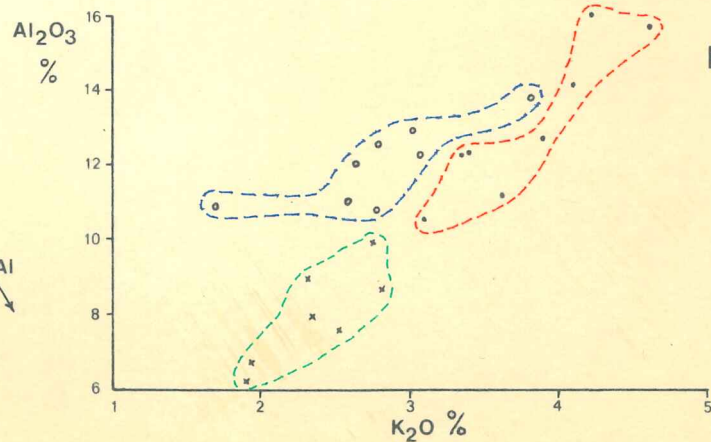
FIG 5



C. Classification of sediments using Si-Al-Fe ratios
(after Moore and Dennen, 1970)



A.



B.

A second method using Mn was also attempted. Bostrom (1970) suggested that high concentrations of Mn may be indicative of glacial periods. Values for siltstones sampled in the Sturt Tillite, similar to the shale, gave very high values for Mn (Appendix IV). Within the Tapley Hill Formation the highest values were near the middle and were of approximately the same magnitude as those in the tillite.

The methods gave contradictory results with Bostrom's method indicating a cold climate in the shale at about 1200 metres while the weathering index indicates a warm, highly weathering, environment. Of the two it is felt that more definite anomalies and independence from large scale detrital contribution makes the Mn method more acceptable.

PALEOSALINITY

Observations of modern day fine grained sediments have shown that their trace element concentrations are related to the salinity of the water at the site of deposition (Potter et al., 1963). If this property is to be used effectively however, a good indicator should be:

- (a) markedly effected by salinity changes
- (b) relatively widespread
- (c) abundant enough to be detected and measured with
a reasonable degree of precision
- (d) formed and concentrated in the rock in which it is
found
- (e) relatively unaffected by post depositional changes.

Of those elements which qualify, by the above conditions (Degens et al., 1957), boron has proved to be the most successful, while others are Cr, Cu, Ga, Pb, Ni and V (Potter et. al., 1963).

Trace elements such as these are absorbed into clays, and in particular illite (Harder, 1959), at a rate proportional to the salinity of the transporting water. Complicating factors in this system are water temperature, Eh, and pH, rate of sedimentation and the presence of organic matter (Cody, 1971). Boron has an added problem in that its strong bonding in the clay lattice makes it more likely to be involved in more than one cycle of sedimentation. However, if the source remains constant throughout the period of deposition, relative concentrations of trace elements will still indicate trends in paleosalinity.

Those elements chosen for this study were based on work done by Potter et al. (1963), who was able to separate marine from non marine sediments with an 85% success level using paleontological evidence as a criterion. Trace elements included B, Cr, Cu, Ga, Ni and V as paleosalinity indicators while Zn, Sr, Rb were calculated for additional correlation. Analyses were carried out by atomic absorption (Cr, V), x-ray fluorescence (Cu, Ga, Ni, Zn, Sr, Rb) and optical spectrography (B), (Appendix III). Due to expense the number of samples analysed for boron was limited to 7 from the [†]Surt Tillite, 30 from the Tapley Hill Formation and 10 of J. Sumartojo's samples. A profile plot against stratigraphic height, for the Tapley Hill Formation, of both calculated values and sliding mean has been used (Fig. 6). The sliding mean, which was an average of three values, succeeded in the majority of graphs in displaying trends better than did the raw data. Correlation coefficients of the trace elements, illite and quartz were calculated to show sympathetic or antipathetic relationships between these.

The clays of these rocks will not contain all the trace elements, therefore it is important to know in what manner the elements are bound, whether by detrital or allochemical minerals. By the use of correlation coefficients (Table 1) suggestions can be made as into which of these phases they can be grouped. Illite is correlated

TABLE 1

CORRELATION COEFFICIENTS

Tapley Hill Formation

| | B | V | Cr | Mn | Ni | Cu | Zn | Ga | Rb | Sr | Carbonate | Illite | Quartz |
|-----------|--------|---------|---------|---------|---------|-------|-------|---------|---------|--------|-----------|---------|--------|
| B | 1.000 | | | | | | | | | | | | |
| V | * .521 | 1.000 | | | | | | | | | | | |
| Cr | * .496 | * .500 | 1.000 | | | | | | | | | | |
| Mn | -.406 | * -.443 | * -.580 | 1.000 | | | | | | | | | |
| Ni | .328 | * .493 | .209 | * -.487 | 1.000 | | | | | | | | |
| Cu | -.044 | .118 | .063 | -.244 | .179 | 1.000 | | | | | | | |
| Zn | -.062 | -.143 | -.099 | -.003 | * .439 | .346 | 1.000 | | | | | | |
| Ga | * .580 | * .659 | * .538 | * -.655 | * .552 | -.115 | -.030 | 1.000 | | | | | |
| Rb | * .597 | * .725 | * .697 | * -.828 | * .449 | .233 | .031 | * .748 | 1.000 | | | | |
| Sr | -.360 | * -.510 | * -.442 | * .732 | * -.505 | -.293 | -.001 | * -.581 | * -.718 | 1.000 | | | |
| Carbonate | -.388 | * -.431 | * -.462 | * .867 | * -.565 | -.168 | .034 | * -.706 | * -.719 | * .872 | 1.000 | | |
| Illite | .435 | * .573 | * .494 | -.325 | .204 | .145 | .099 | * .473 | * .466 | -.392 | -.264 | 1.000 | |
| Quartz | -.011 | .094 | .010 | -.392 | .317 | .096 | .015 | .233 | .289 | -.246 | -.353 | * -.505 | 1.000 |
| | B | V | Cr | Mn | Ni | Cu | Zn | Ga | Rb | Sr | Carbonate | Illite | Quartz |

* Values significant at the 99% confidence limit.

with the trace elements Rb, Cr, V, Ga and Ni at a highly significant probability limit. The correlation with boron is not as good but is still significant. Copper and zinc cannot be correlated well with carbonate. The behaviour of Rb and Sr is well understood because of their respective characteristic substitution for K (in illite) and Ca (in carbonate). Comparison of data for the minerals indicates a negative correlation between illite and quartz as being the only value which is significant.

Positions in the Tapley Hill Formation which are anomalous, on the basis of their trace element concentration, are at about 600, 1200 and 1700 metres from the base. Not every element displays all of these anomalies but as a group they are present, at the same stratigraphic height, for more than one element. Seven samples collected at about 400 metres were used to indicate sample to sample variation. In many cases this is large but the anomalous values, in general, are more than the range of values expected from sampling bias.

Graphical interpretation applied by Potter et al. (1963) revealed that a partition line which best separated marine from non-marine samples could be selected by inspection for each element. Concentrations represented by these partitions, when applied to the shale, indicated that all but boron were consistent with a marine depositional history. This absolute value approach was not preferred however since not all sites of deposition exhibit the same trace element concentrations (Levinson and Ludwick, 1966). Therefore relative values of discriminant functions were used. These functions are:

$$F = 4.655 X_1 - 5.1414 X_2 - 0.2598 X_3 + 3.8298 X_4 \\ - 1.7950 X_5 + 6.2389 X_6 \quad (\text{Equation 1})$$

$$F = 5.3415 X_1 + 5.6928 X_6 \quad (\text{Equation 2})$$

where $X_1 = B$, $X_2 = Cr$, $X_3 = Cu$, $X_4 = Ga$, $X_5 = Ni$, and $X_6 = V$ (after Potter et al., op. cit.). Of the two Equation 2 is the more effective because of elimination from Equation 1 of variables which do not make significant contributions to the functions (Rao, 1952). Plots from both equations (Fig. 6) effectively demonstrate this. Although absolute values are slightly different, relative values are very similar. As a whole, the shale sequence has three peaks which are in approximately the same positions as the trace element peaks. There are also highs at either end of the sequence. Matrix material from the tillite and basal siltstone of the Sturt Tillite generally give low values for the discriminant functions when compared with the Tapley Hill Formation.

Over a regional scale concentrations of boron in both units are consistent with those values obtained in the type area. The shale and tillite averages are respectively 27.2 p.p.m. and 33.6 p.p.m. (type area), 31.0 p.p.m. and 41.0 p.p.m. (J. Sumartojo's samples, collected regionally). Therefore if there were differences in the environment of deposition over the Adelaide Geosyncline they are not reflected in boron concentrations.

DISCUSSION

SEDIMENTARY HISTORY

The nature of the sediments of the Sturt Tillite indicates that during the glacier's history it went through a series of advances and retreats. The advances are represented by unsorted tillite while the interbedded arenites generally reflect retreats of the glacier from the area. The laminated shale near the base of the tillite is an exception to this generalization. Lack of a retreat phase, represented by an arenite, underlying it, suggests that silts

were winnowed out of the till by a current which was not strong enough to transport coarse material. Such a drop in current strength would have to be relatively sudden or a gradational sequence from till to silt would be observed. An increase in melt-water velocity is indicated by the ripple marked arenite above the silt unit. Laminated tillite higher in the sequence is consistent with deposition under the floating shelf zone of a wet-base glacier (Carey and Ahmad, 1961). Turbidity flows within this unit are represented by high angle cross bedding.

The conclusion of the principal period of glaciation is indicated by the beginning of the fluvio-glacial sequence. The cobble bed at the base is an ablation tillite. This is typically a thin bed which is deposited at the termini of glaciers, and has been washed clean of most of its finer matrix (Flint, 1971). The overlying "gritty" arenite shows large scale trough cross stratification and rapid variations in grain size which are both characteristic of fluvio-glacial sedimentation. Minor retreats and advances of the glacier, higher in the sequence, are represented by interbedded tillite and fluvial arenites. Carbonate appears in the form of cement for the coarse grained arenites, and as limestones which contain erratics. Such an observation implies that the glacier, in this phase, was a dry-base one since these have an off-shore calcareous facies, or a calcareous facies in their retreat sequence, whereas wet-base glaciers produce environments unsaturated with lime (Carey and Ahmad, op. cit.). It seems less likely that the limestones are of a subglacial origin, as described by Page (1970) since the sequence in which they occur is regarded as being proglacial. An offshore calcareous facies could also explain the dolomite bed at the top of the Sturt Tillite.

In general, it is thought that the glacier was not in contact with the underlying Burra Sub Group sediments in this area but was deposited from a floating ice shelf onto the interbedded silts and sands.

During the latter stages of sedimentation the glacier took on the characteristics of a wet-base type while in the final stage it behaved more like a dry based glacier. The possible source area is to the west, from Eyre and Yorke Peninsulas, where rocks of the same composition as the erratics in the tillite are to be found.

The Tapley Hill Formation begins as a finely laminated, almost structureless, shale indicating that current activity at this time was minor. Laminations are caused by mineralogical and not grain size differences. Shallowing of the basin into which these silts and clays were deposited is demonstrated by abundant ripple marks and cross bedding which occurs higher in the sequence. At this time there was limited arenaceous input producing both starved bedding and thin interbeds. Slumping of laminations at about 1200 metres from the base indicates that the laminae were still in a ^{plastic} quasi-solid state when they were moved since bedding is still continuous. Laminations above and below this unit are parallel which suggests that this structure was caused by unstable slope conditions which only persisted locally. Approximately at this level differences between laminations ^{are} ~~is~~ due to calcite content probably indicating seasonal precipitation of this mineral. Final stages of deposition for the formation, resulted in less frequent laminations and a change in colour from dark grey to mauve. This is consistent with a shallowing basin theory.

Deposition of the Tapley Hill Formation has taken place over a large area of the Adelaide Geosyncline (Parkin, 1969). Sedimentation on this scale necessitates a large basin of deposition. This could take the form of a large, land locked, fresh water basin which was formed by glacial depression and subsequently became shallower by isostatic rebound. A further possibility is of an open sea basin which has been gradually aggraded to sea level by the addition of sediments. Of the two environments it is thought that the second is the more likely since although large sequences of laminated silt

can be built up in fresh water lakes (Bradley, 1948), the basin of deposition was too large and enduring to be of this nature.

GENETIC RELATIONSHIP

Failure, in most cases, to separate the matrix of the tillite from the shale on major component analyses suggests that the silt laid down for the Tapley Hill Formation was directly related to the tillite. However, average world shale is also similar in composition to the tillite (Fig. 4B), therefore similarity may be merely fortuitous due to the similar nature of tillites and shales.

If the relationship is accepted, however, the shale would be the result of glacial winnowing of the fine matrix from the unsorted till. This is not unrealistic as large amounts of unlithified sediment are available and flowing water in the form of glacial meltwater would provide the transporting medium. However, drop pebbles, which could positively indicate glacial conditions were not observed.

Interpretation of values for paleothermometry should also yield this relationship between till and silt since if the two are closely related the first silts laid down will be deposited from cold glacial outwash. If this has been the case high values of Mn, Na and K will occur in the Tindelpina Shale Member. As a control shales which are within the Sturt Tillite, and hence should display these relationships, were also analysed. Manganese values for these were high, suggesting that silts deposited under glacial conditions are rich in this mineral (Bostrom, op. cit.) Concentrations at the base of the Tapley Hill Formation were well below these, however, only reaching higher values near the middle of the unit. Sodium and Potassium ^{is} are considered to reflect illite input, and not degree of weathering, since potassium is held strongly by this type of clay and will mainly be residual. Figure 5B demonstrates this because as alumina (illite) increases, so does potassium. Therefore alkalis were of little value in this aspect of study.

In general paleothermometric methods gave answers which were not consistent with a glacial origin for the shale, unless waters from the glacier became warmer by the time they reached the basin of deposition.

PALEOSALINITY

Although the validity of paleosalinity determinations, using trace element analyses (and in particular boron), has been questioned in recent years (Cody, 1971; Harder, 1970) it has still been successful (Couch, 1971; Potter et. al., 1963). Moreover, use of more than one element in discriminating between environments has undoubtedly increased the reliability of the method. For example, this study indicates that if boron values alone were considered a fresh water environment would be postulated (using Potter's partition value). The other elements, however, would all indicate marine conditions. For this reason, classification was performed on the basis of relative values of the discriminant functions. (Eq. 1 and Eq. 2). Interpretations of these results have been plotted against the values of the function (Fig. 6).

These analyses indicate deposition of the sediments of the Tapley Hill Formation began with a marine phase, which is also represented at approximately 600, 950 and 1800 metres. Fresher water deposition took place at 400, 800 and 1200 metres. The general trend is for the values to decrease in the middle portion of the unit while the ends display relatively large values. This indicates that the basin began as one open to the ocean but lost this character as aggradation of the basin floor, coupled with constant fresh water input, caused it to become restricted from the full marine environment. Later, marine conditions returned with a deepening of the basin. Peaks in the middle of the formation are more isolated and short when compared with the ends and possibly indicate short-lived ^{open} marine periods occurred during this otherwise marine phase.

CONCLUSIONS

Glaciation of the study area during the Sturtian epoch resulted in deposition of till and interbedded sands from the terminus of the glacier. Extent of the formation over the Adelaide Geosyncline indicates the glacier took the form of an ice sheet, with a source area to the west or north west. A glacial retreat phase is represented by a fluvio-glacial sequence at the top of the unit.

Geochemically the Tapley Hill Formation and the Sturt Tillite are related, as silts of the former unit were transported by glacial outwash from the finer material in the till. The ^{sediments} ~~sediments~~ were deposited in a marine basin at a relatively large distance from the glacier terminus, in a low energy environment. Seasonal variations in detrital input and chemistry of the water resulted in compositional laminations. During the basinal history it became progressively shallower and was at times barred from the open sea. Final deposition took place in a shallow marine sea.

Results from this geochemical approach to environmental analyses were generally encouraging but lack of supporting evidence makes conclusions, only on this ground, highly speculative. The major source of error is seen to come from sampling which, in this case, was widely spaced and incomplete. Future studies of this nature should attempt to approach the ideal of continuous sampling. In this way more definite conclusions could be made.

**Brrata: In place of marine and non-marine read
more marine and less marine respectively.**

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APPENDIX I

Thin Section Descriptions

380/1C

Macro: Dark grey laminated tillite

Micro: Range of grain sizes .1 mm to 5 mm, average .2 mm.
Sorting poor. Graded bedding and ripple marked.
10% matrix.

Quartz: 90% strongly undulose, sub round.

Feldspar: 1% plagioclase (58% Alb) and
microcline perthite.

Rock Fragments: 7% composite quartz

Opagues: 2%

380/2

Macro: Dark grey ill sorted silty tillite

Micro: Bimodal grain sizes. 10% is .5 mm and the rest
of the framework grains are .1 mm. Large clasts
are rare, 60% matrix.

Quartz: 85%

Feldspar: 1%

Rock Fragments: 12% composite quartz

(igneous) and sedimentary

Opagues: 2% pseudomorph pyrite

380/32D

Macro: Dark grey very poorly sorted tillite

Micro: Bimodal, 10% with a range .7 mm to 7 mm and average
of 1 mm. 90% with range .1 mm to .7 mm and average
of .2 mm. Grains sub angular and elongate. 40%
matrix.

Quartz: 85% medium to strongly undulose

Feldspar: 4% plagioclase (73% Alb) and
microcline perthite

Rock Fragments: 10% composite quartz

380/9

Macro: Greeny grey medium sorted coarse litharenite.

Micro: Size range .05 mm to 1 mm, average .5 mm.

Medium sphericity, grains slightly elongate, sub round. Calcite cement (20%)

Quartz: 50% medium to strongly undulose

Feldspar: 10% plagioclase (63% Alb),
microcline perthite

Rock Fragments: 35% composite quartz and
quartz - feldspar.

Opaques: 5% ilmenite

380/13

Macro: Brownish grey medium to well sorted coarse litharenite.

Micro: Range of grain sizes .05 mm to 1 mm, 90% ore .75 mm.

Grains are sub angular to sub round. Moderate pressure solution effects. Calcite cement (10%).

Quartz: 50% moderately undulose

Feldspar: 10% plagioclase (65 Alb) and
perthitic microcline.

Rock Fragments: 35% composite quartz,
feldspar, limestone.

Opaques: 5% ilmenite

380/60

Macro: Dark grey well sorted rippled biotite rich
feldsarenite.

Micro: Range of grain sizes .7 mm to 1 mm, average .5 mm.

Micaceous planes through sand size material.

Grains have a medium sphericity and are sub
angular. 10% matrix.

Quartz: 85% strongly undulose

Feldspar: 10% plagioclase (68% Alb) and
microcline.

Biotite: 4%

Opaques: 1% pseudomorph pyrite, replaced by
haematite or goethite.

380/3C

Macro: Light coloured ill sorted coarse feldspathic litharenite.

Micro: Bimodal, 60% approximately .05 mm and 40% of 1 mm size. Sub round grains, calcite cement (10%)

Quartz: 80% strongly undulose

Feldspar: 5% plagioclase (62% Alb), microcline perthite and microcline. Alteration to sericite.

Rock Fragments: 15% composite quartz.

380/59A

Macro: Light grey medium sorted coarse litharenite

Micro: Ill sorted, immature. Size range .3 mm to 6 mm average .7 mm. Grains angular to sub angular.

Calcite cement (10%)

Quartz: 60% strongly undulose, angular.

Feldspar: 10% microcline perthite and plagioclase (73% Alb)

Rock Fragments: 30% composite quartz, quartz-feldspar, limestone.

380/59B

Macro: Dark grey well sorted fine grained quartzarenite.

Micro: Range of grain sizes .05 mm to .4 mm, average .2 mm.

Grains are elongate and sub round, 50% matrix.

Quartz: 95% slightly undulose

Feldspar: 4% plagioclase (73% Alb)

Opaques: 1%

380/141

Macro: Light coloured well sorted ripple marked sub
feldsarenite

Micro: Range of grain sizes .1 mm to 1 mm, average .2 mm.
Grains are sub angular. Silt bands cross cut the
coarser material. 10% matrix.

Quartz: 80% slightly to medium undulose.

Feldspar: 20% plagioclase (70% Alb) and
perthitic microcline.

380/153

Macro: Black finely laminated shale

Micro: Average grain size .05 mm. Laminations are of two
sizes, .2 mm and 1 mm. Smaller laminations
lighter in colour due to higher calcite content.
Rare occurrences of graded bedding.

380/117

Macro: Black finely laminated shale

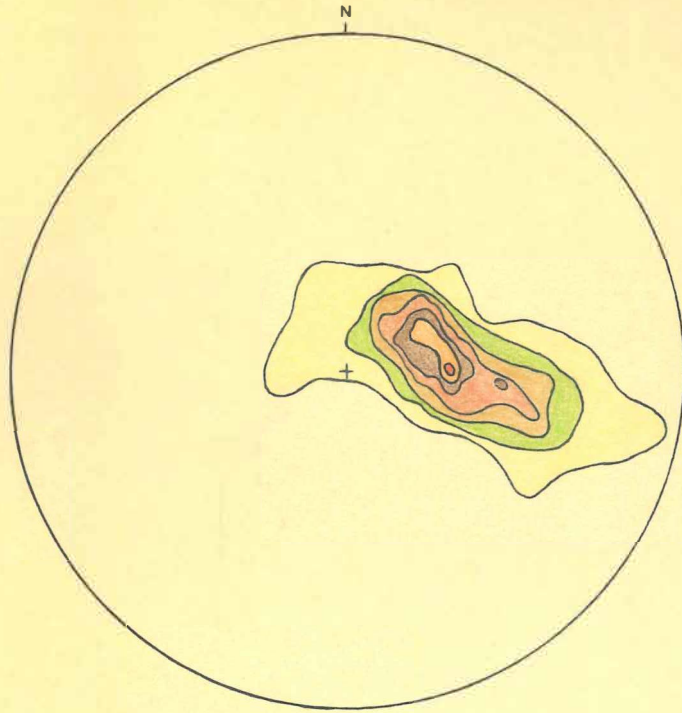
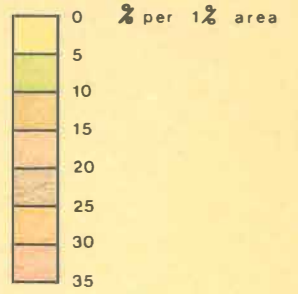
Micro: Average grain size .05 mm. Laminations are of
two sizes. The smaller laminations are darker,
possibly due to concentration of organic matter.
The coarser laminations contain more calcite.

APPENDIX II

Structure

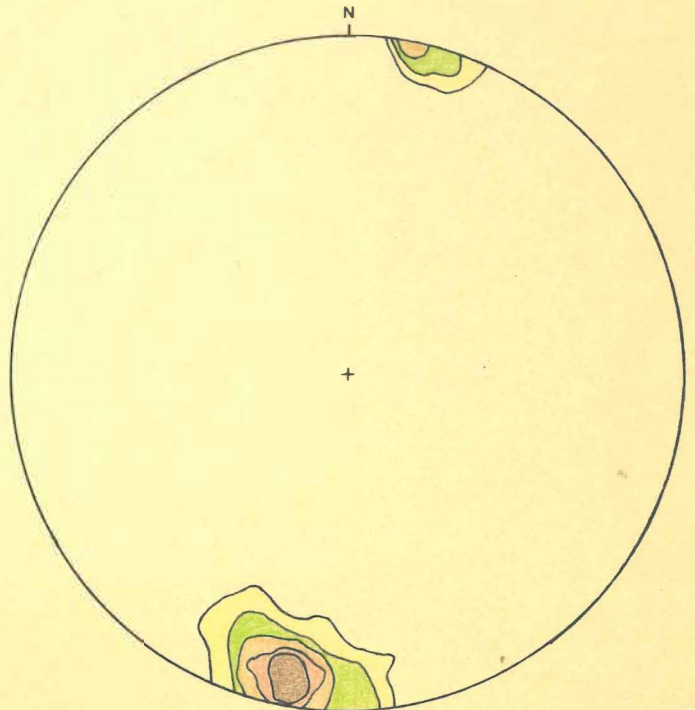
EQUAL AREA PLOTS

Tapley Hill Formation



POLES TO BEDDING
77 readings

BEDDING - CLEAVAGE INTERSECTION
41 readings



APPENDIX III

Sample Preparation and Analytical Techniques

Sampling

Samples were collected in the field. Average sample weight was 200 grams and consisted of unweathered material. They were first placed in cloth sample bags and later transferred to plastic bags for storage.

Stratigraphic height of each of the samples collected from the Taploy Hill Formation was calculated by trigonometry involving difference in altitude, distance and dip between two adjacent sample localities. A working map was made from the Department of Lands, Adelaide and Environs Sheet O3 for this purpose. Forty six samples were finally chosen, from the collection of samples of this formation, to be used in analytical work (see MAP 2).

Samples in Sturt Tillite were collected in a similar manner and chosen to provide a variation in stratigraphic height and lithology. Nine of these were used in trace element analysis and a further seven for whole rock analysis.

Crushing

Jaw and ball crushers were used to crush the samples to a coarse sand size. To obtain only the matrix material of the tillite, clasts 1 mm in size or greater were removed at this stage. Further crushing was done using a tungsten carbide Seibtechnic Mill for 3 minutes at 960 r.p.m. The process was repeated until about 50 grams of powdered sample was obtained. They were then placed in 11 mm x 6.5 mm paper bags. Cleaning of the mill was done after every sample had been run, with tissues and acetone.

X-Ray Diffractometer

Clay slides were made of 55 samples. These were prepared by adding approximately 10 grams of sample to 80 ^{ml} ~~in~~ of distilled water and then disaggregated by the action of a sonic probe for one minute. After a settling period of 24 minutes and 24 seconds the finest fraction was collected, centrifuged and played onto the surface of a glass slide.

The analyses were carried out using a Phillips Diffractometer with Cu K_α radiation, nickel filter, 40 KV and 24 M A, $\frac{1}{2}^\circ$ slits and a scan rate of 1° per minute. In most cases optimum count rate was 300 c.p.s. $\pm 3\%$. Interpretation of mineralogy was made by using overlay charts drawn from A.S.T.M. data.

Semi quantitative analysis of the mineralogy involved use of certain peak heights, multiplying by factors and recalculating to 100%.

| Mineral | Peak (\AA) | Factor |
|----------|-----------------------|--------|
| Chlorite | 14 | 2 |
| Illite | 10 | 8 |
| Quartz | 4.25 | 10 |
| Feldspar | 3.2 | 5 |
| Calcite | 3.03 | 4 |

Flame Photometer

Solutions were prepared by placing accurately about .04 grams of dried sample in a platinum crucible and adding in succession 1 ~~ml~~ ^{ml} of HClO_4 and 25 ~~ml~~ ^{ml} of 40% HF. The contents were allowed to evaporate to dryness on a sand bath and the residue left was taken up in 100 ~~ml~~ ^{ml} of distilled water. These solutions were kept in plastic flasks.

Sodium and Potassium analyses were made on these solutions using an air-coal gas flame and calibrating against standards already prepared.

Atomic Absorption

The metals of interest were taken into solution by placing .4 grams in a 25 ~~ml~~ ^{ml} test tube and adding 4 ~~ml~~ ^{ml} of 15% Phosphoric Acid in Perchloric Acid. The test tubes were then placed on a sand bath for 3 days at 240°C . This amount of time was considered necessary to fully extract the metals from the sample. On removal of the test tubes each was made up to 20 mls with 1 N HNO_3 .

Either the AA - 1 or AA - 3 was used according to whether an air-acetylene or nitrous oxide - acetylene flame was needed.

Optical Spectrograph

This method was used for the determination of Boron in 36 samples. Standards used were a Canadian Syenite (63 p.p.m. B) and Silica Brick No. 102 (23 p.p.m. B). Fifteen milligrams was placed in a first grade graphite cup and sparked for 90 seconds at an operating voltage and amperage of 40 V and 35 A. The spectra obtained was from $4530 \text{ \AA} - 5900 \text{ \AA}$ and photographed on an Agfa photographic plate. Semi quantitative values were obtained by visually estimating line intensities and widths and comparing with the standards mentioned above.

Carbonate Analyses

A relatively quick and accurate method was used for the calculation of the amount of carbonate in the samples. Accurately about 1 gram of sample was placed in a 100 ~~ml~~^{ml} beaker to which 20 ml of 1 N HCl was added. After the effervescence had ceased the contents of the beaker were filtered, dried and reweighed. Weight lost was due to carbonate loss. A 5% spike of Ca CO₃ in quartz powder standard and quartz powder blank were used. In both cases a high degree of reproducibility was achieved.

X-Ray Fluorescence

Samples were prepared in the form of pressed mounts. Mass absorption coefficients on these were obtained by using a method developed by Mr. Sumartojo, of this department. This involved the time for the accumulation of 200,000 counts on the Mo Compton scatter peak for both sample and ultrasil. After a dead time correction of .3334 seconds the times were placed in equations to give the appropriate mass absorption coefficients.

(a) Operating Conditions:

Mo Tube

Scintillation Counter 150/300

Compton Peak 29.76°

H. V. 3.49

Fine Collimator

(b) Equations:

$$\mu_{\text{Sr}}^{K_{\alpha}} = 0.317922 \cdot \text{Mo } K_{\alpha} \text{ C} + 0.377020$$

$$\mu_{\text{Rb}}^{K_{\alpha}} = 0.371983 \cdot \text{Mo } K_{\alpha} \text{ C} + 0.518740$$

$$\mu_{\text{Ga}}^{K_{\alpha}} = 1.060924 \cdot \text{Mo } K_{\alpha} \text{ C} + 1.276882$$

$$\mu_{\text{Zn}}^{K_{\alpha}} = 1.287218 \cdot \text{Mo } K_{\alpha} \text{ C} + 2.255683$$

$$\mu_{\text{Cu}}^{K_{\alpha}} = 1.571257 \cdot \text{Mo } K_{\alpha} \text{ C} + 2.255683$$

$$\mu_{\text{Ni}}^{K_{\alpha}} = 1.932846 \cdot \text{Mo } K_{\alpha} \text{ C} + 2.749666$$

$$\text{where Mo } K_{\alpha} \text{ C} = \frac{\text{Standard Count Time for U/S}}{\text{Obtained Count Time for U/S}} \cdot \begin{matrix} \text{Count} \\ \text{Time for} \\ \text{the} \\ \text{Sample} \end{matrix}$$

The samples were then analysed for these elements using the conditions noted on the next pages.

| ELEMENT | TUBE | VOLTS | AMPS | CRYSTAL | COLLIMATOR | COUNTER | COUNT TIME (Seconds) | E.H.T. |
|---------|------|-------|------|---------|------------|-------------------|-------------------------|--------|
| Sr | Mo | 60 | 40 | LiF220 | Fine | Scint. 150/300 | 40 | 3.59 |
| Rb | Mo | 60 | 40 | LiF220 | Fine | Scint. 150/300 | 40 | 3.59 |
| Ga | Mo | 60 | 40 | LiF200 | Fine | Scint. 150/300 | 40 | 3.59 |
| Zn | Au | 55 | 35 | LiF220 | Fine | Scint. 150/300 | 40 | 3.67 |
| Ni | Au | 55 | 35 | LiF220 | Fine | Scint. 150/300 | 40 | 3.67 |
| Cu | Au | 50 | 40 | LiF220 | Coarse | Scint. 150/300 | 40 | 3.67 |

| ELEMENT | PEAK | BACKGROUND | SLOPE FACTOR | STANDARD USED | RECOMMENDED VALUE (p.p.m.) |
|---------|-------|------------|--------------|------------------------|-------------------------------|
| Sr | 35.99 | 36.99 | 1.123 | NBS 70A | 65 |
| Rb | 38.07 | 36.99 | 0.925 | NBS 70A | 530 |
| Ga | 39.12 | 40.50 | 1.194 | Ga Spike of 380/104 | 15.4 |
| Zn | 60.42 | 59.50 | 1.043 | BCR- 1 | 132 |
| Ni | 71.15 | 70.00 | 1.381 | PCC- 1 | 2430 |
| Cu | 65.52 | 64.50 | 1.224 | CuO Spike in Quartz | 1000 |

APPENDIX IV

Analytical Results

TAPLEY HILL FORMATION

| | 104 | 118A | 118B | 129 | 142 | 150A | 160 | 165A |
|--------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Fe ₂ O ₃ | 5.752 | 5.904 | 2.636 | 6.197 | 5.784 | 4.698 | 5.153 | 5.057 |
| MnO | .032 | .050 | .014 | .060 | .073 | .060 | .047 | .033 |
| TiO ₂ | .941 | .849 | .737 | .803 | .763 | .653 | .751 | .711 |
| Ca ₂ | 6.941 | 6.339 | .510 | 5.903 | 7.230 | 11.205 | 8.172 | 5.055 |
| K ₂ O | 3.800 | 2.780 | 1.680 | 2.627 | 3.008 | 2.579 | 3.055 | 2.767 |
| SiO ₂ | 55.732 | 57.689 | 77.386 | 58.441 | 51.383 | 54.406 | 54.543 | 65.304 |
| Al ₂ O ₃ | 13.780 | 12.542 | 10.869 | 12.001 | 12.933 | 10.979 | 12.238 | 10.757 |
| P ₂ O ₅ | .204 | .196 | .228 | .239 | .209 | .226 | .204 | .184 |
| MgO | 3.006 | 5.001 | .854 | 4.974 | 4.618 | 4.682 | 5.144 | 3.259 |
| Na ₂ O | .970 | 1.270 | 3.680 | 1.690 | 1.440 | 1.480 | 1.260 | 1.460 |
| Loss | 10.210 | 9.010 | 1.740 | 8.250 | 9.630 | 12.610 | 10.500 | 6.430 |
| Total | 101.37 | 101.63 | 100.33 | 101.19 | 101.07 | 100.58 | 101.07 | 101.02 |

ARENITES IN STURT TILLITE

| | 73 | 75 | 37 | 9 | 59A | 59B | 60 |
|--------------------------------|--------|--------|--------|--------|--------|--------|--------|
| Fe ₂ O ₃ | 2.322 | 4.119 | 3.008 | 1.369 | 2.559 | 5.329 | 3.199 |
| MnO | .005 | .016 | .017 | .088 | .130 | .062 | .042 |
| TiO ₂ | .496 | .377 | .366 | .183 | .213 | .422 | .396 |
| CaO | .046 | .153 | .052 | 6.938 | 9.503 | 5.237 | 4.367 |
| K ₂ O | 2.531 | 2.752 | 1.903 | 1.941 | 2.336 | 2.322 | 2.805 |
| SiO ₂ | 84.831 | 77.894 | 84.844 | 71.752 | 63.462 | 67.707 | 74.403 |
| Al ₂ O ₃ | 7.571 | 9.895 | 6.187 | 6.698 | 7.936 | 8.930 | 8.624 |
| P ₂ O ₅ | .058 | .110 | .059 | .073 | .082 | .128 | .145 |
| MgO | .626 | 2.187 | 1.756 | 2.123 | 2.332 | 3.047 | 1.690 |
| Na ₂ O | 1.710 | 1.740 | 1.500 | 2.100 | 2.160 | 1.180 | 1.370 |
| Loss | 1.390 | 1.840 | 1.290 | 7.920 | 10.040 | 6.880 | 5.300 |
| Total | 101.59 | 101.08 | 100.98 | 101.18 | 100.75 | 101.24 | 102.34 |

STURT TILLITE

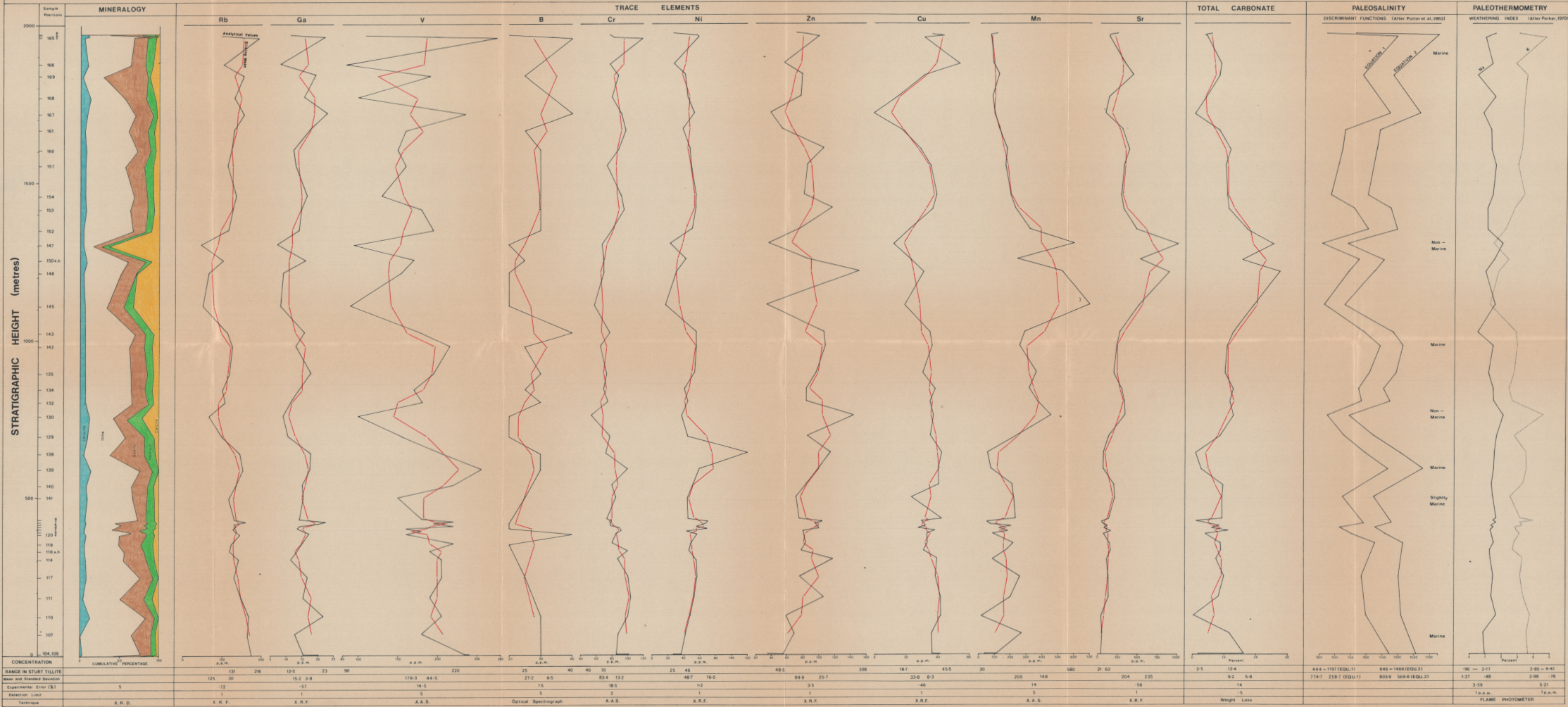
| | 32A | 32B | 50 | 51 | 77 | 2 | 58 | 59C |
|--------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Fe ₂ O ₃ | 5.060 | 4.872 | 5.201 | 7.979 | 5.392 | 6.098 | 5.853 | 5.026 |
| MnO | .044 | .020 | .059 | .159 | .090 | .037 | .092 | .009 |
| TiO ₂ | .844 | .799 | .917 | 1.051 | .802 | .910 | .690 | 1.049 |
| CaO | .259 | .197 | 1.649 | .283 | 6.067 | .212 | 3.977 | .228 |
| K ₂ O | 3.364 | 3.385 | 3.876 | 4.613 | 3.614 | 4.087 | 3.164 | 4.207 |
| SiO ₂ | 71.354 | 72.199 | 67.559 | 61.726 | 56.210 | 69.072 | 64.215 | 66.490 |
| Al ₂ O ₃ | 12.236 | 12.297 | 12.691 | 15.671 | 11.942 | 14.146 | 10.542 | 15.993 |
| P ₂ O ₅ | .176 | .177 | .189 | .200 | .149 | .122 | .134 | .153 |
| MgO | 2.660 | 2.344 | 3.195 | 4.023 | 5.247 | 3.086 | 3.965 | 3.168 |
| Na ₂ O | 1.250 | 1.340 | 1.440 | .960 | 1.370 | 1.600 | 1.420 | 2.170 |
| Loss | 2.800 | 2.930 | 4.110 | 4.360 | 10.160 | 2.930 | 7.230 | 2.980 |
| Total | 100.05 | 100.56 | 100.89 | 101.02 | 101.04 | 102.30 | 101.22 | 101.47 |

STURT TILLITE

| | 32A | 32B | 50 | 51 | 77 | 74 | 2 | 58 | 59C |
|-----------------------|------|------|------|------|-------|------|------|------|------|
| B (p.p.m.) | 40 | - | 30 | 40 | 30 | 40. | - | 25 | 30 |
| Na ₂ O (%) | 1.25 | 1.36 | 1.44 | .96 | 1.37 | 1.51 | 1.60 | 1.42 | 2.17 |
| MgO (%) | 2.66 | 2.35 | 2.98 | 4.00 | 5.19 | 4.53 | 2.89 | 4.17 | 2.89 |
| K ₂ O (%) | 3.19 | 3.31 | 3.60 | 4.41 | 3.34 | 2.85 | 3.83 | 2.99 | 4.08 |
| V (p.p.m.) | 110 | 120 | 140 | 220 | 140 | 110 | 150 | 90 | 170 |
| Cr (p.p.m.) | 55 | 46 | 58 | 70 | 58 | 46 | 68 | 44 | 68 |
| Mn (p.p.m.) | 195 | 55 | 235 | 580 | 370 | 105 | 120 | 385 | 20 |
| Ni (p.p.m.) | 29 | 43 | 33 | 46 | 25 | 27 | 27 | 29 | 35 |
| Cu (p.p.m.) | 26 | 24 | 25 | 46 | 36 | 26 | 19 | 22 | 21 |
| Zn (p.p.m.) | 66 | 112 | 61 | 109 | 58 | 122 | 70 | 49 | 308 |
| Ga (p.p.m.) | 15 | 15 | 14 | 21 | 13 | 13 | 17 | 13 | 23 |
| Rb (p.p.m.) | 151 | 151 | 175 | 216 | 161 | 131 | 187 | 137 | 190 |
| Sr (p.p.m.) | 30 | 31 | 52 | 21 | 62 | 43 | 33 | 52 | 44 |
| Carbonate (%) | 3.05 | 3.02 | 4.32 | 2.47 | 12.39 | 3.52 | 3.20 | 8.86 | 2.73 |
| Chlorite (%) | 6.7 | 6.4 | 4.1 | 2.7 | 3.4 | 12.4 | 3.9 | 5.2 | 3.9 |
| Illite (%) | 57.2 | 41.7 | 42.3 | 87.5 | 47.4 | 64.0 | 58.3 | 63.7 | 47.1 |
| Quartz (%) | 25.0 | 36.4 | 32.6 | 7.7 | 30.4 | 13.3 | 23.8 | 19.6 | 28.8 |
| Feldspar (%) | 8.1 | 11.4 | 17.8 | 0 | 12.9 | 6.7 | 10.5 | 8.5 | 20.2 |
| Calcite (%) | 3.0 | 4.0 | 3.3 | 2.2 | 6.1 | 3.6 | 3.4 | 3.1 | 0 |

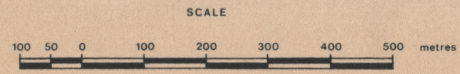
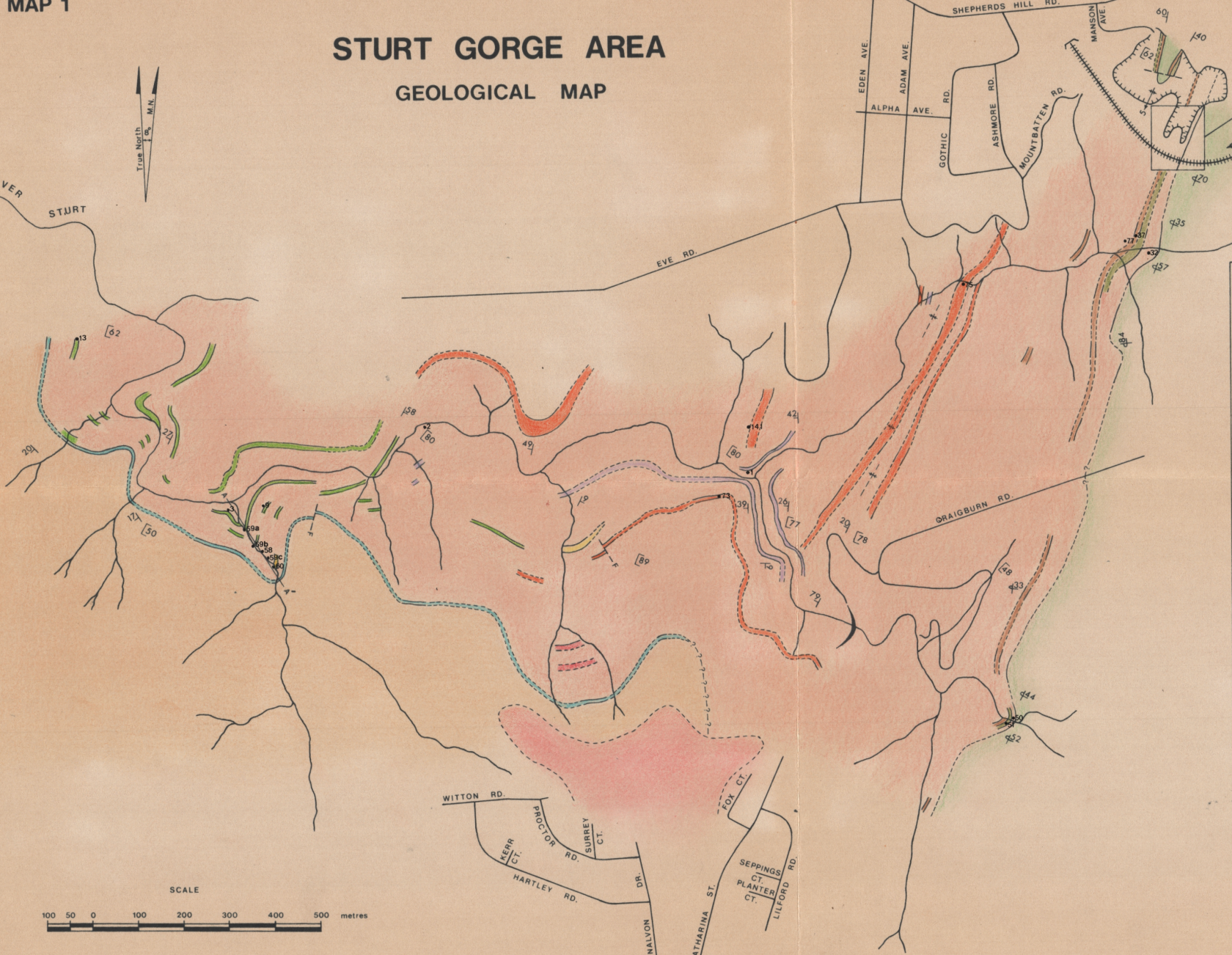
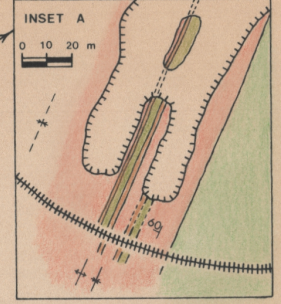
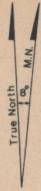
FIG 6

GEOCHEMISTRY OF THE TAPLEY HILL FORMATION, NEAR DARLINGTON, SOUTH AUSTRALIA



STURT GORGE AREA

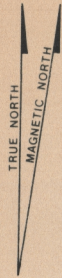
GEOLOGICAL MAP



LEGEND

| | | |
|----------|--|---|
| TERTIARY | | LATERITE: Ferruginous residual of old weathering profile. |
| | | TAPLEY HILL FORMATION: Blue-grey finely laminated, calcareous siltstones and slates. |
| | | STURT TILLITE: Massive dark grey boulder tillite interbedded with arenites, siltstones and limestones. Dolomite at top. |
| STURTIAN | | Dolomite |
| | | Cross bedded and laminated subfeldsarenite |
| | | Dark grey subfeldsarenite |
| | | Calcareous arenite |
| | | Coarse feldspathic litharenite |
| | | Subfeldsarenite, local lenses of siltstone |
| | | Laminated tillite |
| | | Cross bedded subfeldsarenite |
| | | Cross bedded siltstone |
| | | BELAIR SUB GROUP: Interbedded siltstones and quartzarenites |

| | | |
|-------------------------|-------------|-------------|
| GEOLOGICAL BOUNDARIES | | |
| OBSERVED | --- | --- |
| APPROXIMATE | - - - - - | - - - - - |
| INFERRED | - · - · - · | - · - · - · |
| FAULTS | | |
| | --- | --- |
| BEDDING | | |
| STRIKE AND DIP | --- | 130 |
| OVERTURNED | --- | 98 |
| CLEAVAGE | | |
| | --- | 130 |
| ANTICLINE (WITH PLUNGE) | | |
| OBSERVED | --- | 8 |
| INFERRED | --- | 8 |
| SYNCLINE (WITH PLUNGE) | | |
| OBSERVED | --- | 8 |
| INFERRED | --- | 8 |
| ROAD | | RD. |
| RAILWAY | | |
| QUARRY | | ⊖ |
| RIVER | | ~~~~~ |
| DAM | | ⌋ |
| TUNNEL | | ⌈ |
| STRATIGRAPHIC SECTION | | A --- A' |
| SAMPLE LOCALITY | | •20 |



LEGEND

- BRIGHTON LIMESTONE:** Oolitic limestone and dolomitic limestones.
- TAPLEY HILL FORMATION:** Blue-grey calcareous, laminated siltstones and slates. Blue finely laminated slates at the base.
- STURT TILLITE:** Massive boulder tillite interbedded with arenites and siltstones. Dolomite at top.

- FORMATION BOUNDARIES (TRACED) -----
- FORMATION BOUNDARIES (INFERRED) - - - - -
- BEDDING STRIKE AND DIP ----- 25°
- CLEAVAGE ----- 40°
- ROAD -----
- TRIANGULATION STATION ----- ▲
- QUARRY ----- []
- RIVER -----
- SAMPLE LOCATION ----- ● 100

SAMPLE LOCALITY MAP
TAPLEY HILL FORMATION
TYPE AREA S.A.

SCALE

