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# THE TERTIARY GEOLOGY OF THE COWARD CLIFF AREA, BETWEEN LAKE EYRE AND LAKE TORRENS, SOUTH AUSTRALIA.

by

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# THE TERTIARY GEOLOGY OF THE COWARD CLIFF AREA, BETWEEN LAKE EYRE AND LAKE TORRENS, SOUTH AUSTRALIA

## ABSTRACT

Fluvial and lacustrine sediment of presumed Tertiary age disconformably overlies the Early Cretaceous Marree Formation in the Coward Cliff area. Within the Tertiary succession, two periods of fluvial sedimentation are separated by a widespread lacustrine deposit of clayey silt and very fine sand.

Silcrete formed in swampy environments and channel deposits in the first period of locally ponded fluvial deposition of conglomerate, sand and silt. Early formed silcrete was eroded and clasts were incorporated in succeeding fluvial deposits.

The second period of fluvial sedimentation blanketed the area with pebbly fine to medium sand. A continental sabkha and associated dune system developed. Sand underlying sabkha surfaces (interdunal areas) was ferruginised and cemented with silica and calcite in continuous linear zones. Later differential erosion etched out a system of parallel arcuate ridges capped by silica and calcite cemented sand. These are best developed west and south of the Coward Cliff area.

The Tertiary sediment correlates with the Mount Sarah Sandstone of probable Miocene - Pliocene age. Silcrete formed locally prior to widespread development in the ?Pliocene and is unrelated to the weathering profile developed in underlying sediment. Opal formation post-dates deposition of the Tertiary succession and is considered to be related to the widespread ?Pliocene silicification.

# INTRODUCTION

North of Andamooka, a major world producer of precious opal (Carr et al 1979), are the small and isolated opal diggings of Stuart Creek, Yarra Wurta Cliff and Charlie Swamp (Figure 1). Geological investigations at these diggings by Officers of the South Australian Department of Mines and Energy (SADME) are detailed in Barnes and Scott (1979). On the basis of recommendations contained in that report, the SADME sponsored two research projects centred on the Stuart Creek (Vnuk, 1978) and Charlie Swamp (Nicol, 1979) opal diggings during 1978. The current project, again sponsored by the SADME, continues the investigation northward to a small opal occurrence at Coward Cliff (Figure 7).

## Location and Access

The study area (Figure 1), centred on Coward Cliff, lies midway between Lake Eyre and Lake Torrens on the pastoral leases of Stuart Creek, Finniss Springs and Mulgaria.

Coward Cliff, 75km north of Andamooka, is approximately 735km by road from Adelaide. From Andamooka, a track passes through the Stuart Creek and Charlie Swamp opal diggings to the study area. Access can also be gained from Farina or Stuart Creek homesteads.

## Aims

This investigation pursues three main aims:

(1) A study of the Tertiary geology with emphasis on stratigraphy, weathering, silicification and the genesis of opal.

At present, a dilemma faces geologists studying the Tertiary stratigraphy of northern South Australia. It centres on the ambiguous relationship between the Eyre Formation (Wopfner et al 1974) of Palaeocene-Eocene age and the Mount Sarah Sandstone (Barnes and Pitt, 1977) of probable Miocene-Pliocene age. The problem arises because of their similar lithologies and silicification, and they have undoubtedly been confused in the past.

The nature of silicification and its relation to Tertiary stratigraphy is an important, and as yet unresolved, problem. Until recently, it was widely believed that there were two main periods of silicification during the Cainozoic (Wopfner et al, 1974) related to the weathering of peneplanation surfaces. Barnes and Pitt (1976) however, proposed repeated silicification throughout most of the Tertiary period associated with local areas of non-deposition.

Little is known of the genesis of precious opal in South Australia. Wopfner (1978) related it to silicification associated with the Warrina Surface of Pliocene-Pleistocene age. Barnes and Scott (1979) however, suggest a relation to silicification of the Mount Sarah Sandstone, an older event. Many workers (eg. Carr et al 1979) have supported a genetic connection with a major weathering profile, and others (eg. Barker, in prep.) have suspected a diagenetic origin associated with the deposition of the Marree Formation.

(2) Determination of the distribution of potentially opal bearing Mesozoic sediment, the Marree Formation.

(3) During 1978, a previously unmapped unit at the base of the Mesozoic section, the "Stuart Creek Beds", was mapped in the Stuart Creek (Vnuk, 1978) and Charlie Swamp (Nicol, 1979) area. It was hoped to be able to trace this unit northward into the study area.

## Methods of study

The investigation occupied six months. Four field excursions enabled six weeks of field work to be done with the remaining time spent in laboratory study and preparation of the report.

Bench Marks (BM) were set up in the study area by A.B. Hack (Technical Officer, SADME). Required locations were subsequently levelled from the Bench Marks. All elevations are relative to Australian Height Datum (AHD).

Approximately 400km$^2$ of the CURDIMURKA (Daly and Coats, 1971) geological sheet were mapped (Figure 21) using 1:40,000 colour aerial photographs supplied by the Department of Lands.

29 levelled and measured geological sections are included as Figures and Appendix C. Locations of the numbered sections are shown in Figure 21.

31 thin sections (TS) were prepared by the Australian Mineral Development Laboratories (Amdel) and 2 by the University of Adelaide Geology Department, to supplement field descriptions. Descriptions of 26 of these are included in Appendix B.

37 samples were examined by X-Ray diffraction (XRD) at the University of Adelaide for routine confirmation of mineralogy.

21 specimens of silcrete and associated sediment were submitted to Amdel for silicate analysis. However, the analyses were received too late to be examined in detail. They are included as Appendix D.

Results

This report presents new data from the Coward Cliff area which advances the current understanding of Tertiary geology in northern South Australia. Silicification of the Tertiary sediment, which correlates with the Mount Sarah Sandstone, is closely related to stratigraphy and sedimentary environment. Silicification proceeded locally over a protracted period, with a major widespread development during the Pliocene. It is unrelated to the major weathered profile present in the study area. Evidence is presented that documents the environment in which silicification occurred and accounts for the variable mineralogy and structure of silicified rocks.

Observations at Coward Cliff and the Stuart Creek Precious Stones Field support the suggestion by Barnes and Scott (1979) that opal formation is related to silicification of the Mount Sarah Sandstone.

The origin of a series of arcuate ridges west of Coward Cliff (Figure 1) has been variously interpreted by Webb and Wopfner (1961), Jessup and Norris (1971), Murrell (1977) and most recently by Ambrose and Flint (1979). This report presents yet another explanation.

The distribution of the Marree Formation is presented in Figure 21. A significantly greater exposure of Adelaidean rock than shown on the CURDIMURKA (Daly and Coats, 1971) geological sheet has been mapped resulting in reduced areal extent of the Marree Formation. More importantly however, it is shown that the Marree Formation rests on a generally planar unconformity surface (Figure 21, cross section). Thus, over much of the study area it is of minimal thickness.

The "Stuart Creek Beds" could not be traced northward from Charlie Swamp. They appear to be absent from the study area.

## STRATIGRAPHY

### Introduction

Folded Adelaidean quartzite and shale are overlain with angular unconformity by Early Cretaceous marine mudstone of the Marree Formation, the upper part of which is intensely weathered (Figure 7). (Further detail of pre-Cainozoic stratigraphy is included as Appendix A). Tertiary fluvial and lacustrine sediment rests disconformably on the Marree Formation, reaching a thickness of 20m although the top is eroded. A ?Late Tertiary-Quaternary colluvium, the "jasper-breccia" unit (Nicol, 1979) is locally developed on eroded Tertiary sediment and colluvial and alluvial sand and conglomerate and aeolian dune sand mantle the older rocks.

Tertiary sediment rests on both weathered and fresh (relatively unweathered) Marree Formation (Figure 21, cross section). The contact, which has a relief in excess of 30m, can be sharp, cracked, brecciated, or indistinct. It is generally irregular, but in places planar. The Tertiary succession can be divided into four sequences[1] of progressively younger age:-

- sequence A - a silcrete[2].
- sequence B - a basal lag of silcrete clasts; fluvial and lacustrine sand and silt; silicified in part.
- sequence C - lacustrine silt.
- sequence D - fluvial pebbly sand; silicified in part.

The four sequences, represented in Figures 3 and 4, are discussed below.

### Sequence A

A silcrete represents the earliest record of Tertiary sedimentation. It is strongly indurated with a columnar or nodular structure (Figure 8) and comprises scattered detrital quartz grains in an olive greenish grey to grey siliceous groundmass. In places it contains rounded cobbles of quartzite. In thin section, (Appendix B), medium to very coarse sand size grains 'float' in a microcrystalline quartz groundmass that has a swirled and banded structure.

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1 'Sequence' is not used in a formal sense.
2 The term silcrete was first coined by Lamplugh (1902) for "masses ........ indurated by a siliceous cement". It is used here in the same general way as a lithological term. Where appropriate, a more descriptive phrase such as silicified sandstone is employed.

The silcrete crops out in two locations only (Location Nos. 246 and 365), with a maximum thickness of 2m. Its base is indistinct, passing gradationally down into altered Marree Formation. The eroded upper surface is disconformable with overlying sediment.

Thorough silicification has destroyed primary sedimentary features of the silcrete. However, the coarse detrital grainsize and the shape of the outcrop in cross-section (Figure 4, Unit No. 2), indicate deposition as a fluvial channel fill.

Sequence B

At the base of many Tertiary sections is a lag deposit of silcrete and quartzite clasts (Figure 9). The rounded quartzite clasts have been derived by erosion from the Marree Formation. The silcrete clasts are lithologically similar to silcrete of sequence A. (Appendix B). The silcrete lag layer laps onto thinned edges of sequence A (Figure 4) and silcrete clasts infill fissures in the upper part of sequence A (Figure 3). These features conclusively demonstrate derivation of the clasts from silcrete of sequence A, which provides pre-formed sub-rounded clasts due to its columnar structure and nodular weathering habit.

Sediment accumulated in channels and low-lying areas. It is characteristically lenticular and discontinuous, and silicification is common. Because of its variability, discussion of several sections will best illustrate the nature of sequence B.

At location 365 (Figure 3, Unit 4) sequence B, which is 5m thick, comprises silt and very fine sand with silcrete conglomerate lenses near the base, overlain by well bedded fine sand with some silt and clay. Many of the beds have planar upper surfaces from which root channels descend. Bedding is enhanced by variable silicification.

At location 379 (Figure 5, Units 2, 3, 4), silcrete upto 1.5m thick has developed over a thin basal lag. The silicified zone, which lenses out over a distance of about 100m from its maximum development, has formed partly on silt and partly on sandy sediment (Figure C4). In thin section (Appendix B, 550/379-1), scattered medium quartz grains 'float' in a microcrystalline groundmass. The silcrete has a flat pavement-like surface and polygonal prismatic jointing (Figure 10). Fossil plant impressions are common in the upper part and root channels descend from the upper surface. Spherical concretionary nodules of iron oxide, upto 3cm in diameter are scattered through the silcrete (Figure 11). A friable, ferruginised cross bedded medium sand overlies the silcrete with sharp contact. This passes upward into flat laminated fine to very fine sand. A thin capping of siltstone with granule layers is cemented by iron oxide and silica. It has a planar surface, nodules of iron oxide and vertical root channels. Nearby, silica cements part of the underlying sand.

At location 246, (Figure 4, Unit 3) massive, silicified grey to mauve sandy silt overlies the basal lag layer. In part, pebbly crossbedded sand with wood stem and leaf impressions, grades up to flat laminated sand. Root channels descend from the sharp planar upper surface.

At Coward Cliff (Figure 6, Unit 3), overlying the basal lag a pebbly coarse sand grades upwards to kaolinitic fine sand. It is crossbedded at the base but generally flat bedded, with a maximum thickness of 1m. Opaline silica and microcrystalline quartz weakly cement both sequence B and the underlying bleached Marree Formation. The disconformity surface is very flat (Figure 7) and the Tertiary sand probably formed by sheet flooding or near shore lacustrine deposition.

3.2km south of Wimbrinna Dam, 4m of fine sand fills a channel cut into the Marree Formation. The silicified fluvial sand contains strap-like plant impressions, silicified fragments of woody appearance and leaf impressions.

Silicified sandy silt with root channels and rare silcrete pebbles caps many of the mesas at relatively low elevations (Figures C4 and C5, locations 383,371,364). This silcrete probably represents sequence B, and predates lacustrine deposition of sequence C within the study area.

## Plant Fossils

Strap-like impressions with ribbing parallel to the length are compressed remnants of aquatic monocotyledons (D. Christophel pers. comm. 1979). They resemble the modern day bulrush (Genus Typha). Similar uncompressed reed-like fragments are present in the silcrete at location 379. Larger fragments of woody appearance, although now partially compressed, have a ribbed surface with nodes and bear some resemblance to bamboo. Leaves with a central midrib and of unknown affinity are also present. The structure of the root channels commonly found in silcrete is not inconsistent with them having been produced by aquatic monocotyledons.

Summary

A basal silcrete and quartzite lag developed on an erosional surface, overlying the Marree Formation and sequence A. Fluvial and lacustrine sediment comprising silcrete pebble conglomerate, sand and silt was deposited in channels and depressed areas. Non-depositional periods are marked by silicification and planar bedding surfaces with descending root channels. The growth of aquatic vegetation in generally fine grained sediment which accumulated in the shallow depressions indicates ponding of a riverine system with subsequent development of swamps.

Sequence C

Uniform lacustrine deposition of sequence C followed the locally ponded fluviatile environment of sequence B. Sediment comprises grey clayey very fine sand and silt. It is mostly detrital quartz, with minor kaolinite, alunite, montmorillonite and halloysite. The generally soft and friable, laminated and cross-laminated sediment contains layers indurated by silica cement that parallel the bedding. These crop out strongly, breaking into slabs 2-15cm thick (Figure 12), and show the bedding to be continuous over a distance of several kilometres. In places, thin lenticular beds of fine to very coarse sand are present. Ferruginisation of these permeable beds and adjacent finer grained sediment produced red, green, yellow and mauve colours. A thick gypcrete (crystalline rosettes of gypsum) has, in places, developed on the upper part of the sequence.

A unique bed of intensely burrowed sediment upto 15cm thick is sandwiched between two layers of silica cemented siltstone (Figures 12 and 13). It is best exposed in the southern part of the study area (Figures 4 and C4), but is present at Coward Cliff, thus extending a distance of 13km in a north-south direction. Sediment above and below this interval is not burrowed.

This sequence is widely distributed in the study area, but is absent over basement highs in the east and southeast parts of the study area where sequence D rests directly on the Marree Formation (Figure C5, location BM 689 and 343). A maximum exposed thickness of 7m is attained in the inferred deepest part of the basin (location 379) but commonly it is 3 to 4m thick.

Lacustrine sediment rests on sequence B, sequence A and the Marree Formation. The contact with silicified rock of sequence B is sharp, but elsewhere the contact is gradational. Where lacustrine sediment rests on sequence A or the Marree Formation, the contact is disconformable and generally marked by a thin sand (Figure 19) or pebble (Figure 4) lag.

## Interpretation

The significance of the burrowed interval is not clear. The trace fossils are the result of burrowing activity by sediment ingesting organisms, probably worms, below the sediment-water interface. Since lithology and energy conditions appear constant, the sudden appearance and disappearance of the organisms may be related to nutrient availability, climatic influence, the opening or closing of a link with a waterway or adjacent lake, or chemical conditions in the lake. Some combination of these factors may be responsible for the unique burrowed interval. However, the latter suggestion is supported by an apparent genetic relationship between the burrowed interval and the encasing silica cemented siltstone layers. The silica cement was probably precipitated diagenetically soon after the sediment was deposited on the lake floor. Thus, whatever factor induced silica precipitation may have inversely affected the population of burrowing organisms.

The widespread uniform distribution of the relatively thin sequence, the fine grainsize, and the continuity of bedding in finely flat laminated and cross laminated sediment indicate a low energy, subaqueous environment with a very slow input of detritus. These features, combined with the widespread distribution of the burrowed interval, indicate that a body of water, at least 13km across in a north-south direction, covered most of the study area. Assuming no post-depositional tectonic movement, and using the burrowed interval as a time marker horizon, the minimum depth of water in the deepest part of the basin was about 20m.

Considering that the basement to the Tertiary succession was the Marree Formation, basically a silty, sandy claystone, it is thus surprising that very little clay was deposited in the basin. If fluvial transport of sediment to the lake was involved, either there was limited erosion of the Marree Formation during the depositional phase in the basin or clay size material was removed from the basin via an outlet linked to a waterway.

It is suggested herein, that much of the detritus may have been transported by wind. In this case, silt and sand size grains would have been deposited on the lake surface in preference to clay size particles, and settled through the water. This suggestion is supported by the uniformly fine grainsize, the continuity of bedding and the relatively uniform thickness of the lacustrine sediment. Furthermore, it accounts for the high, in places extremely high, degree of sorting of the sediment. Although in places, the sediment is cross laminated, there is in general little evidence of subaqueous lateral transport such as scouring or ripple marks.

Rare, thin, lenticular coarse sand beds indicate minor influxes of fluvial sediment. Ripple marks, shrinkage cracks (Figure 14), granule and pebble layers and small vertical burrows are found in one location, 3.2km south of Wimbrinna Dam. These features suggest a near shore, shallow water, perhaps partly subaerial environment. However, such features are not generally present.

## Sequence D

A pebbly sand, sequence D, blankets the lacustrine sequence and surrounding basement highs, with silica cemented portions capping many of the hills and mesas. Lithology is uniform comprising well sorted fine to medium quartz sand with polished pebble layers of milky quartz, clear quartz, black chert and silcrete. Small scale cross bedding is common with some finer fractions being laminated and cross laminated. The pebble beds and cross bedding in the sand indicate fluvial deposition.

Sequence D, the most widely distributed of the four sequences, is thickest where it overlies lacustrine sediment and reaches a maximum thickness of about 10m at Coward Cliff. In the east, southeast and southwest parts of the study area, where sequence D rests on the Marree Formation, it is 3m or less in thickness. The top of the sequence is eroded.

The basal contact with the lacustrine sediment is generally sharp, but in places it appears gradational over 20-30cm. The disconformable contact with the Marree Formation can be sharp but is commonly a zone of brecciation, with the bleached upper part of the Marree Formation being broken up and infiltrated by Tertiary sand. The brecciated zone and the overlying sand are silicified.

The generally friable sand, in places white, but commonly ferruginised to a yellow or reddish brown colour, is cemented in part by iron oxide, silica, calcite and gypsum. Ferruginous rims on the sand grains are continuous and of uniform thickness, indicating that the iron oxide precipitated within the sand from groundwater, probably below the water table.

Sheets of silica cemented sand, yellow, cream, greenish-grey or grey in colour, cap the mesas, and in places form one or more layers below the capping. (Figures 6 and C1). The pillowy and bulbous surfaces (Figure 8 in Wopfner, 1978 or Figure 11 in Ambrose and Flint, 1979) of the silcrete indicate concretionary growth of the silica cement, by precipitation from groundwater.

Silicification post-dates ferruginisation of the sand. This is indicated by the replacement of ferruginous rims by silica (eg. Appendix B, T.S. 550/363-4) and the infilling of pore space in hematite cemented sandstone by microcrystalline quartz (Appendix B, T.S. 550/380-5). The same conclusion was reached by Whitehead (1978b) who examined similar rocks from an area west of Coward Cliff.

Moulds of blade-like, tabular crystals (Figure 16), presumed to be gypsum, are preserved within silicified sand capping the mesas. The habit and orientation of the crystals indicate that they grew within the sand under very saline conditions (Cody, 1976 and Shearman, 1966). Such moulds are present in several locations, the best developed being 5.6km south-south-east of Wimbrinna Dam. At the same location, in the silicified sand, are structures that resemble cauliflower chert (Figure 17). Cauliflower chert is formed by the explosive growth of anhydrite nodules which are subsequently replaced by silica (Shearman, 1966). The association of gypsum and anhydrite, both of which predate silicification, is common in sabkha environments.

In some locations, particularly the south-east part of the study area, bedding in the silicified sand is disrupted. Shrinkage cracks (Figure 15) may be desiccation features or result from drying of a silica gel. In other cases, beds and laminae are broken up but recognisably 'in situ' or completely brecciated. In places, angular fragments appear to have been reworked into thin beds. The sediment, now strongly silicified, had some coherency prior to disruption. It is considered possible, but unlikely, that the sediment was partially silicified at that time. Disruption may be the result of escaping water, driven upward by compaction of underlying sediment, or the growth and dissolution of evaporite minerals. Such evaporite solution breccias are common in carbonate-evaporite type environments (Blatt et al 1972).

Calcite, in close association with silica, cements the sand in part (Figure 15). Although not as common as the silica cement, it is conspicuous in many locations in the study area. The close association of calcite and silica cements has been reported in the vicinty of the Charlie Swamp (Nicol, 1979) and Stuart Creek (Vnuk, 1978) opal diggings and west of Coward Cliff on the arcuate ridges and at Millers Creek plateau (Ambrose and Flint, 1979). Petrographic examination of samples from Charlie Swamp (Whitehead, 1978a), shows evidence of alternation in crystallisation of calcite and quartz, suggesting no great age difference, and of replacement by quartz of some calcite.

## Discussion

Sequence C disconformably overlies sequence A and is transitional from sequence B, but its relationship with sequence D is not clear. The contact with sequence D is in places sharp, in places apparently rapidly transitional and thus conformable. Furthermore, although sequence C is not present on isolated basement highs, the continuous extent of the lacustrine sequence outside the study area is unknown. It is suspected however, that the distribution of sequence C is limited and that in places it is absent so that sequence B passes directly and continuously upward to sequence D. In this case the fluvial sediment of sequences B and D would intertongue in part with the lacustrine sediment of sequence C.

The Tertiary succession, comprising three sequences of relatively uniform thickness, dips gently southward, dropping about 10m from Coward Cliff to the southern part of the study area (Figures C4, C5 and C6). This could be an initial sedimentary dip or the result of post-depositional tectonic movement. The latter suggestion is supported by the uniform thickness of the three Tertiary sequences and the comparitively low elevation of both the sandy conglomeratic horizon and the base of the weathered profile in the Marree Formation. Nicol (1979) reported the conglomeratic horizon and the base of the weathered profile to be everywhere at an elevation of 90 to 100m, from Andamooka to Charlie Swamp. At Coward Cliff they are present at about 94m but in the southern part of the study area occur at 80 to 85m (Figures C4 and C5, Location Nos. 343 and 218). Thus it is probable that, relative to Coward Cliff, the southern part of the study area has been lowered about 10m since deposition of the Tertiary sediments.

## CORRELATION AND REGIONAL RELATIONSHIPS

The Tertiary succession in the Coward Cliff area has not previously been described in detail, and is mapped as "siliceous duricrust" of Lower Tertiary age on the preliminary CURDIMURKA (Daly and Coats, 1971) geological sheet.

Tertiary sediment capping mesas in the vicinity of the Charlie Swamp and Stuart Creek opal diggings comprises upto 10m of ferruginous pebbly sand with silcrete clasts, cemented in part by silica and calcite. In the latter locality, Vnuk (1978) records minor silt and clay along with sand in low lying areas and suggests a pre-erosional thickness in excess of 30m, for the Tertiary sediment. To the west of the Coward Cliff area, a system of arcuate ridges (Figure 1) are capped by 5-10m of conglomeratic sandstone with silcrete clasts, fine to medium sandstone and siltstone, variably altered by silicification, calcification and ferruginisation (Ambrose and Flint, 1979). These sediments, due to their strong lithological similarity and close proximity are considered to correlate in part with Tertiary sediment in the Coward Cliff area (sequences B, C and D).

Tertiary sediment at the Stuart Creek opal diggings and on the arcuate ridges, has been correlated with the Mount Sarah Sandstone and an intertonguing relationship proposed with the Etadunna Formation at Millers Creek plateau (Barnes and Scott, 1979 and Ambrose and Flint, 1979), suggesting a Miocene to Pliocene age. In its type area, at Lake Palankarinna, the Etadunna Formation is overlain disconformably by the ?Pliocene Mampuwordu Sands and younger formations (Stirton et al, 1961). The Mampuwordu Sands, a fluvial pebbly sand, is lithologically similar to Tertiary sediment (particularly sequence D) in the Coward Cliff area and may correlate in part. It contains pebbles of silcrete, but is not recorded as being silicified itself. Thus, Tertiary sediment in the Coward Cliff area (sequences B, C and D) is considered to be of Miocene to Pliocene age. Sequence A, regarded here as an early and local phase of sedimentation of probable Miocene age, may possibly be older than Miocene.

From the Coward Cliff area east-ward to the Willouran Ranges, mesas are generally capped by 2-3m of silicified pebbly sand overlying the Marree Formation. However, green-grey silt (sequence C) with a basal silcrete pebble lag and overlying sand (sequence D) cap the ridge on which the vermin proof fence is situated, several kilometres east of the study area. Dolomite, similar to that capping Millers Creek plateau, caps a group of mesas 26km due east of Coward Cliff (R. Callen <u>pers. comm.</u>, 1979).

PALAEOENVIRONMENT

Much of the bleached profile developed on the Marree Formation was eroded prior to deposition and subsequent silicification of sequence A. Continued erosion inverted the relief and eroded sequence A silcrete. The abundance and widespread distribution of silcrete clasts indicates extensive source silcrete, which probably formed locally over a prolonged period of time during, and perhaps even before, the major erosional phase. This suggestion is supported by the presence of silcrete clasts in the upper part of sequence D which must have been derived from topographically higher silcrete.

Erosion of sequence A silcrete and surrounding softer sediment spread a thin layer of silcrete clasts over the landscape and removed finer material from the area. The lag of silcrete clasts, a product of an essentially erosional phase, is unrelated to deposition of the succeeding sediment. Sequence B and the overlying widespread lacustrine sediments of sequence C, signify the conclusion of erosion over much of the Coward Cliff area.

Pebbly sand and silt, sequence B, deposited in a locally ponded fluviatile environment, supported aquatic vegetation in low-lying swamps. These areas are represented by silcrete with flat pavement-like surfaces, root channels, and in the upper part, reed-like plant impressions. Sand, containing fragments of vegetation, was deposited and silicified in associated fluvial channels. This initial phase of ponded fluviatile deposition was replaced by uniform lacustrine deposition of silt, sequence C. Returning fluvial deposition, sequence D, blanketed the landscape with pebbly sand which was affected by processes related to groundwater. Gypsum and anhydrite formed within the sand above the water table and ferruginisation, silicification and calcification occurred at depth.

The top of sequence D is eroded, cemented sand now forming a capping over friable sand. Since the cement was deposited at depth within the sand, there must have been overlying sediment. The main questions to be answered are (1) what was the nature and thickness of the overlying sediment, and what type of environment was it deposit-in, or subjected to, and (2) what factors related to (1) caused the alteration of the underlying sediment. The answers must be somewhat speculative, since no direct evidence remains. However, a major clue is provided by a system of ridges which dominate the topography west of the Coward Cliff area. The north-south trending ridges are arcuate about the Millers Creek plateau area with the mesas at Yarra Wurta

Cliff and Charlie Swamp being the eastern-most representatives (Ambrose and Flint, 1979). Various interpretations of this ridge system by a number of workers have been discussed and satisfactorily disproved by Barnes and Scott (1979) and Ambrose and Flint (1979), who suggested a relation to a shrinking lake system centred on Millers Creek plateau. They determined that the ridges are capped by fluvial silicified pebbly sand and have formed by erosion of uncemented sediment between them.

Remnants of the same ridge system may be present in the Coward Cliff area. A line of small mesas extends south-ward from Coward Cliff, and erosional valleys in the silcrete capped plateau in the southeast part of the study area tend to be orientated north-south.

Ambrose and Flint (1979) elaborated on a model for development of the ridges as silicified strandlines of a regressive lake system centred on Millers Creek plateau, with the lake at its peak extending at least 100km east-ward to Charlie Swamp. However, there is little concrete evidence to support the former existence of such an extensive lake. Sufficient thickness and continuity of fine grained sediment, indicative of extensive lacustrine conditions, are lacking in the Yarra Wurta Cliff and Charlie Swamp areas and are generally absent in sediment capping the ridges (Ambrose and Flint, 1979). The lack of relief, the uniform thinness of sediment from the postulated basin centre to the margin and the extensive size of the basin make this hypothesis untenable. However, in places local lacustrine deposition is indicated, as in the Coward Cliff area.

It is proposed herein, that cementation of ridge caprocks was controlled by, and took place beneath, the dune system of a continental sabkha. Sabkha surfaces in the interdunal areas, being near the water table, were sites of high evaporation with the concomitant concentration of pore fluids. Gypsum and anhydrite developed within sand above the water table while silica and calcite precipitated below the water table cementing the sand. Thus, there developed continuous linear zones of cemented sand below interdunal areas and later differential erosion etched out the ridges.

Kinsman (1969) describes continental sabkhas in the Persian Gulf area. They comprise fine to medium quartz sand, and range from deflation hollows in a dune dominated landscape to areas where the continental sabkha dominates and dunes cover only a minor part of the surface. The water table lies at a depth of about 1m and the depth of surficial sediment cover over basement rock in many places exceeds 10m. The areas extend upto 100km from the coast with a very shallow coast-ward inclination. A similar situation probably existed in the area under consideration and the arcuate distribution of the ridges suggests a genetic relationship with lacustrine sediment at Millers Creek plateau.

The linear and parallel, in places converging, ridges, resemble a system of aeolian dunes. Although fluvial sediment caps the ridges the structural effect on cementation indicates a genetic connection with an overlying dune system. It is envisaged that the uppermost fluvial sediment was reworked by wind and a system of dunes developed on a sabkha-like surface. Since silica and calcite formed below the water table, which was probably at a depth of about 1m in the inter-dunal areas, the implied thickness of overlying sediment is greater than 1m.

The former presence of gypsum and anhydrite indicates that the environment was arid. This lends some support to the idea of an aeolian dune system and casts doubt on the concept of an extensive water body. A similar suggestion was made by Kinsman (1969):

> continental sediments and associated evaporites may have accumulated without the earlier presence of large inland lakes or "seas". The suggested continental sabkha environment seems to offer a more reasonable interpretation than earlier paleogeographic hypotheses calling for the presence of large standing bodies of water in areas of apparently low hinterland relief and arid climate.

## SILICIFICATION

It is apparent from the foregoing discussion that silicification is closely related to stratigraphy and sedimentary environment. Prominent silcrete bodies developed in sequences A, B and D. These formed in three environments; locally in sediment (1) subjected to swampy conditions and (2) confined to fluvial channels and (3) widespread in the sediment underlying a continental sabkha.

Within sequence B, sediment of variable grainsize was subjected to swampy conditions. Much of the sediment probably accumulated under these conditions and comprises scattered coarse grains in a very fine matrix (silt size or finer), whereas other parts deposited under fluvial conditions comprise sand and conglomerate. Silcrete resulting from silicification under swampy conditions therefore commonly comprises scattered coarse detrital grains 'floating' in a microcrystalline or cryptocrystalline groundmass, where the siliceous matrix obscures the finer detrital fraction. Corrosion, observed commonly on larger grains, probably affected finer grains to a greater extent. Swirled and banded 'flow' structures in the siliceous groundmass can be attributed to silicification in this environment, as can the columnar and nodular structure of sequence A silcrete, which probably formed by prolonged subjection to swampy conditions. Silcrete formed in this environment has a consistently high (0.75% - 1.53%) TiO2 content (Appendix D). A similar environment for silcrete formation (Early Cainozoic ?) was recently proposed by Wopfner (1978).

Fluvial channel sand, also within sequence B, is commonly silicified. Silica may have penetrated downward from an overlying swampy environment or precipitated directly from groundwater flowing in the sand. The latter suggestion is supported by (1) the observation of Lange(1978) that silicification in similar fossiliferous sandstone took place immediately after deposition, thus preserving minute detail of the vegetation;(2) the confinement of silicification to fluvial channel deposits both in the study area and elsewhere (eg. the Mirackina Palaeochannel) and (3) the general absence of a capping silcrete developed under swampy conditions.

Widespread silcrete formation in sequence D took place below an extensive continental sabkha. This silcrete (except for one sample) has a low (0.05% - 0.44%) TiO2 content (Appendix D). A similar arid environment for silcrete formation (Early Cainozoic ?) was favoured earlier by Wopfner et al (1974). Widespread silcrete development in the upper part of the probable Late Cainozoic succession supports the conclusion of Stephens (1971) "that the major periods of formation were in Pliocene time".

Silica cement takes a number of mineralogic forms which are gradational to some extent; cryptocrystalline and microcrystalline quartz (microquartz), quartz overgrowths, chalcedony and opal. Initial silicification proceeded by quartz overgrowth in many cases, with subsequent replacement by microquartz, chalcedony and opal. This is indi - ated by relict quartz overgrowths on individual quartz grains and areas of overgrowth cemented quartz grains, which have been strongly corroded in many silcrete samples. It is probable that prolonged and intensive silicification resulted in much dissolution of host detrital grains and initial overgrowths and led to the formation of microquartz cement.

Wopfner (1978) attempts to classify three major periods of silcrete development based in part on silica mineralogy. However, it is apparent from the variation and gradation of mineralogic forms of silica recognised here, that such a classification is not valid in the Coward Cliff area. This substantiates a similar conclusion by Ambrose and Flint (1979) in the Billa Kalina area. Furthermore, Wopfner (1978) states that Late Tertiary-Quaternary silcrete invariably has an opaline (opal-CT) matrix. However, equivalent silcrete in the Charlie Swamp area, "jasper breccia" (Nicol, 1979), is cemented by chalcedony only (Appendix B, 550/500).

Silica cement has probably been derived by solution of the almost exclusively quartzose Tertiary sediment, and in many cases transported by groundwater. This is indicated by the extensive corrosion of detrital grains in silcrete. Furthermore, silicification has not resulted in an increase in silicon content relative to other elements (Appendix D).

# OPAL

Opal was observed in only one location in the study area, Coward Cliff, where common opal (opal-CT) is present in both Tertiary and Mesozoic rock. The basal Tertiary kaolinitic sand and conglomerate, sequence B, is cemented by common opal (Appendix B, 550/358-1) which also silicifies the upper part of the Marree Formation.

Veins of common opal are present in the Marree Formation, near the base of the weathered profile (Figure 18). They are generally thin, but may be 5cm thick where several veins coalesce, and vary in orientation from horizontal to vertical. The opal is strongly fractured and weathered, probably due to recent exposure. Very porous material is opaque, white, yellow or brown. Less weathered material is translucent to transparent, colourless or grey. Similar common opal has been recovered from shallow diggings in the side of the hill, upto 6m below the base of the weathered profile. Some of this is black, similar to opal in the diggings at Charlie Swamp (Vnuk, 1978).

The relationship of the opal to veins of kaolinite-alunite could not be determined but gypsum veins crosscut veins of opal and thus post-date opal emplacement. The opal veins could not be traced upward to the base of the Tertiary sediment.

Recent activity by miners at the Stuart Creek opal diggings has created a new exposure of considerable significance. Common opal cements the basal Tertiary sand (which correlates with sequence D in the Coward Cliff area) and 20cm of the underlying fresh brown mudstone (the Marree Formation). It also fills cracks in the silicified mudstone. Precious opal has been recovered by miners from vertical joints in the Marree Formation directly below this exposure.

## Genesis of Opal

It is considered herein that common opal cementing basal Tertiary sand is related to veins of common opal (at Coward Cliff) and precious opal (at the Stuart Creek opal diggings) in underlying sediment. Opal at Coward Cliff may have formed prior to deposition of sequence D or, as with opal at the Stuart Creek opal diggings, during the major phase of silicification of sequence D, or a later silicification. Thus, opal formation at the two localities may have resulted from one or more phases of silicification. At least two phases of opal formation have been recognised in the area by Vnuk (1978).

Wopfner (1978) related the genesis of precious opal to a ?Pliocene-Pleistocene silicification (mainly opaline silica) of sediment equivalent to the "jasper breccia" unit (Nicol, 1979). In the Stuart Creek - Coward Cliff area however, the unit is poorly developed and cemented with chalcedonic silica and is considered by the writer unlikely to be related to opal formation. Thus, in agreement with the conclusion of Barnes and Scott (1979), opal formation appears to be related to the major phase of silicification of Late Tertiary sediment (sequence D).

## WEATHERING

The originally soft grey or brown fresh mudstone of the Marree Formation has been intensely weathered in the upper part to white, porous, indurated, massive mudstone (called Kopi by miners at Andamooka) or almost pure, friable, white alunite. Kopi comprises quartz (detrital) and kaolinite, in places weakly silicified at the top with overlying Tertiary sediment, and in places ferruginised to a pink, mauve and yellow colour. In the upper part of the weathered profile at Coward Cliff, are weathered white veins upto 30cm thick with a fibrous structure perpendicular to vein length. They comprise kaolinite and alunite now, but presumably were satin spar gypsum prior to weathering. In places, alunite forms veins which cross-cut bedding or irregular patches and spots.

The upper part of the Marree Formation may also be altered to friable white alunite upto 5m thick. The presence of rounded quartzite, sandstone and shale pebbles and cobbles in beds and as scattered clasts in the almost pure alunite shows that it is altered Marree Formation (Figure 20). In places, alunite forms large elongate pods, 0.5m wide and 4m deep in fresh mudstone (Figure C6, Location No. 287). The base of the weathered profile is gradational to the underlying fresh mudstone.

The top of the weathered profile is eroded, but Barnes and Scott (1979) have suggested a minimum thickness of 30m. The weathered profile has a maximum thickness in the study area of 22m, 8km southeast of Wimbrinna Dam (Location No. 343) but is only 10m thick at Coward Cliff.

The following evidence shows that the weathered profile developed prior to deposition of the Tertiary sediment.

(1) The base of the Tertiary succession cuts down through the weathered profile (Figure 21, cross section)

(2) The basal Tertiary contact with the weathered profile is in places highly irregular, in places cracked, and the weathered sediment is penetrated by Tertiary sand.

(3) Alunite is included in basal Tertiary sediment below a topographic high in the alunitic weathered profile (Location No. 218)- probably a result of downslope slumping.

(4) Bleached mudstone clasts in the basal Tertiary sand at Coward Cliff may be eroded and rounded clasts of Kopi or they may have been bleached "in situ". In thin section (Appendix B, 550/357-3A and 3B) the clasts appear to have been indurated when deposited,

not soft fresh mudstone. Thus they were weathered prior to erosion, rounded and incorporated into the Tertiary sediment. Erosion of the Tertiary valley in the southern part of the study area (Figure 21, cross section), may have been due to the softer alunitic part of the weathered profile in this area. Thus, the major weathered profile developed on the Marree Formation in the Coward Cliff area predates and is unrelated to deposition and silicification of Tertiary sediment.

Nicol (1979) recognised a later bleaching event, probably late Tertiary or Quaternary in age, in the Marree Formation southeast of Charlie Swamp at "Cockatoo Cliff". It is also present in the study area, in the extreme southeast part, and several kilometres east along the vermin proof fence. However, no further relationship with Tertiary sediment or silicification could be established.

There is no evidence to suggest that the Tertiary sediment has been subjected to intense weathering, even though much kaolinite is present. The incorporation of kaolinite and alunite by erosion of the underlying weathered Marree Formation gives much of fine grained sediment, especially the lacustrine sequence, a pale colour. Alunite in the form of nodules, in places botryoidal, has developed in the lacustrine sediment. Gypcretes and extensive gypsum veins appear to be related to alunite development and horizontal ferruginous 'liesegang' banding. This is probably a late Tertiary - Quaternary event, possibly related to the second bleaching (Nicol, 1979) and the Warrina Surface (Wopfner, 1978).

## SUMMARY

Non-marine sediment of presumed Tertiary age disconformably overlies the Early Cretaceous shallow water marine Marree Formation. Within the Tertiary succession, which reaches a maximum thickness of 20m, two periods of fluviatile sedimentation are separated by a widespread lacustrine deposit.

The Tertiary succession can be divided into four sequences of progressively younger age, the first two sequences representing the first fluviatile period of deposition. Silcrete with a columnar and nodular structure (sequence A), developed locally in conglomeratic sandy silt deposited in a ponded fluviatile environment during a major erosional phase. Clasts eroded from sequence A silcrete formed a widespread lag and were incorporated in succeeding sediment. Conglomerate, sand and silt (sequence B) were deposited in depressions and channels, subsequent to erosion of sequence A, which formed topographic highs of resistant silcrete. The fossiliferous sediment was deposited in a ponded fluviatile environment and silicified locally in swamps and channels.

Widespread lacustrine sedimentation (sequence C) followed the locally developed ponded fluviatile sequences A and B. Much of the sediment, comprising clayey silt and very fine sand, was probably transported by wind to the lake surface. The sequence is silicified in part and contains a widespread intensely burrowed interval in otherwise essentially unbioturbated sediment.

The widespread second period of fluvial sedimentation blanketed the area with pebbly fine to medium sand (sequence D), in places exceeding 10m in thickness. A continental sabkha and associated dune system developed in the upper part, probably related to an extensive lake to the west. Gypsum and anhydrite formed in fluvial sediment underlying the sabkha surfaces (interdunal areas) which was ferruginised and cemented by silica and calcite in continuous linear zones. These zones were etched out by later differential erosion to form a system of parallel arcuate ridges.

The Tertiary succession in the Coward Cliff area is similar to sediment which intertongues with the Etadunna Formation at Millers Creek plateau, and is equivalent in part to the Mount Sarah Sandstone of probable Miocene-Pliocene age. Sequence A, however, may be older. Silcrete formed locally prior to widespread development in the ?Pliocene and is unrelated to the weathering profile of probable Late

Cretaceous or Early Tertiary age developed in underlying sediment.

Common opal cements sand in sequences B and D of the Tertiary succession and the underlying Marree Formation. The formation of common opal (and precious opal?) is considered to be related to the widespread ?Pliocene silicification.

## Recommendations

It is recommended that the included silicate analyses (Appendix D) be examined more closely for trends related to silicification and compared with published analyses of similar rocks (eg Wopfner, 1978).

Examination of the surfaces of detrital grains in the lacustrine sequence using a scanning electron microscope may detect features characteristic of aeolian transport such as 'frosting'. A positive result would be conclusive and of significance to the environmental interpretation.

The stratigraphic relationships and the extent of the four sequences described herein should be investigated in surrounding areas. This may lead to clarification of the ambiguous relationship between the Eyre Formation and the Mount Sarah Sandstone. Furthermore, sediment overlying silcrete of sequence D should be sought and examined to clarify the environmental interpretation presented for the origin of extensive silica and calcite cemented sand now capping the ridges.

The extensively developed, seemingly pure alunite deposits may be of economic significance and this should be investigated. The chemistry involved in the formation of alunite by weathering of the fresh mudstone and its relation to Kopi is an interesting problem.

Further work is necessary to determine the relationship between precious opal, common opal and the silicification of the Tertiary sediment. Opaline cement in Tertiary sediment may be a useful prospecting guide. It is likely that opal formed in underlying rock also.

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- R. Betterman (Andamooka Area Officer) for assistance while in the field area.

-Staff of the University of Adelaide, Geology Department.

- Dr. J. Jones and Dr. B. Daily - for supervision, guidance and discussion in the field and office.
- Dr. B. McGowran - for discussion.
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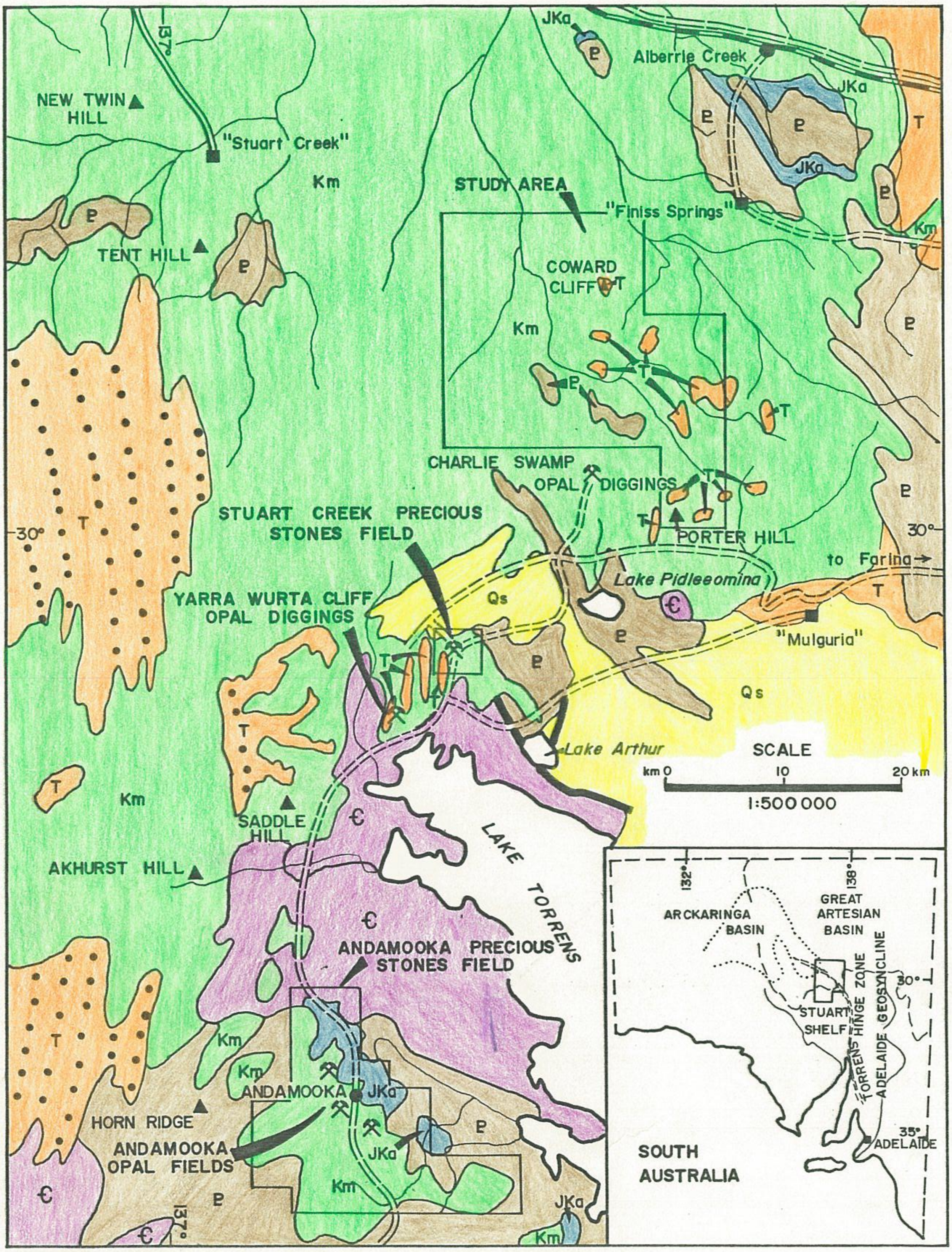
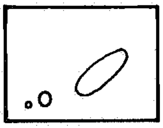
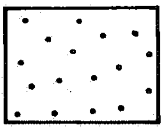
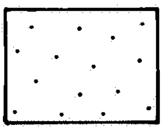
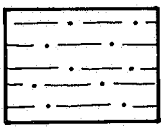
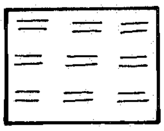
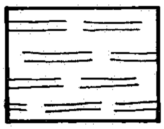
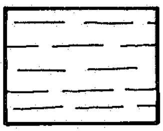
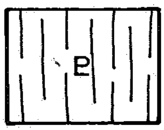
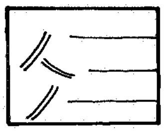
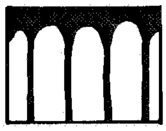
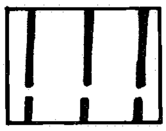
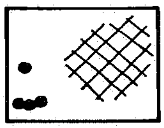
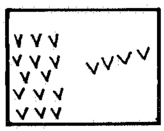
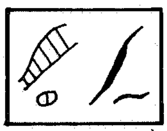
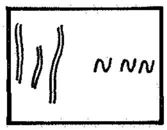



Adapted from
Barnes and Scott (1979)
and Vnuk (1978)

For Legend see Fig. 21

| Fig. 1 | | DEPARTMENT OF MINES AND ENERGY<br>SOUTH AUSTRALIA | SCALE 1:500 000 |
|---|---|---|---|
| COMPILED G. NICOL | | STUART CREEK COWARD CLIFF AREA<br>REGIONAL GEOLOGY AND LOCALITY PLAN | DATE 16-10-79 |
| DRN S.R. | CKD: | | PLAN NUMBER<br>S14416 |

1604

| | |
|---|---|
|  | Gravel; granules, pebbles, cobbles to boulders |
|  | Sand: fine, medium, course, very course |
|  | Sand: very fine |
|  | Silt |
|  | Alunite white, friable |
|  | Kopi: Bleached, massive, porous mudstone<br>White (also yellow, pink, mauve) |
|  | Mud or clay |
|  | Adelaidean basement |
|  | Cross bedding, lamination; flat bedding, lamination |
|  | Silicification, columnar or nodular |
|  | Silicification, massive, strong uniform / patchy |
|  | Silicification, massive, weak uniform / patchy |
|  | Ferruginous nodules; Ferruginisation |
|  | Gypsum; rosettes forming massive gypcrete; veins of selenite and satin spar |
|  | Kaolinite; alunite, veins or pods. Opal, veins |
|  | Root canals, near vertical;<br>Burrows, horizontal |
|  | Fossils: bivalve, wood stem, leaf |
|  | Silcrete clasts |
|  | Unconformity |

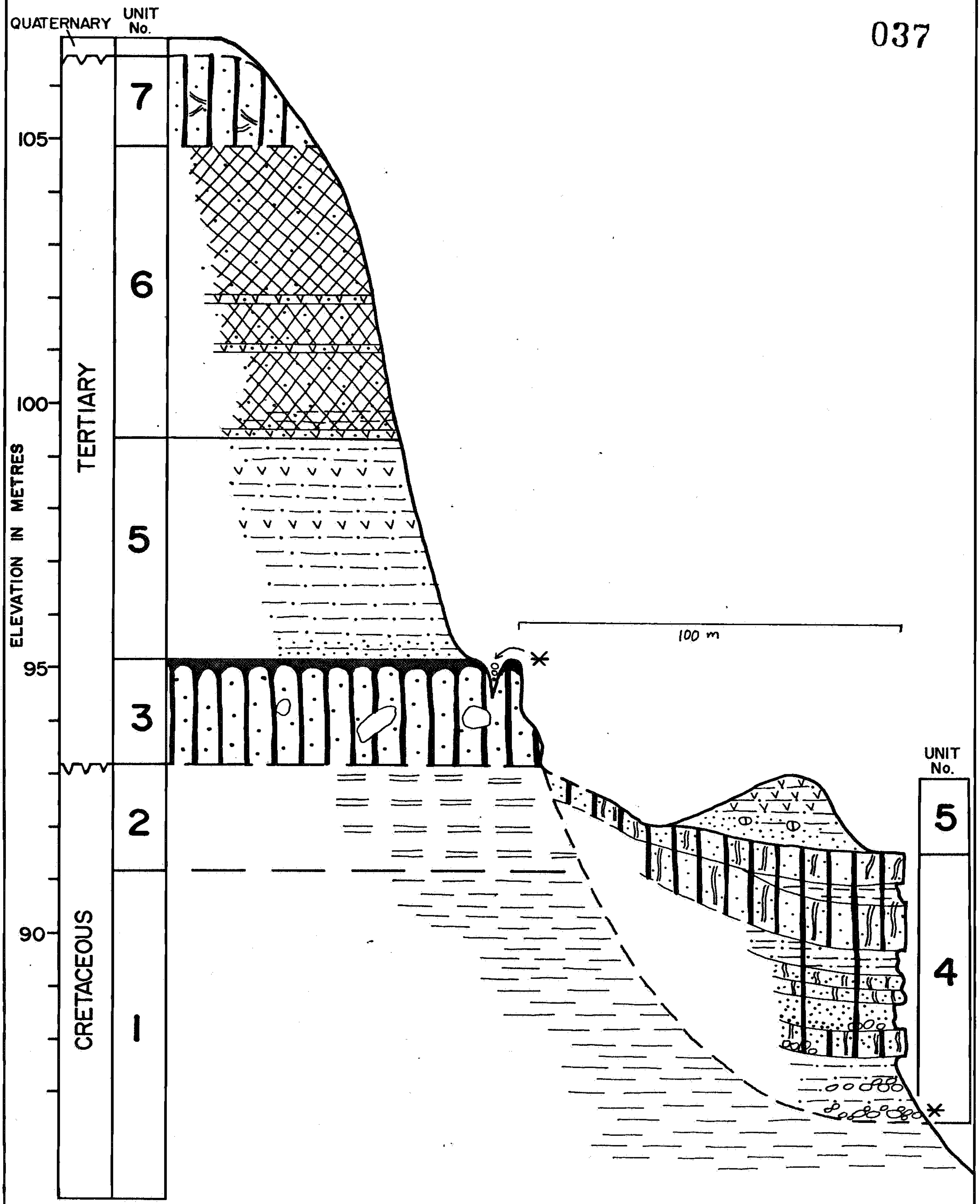
| | | |
|---|---|---|
| Fig. 2 | DEPARTMENT OF MINES AND ENERGY<br>SOUTH AUSTRALIA | SCALE |
| COMPILED: G. NICOL | STUART CREEK COWARD CLIFF AREA<br>LEGEND FOR GEOLOGICAL SECTIONS | DATE 15-10-79 |
| DRN M.B. | CKD | | PLAN NUMBER<br>S14428 |

1604

Figure 3. Geological Section, Location No. 365.

| Sequence | Unit No. | Description |
|---|---|---|
| | 1 | Fresh grey mudstone. |
| | 2 | Weathered white mudstone and friable alunite. Gradational change from Unit No. 1. |
| A | 3 | Strongly indurated greyish silcrete with nodular structure. Cobbles and scattered medium to coarse quartz grains in a microcrystalline groundmass. Lower contact is gradational onto altered mudstone. Upper surface is eroded, sharp and irregular with silcrete pebbles lodged in crevices. (T.S. and silicate analysis 550/365-1). |
| B | 4 | Lenticular silcrete conglomerate, siltstone and fine sandstone. Upper beds are silicified and have planar upper surfaces and root channels. Basal silcrete lag disconformably overlies fresh Marree Formation. |
| C | 5 | Grey clayey silt and very fine sand, laminated, with gypsum veins, gypcrete and botryoidal alunite nodules. Sharp basal contact with Unit Nos. 3 and 4. |
| D | 6 | Friable fine to medium quartz sand, ferruginised yellow to reddish-brown, with gypsum veins. Basal contact is sharp, but the lower 0.5m is clayey. |
| D | 7 | Greyish silicified fine to medium sandstone, cross bedded. Base is irregular and gradational over a short distance to friable sand. Top is erosional with Quaternary soil development. |

037




| | | |
|---|---|---|
| Fig. 3 | DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA | SCALE 1:100 Vertical |
| COMPILED G. NICOL | STUART CREEK COWARD CLIFF AREA GEOLOGICAL SECTION LOCATION No. 365 | DATE 12-10-79 |
| DRN M.B. CKD | | PLAN NUMBER S14422 |

1604

Figure 4. Geological Section, Location No. 246.

| Sequence | Unit No. | Description |
|---|---|---|
| | 1 | Cretaceous, Marree Formation. Mudstone; fissile, grey and fresh to massive and indurated, with some alunite near the top, slightly weathered. |
| A | 2 | Greyish silcrete with columnar and nodular structure. Medium to coarse quartz grains float in a microcrystalline groundmass. Base is transitional to underlying altered mudstone. Upper surface is planar, erosional. (T.S. and silicate analysis 550/247/9, 550/247/10, 550/247/11-1, 550/247/11-2). |
| B | 3 | Silicified pebbly sand and silt, in part flat laminated, cross bedded but elsewhere massive. Contains fossil leaves, stems and root channels. Base marked by a silcrete lag which extends onto Unit No. 2.Upper surface is planar. (T.S. and silicate analysis 550/247/8). |
| C | 4 | Grey clayey silt and very fine sand, with burrowed interval which laps onto high ground, and gypcrete in upper part. |
| D | 5 | Friable white fine to medium quartz sand, cemented in part by gypsum at base where it sharply overlies Unit No. 4. Silicified at top (see Figure C3). |

1604

# Fig. 4

COMPILED: G. NICOL

DRN. M.B. | CKD:

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

## STUART CREEK COWARD CLIFF AREA
## GEOLOGICAL SECTION
## LOCATION No. 246

SCALE 1:100 Vertical

DATE 16-10-79

PLAN NUMBER

S14424

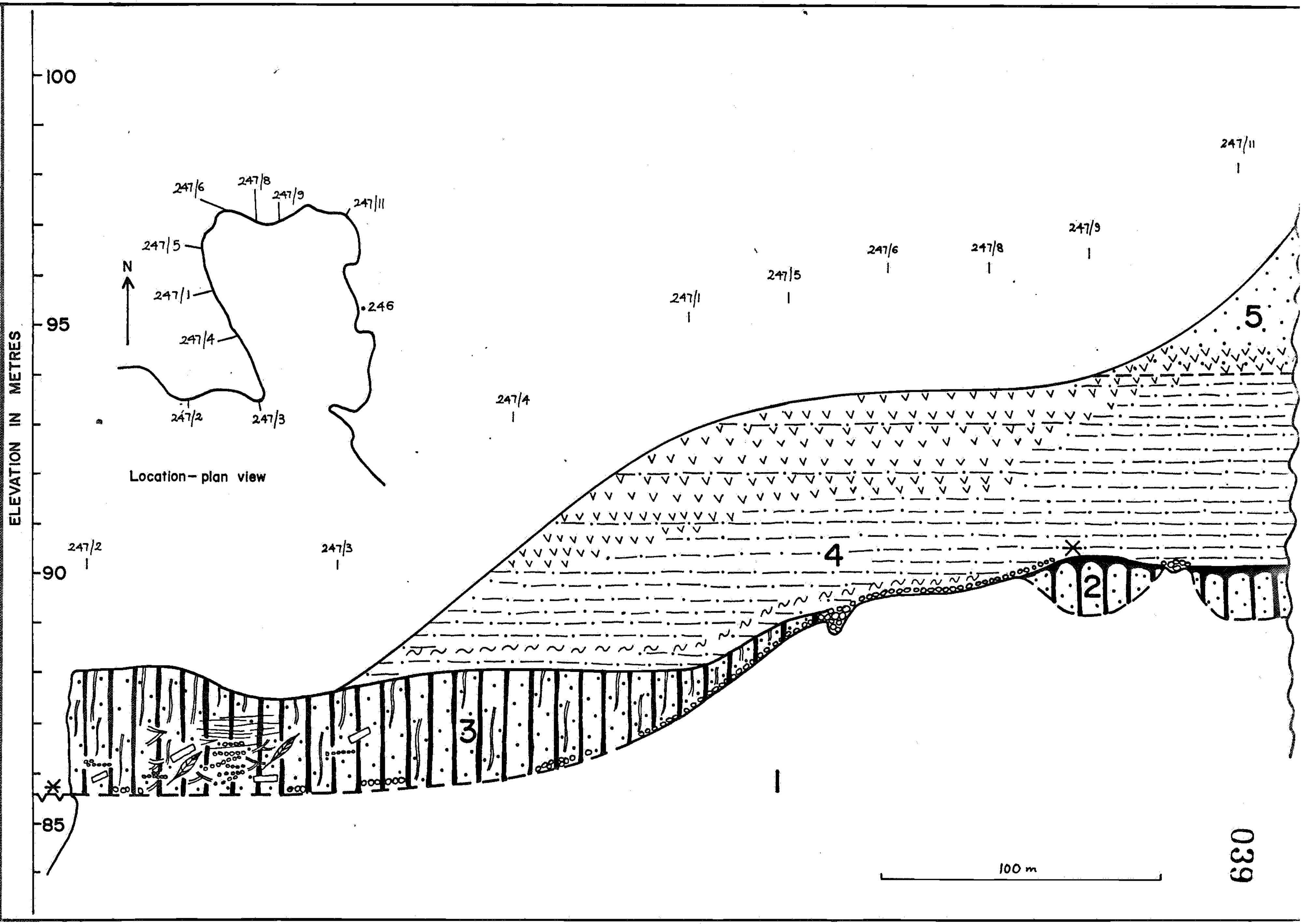
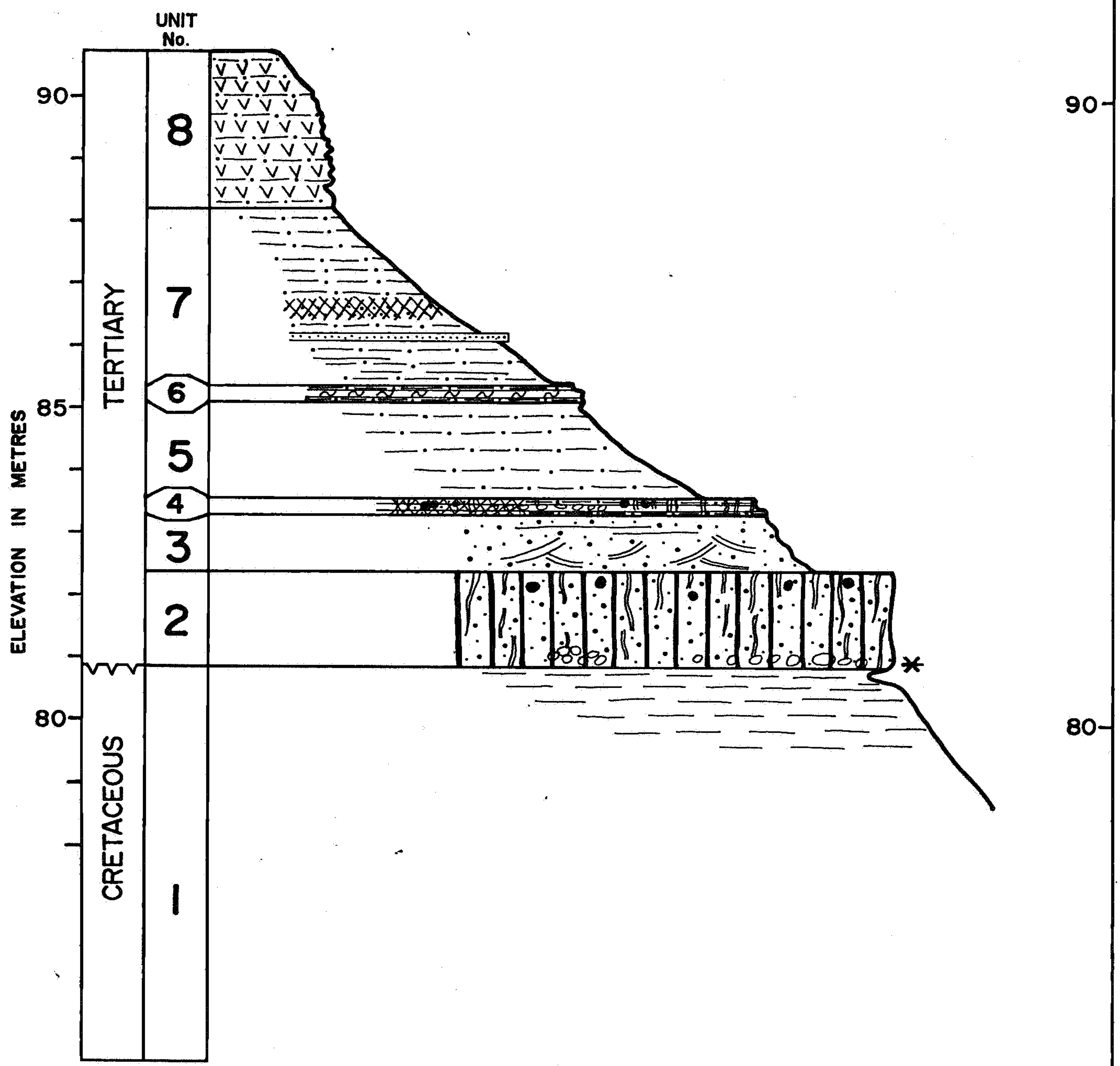


Figure 5. Geological Section, Location No. 379.

| Sequence | Unit No. | Description |
|---|---|---|
| | 1 | Fresh grey mudstone. Upper 2m is yellowish. |
| B | 2 | Grey silicified sandstone with spherical goethite nodules. Medium quartz grains float in a microcrystalline groundmass. Planar upper surface, reed-like plant impressions in upper part and root channels. Sharp base with silcrete and quartzite lag. (T.S. and silicate analysis 550/-379-1). |
| B | 3 | Fining upward, ferruginised friable sand. Yellow, cross bedded medium sand at base to mauve flat laminated fine sand at top. Sharp base on silcrete upper surface. |
| B | 4 | Ferruginised and silicified yellow siltstone with granule layers. Planar upper surface and contains goethite nodules and root channels. Base is gradational onto friable fine sand. |
| C | 5 | Grey clayey finely bedded silt and very fine sand |
| C | 6 | Burrowed interval between two silicified siltstone layers. (T.S. 550/379-5). |
| C | 7 | Grey clayey silt and very fine sand. Fine sand and ferruginised, thin, lenticular coarse sand beds. |
| C | 8 | Gypcrete, alunite and ferruginous staining developed in silt and very fine sand. |



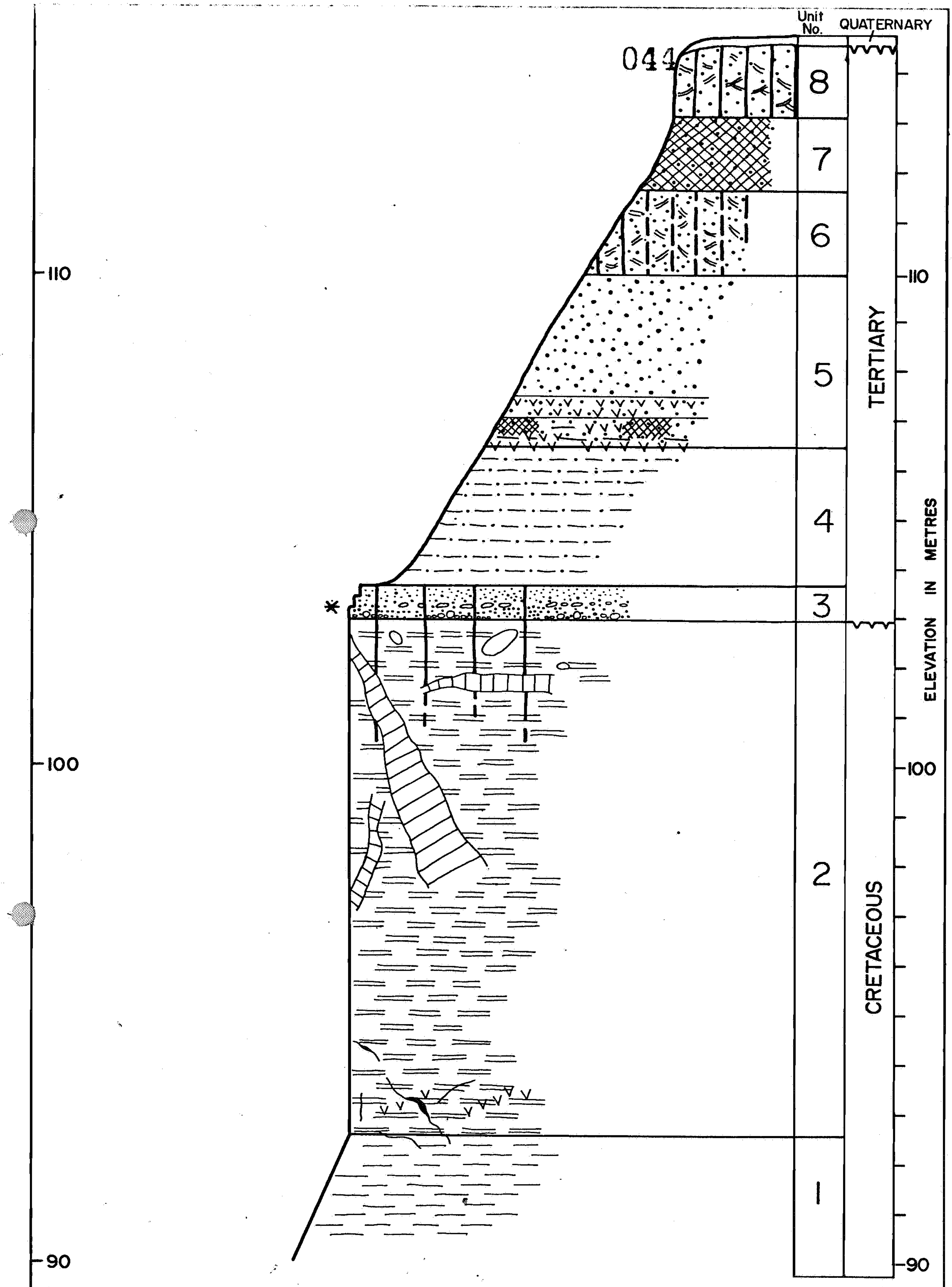

| Fig. 5 | DEPARTMENT OF MINES AND ENERGY<br>SOUTH AUSTRALIA | SCALE 1:100 Vertical |
|---|---|---|
| COMPILED G. NICOL | STUART CREEK COWARD CLIFF AREA<br>GEOLOGICAL SECTION<br>LOCATION No. 379 | DATE 11-10-79 |
| DRN M.B. \| CKD | | PLAN NUMBER<br>S14420 |

1804

Figure 6. Geological Section, Location No. 357.



| Sequence | Unit No. | Description |
|---|---|---|
| | 1 | Fresh mudstone, yellowish-brown at the top grading down to dark grey. Contains opal veins in upper part, and iron-rich concretions. |
| | 2 | Weathered mudstone, indurated and porous with lenticular silt and sand beds and scattered pebbles and cobbles. White and weakly silicified with kaolinite-alunite veins in upper part to yellow, pink and mauve with opal and gypsum veins near base. Gradational lower contact with fresh mudstone. |
| B | 3 | Fining upward conglomeratic sandstone. Basal silcrete lag, very coarse sand, granules and pebbles, to kaolinitic fine sand at top. Basal contact is sharp and planar, in places cracked. Weakly cemented by opaline silica. (T.S. 550/-357-9, 550/358-1, 550/357-3A and 3B, and 550/-357-3) |
| C | 4 | Grey clayey silt and very fine sand, laminated. Gradational contact with Unit No. 3. |
| D | 5 | Friable, white, fine to medium sand, veined with gypsum in part. Clayey and ferruginised patchily near base, where it gradationally passes down to grey very fine sand. |
| D | 6 | Greyish, silicified fine to medium sandstone, cross bedded. Transitional to Unit No. 5. |
| D | 7 | Friable fine to medium sand. Ferruginised reddish brown. Transitional to Unit No. 6. |
| D | 8 | Greyish, silicified fine to medium sandstone, cross bedded. Transitional to Unit No. 7. |




| | | |
|---|---|---|
| Fig. 6 | DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA | SCALE 1:100 Vertical |
| COMPILED G. NICOL | STUART CREEK COWARD CLIFF AREA GEOLOGICAL SECTION LOCATION No. 357 | DATE 10-10-79 |
| DRN M.B. / CKD | | PLAN NUMBER S14421 |

1604

Figure 7. Coward Cliff. Capping the mesa: Tertiary reddish sand (silicified at top) over grey silt. Basal silicified sandstone forms horizontal line along clifftops, overlying white bleached profile in Marree Formation; passes down to yellow then grey "fresh" mud. Black iron rich concretions weather from grey mud in right foreground. (Refer Figure 6 .)

Figure 8. Columnar silcrete. Strongly indurated silcrete with vertical columnar structure and flat, pavement-like, nodular weathered upper surface. Nodules have been reworked into younger sediment as clasts. Location 247/11, Figure 4 .

Figure 9. Tertiary - Cretaceous contact, Coward Cliff. Basal Tertiary silcrete clast conglomerate and kaolinitic sandstone, cemented in part with opaline silica, unconformably overlie bleached white mudstone of the Marree Formation. (Upper edge of cliff, Figure 7.)

Figure 10. Silcrete. Polygonal prismatic jointing in a silcrete with flat pavement-like surface. Root channels extend downward from holes in upper surface (Figure 11 ). Location 379.

Figure 11. Silcrete. Ribbed and branching root channels in silcrete. Brown spherical nodules of goethite. Location 379.

Figure 12. Burrowed interval. Two silicified layers in a uniform sequence of laminated and cross-laminated silt, sandwich between them a unique burrowed interval. Burrow casts are preserved on the lower surface of the upper silicified layer. (Figure 13 ). Location 218.

Figure 13. Burrow casts. A network of cross-cutting, horizontal burrows in siltstone. The burrows are cylindrical and of uniform diameter; some are branched. Location 218.

Figure 14. Shrinkage cracks. Slabs broken from a silica cemented siltstone layer with shrinkage cracks in a thin lamina on the upper surface. Note the wide separation of adjoining fragments. Location, 3.2km south of Wimbrinna Dam.

Figure 15. Calcite and silica cemented sand. Adjoining areas of calcite and silica cemented fine sand with granules of quartz and silcrete. Shrinkage cracks in silica cemented areas. Location, 5.6km south-southeast of Wimbrinna Dam.


Figure 16. Gypsum crystal moulds. Moulds of blade-like, tabular gypsum crystals in fine sand cemented with silica. Gypsum crystallised in the sand prior to silicification. Location, 5.6km south-southeast of Wimbrinna Dam.

Figure 17. Cauliflower chert structure. Structures resembling cauliflower chert in silica cemented fine sand with scattered quartz and silcrete granules. Cauliflower chert forms by replacement of anhydrite by silica.

Figure 18. Opal at Coward Cliff. Horizontal veins of opaque white opal with red iron oxide staining on fracture surfaces, in Marree Formation mudstone near base of bleached profile (Figure 7.) Note the white gypsum on rock fracture surfaces above opal veins.

Figure 19. Tertiary - Cretaceous contact. Tertiary grey laminated silt and thin (1cm) basal layer of medium sand rest with sharp disconformable contact on friable, white alunite (altered Marree Formation). Location 218.

Figure 20. Clasts in alunite - altered Marree Formation. Rounded pebbles of quartzite and weathered sandstone in friable, white alunite. Yellow-brown staining by iron oxide. Location 218.

# APPENDIX A

## PRE-CAINOZOIC STRATIGRAPHY

### Proterozoic

Proterozoic sediment in the study area can be divided into two units, Pb and an overlying unit Pa (Figure 21). Pb comprises essentially quartzite and siltstone. The grey quartzite ranges from thick bedded and massive to finely laminated, weathering dark brown and flaggy. In places it contains rounded shale, quartz and lithic pebbles, ripple marks, cross bedding and current lineations. Green, grey and brown siltstone, in places calcareous, and minor green sandstone and thin yellow dolomite are interbedded with the quartzite.

In the southeast part of the study area, Pb is apparently overlain by purple, red, green and brown shale interbedded with yellow, green and brown blocky limestone and calcareous siltstone (Pa). A band of pink, cream and grey dolomite, 1m thick, which forms a low ridge 0.8km north of Porter Hill, is represented on the CURDIMURKA (Daly and Coats, 1971) geological sheet as the Wearing Dolomite Member of the Bunyeroo Formation. Pa is traceable continuously toward the southwest from Porter Hill, to where it was mapped as the Wonoka Formation by Johns et al (1966) and Nicol (1979). The lithology of this unit in the central to northern part of the study area is similar. Flat bedded and cross bedded blocky green and yellow limestone with intraformational conglomerate is common south and southeast of Gregory Dam.

### Structure

Structural detail is more complex in part than presented here, but a relatively simple structural pattern emerges using the limited data available. Pb, although strongly folded southwest of Wimbrinna Dam, generally maintains a shallow to moderate dip toward the south or southwest. In the southeast part of the study area, Pa also dips shallowly southward, the structural continuity indicating that Pa overlies Pb. This data supports the suggestion by Nicol (1979), of a northwest - southeast trending synclinal axis through Charlie Swamp.

In the vicinity of Gregory Dam, Pa and Pb are in faulted contact. Outcrop along the fault comprises strongly brecciated and ferruginised quartzite and calcareous siltstone striking parallel to the fault, dipping vertically and facing southward. Bedding either side of the fault dips northward, indicating that the northern block is downthrown. This is consistent with the stratigraphic interpretation of Pa being younger, and overlying Pb. North of the fault, Pa dips shallowly and in places is flat-lying, thus cropping out over an extensive area.

Correlation

Proterozoic sediment in the Charlie Swamp area was mapped by Johns et al (1966) and Nicol (1979). Correlation of Proterozoic sediment in the Charlie Swamp area with that in the study area is made on the basis of lithological similarity and continuity of outcrop and structure. Pb is considered equivalent to the ABC Range Quartzite, but may also include the Brachina Formation. Pa is equivalent to the Bunyeroo Formation and the Wonoka Formation.

Mesozoic

The shallow water marine Marree Formation of early Cretaceous age, rests with angular unconformity on folded Proterozoic sediment. A basal conglomerate, upto 0.5m thick, containing rounded quartzite pebbles, cobbles and boulders is overlain by soft mudstone. The mudstone is dark brown to grey, in places fissile, but generally massive and bioturbated. It contains a variable proportion of silt and sand concentrated in thin wispy lenses and lenticular beds which are in places cross laminated. Yellow powdery jarosite, alunite and carphosiderite line joint surfaces in the mudstone.

Rounded pebbles, cobbles and boulders are scattered through the mudstone and in places there are lenticular sandy conglomeratic interbeds. The clasts comprise quartzite, red porphyry, shale and sandstone. Other rounded clasts seen in float and presumed to have weathered from the Marree Formation include black chert, conglomerate which resembles the Sturt Tillite, and greyish chert similar to the nodules that weather from the Cambrian Andamooka Limestone south of the Stuart Creek opal diggings.

Prominent dark grey carbonate concretions, about 1m in size, within the mudstone, form low ridges northwest of the study area. These are similar to fossiliferous carbonate concretions in the Marree Formation at Coober Pedy and elsewhere. Concretions of iron oxide (hematite and goethite) within the fresh mudstone crop out near Coward Cliff (Figure 7), and may be related to the weathered profile in the upper part of the sequence.

The Marree Formation, which is widely distributed over the study area, reaches a maximum thickness of about 60m at Coward Cliff, but is generally much thinner. The base has a low relief where it rests on the Proterozoic unit Pa, but is highly irregular over Pb. Bedding structure in the mudstone is poorly defined, but it is presumed to be generally flat-lying. However, in places it has a variable shallow dip.

Nicol (1979) suggested that coarse material was ice-rafted into the fine grained mudstone sequence and that most of the clasts were derived from locally outcropping basement. In the Coward Cliff area, quartzite, sandstone and shale clasts are common and may have been derived from local Proterozoic basement. However, large numbers of red porphyry clasts, presumably derived from the Gawler Range Volcanics and rare black chert and ?tillite clasts, which may have been derived from the Willouran Ranges, suggest a derivation from more distant sources.

A single thin sandy conglomeratic interbed extends from Andamooka (the Level) to Charlie Swamp with an elevation of 90-100m (Nicol, 1979). A similar horizon, although intermittent, is present in the Coward Cliff area, and likewise corresponds closely with the base of the bleached profile. The conglomeratic interbed crops out 8km southeast of Wimbrinna Dam (Location No. 343, EL 80.5m), 0.4km east of Coward Cliff (Location No. 387, EL 94.6m) and 5.2km southwest of Wimbrinna Dam (Location No. 218, EL 84-85m) where it lies within friable, white alunite (Figure 20).

# APPENDIX B

## THIN SECTION DESCRIPTIONS

| TS (described) and No. | Location and Sample No. | Figure Reference | Sample Description | |
|---|---|---|---|---|
| TS C24170 | 550/246-5 | C3 | Silcrete clasts from lag layer at base of Tertiary succession | |
| TS C24171 | 550/247/8 | 3 | | |
| TS C24172 | 550/356-2 | | | |
| | 550/357 | | | |
| TS C24173 | 550/247/9 | 3 | Nodular silcrete | SEQUENCE A |
| TS C24174 | 550/247/10 | 3 | Nodular silcrete | |
| TS C24175 | 550/247/11-1 | 3 | Nodular silcrete | |
| TS C24176 | 550/247/11-2 | 3 | Nodular silcrete | |
| TS C24177 | 550/365-1 | 2 | Silcrete | |
| TS C24188 | 550/379-1 | 4 | Silcrete | SEQUENCE B |
| TS C24189 | 550/383 | | Silcrete | |
| TS C24190 | 550/247/17-2a | | Silcrete | |
| TS C24191 | 550/247/17-2b | | Silcrete | |
| TS C24705 | 550/357-3A | 6 | Pebbly sandstone | |
| TS C24706 | 550/357-3B | 6 | Pebbly sandstone | |
| TS C24179 | 550/358-1 | 6 | Opaline sandstone | |
| C24193 | 550/357-3 | 6 | Pebbly sandstone | |
| C24178 | 550/357-9 | 6 | Opaline sandstone | |
| TS C24702 | 550/388-2 | | Goethite nodule | |
| TS C24703 | 550/380-1 | C2 | Silicified siltstone | SEQUENCE C |
| TS C24704 | 550/380-1 | C2 | Silicified siltstone | |
| C24192 | 550/379-5 | 5 | Silicified siltstone | |
| TS C24184 | 550/363-3 | C1 | Silicified sandstone | SEQUENCE D |
| TS C24185 | 550/363-4 | C1 | Silicified sandstone | |
| TS C24186 | 550/363-6 | C1 | Silicified sandstone | |
| TS C24187 | 550/246-1 | C3 | Silicified sandstone | |
| TS C24180 | 550/380-5 | C2 | Ferruginous sandstone | |
| TS C24183 | 550/313 | | Silicified conglomerate | (? sequence D) |
| TS | 550/500 | | Jasper breccia | |
| C24181 | 550/219-1 | | Pebbly quartzite | (? ~~Adelaidean~~) |
| TS C24182 | 550/219-2 | | Quartzite | |

Sample 550/219-2 (C24182)

Rock name: Quartzite

Location : 0.6km north of Bench Mark 654

HS : Yellowish grey, bedded, silicified fine sandstone.

TS : Detrital quartz grains are well sorted, comprising interlaminated sand (0.2mm) and silt (0.05mm). Relict textures suggest that the larger grains were rounded. Zircon, tourmaline and rutile grains (less than 1%) are present.

An interlocking network of quartz overgrowths cement the rock. The cement contains a variable concentration of minute inclusions (clay ?), and in places appears almost opaque.

Sample 550/246-1 (C24187)

Rock name: Silicified sandstone

Location : 1.6km west of Wimbrinna Dam

HS : Greyish silicified rock, generally very fine grained with thin flat laminae of fine to medium quartz sand. Outer surface has a ropey structure, and this is expressed internally by concentric cream coloured banding.

TS : Detrital quartz grains are mostly coarse silt size (0.04-0.08mm) with scattered grains and thin (upto 2mm) laminae of fine to medium size (0.2-0.4mm) grains. The sand grains, which are rounded to angular and in places bear overgrowths and the silt grains which are all angular, have been corroded.

The rock is cemented with microcrystalline quartz which includes a high concentration of minute particles ($TiO_2$?), and has corroded the detrital grains. Chalcedony, free of inclusions, fills remaining voids, and postdates cementation by microcrystalline quartz.

Sample 550/246-5 (C24170)

Rock name: Silcrete clast

Location : 1.6km west of Wimbrinna Dam

HS : A very fine grained, greyish silicified rock with cream coloured patches.

TS : Detrital quartz grains are commonly less than 0.2mm but scattered grains upto 0.7mm are present. Most grains, however, are less than 0.04mm in size and virtually indistinguishable within the microcrystalline groundmass. The detrital grains are strongly corroded. Scattered claystone grains upto 2mm in size and some heavy minerals are present.

Microcrystalline quartz with a variable concentration of minute inclusions (clay and $TiO_2$?) cements the rock. The cream coloured patches in hand specimen are opaque (rich in clay?) and have a swirled and banded, in places brecciated structure.

Sample 550/247/8 (C24171)

Rock name: Silcrete clast

Location : 1.6km west of Wimbrinna Dam

HS : Very fine grained greyish silicified rock with cream coloured patches. Scattered quartz grains are visible.

TS : Detrital quartz grains upto 0.7mm are scattered among grains that are commonly less than 0.2mm in size. Many grains have quartz overgrowths, and are angular due to extensive corrosion. Rutile, zircon and tourmaline (less than 1%) are present.

Microcrystalline quartz with a variable concentration of minute inclusions (clay and $TiO_2$?) forms a groundmass in which the coarser detrital grains 'float'. Opaque areas which are cream coloured in hand specimen (rich in clay?) appear to be folded and brecciated and have a banded structure.

Sample 550/247/9 (C24173)

Rock name: Nodular Silcrete

Location : 1.6km west of Wimbrinna Dam

HS : Greyish silicified rock containing sand grains in an aphanitic groundmass, forms nodules upto 1.2cm across within a more porous (weathered?) cream coloured matrix of similar composition.

TS : Detrital quartz grains, commonly 0.3 to 1.0mm but upto 2mm in size, 'float' in a microcrystalline quartz groundmass. The grains are extensively corroded and replaced by the siliceous matrix. Zircon, tourmaline and rutile grains (less than 1%) are present.

Microcrystalline quartz with a variable concentration of minute inclusions (clay and $TiO_2$?) cements the rock. Some opaque areas (clay rich?) have a concentric banded structure.

The nodular structure is defined by the concentration of opaque inclusions. The nodules have a high content of included material in the siliceous cement, but are otherwise identical and gradational to their weathered matrix. An apparent clast of similar lithology may have been reworked from a former silcrete.

Sample 550/247/10 (C24174)

Rock name: Nodular Silcrete

Location : 1.6km west of Wimbrinna Dam

HS : Greyish silicified rock with scattered sand grains in an aphanitic groundmass. Slight colour variations give the rock a nodular appearance.

TS : Detrital quartz grains are poorly sorted. They are generally 0.05-0.1mm in size, but medium sand grains (0.3-0.5mm) are common and grains range upto 5mm in size. The larger grains are rounded and in places have overgrowths. Zircon, tourmaline and rutile grains (less than 1%) are present.

Microcrystalline quartz with a variable concentration of minute inclusions (clay and TiO2?) cements the rock. It has in places corroded and replaced the detrital grains. The nodular structure is defined by inclusions in the cement, which appear opaque in the nodules (TiO2?) but brownish (clay?) between the nodules.

Sample 550/247/11-1 (C24175)

Rock name: Nodular Silcrete

Location : 1.6km west of Wimbrinna Dam

HS : Greyish silicified rock comprising scattered quartz grains in an aphanitic groundmass. Nodules upto 5cm across are strongly silicified and contain cream coloured patches (clay rich?). The areas between the nodules are less silicified, porous, paler in colour (weathered?) and contain root channels.

TS : The nodules appear to be clasts in thin section with sharp boundaries. They comprise scattered detrital quartz grains generally 0.2mm in size or less but upto 1mm, 'floating' in a microcrystalline quartz groundmass with a variable concentration of included particles (clay and TiO2?). The detrital quartz grains, some with overgrowths, have been strongly corroded.

Areas between the nodules comprise detrital quartz grains typically 0.05-0.15mm in size but upto 1mm, and grains of silicified claystone upto 1mm in size with a concentrically banded structure. These areas are cemented with microcrystalline quartz with a variable concentration of minute inclusions (clay and TiO2?). Corrosion of grains is not as prominent as in the nodules and a greater volume of the rock is made up of recognisable detrital grains.

Thus, the rock comprises reworked silcrete clasts in a silicified matrix, of similar lithology. It probably formed by 'in situ' disintegration, as a colluvium overlying columnar silcrete, and was subsequently silicified.

Sample 550/247/11-2 (C24176)

Rock name: Nodular Silcrete

Location : 1.6km west of Wimbrinna Dam

HS : Greyish silicified rock with colour variation defining nodules 2-12mm in size. Sand size quartz grains 'float' in an aphanitic groundmass.

TS : Detrital quartz grains, commonly 0.2mm or less, but upto 1.5mm in size have been strongly corroded. Zircon, tourmaline, rutile and claystone grains are also present.

Microcrystalline quartz with a variable concentration of minute inclusions, cements the rock. The nodules are defined by high concentrations of inclusions (clay and TiO2?) compared with areas between the nodules. Their similar lithologies and transitional boundaries suggest that the nodules developed 'in situ' and are not clasts.

Sample 550/247/17-2a (C24190)

Rock name: Silcrete

Location : 1.6km west of Wimbrinna Dam

HS : Porous, pale grey, silicified rock comprising scattered claystone granules and quartz sand grains in an aphanitic groundmass.

TS : Detrital quartz grains, commonly about 0.1mm in size but upto 1.3mm, occupy about 40% of the rock volume. Some grains are rounded and bear overgrowths and many have been strongly corroded. Silicified mudstone grains form about 1% of the rock. Trace amounts of zircon and rutile are present.

Microcrystalline quartz, about 50% of the rock, includes minute particles (clay?) and cements the rock.

Sample 550/247/17-2b (C24191)

Rock name: Silcrete

Location : 1.6km west of Wimbrinna Dam

HS : Greyish silicified rock comprising scattered pink aphanitic granules and quartz sand grains in an aphanitic groundmass.

TS : Scattered rounded quartz grains upto 2mm in size are present, but detrital grains are typically 0.1mm in size, angular and corroded. Smaller grains merge into the microcrystalline groundmass. Granules of silicified sandy, silty claystone upto 4mm in size constitute about 2% of the rock, and trace amounts of heavy minerals are present.

Microcrystalline quartz forms a groundmass to scattered coarser grains and cements the rock. Inclusions, probably iron oxide, are concentrated along grain boundaries of the microcrystalline quartz and in the claystone granules (giving them a pink colour). Much of the microcrystalline quartz groundmass appears to have been detrital silt, but corrosion and silicification obscure the original grain shape in most cases.

Sample 550/313 (C24183)

Rock name: Silicified conglomerate

Location : 0.4km east of Bench Mark 675

HS : A conglomerate comprising pebbles of silcrete, quartz, quartzite and silicified claystone in a matrix of yellow-brown fine to medium quartz sand.

TS : The matrix to the clasts comprises moderately well sorted medium quartz sand (0.3-0.4mm) but grainsize ranges from 0.2 to 1.0mm. The grains are generally subrounded. Zircon, tourmaline and rutile (less than 1%) are present.

The rock is cemented in part by quartz overgrowths which form an interlocking network, relatively free of inclusions. However, much of the cement is microcrystalline quartz which fills all pore space and replaces quartz grains and their overgrowths. Minute inclusions (clay?) are concentrated along grain boundaries of the microcrystalline quartz. Thus, initial silicification by quartz overgrowth was followed by corrosion, replacement and cementation of the rock by microcrystalline quartz.
(Note: sample submitted for silicate analysis was free of clasts.)

Sample 550/356-2 (C24172)

Rock name: Silcrete clast

Location : Coward Cliff

HS : Very fine grained greyish silicified rock with cream coloured patches. Scattered coarse quartz grains are visible.

TS : Scattered detrital quartz grains upto 2mm in size are present in the rock, but grains are commonly between 0.3 and 0.04mm, the smaller grains merging into the microcrystalline matrix. Some of the grains have overgrowths and are strongly corroded. Rutile, zircon and tourmaline constitute less than 1% of the rock.

Microcrystalline quartz including a variable concentration of minute particles (clay and $TiO_2$?) forms the groundmass in which detrital grains 'float'. Opaque areas (clay rich?), cream coloured in hand specimen, have a swirled and banded structure and some were probably claystone clasts.

Sample 550/357-3A and 3B (C24705 and C24706)

Rock name: Kaolinitic pebbly sandstone

Location : Coward Cliff

HS : The rock is porous, pale grey and weakly cemented. It comprises bedded coarse to fine quartz sand with rounded pebbles of white and pink weathered mudstone.

TS : A pebbly coarse quartz sand bed grades upwards to a coarse silt with scattered sand grains. The coarse quartz grains are rounded and some have overgrowths. Silt and clay fill interstices. Rare zircon and rutile grains are present.

The rock is cemented in part by opal, which is brown and cracked, and fills some interstices.

The pebbles of weathered mudstone are rounded and elongate, but some are equidimensional. Elongate pebbles lie roughly parallel to bedding. The pebbles comprise silty and sandy (less than 30%) claystone and are similar in appearance to mudstone of the Marree Formation. The clasts are not deformed and appear to have been indurated prior to rounding and deposition. Thus, it is probable that the weathered mudstone clasts were derived by erosion from the underlying Kopi of the weathered profile developed on the Marree Formation.

Sample 550/358-1 (C24179)

Rock name: Opaline very coarse sandstone

Location : Coward Cliff

HS : Porous, pale grey rock, comprising moderately well sorted very coarse grains of quartz and silcrete with a weathered white opaline cement.

TS : Very coarse detrital grains are framework supported, occupy 50% of the rock volume, and have no interstitial detritus. 20% of the grains are subrounded quartz, the remaining 30% being variably rounded silcrete grains which are 1-2mm in size.

Opaline cement (opal-CT) fills all pore space and cements the rock. It is a honey-brown colour under plane polarised light and in places is cracked (shrinkage cracks?). The opal has strongly corroded and in part replaced the detrital grains.

Sample 550/363-3 (C24184)

Rock name: Silicified sandstone

Location : 2.2km south of Coward Cliff

HS : Greyish silicified fine to medium sandstone. Some zones along bedding planes are stained reddish-brown.

TS : Detrital quartz grains, commonly 0.2-0.4mm but upto 0.7mm in size, occupy 50% of the volume. Many of the grains bear overgowths that appear to have developed 'in situ', but are strongly corroded and extensively replaced by the microcrystalline quartz matrix. They are generally subrounded. Zircon and rutile (less than 1%) are present.

The matrix (the remaining 50%) comprises microcrystalline quartz relatively free of inclusions. Where bedding zones are stained reddish brown in hand specimen the siliceous matrix is impregnated with opaque (iron oxide?) inclusions.

Sample 550/363-4 (C24185)

Rock name: Silicified sandstone

Location : 2.2km south of Coward Cliff

HS : Greyish silicified fine to medium sandstone. Some zones along bedding planes are unsilicified and the quartz grains bear a reddish brown ferruginous stain.

TS : Well bedded, angular fine and subrounded medium quartz grains occupy 50-60% of the rock volume. Many of the grains bear overgrowths developed 'in situ' and although subsequently strongly corroded, in places the boundaries of the overgrowths still match adjacent grain boundaries. Zircon and rutile (less than 1%) are present.

The rock is cemented with chalcedony and microcrystalline quartz which are gradational from one form to the other. The cement is generally free of inclusions but in part is virtually opaque where it contains abundant minute particles of ?iron oxide.

Where the rock is unsilicified, thin rims of hematite coat the quartz grains, and give the rock a reddish brown colour. The uniform rims generally line cavities rather than forming coatings on individual grains, indicating that ferruginisation is a post deposition event. In adjacent areas, these cavities are infilled with siliceous cement and the ferruginous rims replaced in part by silica. Thus, silicification of this rock post-dates ferruginisation. Silica has replaced much iron oxide that was originally present in the rock, indicated by the common occurrence of (siliceous) rims in the silicified portion.

Sample 550/363-6 (C24186)

Rock name: Silicified sandstone

Location : 2.2km south of Coward Cliff

HS : Greyish silicified fine to medium sandstone

TS : Moderately well sorted detrital quartz grains, commonly 0.2-0.3mm but upto 0.6mm in size, occupy 60% of the rock volume. The grains are framework supported with no interstitial detritus. Large grains are subrounded and small grains are angular. Zircon, tourmaline and rutile (less than 1%) are present.

Many of the quartz grains bear overgrowths, and in places these form an interlocking network to cement the rock. However, the quartz grains and overgrowths have undergone considerable corrosion and replacement by chalcedony and microcrystalline quartz, which appear to have the capacity to penetrate along grain boundaries. Thus, evidence indicates initial silicification by quartz overgrowth, with subsequent corrosion, replacement and silicification by chalcedony and microcrystalline quartz.

Sample 550/365-1 (C24177)

Rock name: Silcrete

Location : 0.6km southwest of Bench Mark 669

HS : Greyish silicified aphanitic rock with cream coloured patches and scattered quartz sand grains.

TS : Detrital quartz grains are commonly less than 0.2mm in size, strongly corroded and merge into the microcrystalline groundmass. Scattered grains upto 1.0mm in size, in places bearing overgowths, are strongly corroded. Relict textures suggest that they were rounded prior to overgrowth development and corrosion. Some very small grains of zircon and rutile are present.

Microcrystalline quartz with a variable concentration of minute inclusions (clay and $TiO_2$?), cements the rock.

Nodules, in part of the rock, are cemented by microcrystalline quartz with a relatively low concentration of inclusions. They are separated by areas rich in inclusions. Some of the more porous opaque areas (rich in clay?) have a concentric banded structure.

Sample 550/379-1 (C24188)

Rock name: Silcrete

Location : Bench Mark 654

HS : Greyish silicified aphanitic rock with scattered quartz sand grains. The rock contains root channels as ribbed moulds, generally as cavities, but in places infilled with siliceous material similar to the enclosing rock.

TS : Detrital quartz grains are commonly 0.2mm or less in size but scattered grains upto 0.5mm are present. They occupy about 20% of the rock volume, the smaller grains merging into the microcrystalline groundmass, in which the coarser grains appear to 'float'. Many of the grains bear overgrowths and have been extensively corroded and replaced by the siliceous matrix. Zircon and rutile (less than 1%) are present.

Microcrystalline quartz with inclusions ($TiO_2$?) cements the rock and occupies about 80% of the volume.

Root channels, in some spaces as cavities, in other places are rimmed by opaque material (silicified clay?) and infilled by microcrystalline quartz and detrital quartz grains.

Sample 550/380-1 (C24703 and C24704)

Rock name: Silicified siltstone

Location : 0.5km northeast of Bench Mark 654

HS : Pale grey, very porous, weakly cemented coarse siltstone. Burrow casts have weathered out in relief on the lower surface but the rock is essentially unbioturbated, being well laminated and cross laminated.

TS : The rock is very well sorted comprising coarse silt size quartz grains (0.04mm) and trace tourmaline, zircon and rutile. Laminations result from a very slight change in grainsize and fine upward. Rare scattered quartz grains upto 0.2mm are present. There is very little clay in the rock.

The rock is cemented by microcrystalline quartz and in places quartz overgrowths.

Burrows are confined to the lower 1cm of the rock where there is some, but only minor, clay. The burrows, circular and 2mm in diameter, are infilled with silt and devoid of any clay. Some vertical burrows are trucated by fining upward silty laminae.

Thus, burrows are confined to a discrete interval, probably associated with the slightly higher clay content, and were formed close to the sediment-water interface.

Sample 550/380-5 (C24180)

Rock name: Ferruginous sandstone

Location : 0.4km north of Bench Mark 654

HS : Reddish black, fine to medium sandstone cemented with iron oxide.

TS : Detrital grains are mostly quartz, but some silcrete grains are present. Grainsize varies between 0.04mm and 1.0mm but is commonly 0.2-0.3mm. The grains are framework supported with very little interstitial detritus. Many grains bear overgrowths which appear to have formed in the sediment prior to ferruginisation, and all are strongly corroded by the ferruginous cement.

The rock is cemented by hematite which forms rims upto 0.1mm thick around the grains. In places, microcrystalline quartz infills interstices, post-dating the ferruginous cement.

Sample 550/383 (C24189)

Rock name: Silcrete

Location : 0.2km east of Bench Mark 656

HS : Greyish mauve silicified rock comprising small quartz pebbles and sand grains scattered through an aphanitic groundmass.

TS : Detrital quartz grains, commonly about 0.1mm but upto 1.3mm in size occupy about 20% of the volume and 'float' in the siliceous groundmass. Some of the grains bear overgrowths, which in places form an interlocking network, and have been extensively corroded. Tourmaline, zircon and rutile grains (less than 1%) are present.

The siliceous groundmass, occupying about 80% of the rock, comprises microcrystalline quartz with a variable concentration of minute inclusions (clay and $TiO_2$?).

Sample 550/388-2 (TS C24702)

Rock name: Ferruginous silicified sandstone

Location : Bench Mark 654

HS : A concentrically zoned spherical nodule rich in iron oxide, 3cm across, is present in silicified fine to medium sand.

TS : Detrital quartz grains are moderately well sorted and commonly 0.1-0.2mm in size, but scattered grains upto 0.4mm are present. Many of the grains bear overgrowths and have been extensively corroded and replaced by microcrystalline quartz.

Sandstone surrounding the nodule contains some yellowish iron oxide on the quartz grains and intertstices are filled with microcrystalline quartz. Within the rim of the nodule, quartz grains and their overgrowths are extensively replaced by iron oxide, so that angular corroded and embayed grains 'float' in a dark reddish groundmass. In the centre of the nodule the quartz grains and their overgrowths are severely corroded by microcrystalline quartz with a high concentration of included iron oxide. The nodule has developed in part across a root channel infilled with silt.

Thus, the following sequence of events is indicated; root channel, quartzitic overgrowth, iron oxide replacement and nodule formation and lastly cementation by microcrystalline quartz.

Sample 550/500

Rock name: Jasper breccia

Location : 5km southeast of Charlie Swamp

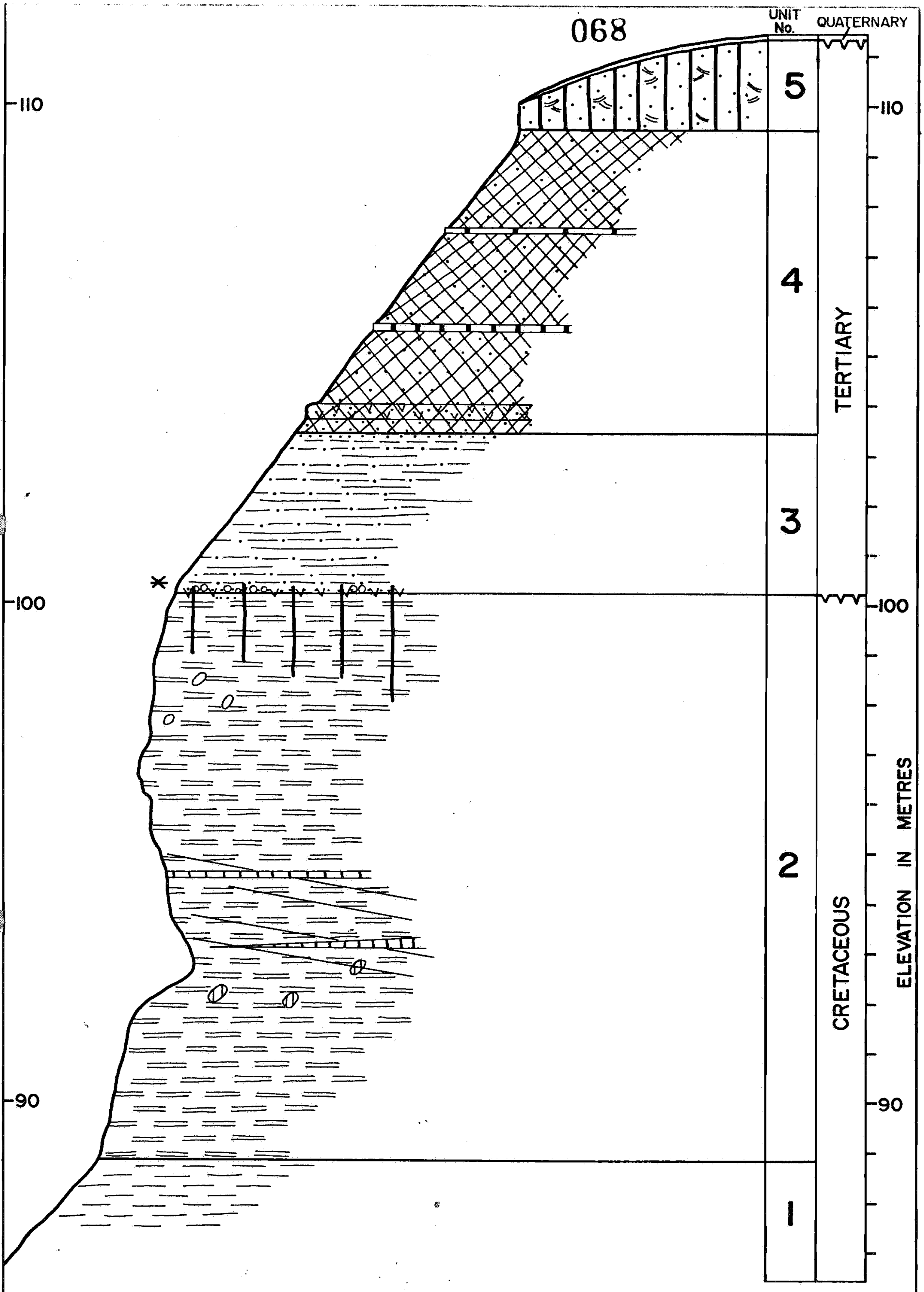
HS : A silicified conglomeratic reddish brown medium quartz sand. Angular clasts comprising yellowish grey sandstone, are elongate and aligned roughly parallel to bedding within the clasts.

TS : Detrital quartz grains are rounded to angular, poorly sorted (0.1 to 2.0mm) and have corroded margins. The quartz grains and clasts are rimmed by hematite upto 0.1mm thick which gives the rock its reddish brown colour. Interstices are filled and the rock cemented by chalcedony.

The clasts comprise detrital quartz grains 0.1mm to 1.0mm in size, the sorting defining the bedding. Larger grains are subrounded but small grains are angular, in places shard-like, and they have all been extensively corroded. Cement comprises microcrystalline quartz with minute (?$TiO_2$) inclusions, and chalcedony infills cavities.

Figure C1. Geological Section, Location No. 363.

| Sequence | Unit No. | Description |
|---|---|---|
| | 1 | Fresh grey mudstone. |
| | 2 | Weathered mudstone, indurated and porous with lenticular silt and sand beds and scattered pebbles. Veins and patches of white alunite. Upper part weakly silicified, white. Lower part mauve to grey, gradationally passing down to fresh mudstone. |
| C | 3 | Grey clayey silt and very fine sand, laminated. Basal silcrete lag rests on sharp and slightly irregular, in places cracked, contact with underlying weathered mudstone, and is weakly silicified. |
| D | 4 | Friable fine to medium quartz sand, ferruginised reddish brown and cemented in part with gypsum. Two thin horizontal grey sandstone layers cemented with silica. Sharp, wavy basal contact with grey muddy fine sand. (T.S. and silicate analysis - lower silicified layer 550/363-6; silicate analysis - friable sand 550/363-5 from top and 550/363-7 from bottom of Unit No.4). |
| D | 5 | Grey, silicified fine to medium sandstone, cross bedded. Base is irregular and transitional to friable sand. (T.S. and silicate analysis - 550/363-3 from top and 550/363-4 from bottom of Unit No. 5). |

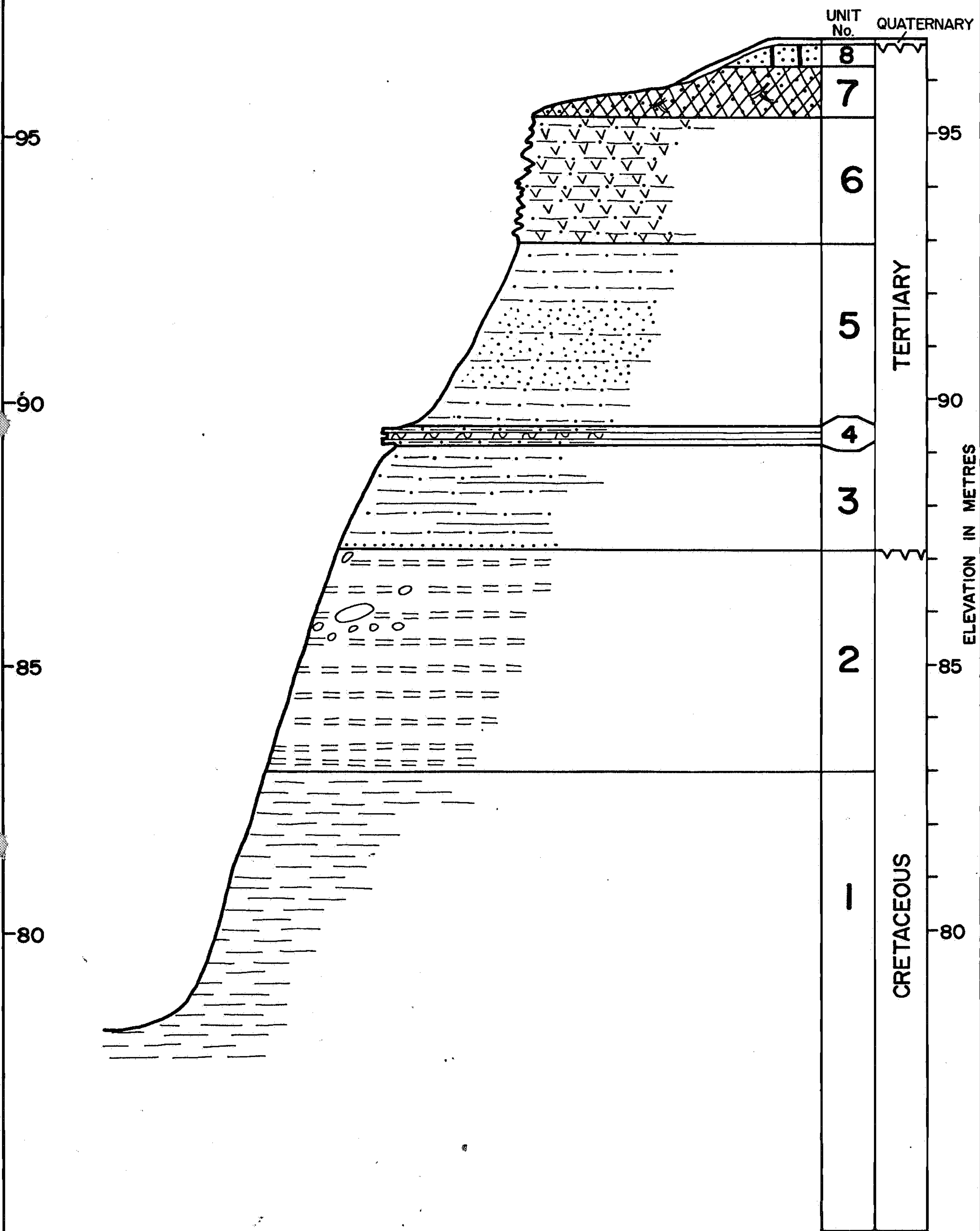



| | | |
|---|---|---|
| Fig. C1 | DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA | SCALE 1:100 Vertical |
| COMPILED G. NICOL | STUART CREEK COWARD CLIFF AREA GEOLOGICAL SECTION LOCATION No. 363 | DATE 11-10-79 |
| DRN M.B. CKD | | PLAN NUMBER S14423 |

1604

Figure C2. Geological Section, Location No. 218.

| Sequence | Unit No. | Description |
|---|---|---|
| | 1 | Fresh grey mudstone. Mauve in upper part. |
| | 2 | Friable white alunite, in lower part stained yellow by iron oxide. It contains scattered and poorly defined layers of rounded quartzite and weathered sandstone pebbles and cobbles (Figure 20). Passes gradationally, over a short distance, down to mauve and grey mudstone. |
| C | 3 | Grey laminated siltstone, with basal 1cm thick layer of medium sand, rests with very sharp and planar, in places cracked contact on friable white alunite (Figure 19). |
| C | 4 | Friable burrowed interval sandwiched between two silicified layers. Siltstone; where not burrowed it is laminated and cross laminated. (Figures 12 and 13. T.S. 550/380-1). |
| C | 5 | Grey clayey silt and very fine sand, laminated. Minor thin, lenticular, ferruginised, cross cutting coarse sand beds. Alunite nodules. |
| C | 6 | Gypcrete, alunite and ferruginisation in silt and very fine sand. |
| D | 7 | Reddish black, cross bedded fine to medium sandstone, porous and cemented by hematite. Gradational basal contact. (T.S. 550/380-5). |
| D | 8 | Grey, silicified, cross bedded, pebbly fine to medium sandstone. In float only, outcrop obscured by Quaternary soil cover. |

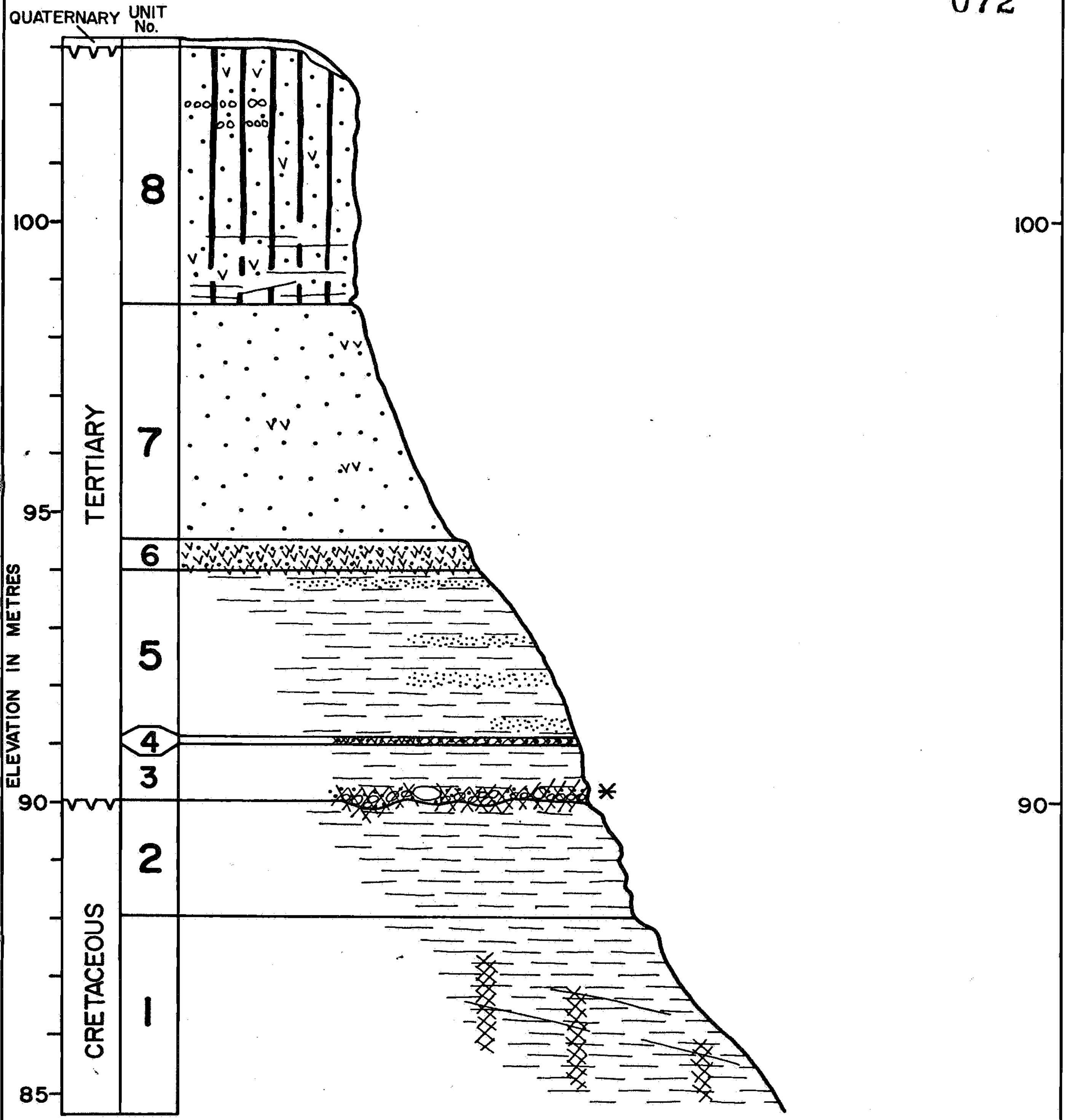



| | | |
|---|---|---|
| Fig. C 2 | DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA | SCALE 1:100 Vertical |
| COMPILED G. NICOL | STUART CREEK COWARD CLIFF AREA GEOLOGICAL SECTION LOCATION No. 218 | DATE 11-10-79 |
| DRN M.B. / CKD | | PLAN NUMBER S14425 |

1604

Figure C3. Geological Section, Location No. 246.

| Sequence | Unit No. | Description. |
|---|---|---|
| | 1 | Fissile fresh grey mudstone, with ferruginous yellow-brown staining on vertical joints. |
| | 2 | Fresh grey mudstone, massive and more indurated than Unit No. 1 to which it changes gradationally. |
| C | 3 | Grey, indurated and massive mudstone or clayey siltstone - similar to Unit No. 2. Basal ferruginised silcrete lag rests with sharp irregular contact on mudstone. (T.S. and silicate analysis 550/246-5). |
| C | 4 | Thin lenticular bed of friable, ferruginised (red) coarse sand. |
| C | 5 | Grey clayey silt and very fine sand, laminated. |
| D | 6 | Gypsum cemented, white, fine to medium sand. Sharp planar contact with underlying Unit No.5. |
| D | 7 | Friable white fine to medium sand with some gypsum cemented layers. (Silicate analysis 550/246-2). |
| D | 8 | Greyish, silicified fine to medium sand. Pebbly in part with some flat laminated fine sand and silt near the base. (T.S. and silicate analysis 550/246-1). Gypsum developed in joints. Pillowy structure at the base where it is transitional to the underlying friable sand. |




| Fig.C 3 | DEPARTMENT OF MINES AND ENERGY<br>SOUTH AUSTRALIA | SCALE 1:100 Vertical |
|---|---|---|
| COMPILED G. NICOL | STUART CREEK COWARD CLIFF AREA<br>GEOLOGICAL SECTION<br>LOCATION No. 246 | DATE 12-10-79 |
| DRN M.B. CKD | | PLAN NUMBER S14417 |

1604

1604

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

# STUART CREEK COWARD CLIFF AREA
## COMPILATION OF GEOLOGICAL SECTIONS

Fig. C4

COMPILED: G. NICOL

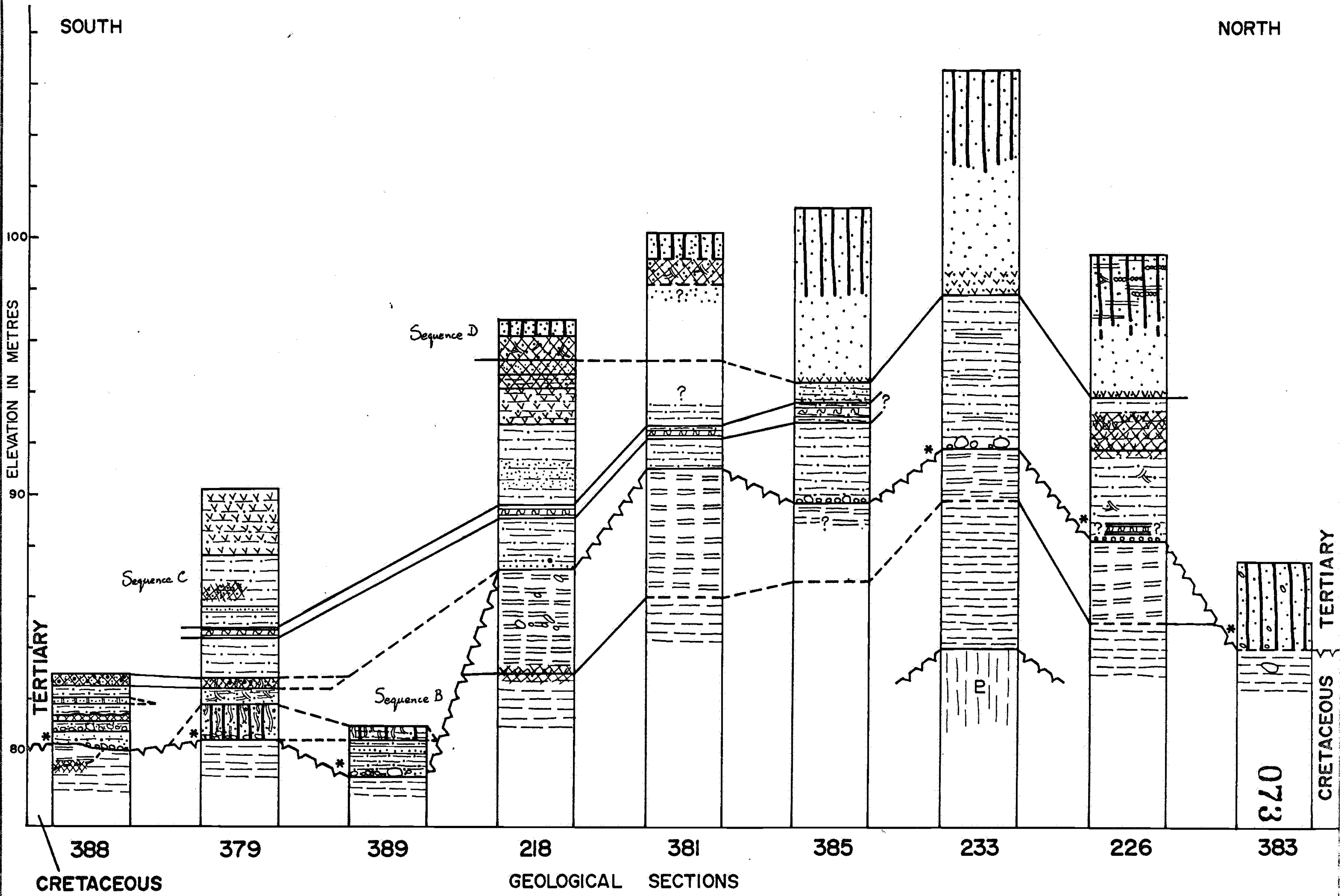
DRN: M.B. | CKD:

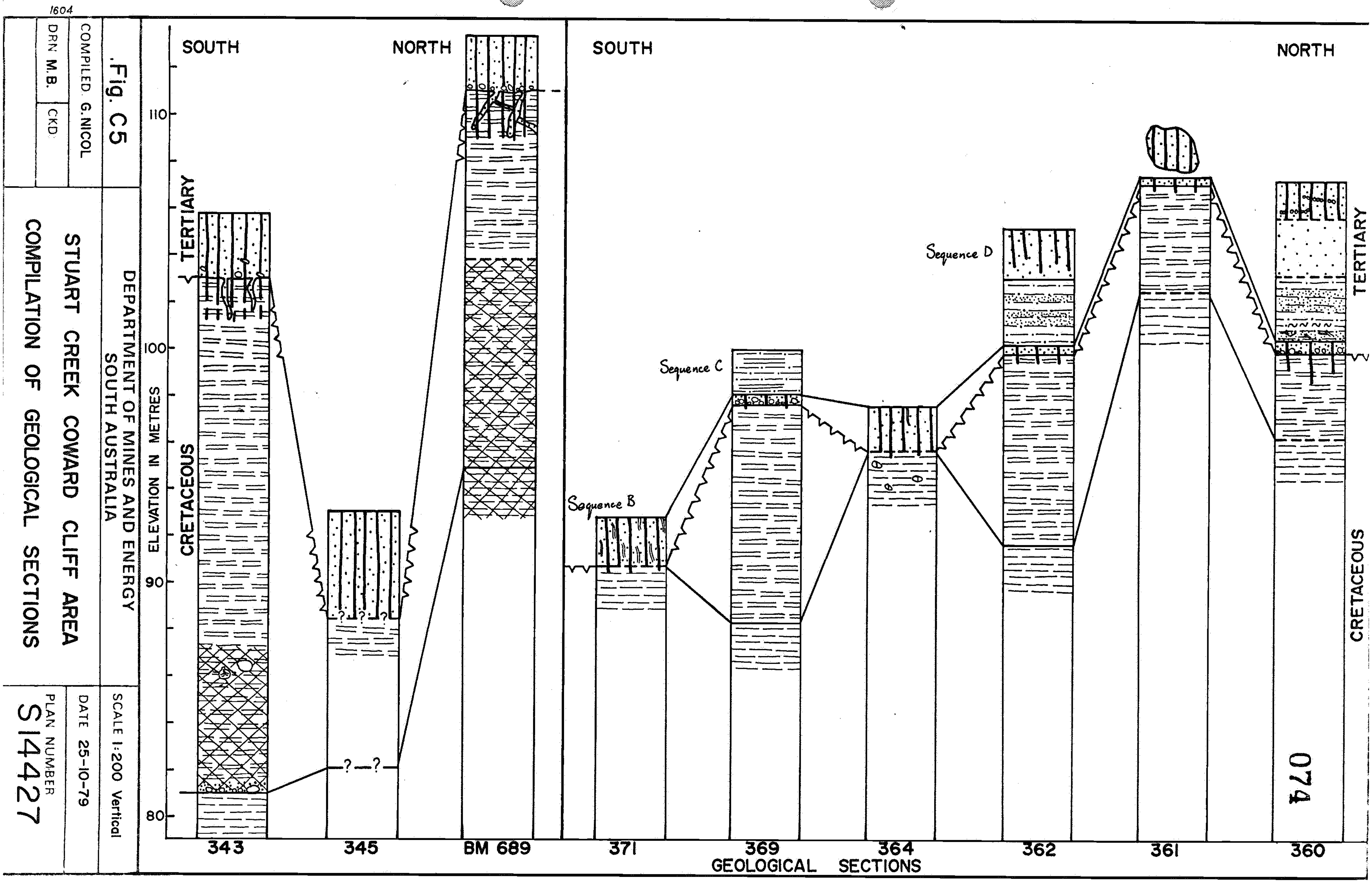
SCALE 1:200 Vertical

DATE 23-10-79

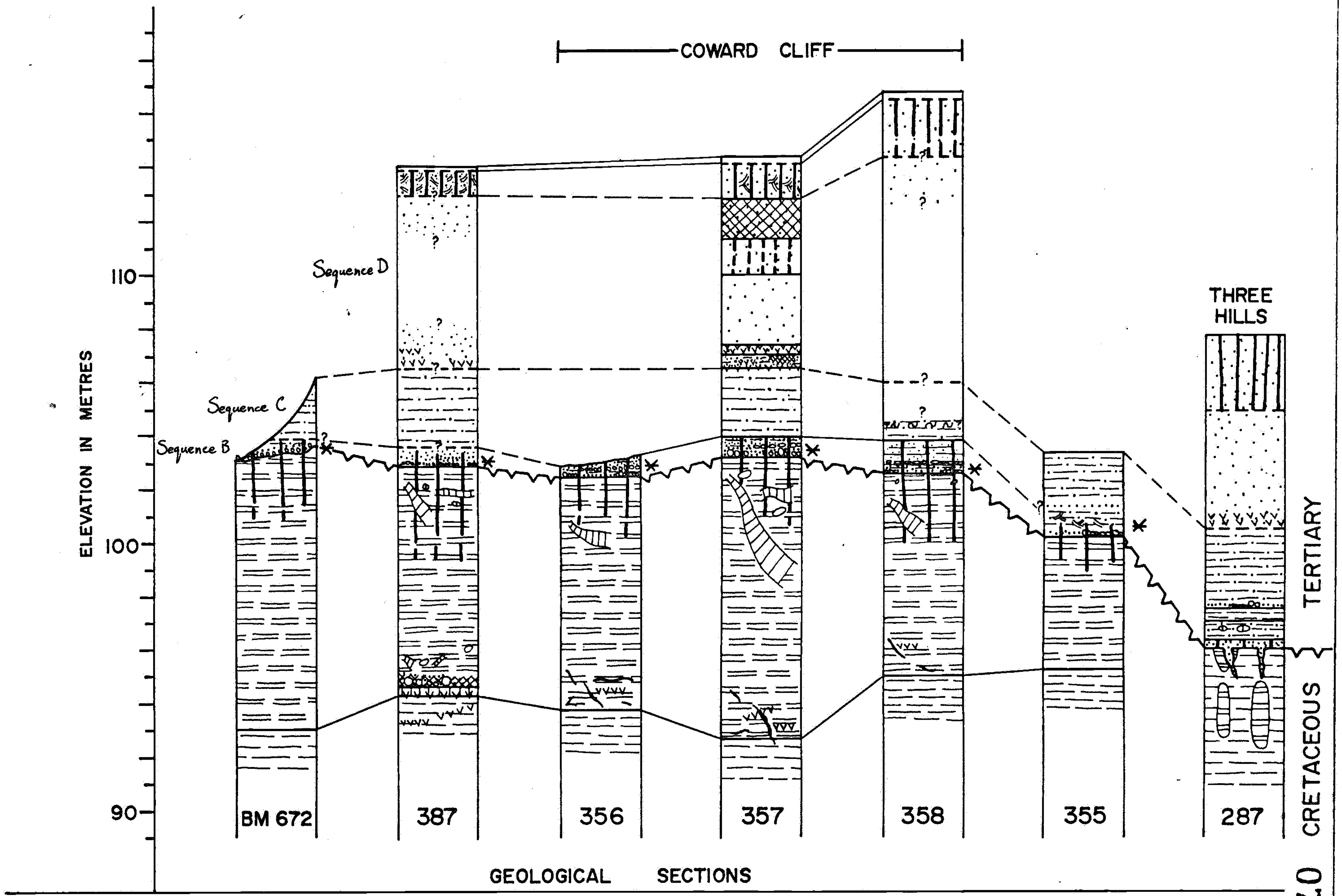
PLAN NUMBER

S14419




1604
Fig. C5
COMPILED G. NICOL
DRN M.B.
CKD.
DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA
STUART CREEK COWARD CLIFF AREA
COMPILATION OF GEOLOGICAL SECTIONS
SCALE 1:200 Vertical
DATE 25-10-79
PLAN NUMBER
S14427
SOUTH
NORTH
SOUTH
NORTH
TERTIARY
CRETACEOUS
TERTIARY
CRETACEOUS
ELEVATION IN METRES
110
100
90
80
Sequence B
Sequence C
Sequence D
343
345
BM 689
371
369
364
362
361
360
GEOLOGICAL SECTIONS
074

1604




DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

# STUART CREEK COWARD CLIFF AREA
## COMPILATION OF GEOLOGICAL SECTIONS

Fig. C6

COMPILED: G. NICOL

DRN: M.B. | CKD:

SCALE: 1:200 Vertical

DATE: 17-10-79

PLAN NUMBER
S14426

# APPENDIX D
## SILICATE ANALYSES

The following data is extracted from Amdel Report AC 1093/80. (Results in percentages).

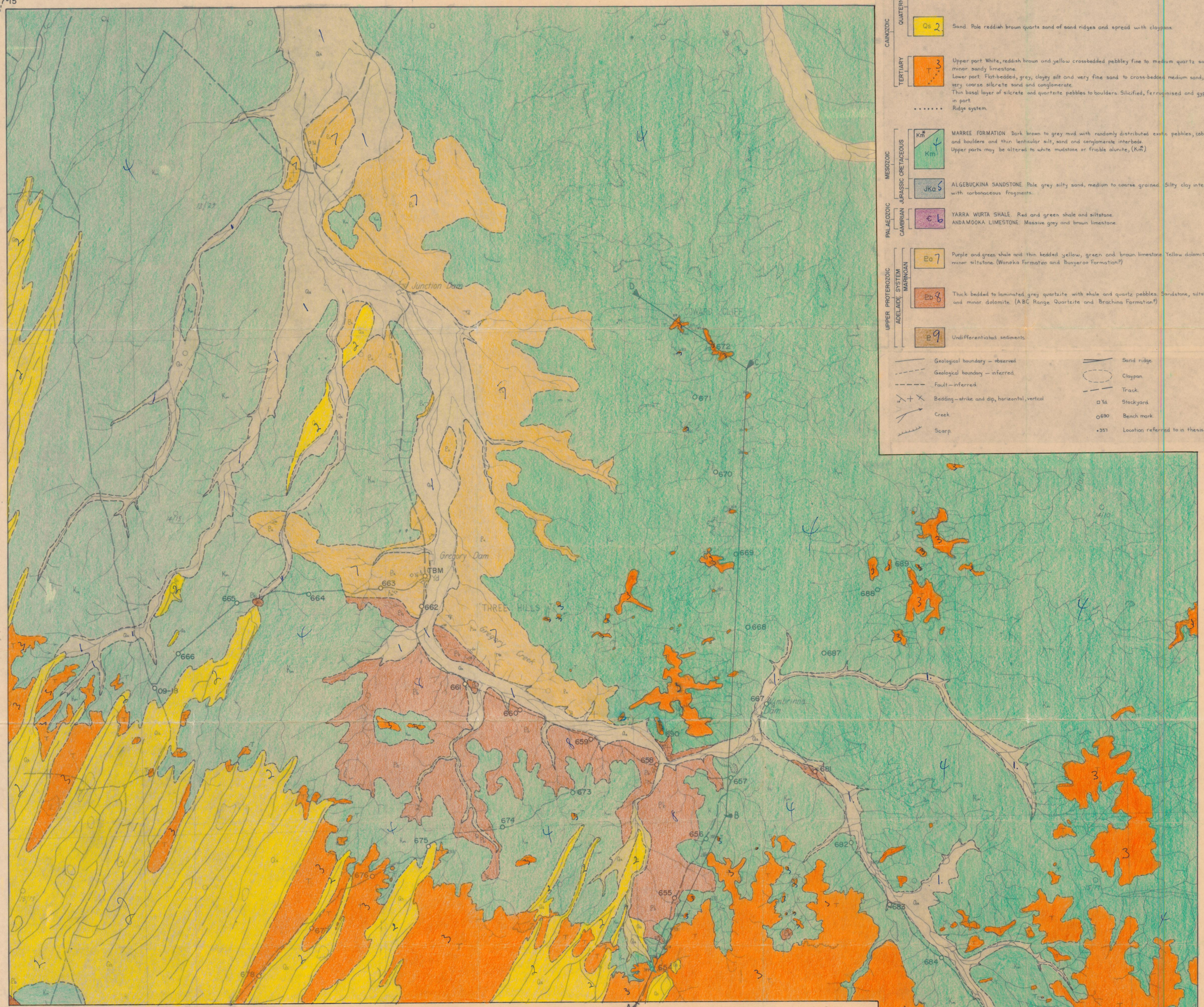
| R.S. No. | Location and Sample No. | Figure Reference | Sample Description | |
|---|---|---|---|---|
| 3 | 550/246-5 | C3 | Silcrete clasts from lag layer at base of Tertiary succession | |
| 4 | 550/247/8 | 3 | | |
| 5 | 550/356-2 | | | |
| 6 | 550/247/9 | 3 | Silcrete of SEQUENCE A. | |
| 7 | 550/247/10 | 3 | | |
| 8 | 550/247/11-1 | 3 | | |
| 9 | 550/247/11-2 | 3 | | |
| 10 | 550/365-1 | 2 | | |
| 11 | 550/379-1 | 4 | Silcrete of SEQUENCE B. | |
| 12 | 550/383 | | | |
| 13 | 550/247/17-2a | | | |
| 14 | 550/247/17-2b | | | |
| 15 | 550/363-3 | C1 | Silicified sand | SEQUENCE D. |
| 16 | 550/363-4 | C1 | Silicified sand | |
| 17 | 550/363-6 | C1 | Silicified sand | |
| 18 | 550/363-5 | C1 | Friable sand | |
| 19 | 550/363-7 | C1 | Friable sand | |
| 20 | 550/246-1 | C3 | Silicified sand | SEQUENCE D. |
| 21 | 550/246-2 | C3 | Friable sand | |
| 22 | 550/219-2 | | Silicified sand (? Adelaidean) | |
| 23 | 550/313 | | Silicified sand (? sequence D) | |

| | RS 3 | RS 4 | RS 5 | RS 6 | RS 7 |
|---|---|---|---|---|---|
| SiO2 | 95.0 | 94.1 | 96.1 | 94.9 | 96.0 |
| TiO2 | 1.53 | 1.24 | 1.06 | 1.21 | 1.09 |
| Al2O3 | 0.54 | 0.53 | 0.21 | 0.34 | 0.25 |
| Fe2O3 | 0.07 | 0.06 | 0.06 | 0.10 | 0.02 |
| FeO | 0.10 | 0.14 | 0.01 | 0.12 | 0.10 |
| MnO | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 |
| MgO | 0.25 | 0.16 | 0.05 | 0.00 | 0.06 |
| CaO | 0.08 | 0.16 | 0.03 | 0.44 | 0.06 |
| Na2O | 0.20 | 0.16 | 0.04 | 0.07 | 0.06 |
| K2O | 0.06 | 0.08 | 0.03 | 0.05 | 0.04 |
| P2O5 | 0.01 | 0.01 | <0.01 | 0.16 | 0.01 |
| H2O+ | 0.82 | 1.06 | 0.38 | 0.57 | 0.53 |
| H2O- | 0.18 | 0.20 | 0.06 | 0.18 | 0.11 |
| Total | 98.9 | 98.0 | 98.0 | 98.2 | 98.3 |

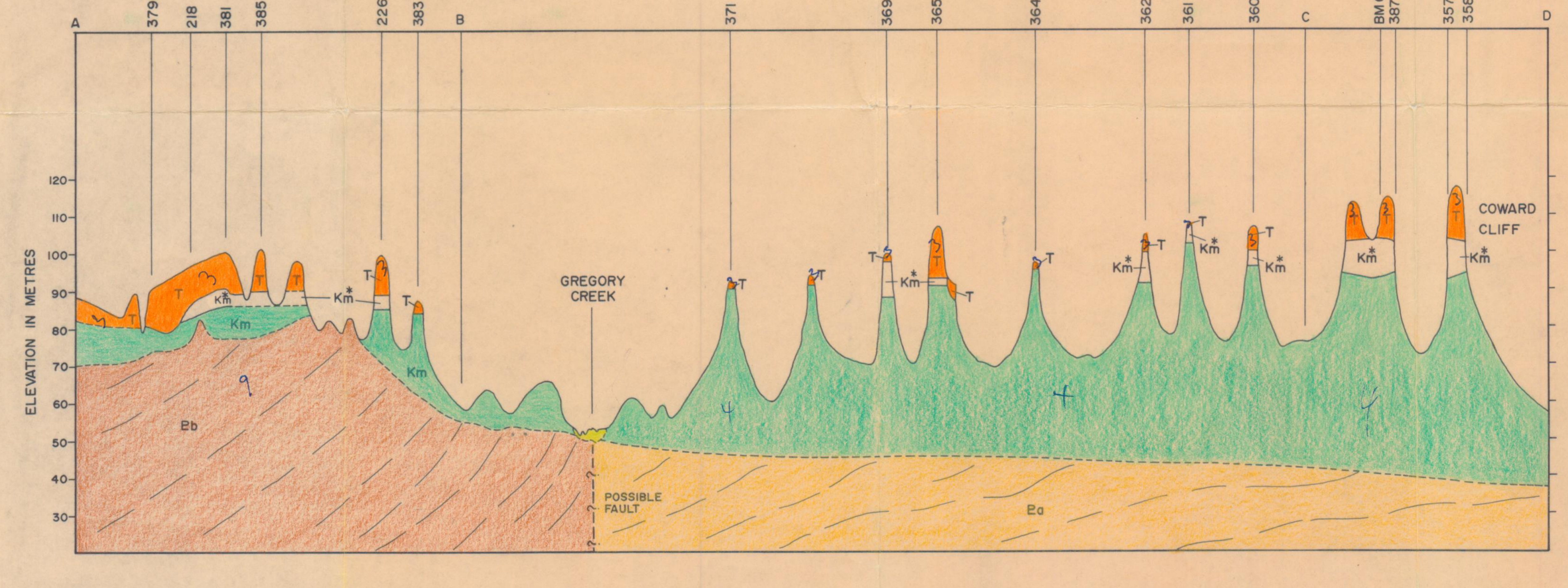
| | RS 8 | RS 9 | RS10 | RS11 | RS12 |
|---|---|---|---|---|---|
| SiO2 | 96.1 | 95.9 | 95.8 | 95.4 | 95.6 |
| TiO2 | 0.92 | 1.03 | 0.75 | 0.80 | 1.00 |
| Al2O3 | 0.63 | 0.36 | 0.49 | 0.31 | 0.54 |
| Fe2O3 | 0.03 | 0.13 | 0.02 | 0.01 | 0.19 |
| FeO | 0.12 | 0.08 | 0.14 | 0.14 | 0.14 |
| MnO | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 |
| MgO | 0.05 | 0.00 | 0.16 | 0.19 | 0.20 |
| CaO | 0.05 | 0.11 | 0.09 | 0.03 | 0.14 |
| Na2O | 0.06 | 0.07 | 0.06 | 0.07 | 0.11 |
| K2O | 0.07 | 0.04 | 0.07 | 0.04 | 0.09 |
| P2O5 | 0.04 | <0.01 | 0.01 | 0.03 | 0.01 |
| H2O+ | 0.71 | 0.46 | 0.54 | 0.47 | 0.62 |
| H2O- | 0.09 | 0.11 | 0.12 | 0.13 | 0.21 |
| Total | 98.9 | 98.3 | 98.2 | 97.6 | 98.8 |

| | RS13 | RS14 | RS15 | RS16 | RS17 |
|---|---|---|---|---|---|
| SiO2 | 93.9 | 96.0 | 96.2 | 96.2 | 93.5 |
| TiO2 | 0.83 | 1.09 | 0.27 | 0.22 | 0.44 |
| Al2O3 | 1.40 | 0.60 | 0.11 | 0.22 | 0.19 |
| Fe2O3 | 0.21 | 0.42 | 0.07 | 0.05 | 0.05 |
| FeO | 0.10 | 0.33 | 0.06 | 0.08 | 0.04 |
| MnO | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 |
| MgO | 0.33 | 0.35 | 0.32 | 0.50 | 0.22 |
| CaO | 0.07 | 0.05 | 0.45 | 0.55 | 1.19 |
| Na2O | 0.21 | 0.12 | 0.05 | 0.06 | 0.06 |
| K2O | 0.25 | 0.07 | 0.03 | 0.03 | 0.02 |
| P2O5 | 0.02 | 0.01 | $<0.01$ | $<0.01$ | $<0.01$ |
| H2O+ | 0.77 | 0.65 | 0.31 | 0.32 | 0.33 |
| H2O- | 0.40 | 0.19 | 0.21 | 0.46 | 0.72 |
| Total | 98.5 | 99.9 | 98.1 | 98.8 | 96.8 |

| | RS18 | RS19 | RS20 | RS21 | RS22 | RS23 |
|---|---|---|---|---|---|---|
| SiO2 | 89.8 | 91.4 | 93.7 | 95.5 | 97.2 | 98.4 |
| TiO2 | 0.23 | 0.11 | 1.68 | 0.15 | 0.21 | 0.05 |
| Al2O3 | 2.56 | 1.02 | 0.29 | 0.18 | 0.20 | 0.20 |
| Fe2O3 | 0.90 | 0.30 | 0.14 | 0.05 | 0.31 | 0.08 |
| FeO | 0.10 | 0.80 | 0.02 | 0.01 | 0.27 | 0.14 |
| MnO | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 |
| MgO | 0.84 | 0.57 | 0.27 | 0.37 | 0.70 | 0.68 |
| CaO | 0.82 | 1.78 | 0.11 | 0.88 | 0.03 | 0.10 |
| Na2O | 0.07 | 0.05 | 0.08 | 0.06 | 0.05 | 0.06 |
| K2O | 0.21 | 0.07 | 0.04 | 0.03 | 0.03 | 0.03 |
| P2O5 | 0.01 | $<0.01$ | 0.01 | $<0.01$ | 0.06 | 0.01 |
| H2O+ | 1.66 | 1.09 | 0.71 | 0.42 | 0.21 | 0.37 |
| H2O- | 1.23 | 1.18 | 0.55 | 0.49 | 0.15 | 0.13 |
| Total | 98.4 | 97.7 | 97.6 | 98.2 | 99.5 | 100.2 |




## CROSS SECTION




| B.M. | ELEVATION m. | B.M. | ELEVATION m. | B.M. | ELEVATION m. | B.M. | ELEVATION m. | B.M. | ELEVATION m. |
|---|---|---|---|---|---|---|---|---|---|
| 657 | 62·571 | 659 | 49·360 | 681 | 57·480 | 689 | 113·519 | 661 | 41·389 |
| 667 | 56·854 | 673 | 62·733 | 682 | 60·717 | 658 | 52·167 | 662 | 40·362 |
| 668 | 72·190 | 674 | 73·715 | 683 | 63·358 | 690 | 90·058 | TBM | 40·156 |
| 669 | 73·824 | 675 | 75·849 | 684 | 69·291 | 654 | 84·124 | 663 | 48·955 |
| 670 | 65·974 | 676 | 96·631 | 685 | 80·590 | 655 | 80·355 | 664 | 57·998 |
| 671 | 68·735 | 677 | 91·583 | 686 | 83·324 | 656 | 70·559 | 665 | 62·885 |
| 672 | 103·622 | 678 | 89·215 | 687 | 69·137 | 666 | 67·467 | | |
| COWARD CLIFF TRIG | 117·053 | 660 | 46·544 | 688 | 78·576 | 09–18 | 70·213 | | |

SCALE 1:40 000

1 0 1 2 3 4 5 KILOMETRES

| Fig. 21 | DEPARTMENT OF MINES AND ENERGY SOUTH AUSTRALIA | SCALE: 1:40 000 |
|---|---|---|
| COMPILED: G.NICOL | STUART CREEK COWARD CLIFF AREA | DATE: 8–11–79 |
| DRN: M.B. CKD: | GEOLOGICAL PLAN AND SECTION | PLAN NUMBER 79-789 |

(ENV 3600-1)