DEPARTMENT OF MINES AND ENERGY
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CAMBRIAN ALKALI PLAYA-LACUSTRINE SEQUENCE IN THE NORTHEASTERN OFFICER BASIN, SOUTH AUSTRALIA. REPORT NO. 4 OF THE OFFICER BASIN STUDY GROUP

By

A.H. White
COMALCO LIMITED
G.P.O. BOX 2773Y
MELBOURNE, VIC. 3001

and

Bridget C. Youngs
SOUTH AUSTRALIAN GEOLOGICAL SURVEY

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ABSTRACT

Byilkaoora-1, a stratigraphic well drilled in the northeastern part of the Officer Basin in South Australia, intersected aeolian and fluvial sandstones and mudstones overlying 224 m of fine-grained, dolomitic, calcareous and argillaceous sediments assigned to the Cambrian Observatory Hill Beds. The Observatory Hill Beds are remarkable in that they contain oil seepages and organic-rich argillaceous carbonates with good petroleum source characteristics, and abundant sodium carbonate evaporite minerals pseudomorphed by calcite at an early diagenetic stage. They consist of an upper and lower red bed interval, separated by green-grey, pyritic, carbonate-rich mudstones which contain most of the evaporite pseudomorphs and many Magadi-type chert nodules. The formation overlies coarse fanglomerate.

The Observatory Hill Beds are interpreted to have been deposited in a highly alkaline and reducing playa-lacustrine environment, and are thus analogous to the Eocene Green River Formation of Wyoming, U.S.A.

This interpretation is the first record of alkali playa-lacustrine Cambrian sedimentation in Australia and, to our knowledge, is also the first record of Paleozoic alkali playa-lacustrine deposition in the world.

INTRODUCTION

A nearly complete section of Cambrian rocks in the northeastern Officer Basin of South Australia (Fig. 1) was obtained in the Byilkaoora-1 stratigraphic well, drilled by the South Australian Department of Mines and Energy in 1979. Cambrian sequences in adjacent basins are believed to be predominantly marine (Veevers, 1976). We describe in detail the lithologies encountered in Byilkaoora-1 and compare them with those reported from saline playa-lake deposits such as the Eocene Green River Formation in Wyoming, U.S.A., and the Pleistocene-Recent deposits at Lake Magadi in Kenya. We conclude that the Cambrian Observatory Hill Beds at Byilkaoora-1 constitute Australia's first recorded Cambrian saline playa-lacustrine deposits and, to our knowledge, constitute the world's first record of Paleozoic alkali playa-lake deposits.

REGIONAL SETTING

The Officer Basin is a Late Precambrian to Paleozoic sedimentary basin in south central Australia (Fig. 1). In the northeastern portion of the basin, Precambrian sediments are disconformably overlain by the Cambrian 'Davies Bore Conglomerate', Observatory Hill Beds (carbonates, evaporites, siltstones) and Trainor Hill Sandstone (Fig. 2). These Cambrian strata are overlain disconformably by a thick sequence of Ordovician to ?Devonian sandstones (Krieg, 1973).

DESCRIPTION OF LITHOLOGIES

'Davies Bore Conglomerate'

The 'Davies Bore Conglomerate' (Fig. 2) consists of poorly sorted polymict cobble conglomerate, containing rounded clasts of predominantly sedimentary rocks, with minor acid igneous and acid metamorphic rocks, in an abundant cement of calcite and secondary dolomite. Cobble imbrication is conspicuous in the core. The upper 10 m of the conglomerate is bleached, brecciated and contains abundant carbonaceous material filling fractures and interstices. The bleaching is apparently due to recalcification (dedolomitization) of the cement.

Observatory Hill Beds

The Observatory Hill Beds in Byilkaoora-1 are a relatively monotonous sequence of fine-grained dolomitic mudstones and argillites remarkable for the presence locally of sapropelic matter, oil shows, peculiar chert nodules and early diagenetic calcite pseudomorphs of evaporite crystals. In the central part of the formation (Fig. 2) the calcite pseudomorphs comprise up to 50% of the total sediment.

The lowest part of the Observatory Hill Beds (below 335 m) consists of red-brown homogeneous silty dolomite mudstone, which is variably calcitic. Lamination, bedding and cyclic sedimentation, which are clearly preserved higher in the sequence, are almost obliterated below 335 m, calcite- and dolomite-filled hydrofractures are common, and the sediment contains abundant small (1-3 mm) blebs of calcite believed to pseudomorph earlier crystals. These are unlike pseudomorphs above 316 m in which bladed crystals up to 30 mm long are perfectly preserved. The blebs of calcite in thin section appear to pseudomorph the remnants of originally much larger evaporite crystal concentrations, partly redissolved after precipitation but prior to calcite replacement. We suggest that repeated interstitial growth and subsequent solution of the evaporite minerals obliterated primary sedimentary structures in this interval.

Between 335 m and 316 m there is a transition from red beds to pyritic green-grey sediments. Between 316 m and 272 m the sediments consist predominantly of pyritic silty carbonaceous mudstones, dolomite mudstones with some calcite, lime mudstones and algal plate dolomite mudstones (Fig. 3(A)). Minor bituminous matter is present throughout as films and blebs; there are also numerous occurrences of oil bleeding from calcite-lined vugs and veins. Chert nodules and layers are common. The argillaceous intervals contain abundant evaporite minerals pseudomorphed by calcite. The evaporite crystals occurred either as rosettes of bladed crystals up to 30 mm long (Fig. 3(B)) or as disseminated equant rhombic crystals up to 5 mm across (Fig. 3(C)); the former were identified from relict crystal habit and cleavage as being mostly trona, possibly with some pseudo gaylussite, and the latter as being shortite. The crystal shapes are very well preserved, although many of the bladed crystals are bent due to compaction. We believe that the crystals grew in situ as idioblastic aggregates or grains as a consequence of evaporative concentration of sodium bicarbonate brines near the surface, and were subsequently pseudomorphed by calcite after the near surface brines were diluted by episodic fresh water inundation.

The dolomite in these sediments occurs as minute rhombs and appears to be primary rather than a diagenetic replacement of earlier calcite.

Between 272 m and 155 m similar sediments occur, but evaporite crystal pseudomorphs and bleeding oil are rare. The sediments are thinly bedded, laminated and contain abundant pull-apart structures; mudcracks are common on bedding planes. The sediments are pyritic and the algal carbonates contain up to 1.3% organic matter by weight. The sediments are predominantly red in color above 240 m.

Cyclic sedimentation is evident in the Observatory Hill Beds between 316 m and 155m. A complete cycle (Fig. 4) commences with sapropelic argillite which commonly contains evaporite crystal pseudomorphs (particularly between 316 m and 272 m), overlain by calcitic, silty dolomite mudstone which also may contain evaporite crystal pseudomorphs. This is overlain by dolomite mudstone containing chert nodules, dolomitic algal plate boundstone, stromatolite boundstone (Fig. 3(A)) and algal plate breccia. The cycles vary from 50 mm to 2 m thick; tepee structures occur in the upper layers of many cycles and small sedimentary injection dykes are common. Distinctive chert nodules and layers occur in many cycles in the carbonate part of the sequence. The nodules are lenticular parallel to bedding, and are up to 10 mm thick and up to 50 mm long. They are commonly concentrically banded in shades of brown and yellow. Cracks in the rind are common and are interpreted as shrinkage cracks. Some chert layers have been deformed or penetrated by evaporite crystals (Fig. 3(B)), indicating that there was a chert precursor mineral which was soft and plastic during crystal growth.

The silt fraction throughout the sequence is composed of very angular quartz fragments, locally with some angular fresh feldspar fragments.

Trainor Hill Sandstone and Mt. Johns Conglomerate

The basal unit of the Trainor Hill Sandstone (Fig. 2) consists of interbedded micaceous red claystones and red-gray, slightly kaolinitic quartz sandstones. The sandstones are generally well-sorted, have sharp bases on the underlying claystones, and contain clay pellets and intraclasts.

The Mt. Johns Conglomerate (Fig. 2) is a micaceous red bed sequence, comprised of red claystones grading downward to siltstones with a basal 1.5 m bed of pebble conglomerate. The claystones and siltstones contain abundant micaceous laminae, many of which define low-angle cross-beds.

The uppermost unit of the Trainor Hill Sandstone is predominantly white, fine- to medium-grained quartz sandstone which is kaolinitic, well-sorted and shows some evidence of cross-bedding. A few 0.5 m thick red and white claystone interbeds are present and claystone pellets and intraclasts occur in most of the sandstones.

DISCUSSION

The presence of abundant evaporite-crystal pseudomorphs intimately associated with primary dolomitic muds and algal plate and stromatolite boundstones in the Observatory Hill Beds in Byilkaoora-1 indicate beyond doubt that the sequence was deposited in a carbonate-evaporite environment.

Identification of the evaporite minerals as trona, shortite and possibly gaylussite, pseudomorphed by calcite, leads us to compare the Observatory Hill Beds with other trona-bearing sequences. There is a remarkable similarity between parts of the Laney (Surdam and Stanley, 1979) and Wilkins Peak (Eugster and Hardie, 1975) members of the Green River Formation and the carbonate-evaporite sequence in Byilkaoora-1.

Staining of carbonates showed that the calcitic dolomite muds in the Observatory Hill Beds are comprised of dolomite in a matrix of calcite, and that the algal plate and stromatolite boundstones tend to be mostly dolomite. Wolfbauer and Surdam (1974) described a similar distribution of dolomite and calcite in carbonates in the

Laney Member, and concluded that the carbonates were deposited on lacustrine mud flats. They suggested (p. 1738) that the protodolomite formed as a penecontemporaneous replacement of pre-existing calcite in the muds, due to increasing Mg^{++}/Ca^{++} ratios in evaporating surface brines.

Skinner (1963) and Jones (1965) found that in many evaporative lacustrine environments calcite initially precipitates from water with relatively low Mg^{++}/Ca^{++} ratios, and that as the waters become concentrated by evaporation, and the Mg^{++}/Ca^{++} ratio increases, first Mg-calcite, then Mg-calcite and protodolomite, and finally protodolomite alone precipitate from the waters.

The typical depositional cycle observed in Byilkaoora-1 (Fig. 4) is similar to that found in the Laney Member by Surdam and Stanley (1979, Fig. 9). Carbonate layers in each case commence with a rather massive calcitic dolomite mudstone with chert which grade up into algal plate and stromatolite boundstones which tend to be mostly dolomite, and which are overlain by algal plate breccias.

Von der Borch and Lock (1979) described this type of carbonate cycle forming in the Coorong area of South Australia, in ephemeral lakes that seasonally are flooded to depths of less than a metre, and which dry out annually due to evaporation. The massive calcitic dolomite mudstone in Observatory Hill Beds cycles is analogous to the structureless 'yoghurt' dolomite, formed during the lake-full stage in the Coorong area as a result of wavelet stirring of lake sediments (von der Borch and Lock, 1979). The overlying algal plate and stromatolite boundstones form in very shallow water or on the partially dried lake surface, and algal plate breccias form on the dried surface crust.

Organic-rich argillites comprising the lower parts of cycles are present in both the Observatory Hill Beds and the Wilkins Peak and Laney members. Although these sequences respectively are Cambrian and Eocene in age, the elemental composition of their kerogens is strikingly similar, both Type I as defined by Tissot and Welte (1978) (McKirdy and Kantsler, 1980).

Chert nodules and layers in the Observatory Hill Beds appear identical to Magadi-type chert in the Green River Formation (Eugster and Surdam, 1971). Cherts found in outcrops of Observatory Hill Beds at the type section (Wopfner, 1969) have the characteristic surface cracks and reticulation ('crocodile skin', Fig. 3(D)) illustrated on Magadi-type cherts by Eugster and Surdam (1971), and on Lake Magadi chert by Eugster (1969) and Hay (1968). The concentric color banding in chert nodules in Byilkaoora-1 is very similar to that in Magadi-type chert nodules in the Laney and Wilkins Peak members. Magadi-type cherts are believed to form from magadiite by leaching of sodium by percolating groundwaters (Eugster, 1969). The deformation and penetration by evaporite crystals of the chert beds, is consistent with them having formed from magadiite. According to Surdam, Eugster and Mariner (1972, p. 2262) the formation of magadiite and its chert successor 'indicates a very specific depositional environment, namely, that of an alkaline lake or groundwater table. The pH in the brine must be high enough for sufficient silica polymerisation to occur (at least pH 9.5); otherwise not enough silica will be stored for magadiite to precipitate'.

One other noteable feature of the evaporite sequence in Byilkaoora-1 is the absence of gypsum, which commonly precipitates from evaporating brines. Gypsum is also rare in the Green River Formation (Milton, 1971). In the saline deposits of the Dead Sea (Neev and Emery, 1967) and Lake Magadi (Jones, Eugster and Rettig, 1977) the lack of gypsum is postulated to be due to bacterial sulfate reduction, which we suggest may also explain the absence of gypsum and abundance of pyrite in the Observatory Hill Beds in Byilkaoora-1.

INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS IN BYILKAOORA -1

'Davies Bore Conglomerate'

The 'Davies Bore Conglomerate' is interpreted to be a fluvial fanglomerate on the basis of its thickness, sorting, carbonate cement, imbrication and red bed association.

Observatory Hill Beds

The presence of Magadi-type cherts, and pseudomorphed trona and shortite evaporite crystals indicate that much of the Observatory Hill Beds were deposited in a highly alkaline, high bicarbonate evaporative environment. Such an environment is documented in modern Lake Magadi (Eugster and Hardie, 1978) and probably existed during the Eocene in the Green River Basin (Eugster and Hardie, 1975; Surdam and Wolfbauer, 1975). We believe that the Observatory Hill Beds were deposited in a Cambrian playa-lake environment very similar to the younger playa-lake environments of the Green River Basin and Lake Magadi.

The Observatory Hill Beds contain a number of cycles of deposition which typically commence with an organic-rich argillite, interpreted to have been deposited during episodic fresh water inundation of the playa-lake environment. Blue-green algae probably flourished in the Cambrian playa-lake after each inundation, and their preservation in argillaceous layers under reducing conditions has resulted in good oil-source potential of the Observatory Hill Beds. After each inundation the lake commenced to dry up because of evaporation; calcite was precipitated from the concentrating lake brines, and was replaced penecontemporaneously by dolomite to form the massive 'yoghurt' carbonate layer in each cycle. With continued evaporation magadiite, later replaced by Magadi-type chert, and mainly dolomitic algal plate and stromatolite boundstones were deposited. As evaporation proceeded, the surface carbonates dried to a brittle crust, and the surface algal plate material was brecciated due to desiccation and weathering. Idioblastic growths of trona and shortite probably crystallized beneath these carbonate crusts in the organic-rich argillites during the last stage of each evaporative cycle.

The early diagenetic replacement of trona and shortite by calcite in each sedimentary cycle probably occurred as a result of the succeeding fresh water inundation. It is likely that with each inundation the relatively soluble sodium carbonate salts, which crystallized during the last stages of evaporation of the previous cycle, would be susceptible to replacement by less soluble calcite during the early stages of evaporation in the succeeding cycle.

The change from lower red beds to green-gray beds back to red beds at the top of the Observatory Hill Beds in Byilkaoora-1, can be explained in terms of long-term water table fluctuations. We infer that the water table was slightly below the surface during deposition of the red beds. Under these conditions we suggest that there was sufficient percolation of fresh water to partly dissolve sodium carbonate salts prior to calcite replacement, and that oxidation of the iron constituents of the sediments above the water table, imparted their red colour.

A corollary of this inference is that the water table was at the surface during deposition of the green-gray parts of the sequence. This inhibited downward percolation of fresh water and thus the trona and shortite crystal shapes are well preserved.

The inferred water table dispositions during Observatory Hill Beds time at Byilkaoora-1 suggest that arid conditions may have prevailed at the commencement of deposition on the lake, changing gradually to conditions of increased humidity, and followed by a gradual return to arid conditions at the end of playa-lake deposition (Fig. 2).

Trainor Hill Sandstone

The Trainor Hill Sandstone is interpreted as an aeolian and fluvial deposit. The Mt. Johns Conglomerate may represent the distal facies of an alluvial fan; the conglomerate is known to coarsen northwards away from Byilkaoora-1 (Pitt, Benbow and Youngs, 1980).

SUMMARY OF DEPOSITIONAL HISTORY

Early Cambrian sedimentation at Byilkaoora-1 commenced with deposition of the fluvial fanglomerates comprising the 'Davies Bore Conglomerate'. These were transgressed quite abruptly by the Observatory Hill Beds, which were deposited in a gradually subsiding basin dominated by a highly alkaline, bicarbonate playa-lacustrine system. There were repeated cycles of fresh water inundation and brine concentration by evaporation. During deposition of the Observatory Hill Beds, there was a fluctuation in the position of the ground water table which rose to the surface and fell again. This may indicate long term climatic variations during deposition. Reducing conditions during the water-table-at-surface time resulted in preservation of algal detritus in the sediments, imparting good oil-source characteristics to the sequence. The playa-lake regime was gradually transgressed by fluvial/aeolian sands and clays of the Trainor Hill Sandstone.

SUMMARY

This interpretation of the Cambrian sequence in Byilkaoora-1 is the first record of alkaline playa-lacustrine sedimentation in the Cambrian system of Australia, and to our knowledge, is the first record in the world of this type of environment in the Palaeozoic.

Existing concepts of Cambrian geography and tectonics in central Australia must be re-examined to explain non-marine deposition in the Byilkaoora area, since marine depositional environments apparently prevailed widely during the Cambrian in the surrounding basins.

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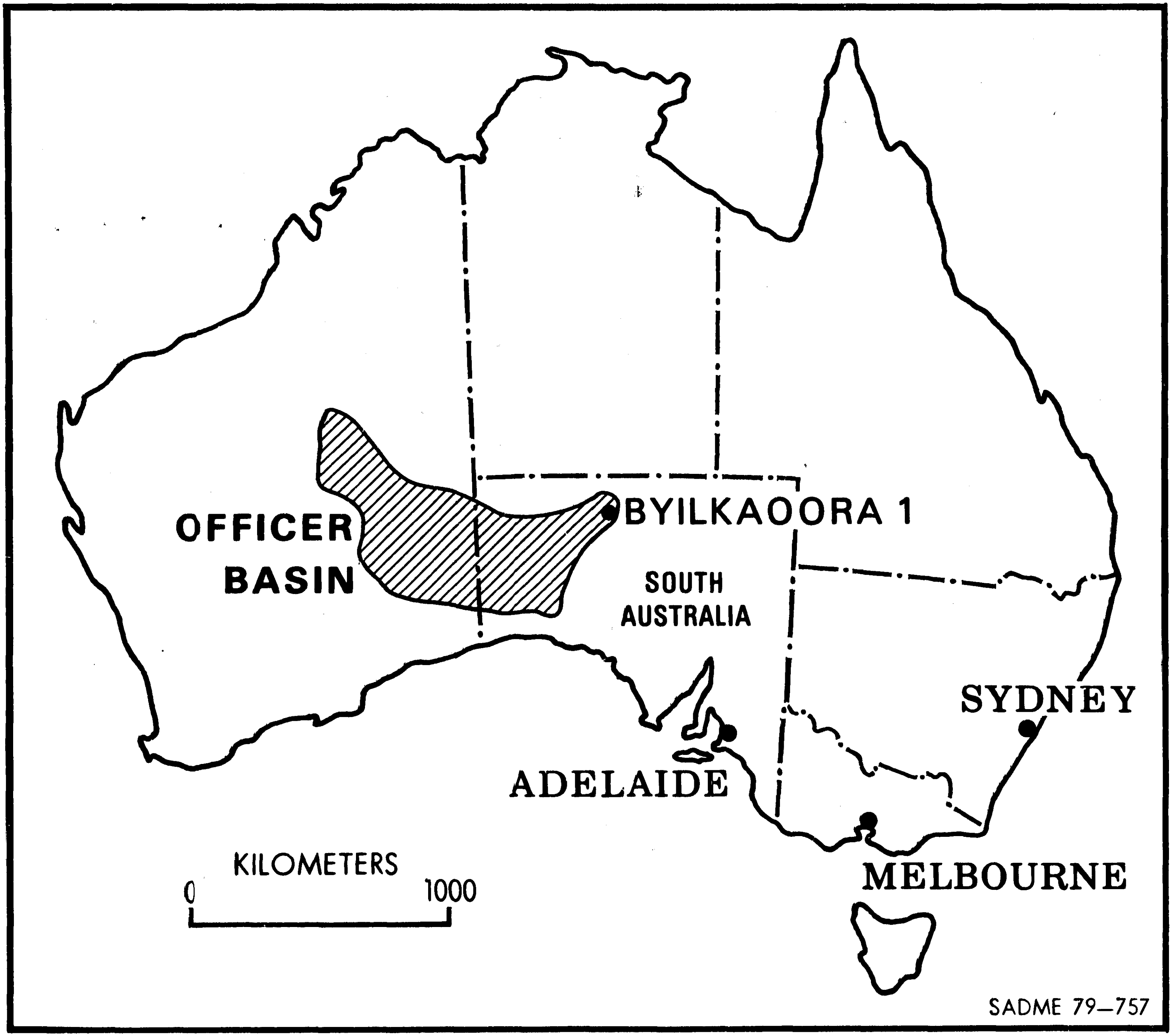

Location of Officer Basin. & Byilkaoora 1

GEOL. SOC. AMERICA

TRAINOR HILL SANDSTONE Upper Unit
MT JOHNS CONGLOMERATE
TRAINOR HILL SANDSTONE Lower Unit
OBSERVATORY HILL BEDS
C A M B R I A N
"DAVIES BORE CONGLOMERATE"
ADELAIDEAN
RODDA BEDS
GAMMA
METERS
POINT RESISTIVITY
CASING
INCREASING HEIGHT OF WATER TABLE
0
49
98
155
200
214
240
272
316
325
335
376
379
486
GEOPHYSICAL LOGGING TO 465 m
TD 497 m
LEGEND
Sandstone
Siltstone
Mudstone
Carbonate
Conglomerate
Calcareous
Dolomitic
Clay intraclast
Algal plate intraclast
Stromatolite, algal mat
Sedimentary injection feature
Mudcracks
Magadi–type chert
Pseudomorphs of evaporite crystals
Cross bedding
Oil show
79–755 S.A. Dept of Mines and Energy Drn T.S.

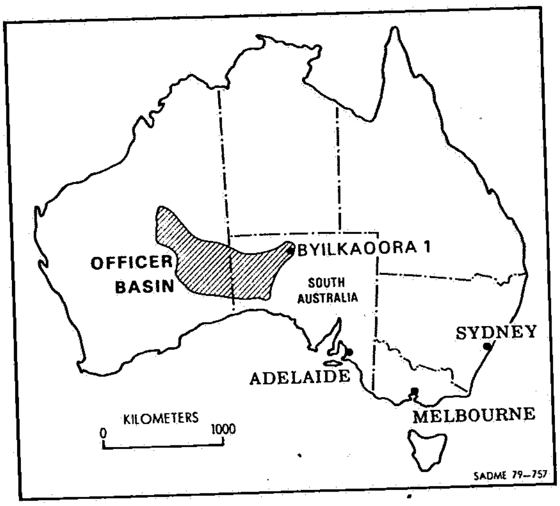

FIG. 1. Location Map

Dwg. No. 79-757

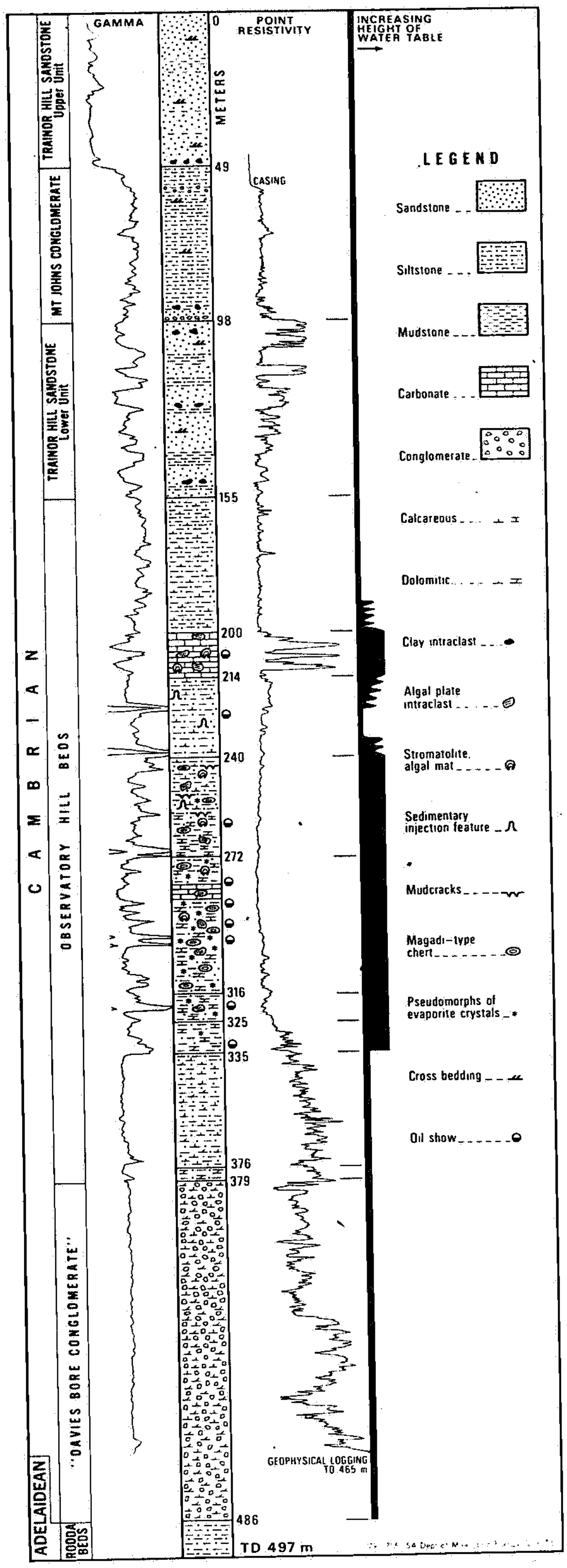

FIG. 2 - Summary well log, Byilkaoora - 1.

Dwg. No. 79-755

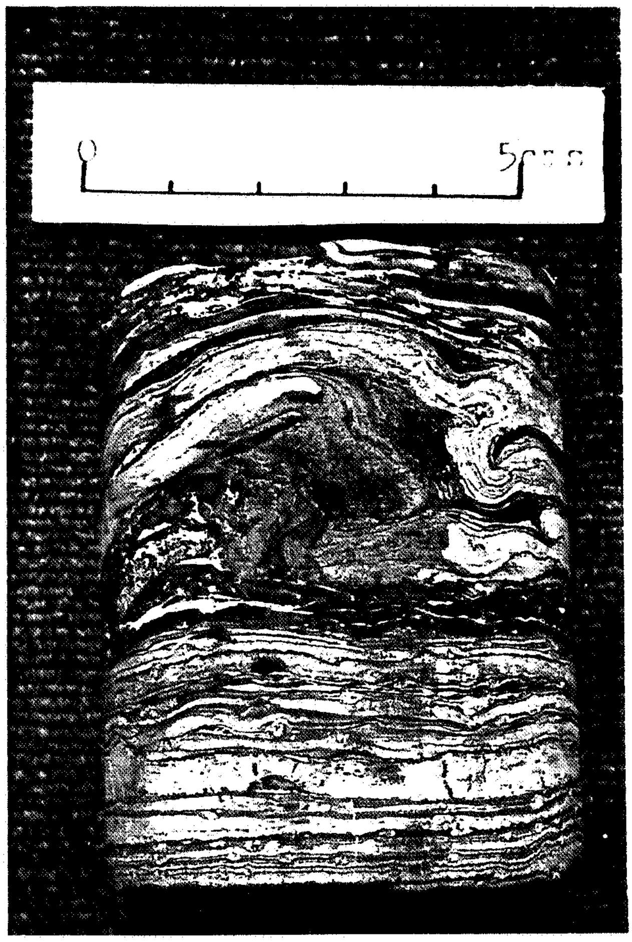

Fig. 3(A) - Algal laminated mudstone showing soft sediment deformation and a pale oil stain (30 mm diameter) around a small vug in the centre. Byilkaoora-1, 278.9m, top of core upwards.

Photo no. 31179

FIG. 3(B) - Calcite pseudomorphs of trona rosettes, and Magadi-type chert lenses showing deformation and cross-cutting of soft chert precursor by idioblastic evaporite crystal growths. Byilkaoora-1, 294.8m, top of core to right.

Photo no. 31278

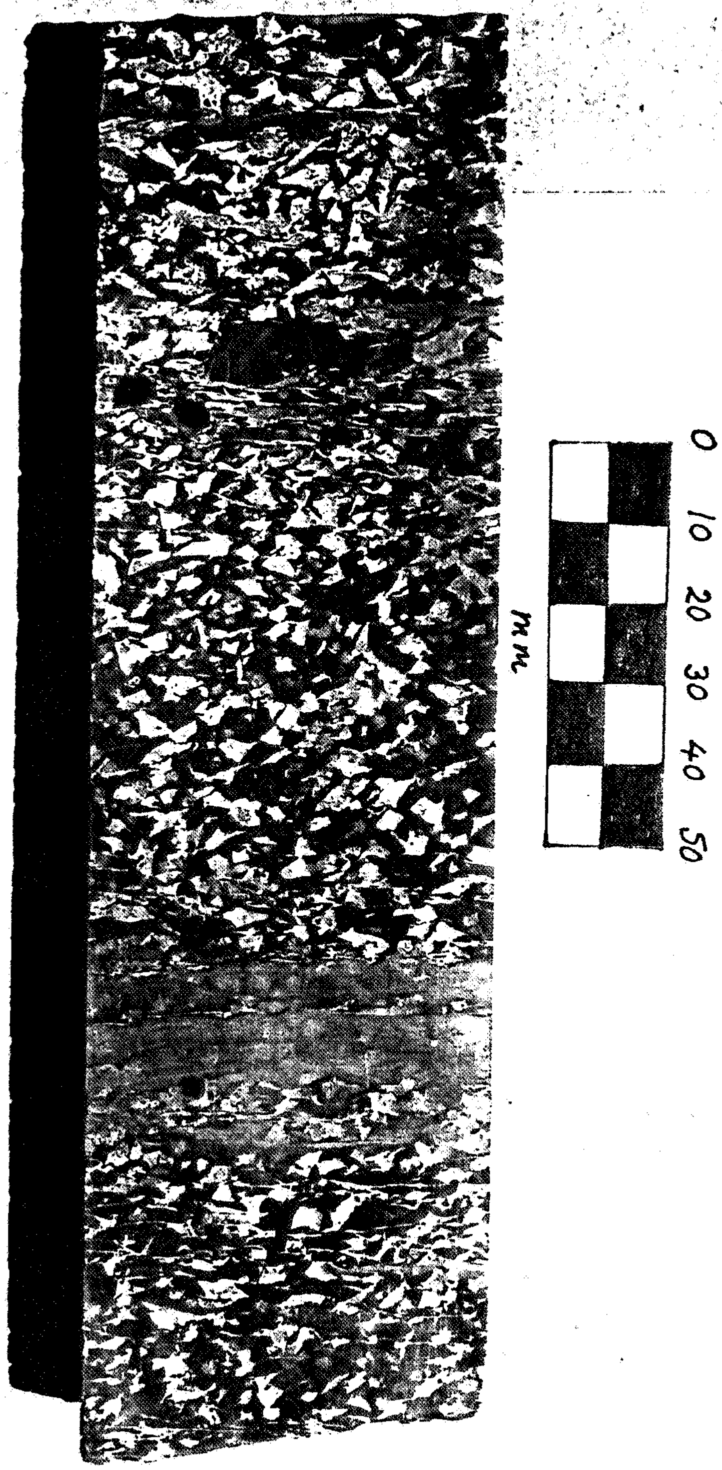

FIG. 3(C) - Calcite pseudomorphs of shortite crystals in sapropelic argillites. Small areas of bleeding oil occur at bottom left. Byilkaoora-1, 295.5m, top of core to right.

Photo no. 31271

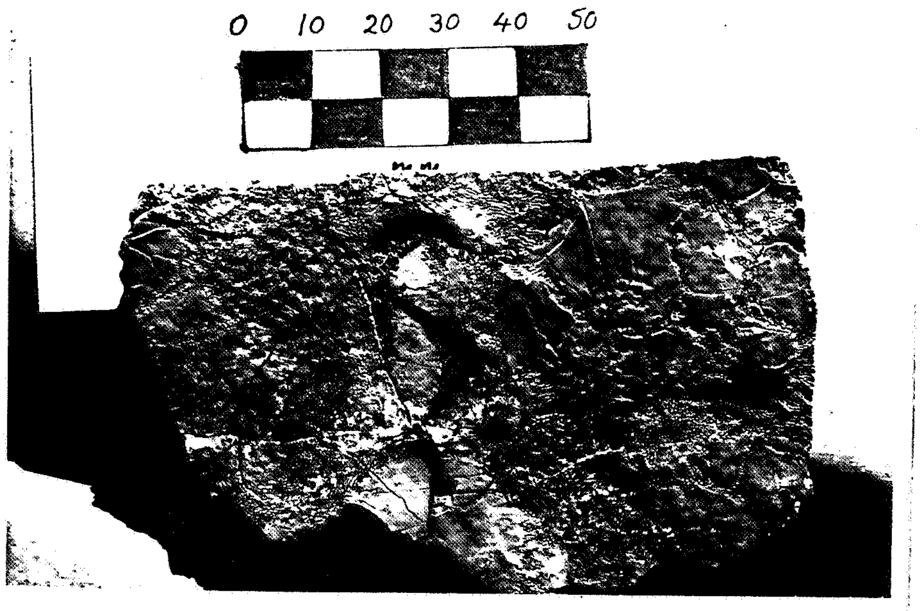

FIG. 3(D) - "Crocodile skin" texture on surface of Magadi-type chert lens from outcrop at the type section of the Observatory Hill Beds.

Photo no. 31280

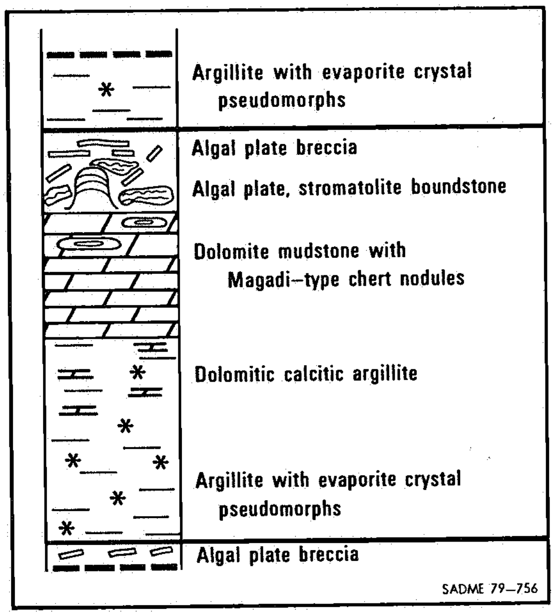

FIG. 4 - Diagrammatic illustration of a complete lacustrine sedimentary cycle deposited during "water-table-at-surface" time, middle Observatory Hill Beds, Byilkaoora-1.

Dwg. no. 79-756