Rept. Bk
773.

CONFIDENTIAL

LITHOFACIES STUDY ON THE TOOLACHEE FORMATION, GIDGEALPA - MOOMBA - BIG LAKE AREA, COOPER BASIN, SOUTH AUSTRALIA

by

R.C.N. THORNTON
GEOLOGIST
PETROLEUM GEOLOGY SECTION.

This report is a copy of the paper submitted to the Australian Petroleum Exploration Association for publication in the 1973 A.P.E.A. Journal

29th Nov, 1972.

Rept. Bk. No. 773.
G.S. No. 4997.
S.R. 27/4/131.

ABSTRACT

A lithofacies study on the Upper Permian Toolachee Formation has been conducted in the Gidgealpa-Moomba-Big Lake area to determine the suitability of the technique in the reconstruction of depositional environments and palaeogeographic trends throughout the Cooper Basin. The Toolachee Formation is one of the main gas producing intervals in the basin, especially in the area of study, which is approximately 2000 square kilometres. Thirty one wells drilled in this region indicate that the formation ranges in thickness from 35 metres to over 115 metres.

A lithofacies map of the Toolachee Formation, taken as a whole, shows no significant features because of the limited area of investigation. However, lithofacies maps of three approximately chronostratigraphic subdivisions of the same formation show both vertical and lateral trends. Vertically, the percentage of sandstone decreases from the lowermost subdivision to the uppermost subdivision; coal percentages show the opposite trend; and core material shows fining upwards sequences. Laterally, isopachous thin areas (depositional highs) in most cases correlate with an increase in shale or coal lithologies. Histograms of coal cycles show that the lower and middle parts have similar composite sequences of, from the base upwards, sandstone-mixture sandstone and shale-shale-coal.

The depositional model proposed is an aggradational floodplain which, prior to the commencement of deposition, had been eroded to a peneplain. Sediments were deposited from rivers of gradually declining flow gradient until marsh and lacustrine conditions prevailed for long periods of time. Deposition ceased at the sediplain stage.

INTRODUCTION

Objectives

Out of more than one hundred wells drilled in the Cooper Basin, the great majority has been designed to intersect oil or gas in structural traps. In the future, the exploration for stratigraphic traps is likely to assume increasing importance.

To this end, therefore, a full understanding of the depositional environment of the formation is a vital prerequisite. The present study has been carried out to assess the value of statistical sedimentological studies in identifying depositional environments.

The Toolachee Formation within the area of the Gidgealpa, Moomba and Big Lake gas fields was chosen for this study for two reasons. Firstly, this formation has been encountered in all wells drilled in the region, with the exception of Spencer 1 (Fig. 5). Secondly, the high well density has resulted in the stratigraphy and structural configuration of this part of the basin being more fully understood than anywhere else.

The techniques used comprise the compilation of lithofacies and ispachous maps, the construction of coal cycle histograms, and detailed inspection of core material.

Location

The Cooper Basin is a Permian-Triassic infra-basin beneath the Mesozoic Great Artesian Basin, trending northeastwards across South Australia's border with Queensland (Fig. 1). The area of study, located at the southwestern end of the Cooper Basin, covers approximately 2 000 square kilometres.

Toolachee Formation

The Toolachee Formation is Upper Permian in age and is the youngest formation within the Gidgealpa Group (Fig. 2). The stratigraphy of the Cooper Basin has been described by Martin (1967), Kapel (1972) and Gatehouse (1972).

The lithology of the Toolachee Formation is one of interbedded sandstones, siltstones, shales and coals.

The sandstones are light grey to tan protoquartzites, with variable amounts of lithics, cemented by a kaolin or silica matrix. Many sandstones contain carbonaceous wisps and specks as well as accessory amounts of muscovite. Units of clean sandstone, which can be up to 15 metres thick, are often medium to coarse grained, and where they overlie coals, are regularly (but not invariably) conglomeratic. Upwards fining sequences and steep planar foreset current bedding are common.

In many cases, however, the sandstones are thinly interbedded with siltstones and shales and are then mostly rather finer grained. Interlaminae and lenses vary in thickness from 1 mm to 5-10 cm and tend to be discontinuous. Small scale current structures such as asymptotic foreset crossbeds, festoon bedding, climbing ripples and "cut and fill" structures abound. Slump and load structures are common.

The siltstones are grey, micromicaceous, and in a few cases pyritic. They are commonly gradational with shales. Beds of dark grey shale occur frequently, in some cases being as thick as 8 metres. They are usually micromicaceous and almost invariably carbonaceous.

The coals, which can be as thick as 5 metres, are sometimes gradational with carbonaceous shales and are generally black and bituminous.Especially within the coals, but also sometimes in the shales, are lenses and bands of hard, smooth, brown siderite, which have replaced much of the original rock (Steveson, in Thornton, 1972).

Where encountered, thickness of the Toolachee Formation varies from 35.1 metres at Gidgealpa 11 to 116.4 metres at Moomba 11.

Apart from thickness, the major difference between the sections is the number of individual lithologic units. For example, in most of the Gidgealpa wells there are only three major coal horizons, which are correlatable across the whole field. Big Lake wells have between six and eight coals and the Moomba wells have more than ten seams.

METHOD OF STUDY

Lithofacies and Isopachous Maps

For the purpose of this study, the Toolachee Formation has been subdivided into three parts equivalent to the three major "cycles" in the Gidgealpa field.

The three major coal horizons in Gidgealpa have been correlated across to Moomba and Big Lake, as well as to the peripheral wells Cooper's Creek 1, Tindilpie 1, Topwee 1 and Wirrarie 1, in the manner described below. Although the result is somewhat subjective, it is considered to be as close as possible to the delineation of three time equivalent segments within the formation. If the correlation is correct and the boundaries are chronostratigraphic, sedimentation was synchronous throughout each portion. These subdivisions are informally described for the purpose of this report as the Upper, Middle and Lower Parts of the Toolachee Formation.

Subdivision Boundaries

The base of the Upper Part is defined in the Moomba wells by a strongly radioactive shale, producing an abnormally high kick on the gamma-ray curve, for example Moomba 9 and Big Lake 1 (Fig. 4). It is distinguishable in some Gidgealpa wells, where it occurs at the level of the middle coal horizon. It is considered to be a time horizon, conceivably being the result of a short lived and ubiquitous event. The base of the Middle Part is not so clearly defined. However, by careful comparison of gamma-ray characteristics, combined with a count of sandstone, shale and coal bodies, a correlation with the top of the lower coal horizon in Gidgealpa has been achieved across the whole area.

Lithological Interpretation

For all wells, coal horizons were interpreted from the sonic log and one value on the gamma ray log (120 API units) was used for the sandstone/shale cut off. Hopefully, therefore, any error (such as a bias towards sandstone) will have been similar in every case. Therefore, the ratios derived from these data should be biased to a similar degree and comparison should be valid.

Map Compilation

The thicknesses of the various sandstone, shale and coal bodies were calculated from the interpreted lithologies. Sandstone-shale and clastic ratios were then computed for each well in the three parts and the Total Section.

The type of lithofacies map chosen was the triangle facies map. After some experimentation it was decided to employ the limiting ratios used on the "standard" triangle (Krumbein and Sloss, 1963; p. 460), shown on Figs. 5-8.

Limiting ratios such as 2 and 4 were not adopted because the resolution of the small scale (1:600) gamma-ray logs used to interpret lithologies was insufficient to show variations for more-detailed subdivision within the "average" part of the triangle (sandstone-shale and clastic ratio values between 1 and 8).

Cyclicity of Sedimentation

Tendencies towards cyclic sedimentation were investigated by a slightly simplified version of the method used by Duff and Walton (1962) and Duff (1967). Duff and Walton (op. cit.) defined the terms:

Cycle: "(A) cycle (is) a group of rock units which tend to occur in a certain order and which contains one unit which is repeated frequently through the succession.

"Modal Cycle: The modal cycle is that group of rock types which occurs most frequently through any succession.

"Composite Sequence: The composite sequence consists of all the rock types investigated in a cyclic succession, arranged in the order in which they tend to occur within the cycles. Once the modal cycle(s) has (have) been erected, then it is possible to consider any extra lithology and assess its position with respect to the units of the modal cycle(s)".

In this study, the number of cycles was counted for each of the three parts of the formation. The top of each cycle was taken to be a coal horizon because it would have been a period of virtual non-clastic deposition. The sediments in between two coals therefore comprised one cycle, ending with the upper coal. The sediments within the cycles were classified as sand, shale and mixture of sand and shale. A sequence was classed as mixture only where the radioactive log indicated fine interbanding of coarse and fine clastics.

The units within each cycle were identified, and the results plotted on histograms (Fig. 9).

Each cycle is plotted from the base upwards. Coal is omitted from the histograms because it is the top unit of every cycle.

Gidgealpa 6: Cores 1 and 2

A litholog and brief environmental interpretation of the two cores from Gidgealpa 6 which were cut within the Toolachee Formation is shown in Fig. 10. The boundary between the Upper and Middle Parts, chosen in the manner described previously, is at 7 143 feet. Inspection of the core at this depth gives clear indication of the arbitrary nature of the choice of the boundary, because it occurs within a gradational shale sequence.

OBSERVATIONS AND INTERPRETATION

Lithofacies and Isopachous Maps

Total Section

The very featureless lithofacies map of the Total Section (Fig. 5), compared with those of the three individual parts, suggests that the area of study is too small to show any meaningful variations in sedimentation patterns for the complete formation.

There is strong parallelism between the top of Permian structure contour ("P") map (Fig. 3) and isopach (Fig. 5), on which the Gidgealpa, Moomba and Big Lake structures are clearly outlined. However, in those areas with low well density this reasoning is to a certain extent circular, and thus invalid, because the "P" map was used as a control for the isopach.

Weller (1960; Fig. 118, p. 303) shows how compaction of sediments on the flank of a pre-existing topographic high can cause drape structures virtually identical to fold structures caused by tectonic uplift and downwarp.

The amount of highly compactible shale and coal in the Toolachee Formation varies from 30% to 70% of the total thickness, and therefore differential compaction must have been an important factor in the sedimentological development of the basin. Nevertheless, it cannot completely explain the similarity between the "P" and isopachous maps because of the absence of topographic highs prior to Toolachee Formation deposition.

The major evidence for peneplenation of the surface on which the Toolachee Formation was deposited is the nature of the contact between the Upper and Lower Permian sediments. The Toolachee Formation lies nearly conformably on top of the Daralingie Beds in the structurally low areas, such as Moomba, but is angularly unconformable on Lower Permian formations, and even basement rocks, over highs like Gidgealpa.

The Toolachee Formation was deposited over the whole of the area under discussion as a blanket of sediments, often 100 metres thick. It is absent only where it has been subsequently eroded (for example, Spencer 1; Fig. 5). There is no evidence for onlap of Toolachee Formation sediments onto previously existing highs. Coarse sands occur on top of the structures as a sheet of material. This would not have occurred under fluviatile conditions if the highs had been present prior to deposition.

Therefore, the parallelism of contours on the isopach with the "P" map can only mean that the Gidgealpa, Moomba and Big Lake areas underwent relative uplift during Toolachee Formation time.

Lower Part

The lithofacies map of the Lower Part (Fig. 6) is more complex than for either the Middle or Upper Parts, indicating a greater amount of variation in sedimentation patterns. Sediments were laid down on an erosional surface. Structural reactivation occurred after a long stable period, presumably within both the source area and the depositional basin. The sediments of the Lower Part were therefore deposited at a period when the landscape was at its most unstable stage, with a relatively high relief. The fairly steep gradient of the rivers would have prevented the formation of meanders. Non-meandering rivers tend to sweep back and forth across the depositional plain, depositing virtually only coarse clastics (Allen, 1965). Under these conditions, extensive back-swamps and coal swamps will not develop.

The lithofacies map (Fig. 6) illustrates these ideas. Over half of the area has a clastic ratio greater than 8, and a sandstone-shale ratio greater than 1. The dominance of coarse clastics in the Lower Part is exemplified by the zone surrounding Gidgealpa where both clastic and sandstone-shale ratios exceed 8.

On first inspection, it might be thought that a rising basement high would have the most energetic depositional environment at its apex. As a result both sandstone-shale and clastic ratios should decrease away from the centre. But this is not shown on the lithofacies map. In fact, the reverse applies, especially on Gidgealpa. Maximum coal development occurs on top and maximum sand development, reflecting increased depositional energy, around the perimeter.

As structural growth began to occur, variation in elevation across the high at any given time probably was very minor (in the order of a few metres only). Nonetheless, there was a natural tendency for rivers to flow around the perimeter of the uplifted area.

The area of uplift therefore received mainly the finer grained sediments of floodplain deposition. Levee development on the banks of the rivers was sufficient to cover the high with vertical accretion (Allen, 1964) and backswamp deposits.

Middle Part

This lithofacies map (Fig. 7), compared with that of the Lower Part, shows less character, indicating a structurally more quiescent period within the basin. About 80% of the map area is covered by the zone of clastic ratio less than 8 and sandstone-shale ratio greater than 1.

For the sake of simplicity, it may be assumed that the ratio of coarse to fine material being supplied from the source area was the same as in the Lower Part. The facies variations therefore indicate that while sand deposition was still dominant over shale, conditions were much more stable, allowing more coal formation than previously. Therefore, the gradient of the rivers was decreasing and they were meandering across the depositional plain much more than previously, forming back swamps and coal swamps.

This depositional model is supported by the lithology in Core 2 from Gidgealpa 6 (Fig. 10).

The sequence between 7 170 ft and 7 150 ft grades upwards from sandstone, to interbedded sandstone and shale, to shale, to coal. The fining upwards sequence is diagnostic of an alluvial floodplain. Furthermore, sedimentary structures observed in the cores coincide with those described by Allen (1964) and Visher (1965) from their studies of recent floodplain sediments. Examples are planar foreset cross bedding in point bars and small scale cross bedding, autochthonous plant material and interlayering of coarse and fine sediments on levees.

Siderite is a fairly common mineral in the cores from Gidgealpa 6. It occurs either as lenses 5 cm thick or else dispersed throughout the interbedded fine sandstones and shales, staining the rock brown. It is an early diagenetic mineral, formed a few centimetres beneath the sediment water interface and requires a strongly reducing environment for its formation (Curtis, 1967). Also, it usually forms only in a non-marine environment (Curtis, op. cit.). At high salinities pyrite is formed instead. The formation of siderite in the sediments would seem to indicate undisturbed, static pond water conditions for considerable lengths of time. The fact that many of the shales are highly carbonaceous and contain abundant plant fragments supports this.

The only part which does not fit this model is the area encompassing Big Lake and the southern part of Moomba. The increase in thickness of 15 metres, accompanied by very high clastic ratios (Fig. 7), indicates that this westerly pointing wedge of material has been deposited within a sub-environment of the floodplain different from that of the rest of the sediments.

Deposits of Middle Part age occur in the Big Lake wells. The possibility of an alluvial fan spreading out from a reactivated fault scarp is therefore ruled out, because such would require a subaerially exposed high on the upthrown side of the fault (Bull, 1972). Nevertheless, the Big Lake fault could have acted as a growth fault with uplift on the Big Lake side being gradual and on a scale small enough not to prevent deposition.

Stream channels carried most of the material over the fault where fluvial fans deposited it. Sedimentation was thus continuous across the fault, but because of subsidence on the downthrown side, the southern Moomba wells received a thicker section than in Big Lake. The fluvial fans interfingered with the other alluvial sediments, but because of the greater rate of influx of sediments, conditions were unsuitable for coal formation.

The relatively low sandstone-shale ratios in the southern Moomba wells can be explained by the poorly sorted nature of the fan deposits. On the other hand, the higher sandstone-shale ratio values for the Big Lake wells suggest that these sands are cleaner than in the southern Moomba wells. This would seem to indicate winnowing in the Big Lake area where, because of the slower rate of burial, there was more opportunity for reworking of the sands.

Upper Part

A further decrease in depositional energy in the Upper Part is shown by the lithofacies map in which about half the area is covered by the field of sandstone-shale ratio less than 1 and clastic ratio less than 8 (Fig. 8).

This dominance of shale over sand in much of the area suggests a gradation in the Upper Part to near lacustrine conditions, with a few sluggish rivers meandering through extensive tracts of swamps and lagoons. Moreover, around Topwee 1 and Wirrarie 1, where the clastic ratio is less than 1, extremely stable conditions with long uninterrupted periods of coal formation, must have prevailed.

Gidgealpa, on the other hand, must have been subjected to rather different conditions. The strong northwards increase in clastic ratios to very high values in some of the northern wells may indicate resurgence of structural activity during Upper Part time.

Supporting evidence for structural reactivation in the Gidgealpa area comes from the sediments in Core 1 of Gidgealpa 6 (Fig. 10). Between 7 133 ft and 7 124 ft there are three cycles grading upwards from conglomerate to sandstone, interpreted mainly as channel lag to point bar deposits. The conglomerates contain well rounded cobbles and pebbles. One point bar deposit shows reverse graded bedding, indicating an increase in stream energy. Two of the cycles have incomplete floodplain sequences, having been truncated at the point bar stage by the sudden transgression of another stream channel. Added to these data, the rapid repetition of the fluviatile cycles would seem to indicate rivers of relatively high flow gradient and low sinuosity sweeping back and forth across the structure.

Coal Cycles Histograms

An investigation of the three histograms (Fig. 9) shows that the Lower and Middle Parts have similar characteristics, but that the Upper Part is very different.

In the Lower Part, with a total of 80 cycles counted in 31 wells, the primary modal cycle is, in ascending order, sand-shale-coal (S-A), with secondary and tertiary modes of shale-coal (A) and sand-coal (S) respectively. In the Middle Part, S-A is even more dominant, occurring in 27 out of 99 cycles. S-A is therefore the primary modal cycle.

Note the absence of M (mixture) in the primary modal cycle. Nevertheless, in all cycles in which M does occur, its most common position is between S and A. Therefore for the Lower and Middle Parts the composite sequence is:

Coal

Shale

Mixture of Sand and Shale

Sand

This is a perfect "fining upwards" sequence. The strong dominance of the modal cycles makes it clear that cyclic sedimentation was an important factor during the Lower and Middle Parts.

The composite sequence obtained for the Lower and Middle Parts is virtually identical to the sequence set up by Duff (1967) for the Permian sediments of the Southern Coalfield (Illawarra Coal Measures) in New South Wales. He identified many sedimentary features that also suggested an alluvial floodplain environment in the Southern Coalfield and therefore considered that the composite sequence derived by him was indicative of floodplain deposition. Further, Allen (1964) has shown that in a vertical section through a floodplain, fine grained sediments will grade upwards from coarse grained sediments resting on an erosional surface. Consequently, it is considered that the histogram evidence very strongly suggests that the Lower and Middle Parts of the Toolachee Formation were deposited on an alluvial floodplain.

In the Upper Part, 31 out of 88 cycles counted consist of shale-coal (A), which is therefore the primary modal cycle. On average, A cycles are significantly thinner than other types. To a certain degree they are probably due to seam splitting. These intra-seam cycles are thus a particular case, different from those formed during inter-seam periods (Duff, 1967). However, the secondary modes, A-S-A and A-S-A-S-A, each have only 7 cycles and cannot be considered dominant (Fig. 9).

Cyclicity within the Upper Part is therefore not satisfactorily proved. However, the dominance of shale-coal sequences is probably indicative of a change within the Upper Part to more lacustrine and marshy conditions over most of the area, with minor variations in water level causing the change from shale deposition to coal formation.

CONCLUSIONS

The coal cycles study, the upwards fining sequences described from cores and the lithofacies maps strongly support a floodplain depositional model. These data seem irreconcilable with deltaic sedimentation.

Corroborative evidence is provided by the fact that no marine acritarchs have been identified during extensive palynological investigations. This seeming lack of marine shales is almost impossible to explain under a deltaic environment. Studies of recent deltaic sequences (e.g. Frazier and Osanik, 1969) and ancient deltaic deposits (e.g. Duff and Walton, 1962; Connolly and Ferm, 1971) always show marine sediments intercolated with freshwater clastic and peat deposits.

The depositional history can be summarised with the aid of three diagrammatic cross-sections showing the basin development (Fig. 11). The sections have been compiled on the assumption that deposition had reached the near-sediplain stage at the end of the Lower, Middle and Upper Parts. Thicknesses were thus taken from the three isopachs and added downwards from a horizontal surface.

Cross section C illustrates the theory that the Toolachee Formation was deposited on a peneplain and finished as a sediplain. The vertical exaggeration on the sections is 166.6. At natural scale, the lines denoting the base and top of the formation would be virtually parallel. Even the slope up the flank of the Gidgealpa High is only about 1 metre/kilometre.

During the deposition of the Toolachee Formation the climate was probably temperate to sub-tropical and moist (Wopfner, 1972). Prior to the commencement of deposition the area had been eroded nearly flat. Uplift of the source area commenced and rivers with relatively high flow gradients began to stream across the area, moving back and forth across the floodplain. Predominantly coarse clastics were deposited, especially around the structural highs, and coal swamps were too short lived for the formation of anything other than minor amounts of coal.

By Middle Part time the source area had been partly eroded and the aggradation plain partly filled up, so that the rivers traversing the basin were slower moving and meandered more than previously. As a result, a larger proportion of fine clastics was deposited and coal swamps were longer lived and more extensive. Activity along the Big Lake fault caused the deposition of predominantly sandstone over the Big Lake High, together with thick accumulations of sandstone and shale on the downthrown side of the fault.

By Upper Part time structural activity had virtually ceased, except on the Gidgealpa High, and the gradient between source area and basin was so low that there were long stable periods when coal swamps dominated. A larger proportion of the basin was covered by lakes and swamps for longer periods of time than during the earlier two parts. As a result, the deposition of shales and coals predominated over sandstone in what had become a near-lacustrine environment. By the end of the Upper Part, clastic deposition had virtually ceased and coal swamps reigned supreme.

The depositional environment of the Toolachee Formation was terminated by the onset of aridity in the Lower Triassic (Wopfner, 1972).

This study has demonstrated that detailed sedimentological investigations will not only help towards a fuller understanding of the sedimentary model but will also outline depositional trends. Examination of such trends should be useful in the locating of additional hydrocarbon deposits.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. B.P. Webb, Director of the South Australian Department of Mines, for permission to publish this paper. Dr. H. Wopfner and Dr. S.B. Devine provided invaluable assistance.

Thanks are recorded to Santos Ltd., Delhi International Oil Corporation and Vamgas N.L. for allowing the release of certain confidential information. The cooperation of Mr. B. Thomas and his staff for drafting the figures at very short notice is gratefully acknowledged.

REFERENCES

Allen, J.R.L., 1964, Studies in fluviatile sedimentation: six cyclothems from the Lower Old Red Sandstone, Anglo Welsh Basin: Sedimentology, v.3, p. 163-198.

____________, 1965, A review of the origin and characteristics of Recent alluvial sediments: Sedimentology, v.5, p. 89-191.

Bull, W.B., 1972, Recognition of alluvial-fan deposits in the stratigraphic record: in J.K. Rigby and W.K. Hamblin, eds., Recognition of ancient sedimentary environments: Spec. Publs. Soc. econ. Palaeont. Miner., Tulsa, no. 16, 340 pp.

Connolly, J.R. and J.C. Ferm, 1971, Permo-Triassic sedimentation patterns, Sydney Basin, Australia: Amer. Ass. Petrol. Geol. Bull., v.55, pt. 11, p. 2018-2032.

Curtis, C.D., 1967, Diagenetic iron minerals in some British carboniferous sediments: Geochim. cosmochim. Acta, v.31, p. 2109-2123.

Duff, P. McL.D., 1967, Cyclic sedimentation in the Permian coal measures of New South Wales: J. geol. Soc. Australia, v.14, pt. 2, p. 293-307.

_______________ and E.K.Walton, 1962, Statistical basis for cyclothems: a quantitative study of the sedimentary succession in the East Pennine coalfield: Sedimentology, v.1, p. 235-255.

Frazier, D.E. and A. Osanik, 1969, Recent peat deposits - Louisiana coastal plain: in E.C. Dapples and M.E. Hopkins, eds., Environments of coal deposition: geol. Soc. Amer. Spec. Pap., no. 114, 204 pp.

Gatehouse, C.G., 1972, Formations of the Gidgealpa Group in the Cooper Basin: Australas Oil Gas Rev., v.18, pt. 12, p. 10-15.

Kapel, A.J., 1972, The geology of the Patchawarra area Cooper Basin: Australian Petrol. Explor. Ass. J., v.12, p. 53-57.

Krumbein, W.C. and L.L. Sloss, 1963, Stratigraphy and sedimentation. 2nd edition. W.H. Freeman and Company, San Francisco, U.S.A., 660 pp.

Martin, C.A., 1967, The Gidgealpa and Merrimelia Formations in the Cooper's Creek Basin: Australas Oil Gas J., v.14, pt. 2, p. 29-35.

Thornton, R.C.N., 1972, Pilot lithofacies study on the Toolachee Formation, Gidgealpa-Moomba-Big Lake area, Cooper Basin, South Australia: S. Australia Geol. Surv. unpubl. report R.B. 770.

Visher, G.S., 1965, Use of vertical profile in environmental reconstruction: Amer. Ass. Petrol. Geol. Bull., v.49, pt. 1, p. 41-61.

Weller, J.M., 1960, Stratigraphic principles and practice. Harper and Brothers, Publishers, New York, 725 pp.

Wopfner, H., 1972, Climate and deposition in Permian and Early Triassic in South Australia: Abstracts, 44th ANZAAS Congress, Sydney.

CAPTIONS TO FIGURES

Figure Number	Title
1	Locality map.
2	Stratigraphic table - Cooper Basin.
3	Structure contour map of the top of Permian ("P").
4	Threefold subdivision of the Toolachee Formation. The boundaries between each part are thought to approximate time lines.
5	Total Section of the Toolachee Formation: Lithofacies and isopachous map.
6	Lower Part of the Toolachee Formation: Lithofacies and isopachous map.
7	Middle Part of the Toolachee Formation: Lithofacies and isopachous map.
8	Upper Part of the Toolachee Formation: Lithofacies and isopachous map.
9	Histograms of coal cycles for each part of the Toolachee Formation. Only the most frequently occurring cycles are lettered.
10	Environmental interpretation of Cores 1 and 2 from Gidgealpa 6 (simplified from Thornton, 1972).
11	Structural and sedimentological development of the Toolachee Formation.

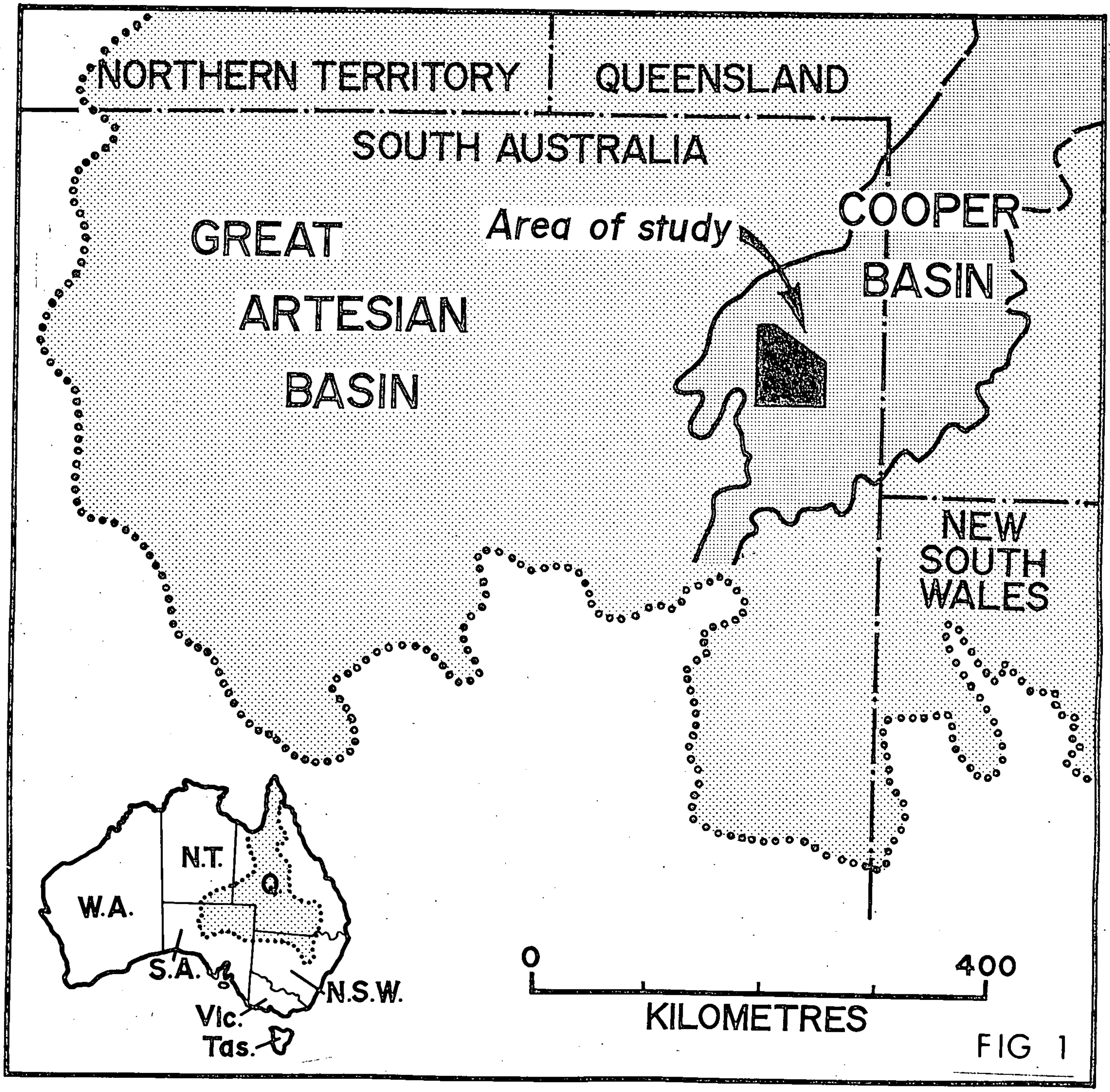

NORTHERN TERRITORY
QUEENSLAND
SOUTH AUSTRALIA
GREAT
ARTESIAN
BASIN
Area of study
COOPER
BASIN
NEW
SOUTH
WALES
N.T.
W.A.
Q.
S.A.
N.S.W.
Vic.
Tas.
0
400
KILOMETRES

FIG 1

<table>
<tr><th colspan="2">NEW TERMINOLOGY
(Kapel, 1972; Gatehouse, 1972)</th><th>AGE</th><th colspan="3">OLD TERMINOLOGY
(Martin, 1967)</th></tr>
<tr><td colspan="2">NAPPAMERRIE FORMATION</td><td>TRIASSIC</td><td colspan="3">NAPPAMERRIE FORMATION</td></tr>
<tr><td rowspan="8">GIDGEALPA GROUP</td><td>TOOLACHEE FORMATION</td><td>TARTARIAN-KUNGURIAN</td><td colspan="2">UPPER MEMBER</td><td rowspan="8">GIDGEALPA FORMATION</td></tr>
<tr><td>DARALINGIE BEDS</td><td rowspan="4">ARTINSKIAN</td><td rowspan="4">MIDDLE MEMBER</td><td rowspan="2">UPPER PART</td></tr>
<tr><td>ROSENEATH SHALE</td></tr>
<tr><td>EPSILON FORMATION</td><td>MIDDLE PART</td></tr>
<tr><td>MURTEREE SHALE</td><td>LOWER PART</td></tr>
<tr><td>PATCHAWARRA FORMATION</td><td rowspan="3">ARTINSKIAN-SAKMARIAN</td><td colspan="2" rowspan="3">LOWER MEMBER</td></tr>
<tr><td>MOORARI BEDS</td></tr>
<tr><td>TIRRAWARRA SANDSTONE</td></tr>
<tr><td colspan="2">MERRIMELIA FORMATION</td><td>SAKMARIAN-(?) CARBONIFEROUS</td><td colspan="3">MERRIMELIA FORMATION</td></tr>
</table>

FIG 2

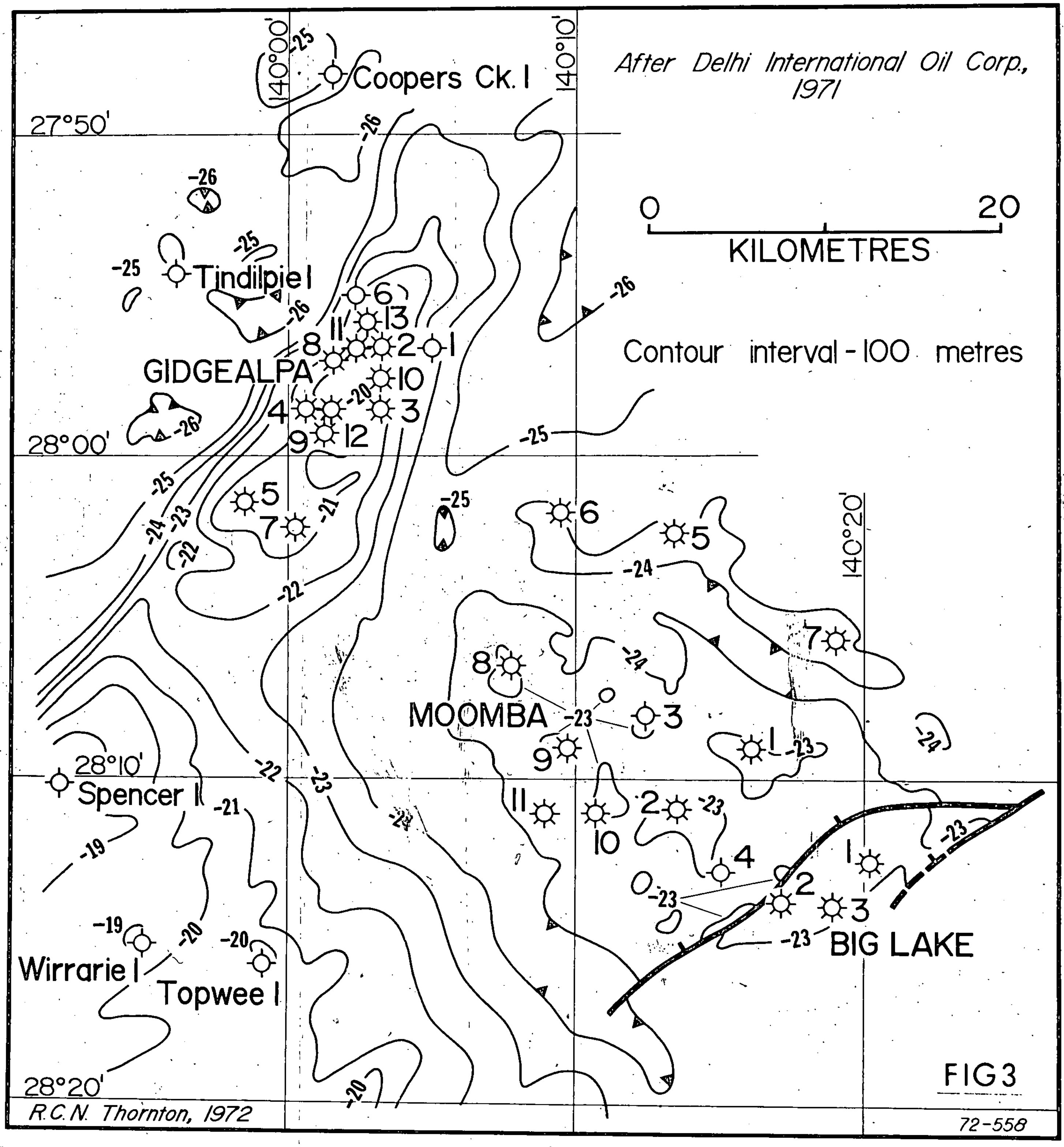
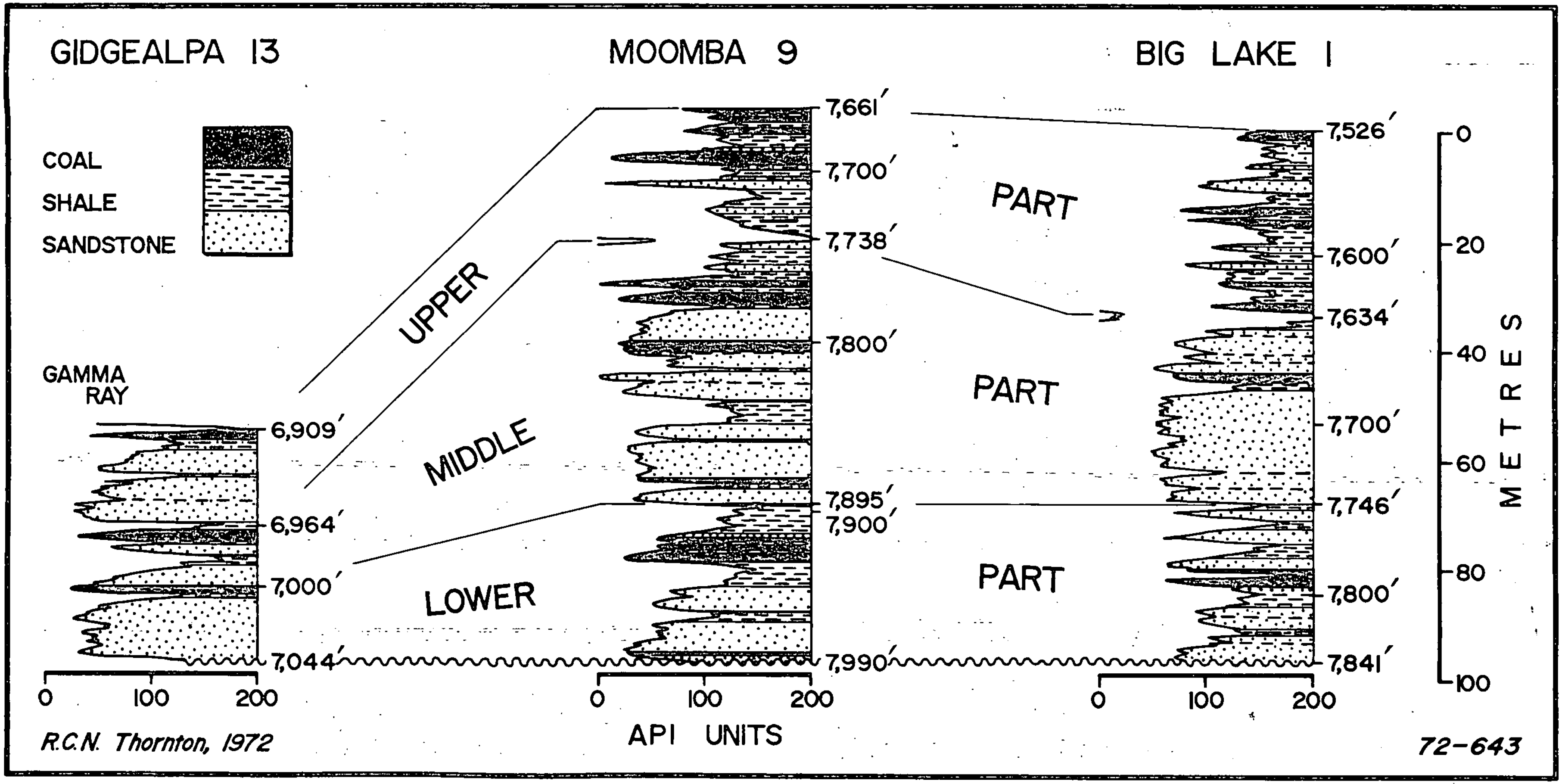
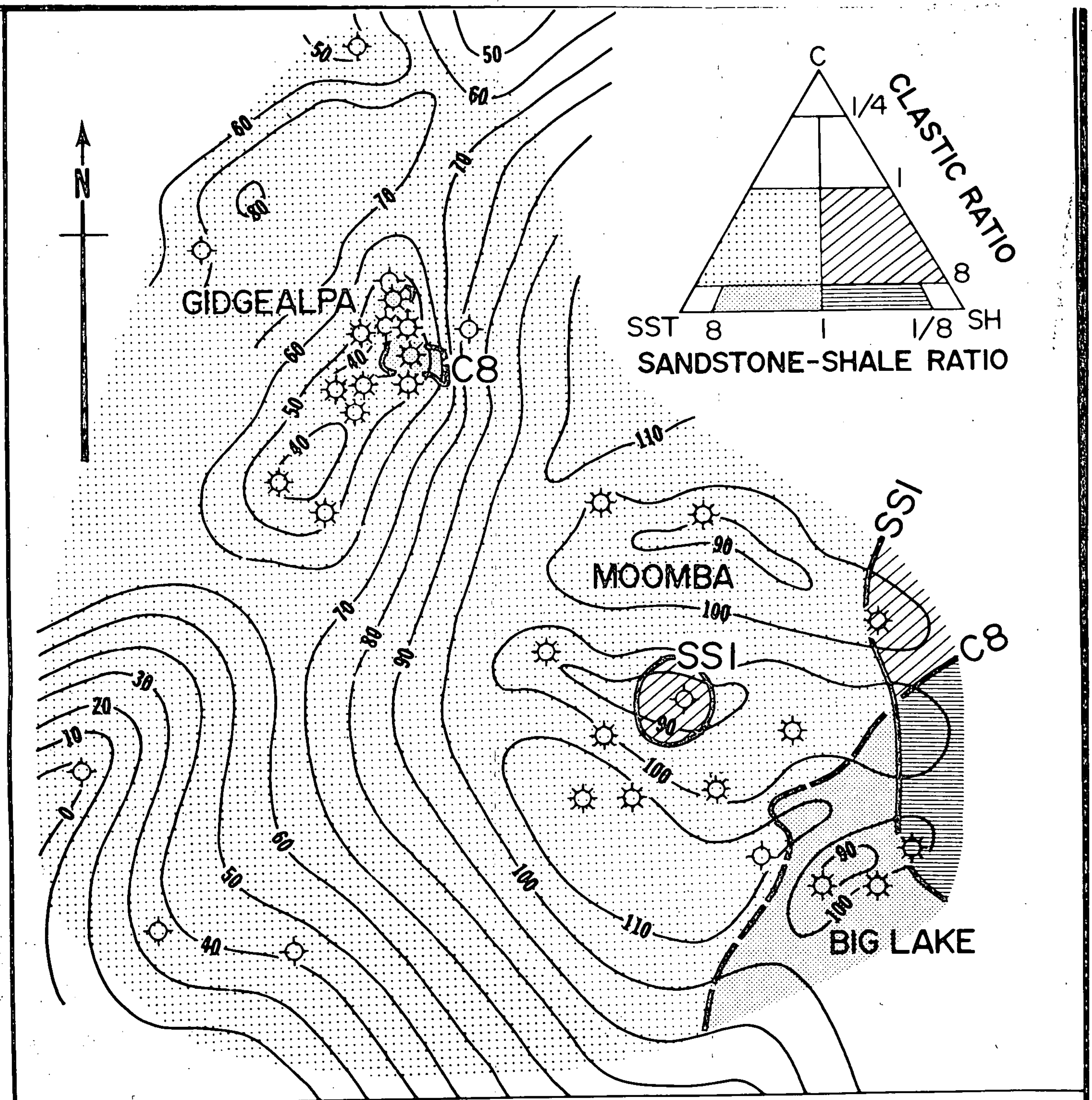

After Delhi International Oil Corp., 1971
0
20
KILOMETRES
Contour interval - 100 metres
140°00'
140°10'
140°20'
27°50'
28°00'
28°10'
28°20'
Coopers Ck. I
Tindilpie I
GIDGEALPA
MOOMBA
BIG LAKE
Spencer I
Wirrarie I
Topwee I
R.C.N. Thornton, 1972
72-558

FIG 3



GIDGEALPA 13
MOOMBA 9
BIG LAKE 1
COAL
SHALE
SANDSTONE
GAMMA RAY
UPPER
MIDDLE
LOWER
PART
PART
PART
6,909′
6,964′
7,000′
7,044′
7,661′
7,700′
7,738′
7,800′
7,895′
7,900′
7,990′
7,526′
7,600′
7,634′
7,700′
7,746′
7,800′
7,841′
METRES
0
20
40
60
80
100
0 100 200
API UNITS
R.C.N. Thornton, 1972
72-643

FIG 4



Sandstone-Shale ratio .... SSI

Clastic ratio C8

Isopach in metres 30

0 20 KILOMETRES

FIG 5

R.C.N. Thornton, 1972

72-559

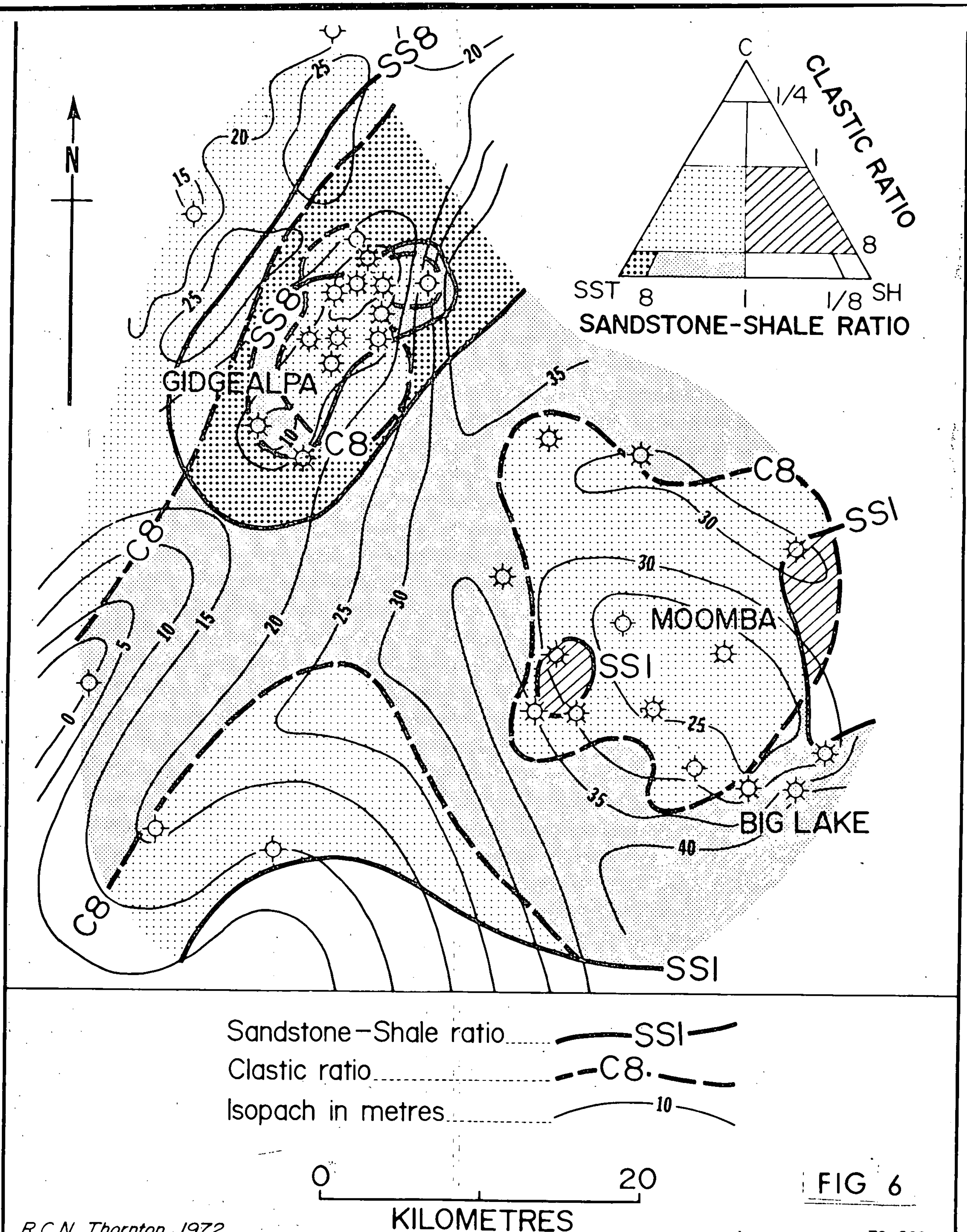
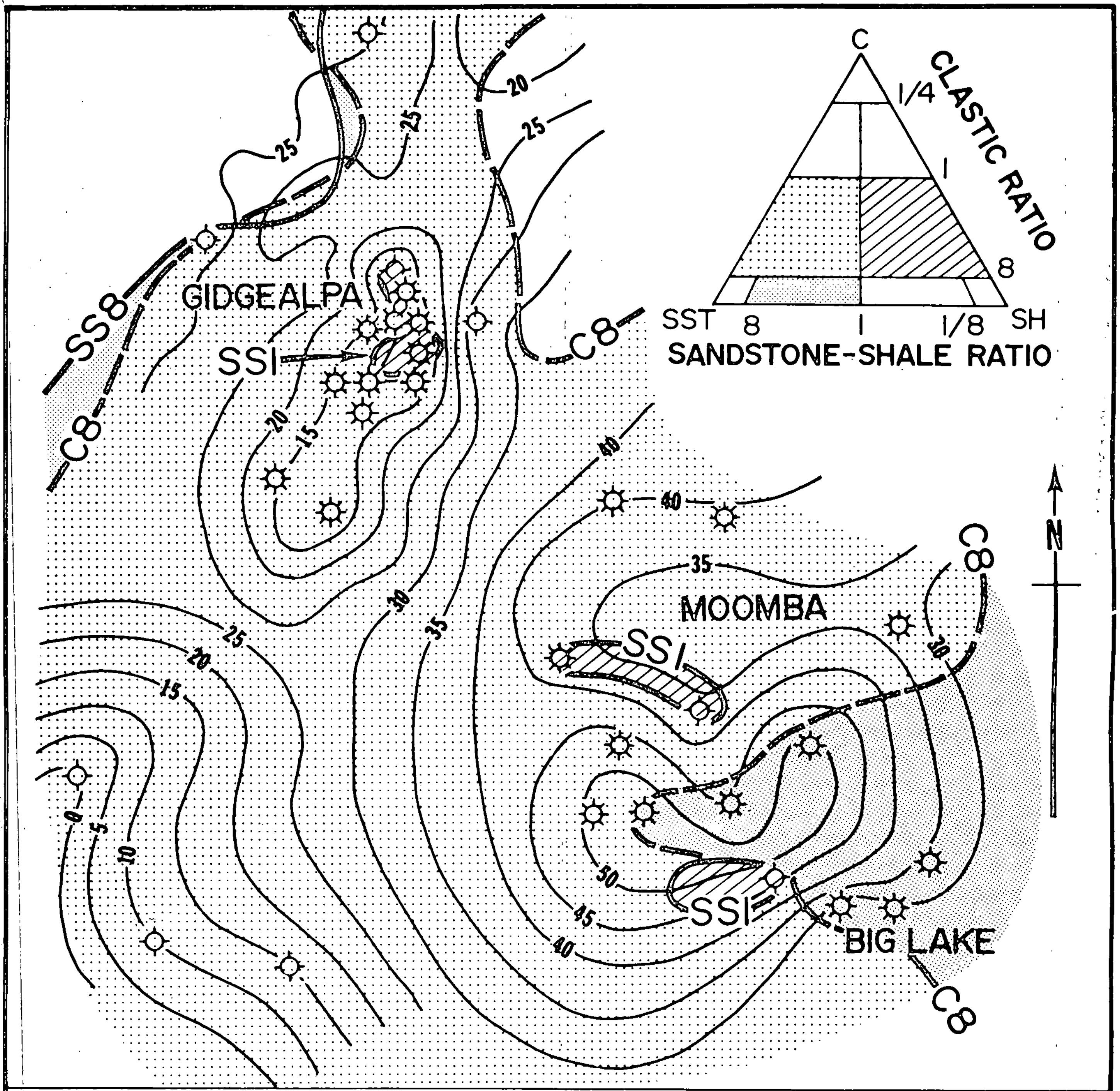


FIG 6

R C N Thornton, 1972

72-560



Sandstone–Shale ratio ..... SSI

Clastic ratio C8

Isopach in metres 40

0 20
KILOMETRES

FIG 7

R.C.N. Thornton, 1972

72–561

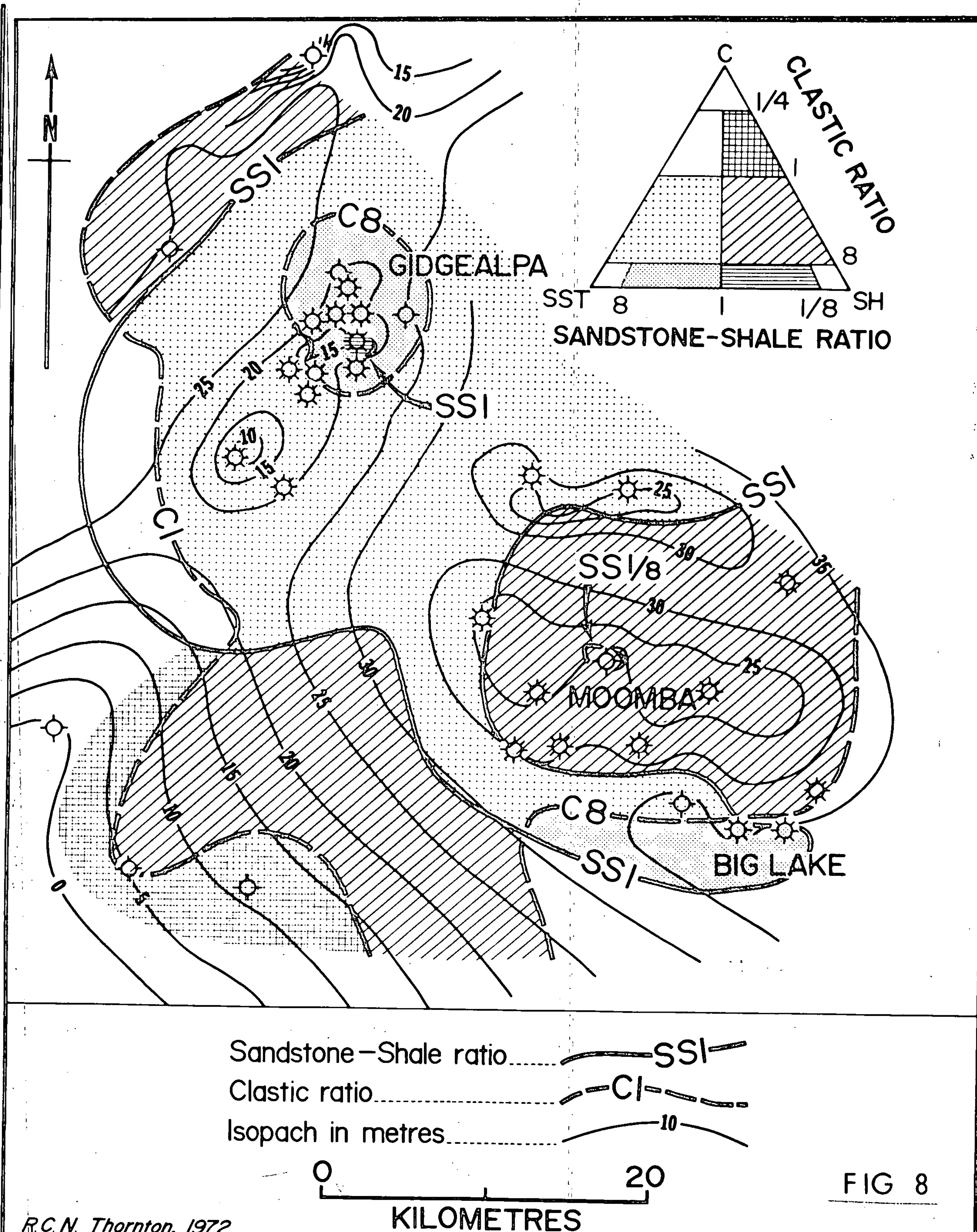


FIG 8

R.C.N. Thornton, 1972

72-562

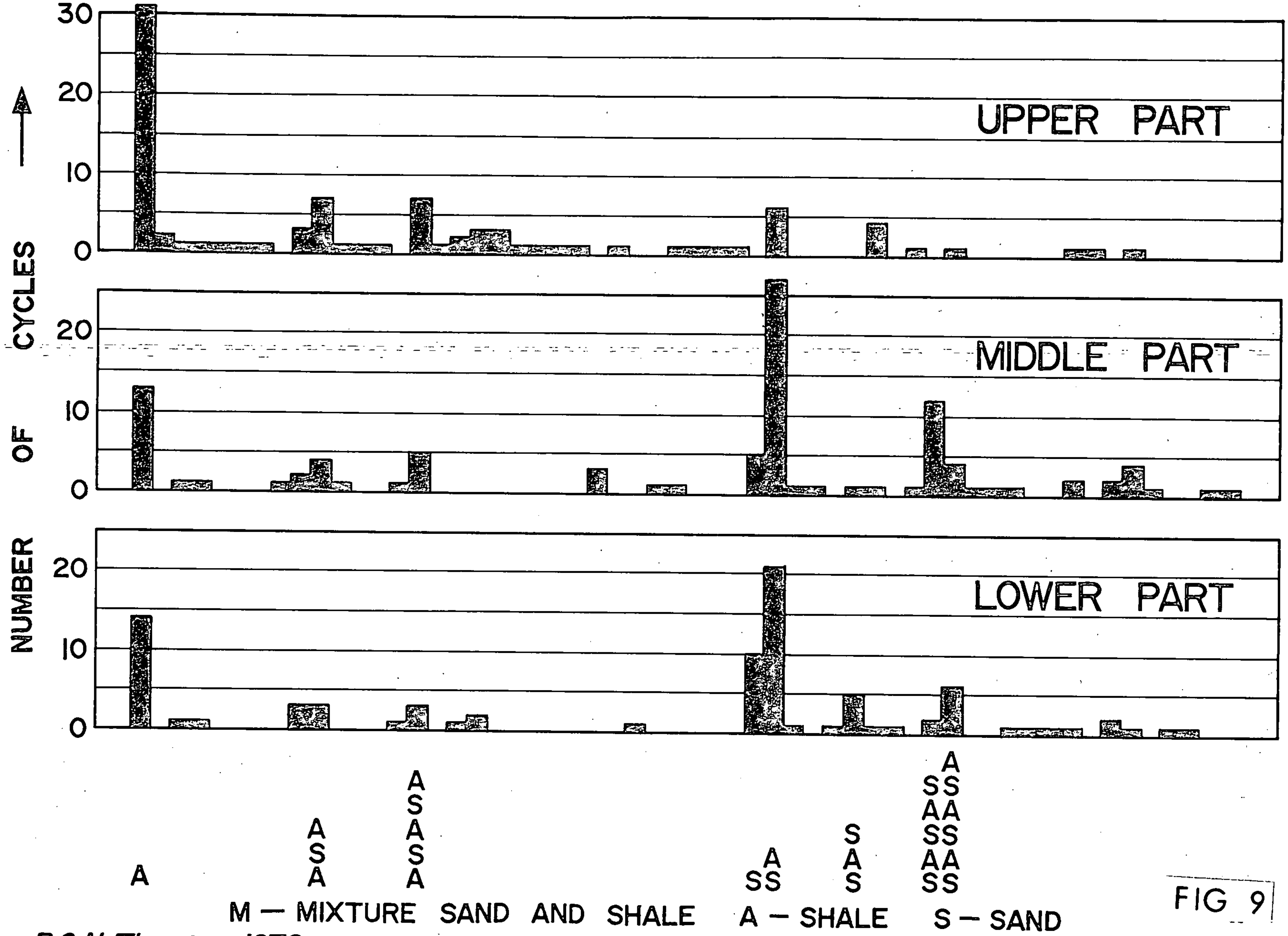


FIG 9

R.C.N. Thornton, 1972

72-642

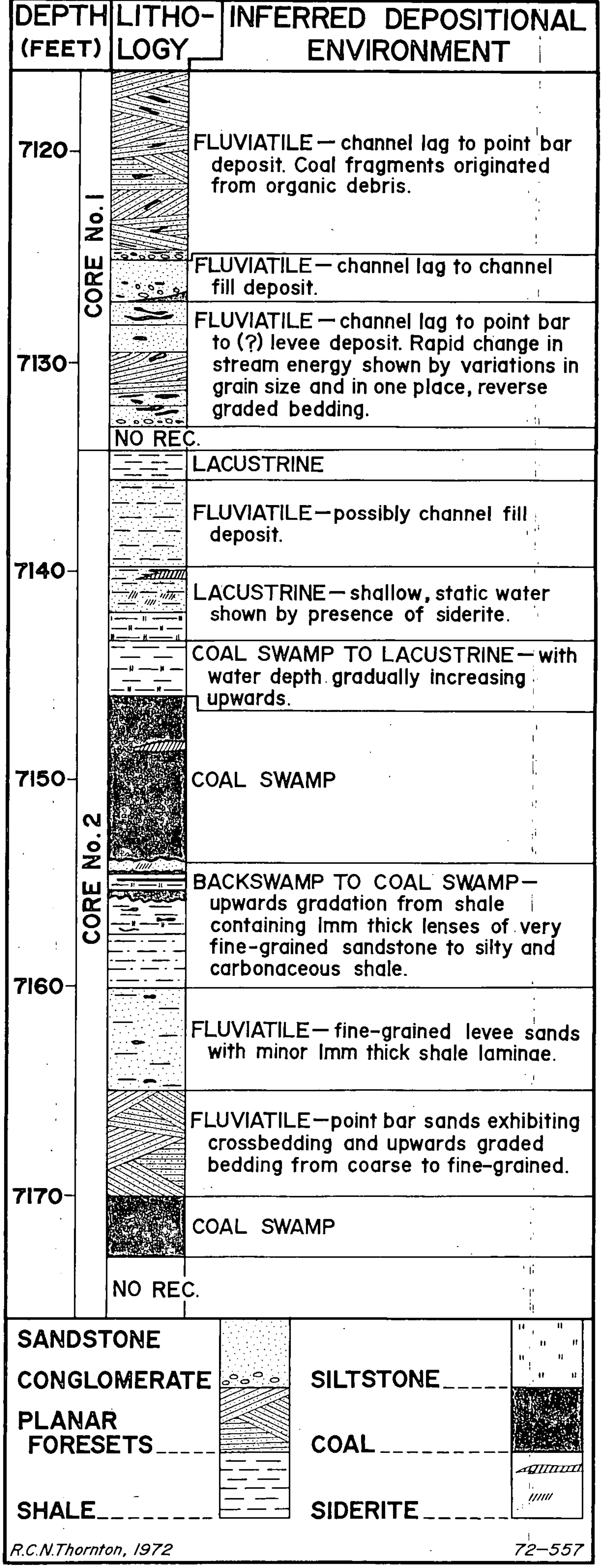

DEPTH (FEET)
LITHOLOGY
INFERRED DEPOSITIONAL ENVIRONMENT
7120
7130
7140
7150
7160
7170
CORE No. 1
CORE No. 2
FLUVIATILE — channel lag to point bar deposit. Coal fragments originated from organic debris.
FLUVIATILE — channel lag to channel fill deposit.
FLUVIATILE — channel lag to point bar to (?) levee deposit. Rapid change in stream energy shown by variations in grain size and in one place, reverse graded bedding.
NO REC.
LACUSTRINE
FLUVIATILE — possibly channel fill deposit.
LACUSTRINE — shallow, static water shown by presence of siderite.
COAL SWAMP TO LACUSTRINE — with water depth gradually increasing upwards.
COAL SWAMP
BACKSWAMP TO COAL SWAMP — upwards gradation from shale containing 1mm thick lenses of very fine-grained sandstone to silty and carbonaceous shale.
FLUVIATILE — fine-grained levee sands with minor 1mm thick shale laminae.
FLUVIATILE — point bar sands exhibiting crossbedding and upwards graded bedding from coarse to fine-grained.
COAL SWAMP
NO REC.
SANDSTONE
CONGLOMERATE
PLANAR FORESETS
SHALE
SILTSTONE
COAL
SIDERITE
R.C.N.Thornton, 1972
72–557

FIG 10

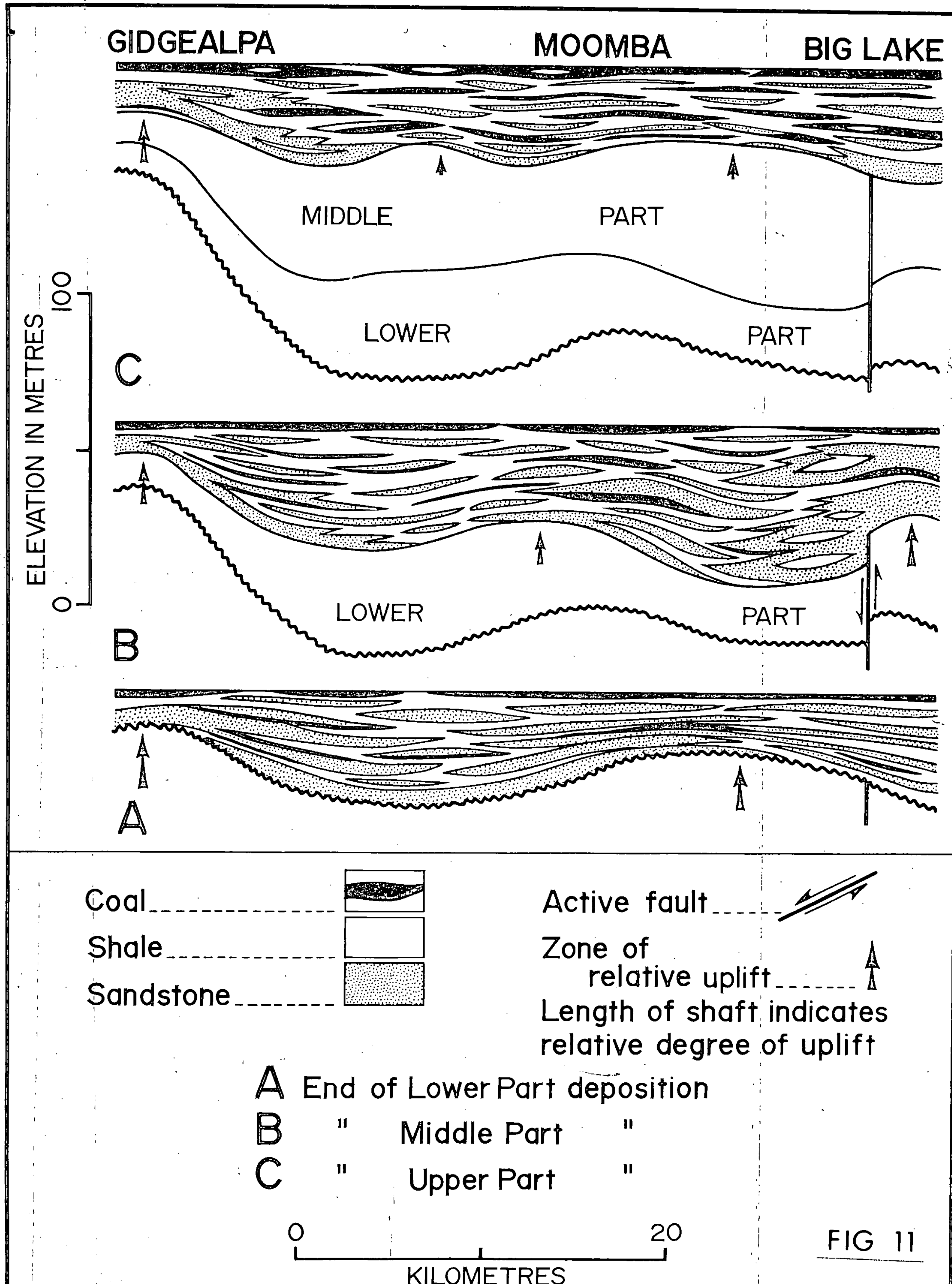


FIG 11

R.C.N. Thornton, 1972

72-644