R/B 67/42

Rept.Bk.No. 67/42
G.S. No. 4070

DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY

PETROLEUM EXPLORATION DIVISION

LOWER CAMBRIAN PALAEOGEOGRAPHY IN RELATION TO OIL SEARCH IN THE FROME EMBAYMENT, SOUTH AUSTRALIA

by

H. WOPFNER
SUPERVISING GEOLOGIST,
PETROLEUM EXPLORATION DIVISION

D.M. 1323/62

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LOWER CAMBRIAN PALAEOGEOGRAPHY IN RELATION TO OIL SEARCH IN THE FROME EMBAYMENT, SOUTH AUSTRALIA+)

by

H. WOPFNER++)

ABSTRACT

Frequent "shows" of hydrocarbons in Cambrian strata in South and Central Australia have considerably strengthened the belief in the petroleum potential of these Cambrian sediments.

In South Australia, prospects for Cambrian hydrocarbon accumulations are thought to exist in the Frome Embayment. This belief is based on the occurrence of thick, basinward dipping Cambrian sediments along the eastern Flinders Ranges, the western margin of the Frome Embayment. Geophysical data indicate 14,000 feet or more of sedimentary basin fill, most of which is considered to consist of Cambrian rocks. The present stratigraphic study, using data from outcrop-sections in the Flinders Ranges, is an attempt to supplement geophysical information by reconstructing Lower Cambrian palaeogeography. Isopach, sand percentage and lithofacies evaluations show a north-east trending, trough-shaped, negative basin in which more than 13,000 feet of Lower Cambrian sediments were accumulated. A shallow, stable carbonate shelf adjoined the negative basin to the west whilst carbonate-sand associations formed on a substable shelf to the east of the negative basin. The main source for the clastic components was the Olary Block, situated to the south-east of the Cambrian basin. Limited intake of fine clastics is also indicated from the Painter Block.

Lower Cambrian Depositional trends are projected basinward and found to corroborate geophysical data in the western portion of the Frome Embayment. Areas of possible sand deposition and biostromal developments are outlined.

+) An abbreviated form of this paper was deliver to Section C at the 40th ANZAAS Congress in Christchurch, N.Z. in January, 1968.

++) Geological Survey of South Australia.

INTRODUCTION

Cambrian oil has not been a very popular exploration target in the past and even when hydrocarbons were found in Cambrian rocks, their presence was generally ascribed to lateral migration from adjacent younger sediments.

Today, however, many petroleum geologists advance the opinion that there is no absolute "age base" for the accumulation of hydrocarbons, providing that the rocks' history allowed the retention of sufficient porosity and permeability, and did not at any time, expose the sediments to temperatures greatly exceeding the cracking temperature of crude oil (Landes, 1967). The correctness of this view has been demonstrated by oil exploration in Central Australia, where the Exoil well Ooraminna No. 1 encountered near-commercial quantities of hydrocarbon gas in the Upper Proterozoic Areyonga Formation (Murray 1965). Radiometric dates obtained from underlying strata indicate an approximate age of the Areyonga Formation of 780 million years.

The first commercial oil field of undisputable Cambrian origin was found in March 1962 on the Lena River, north of Lake Baikal in the Irkutsk Province of Siberia, where the Markovo test well discovered Lower Cambrian pay at 7,100 feet, producing 2,500 to 2,900 barrels of oil per day (Gibson, 1962).

Several years prior to the Russian discovery, Santos Ltd. encountered non-commercial quantities of 26°API crude and paraffin wax residue in a high porous, vugular Lower Cambrian dolomite near Wilkatana in South Australia (Fig. 4). The evidence obtained from the Wilkatana drilling points to a de-roofed oil accumulation of Lower Cambrian age.

Good shows of hydrocarbons also have been encountered, in Cambrian strata in the Coopers Creek Basin, notably in the Delhi-Santos well Gidgealpa No. 1 (Greer, 1965; Wopfner, 1966b). The steep thermal gradient within the central Coopers Creek Basin, however, is thought to prohibit accumulation of anything but gas and condensate. Attention should therefore be directed to areas with less overburden and a less steep thermal gradient. Such an area presents itself in the Frome Embayment which the author regards as an area containing good prospects for Lower Palaeozoic, particularly Cambrian, hydrocarbon production.

The construction of the natural gas pipeline from Gidgealpa-Moomba to Adelaide through the length of the Frome Embayment should further increase incentive for petroleum exploration in this area.

THE FROME EMBAYMENT
(REGIONAL SETTING AND EXPLORATION)

The Frome Embayment is bounded by the Flinders Ranges in the west, the Olary-Broken Hill uplands to the south and the Barrier Ranges to the east. It forms a southern extension of the low-land physiography of the Lake Eyre plains, as well as an embayment of Cretaceous sediments of the Great Artesian Basin (Fig. 1). The Cretaceous sediments attain an average thickness of about 2,000 to 2,500 feet in the northern part of the embayment but they thin out to the south, as indicated by the structural contours of the base of the Cretaceous shown in Figure 1.

Insert Fig. 1

Along the western margin of the Frome Embayment up to 20,000 feet of Lower to Middle Cambrian sediments are frequently observed, dipping basinward beneath the Mesozoic cover of the embayment (Daily, 1956; Dalgarno and Johnson, 1963; Dalgarno, 1964). The eastern margin is largely composed of Precambrian sediments and metamorphics, but some 3,000 feet of folded Middle Cambrian and Lower Ordovician sediments are exposed near Mt. Arrowsmith, on the embayments north-eastern margin (Wopfner, 1966a). The southern margin of the embayment consists largely of crystalline basement, commonly referred to as Olary-Broken Hill Block or Wylliama Block. Granites and related igneous rocks of the Mt. Painter Block form the northeasternmost boundary (Fig. 1).

On the basis of lithological similarities between the Middle Cambrian sediments at Mt. Arrowsmith and sediments of comparable age in the eastern Flinders Ranges, the author suggested that Cambrian sedimentation extended uninterrupted across the major portion of the Frome Embayment (Wopfner, 1966a). This assumption is supported by tentative identification of Middle Cambrian sediments in Cootabarlow No. 2 and of Lower Cambrian limestone in Frome Downs No. 3 (Ker 1966). The locations of these wells are shown in Figure 1.

Furthermore, aeromagnetic and gravity surveys, carried out respectively by the Geological Survey of South Australia and by the Delhi-Santos Group, also indicate a thick sedimentary basin fill, in places exceeding 14,000 feet (Fig. 9).

About 350 line miles of continuous reflection seismograph survey have been carried out in the Frome Embayment by the Geological Survey of South Australia since 1962 and an additional 107 miles of continuous reflection lines were shot by United Geophysical Co. on behalf of the Delhi-Santos Group. Although a deep high speed reflector, thought to originate from the Lower Cambrian Wilkawillina Limestone is recognised in the southwestern and eastern portion of the embayment, the horizon cannot be traced continuously and neither has its identity been confirmed by drilling. Thus correlation with high speed reflectors in other parts of the embayment is difficult and uncertain.

In order to supplement geophysical data and to obtain a better understanding of trends and processes controlling Cambrian sedimentation, stratigraphic studies of Cambrian outcrop-sections were commenced by the Petroleum Geology Section of the Geological Survey of South Australia. The present paper is the result of one of these studies, dealing primarily with

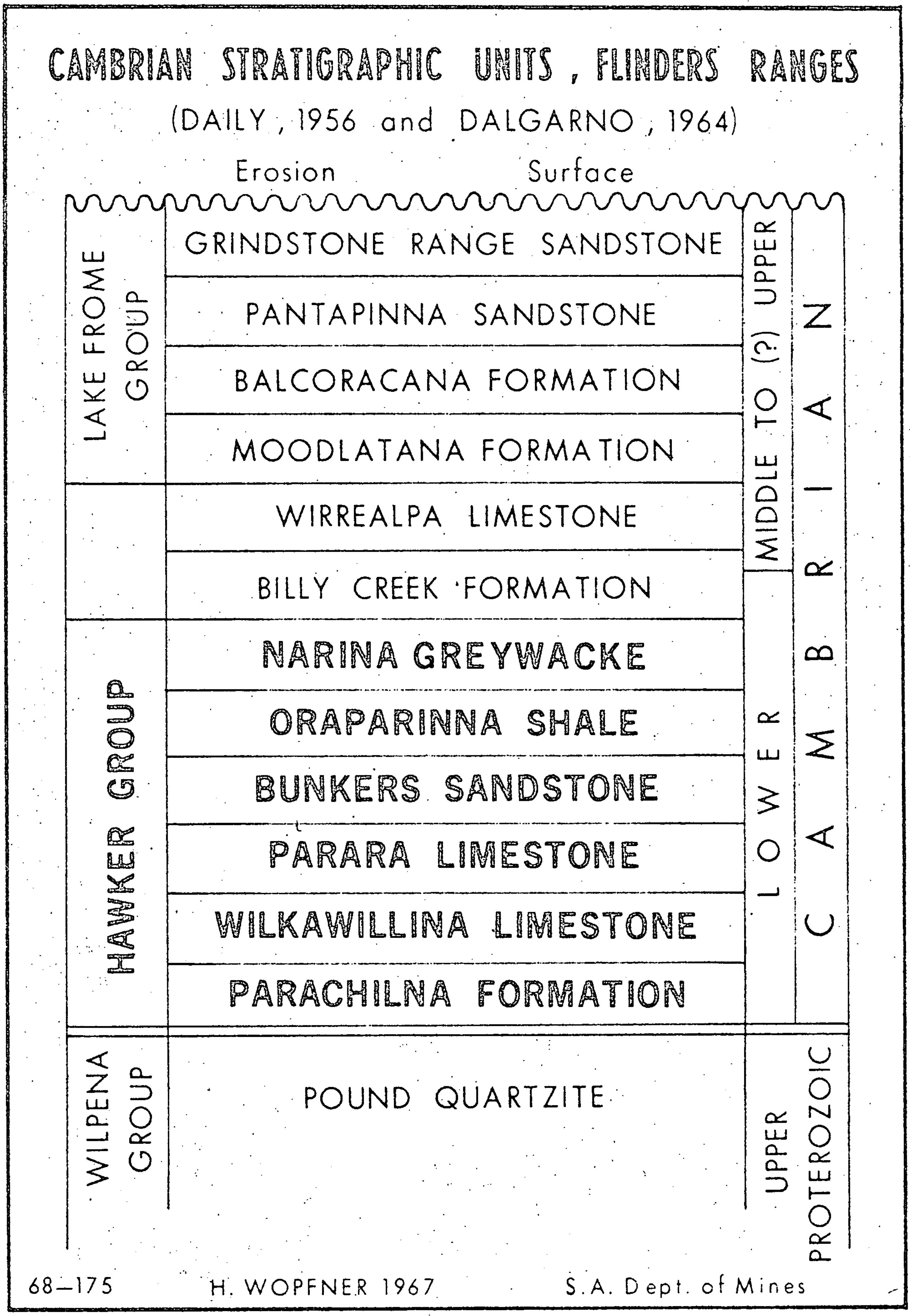
CAMBRIAN STRATIGRAPHIC UNITS, FLINDERS RANGES
(DAILY, 1956 and DALGARNO, 1964)
Erosion Surface
GRINDSTONE RANGE SANDSTONE
PANTAPINNA SANDSTONE
BALCORACANA FORMATION
MOODLATANA FORMATION
WIRREALPA LIMESTONE
BILLY CREEK FORMATION
NARINA GREYWACKE
ORAPARINNA SHALE
BUNKERS SANDSTONE
PARARA LIMESTONE
WILKAWILLINA LIMESTONE
PARACHILNA FORMATION
POUND QUARTZITE
LAKE FROME GROUP
HAWKER GROUP
WILPENA GROUP
MIDDLE TO (?) UPPER
LOWER
CAMBRIAN
UPPER PROTEROZOIC
68–175
H. WOPFNER 1967
S.A. Dept. of Mines

Fig. 2

the Lower Cambrian HAWKER GROUP.

STRATIGRAPHY

The Cambrian sediments of the Flinders Ranges represent the last depositional event in the "Adelaide Geosyncline" prior to the final orogenic deformation of this mobile trough. Cambrian deposition was preceded by a regressive period at the end of the late Precambrian. This regression led to exposure of the western, stable shelf of the Adelaide Geosyncline, termed the Stuart Stable Shelf by Sprigg (1952) (Coats, 1965a), and to deposition of shallow water sediments within the geosynclinal area itself. At the onset of Cambrian time the sea transgressed the Stuart Shelf again, whilst the basin floor of the mobile trough was gradually, but persistently, depressed by negative movements throughout early Cambrian time. Thus, the Lower Cambrian sequence of the Flinders Ranges is characterized by generally dark coloured shales and carbonates. Stabilisation of the negative movements towards Middle Cambrian time led to shallowing of the Cambrian basin and to a mildly evaporitic "red - bed" environment. A short-lived period of carbonate sedimentation was experienced in the Middle Cambrian and is manifested by the Wirrealpa Limestone. Reversion to a "red-bed" environment, but with high intake-rates of clastic material under medium to high energy levels characterised most of the deposition of the Middle to Late Cambrian Lake Frome Group. The Cambrian stratigraphy of the Flinders Ranges has been described by Daily (1956) and by Dalgarno (1964), and the stratigraphic units recognised by these authors are shown on the stratigraphic table, Figure 2.

Insert Fig. 2

The Lower Cambrian Hawker Group is the product of the transgressive - mobile phase of the Cambrian depositional history and is thus characterised by frequent change in thickness and facies, circumstances which make this stratigraphic interval a particularly suitable subject for lithofacies studies. The Hawker Group comprises, in ascending order, Parachilna Formation, Wilkawillina Limestone, Parara Limestone, Bunkers Sandstone, Oraparinna Shale and Narina Greywacke (Fig. 2). However, as some of these formations are interchangeable facies equivalents, they are almost never found together in one single section.

In the Flinders Ranges the Hawker Group rests conformably or disconformably on the late Precambrian Pound Quartzite. However, to the west of the Adelaide Geosyncline proper, as for instance at Yarrawurta Cliff, (Fig. 4) the basal Cambrian overlies slightly older, late Precambrian sediments, demonstrating the transgressive nature of the Cambrian sediments. (Fig.8)

The basal unit of the Hawker Group, the PARACHILNA FORMATION, represents a shallow water, transgressive facies. It consists predominantly of fine to coarse grained, current bedded sandstones, often feldspathic, with intercalations of thinly interbedded siltstones and shales. Thin carbonate bands may be interspersed towards the top of this unit. The sandstones are characterised by an abundance of worm tubes penetrating the sediment normal to the bedding plane and sometimes even burrowing into the underlying Pound Quartzite. Rhizocorallium-type burrows also occur sometimes in the sediments of this interval.

The WILKAWILLINA LIMESTONE, in its typical development is a massive or thickly bedded biostromal limestone with abundant Archaeocyatha and phosphatic brachiopods. (Fig. 3a). In the type area at Billy Creek and along the western margin of the Flinders Ranges its thickness varies between 300 and 1,000 feet. Towards the centre of the area of deposition the Wilkawillina Limestone is often absent or severely reduced in thickness.

Similar reductio[illegible]

as for instance at Angepena (Fig. 3c) where the total thickness of true Wilkawillina facies is reduced to a mere 40 feet. Interfingering of the Wilkawillina Limestone with the Parara Facies occurs along the eastern outcrop-area, whilst inter-tonguing of Wilkawillina Limestone and Oraparinna Shale is prominently displayed in the type area at Billy Creek (Dalgarno and Johnson, 1965).

Along the western margin of the Flinders Ranges (Brachina to Parachilna Gorge) the Wilkawillina Limestone is very pure, consisting of up to 98% $CaCo_3$. To the west of Flinders Ranges the limestone becomes progressively more dolomitic and cherty. At Yarrawurta Cliff, where the equivalent of the Wilkawillina Limestone is referred to as Andamooka Limestone (Johns, 1968) cherty dolomites and algal limestones are very prevalent (Fig. 3b).

Along the eastern Flinders Ranges and adjacent to the Frome Embayment, portions of the Wilkawillina Limestone are frequently bituminous, giving off a penetrating odour when scratched or broken. A sample from the vicinity of Wirrealpa (5 miles east-southeast of Point Well; Fig. 4) was analysed by the Australian Mineral Development Laboratories in Adelaide, who reported on it as follows:

"Some broken portions of the limestone were ground in a closed container and the gaseous hydrocarbons which were liberated by the grinding were determined by gas chromatography of samples of air taken from the sealed grinding vessel. The results shown below are expressed in ppm by weight of the original specimen:

Methane	CH_4	10.0 p.p.m.
Ethane	C_2H_6	3.8
Propane	C_3H_8	4.0
iso-Butane	C_4H_{10}	1.4
n-Butane	C_4H_{10}	3.2
iso-Pentane	C_5H_{12}	2.1
n-Pentane	C_5H_{12}	2.8
iso-Hexane	C_6H_{14}	1.2

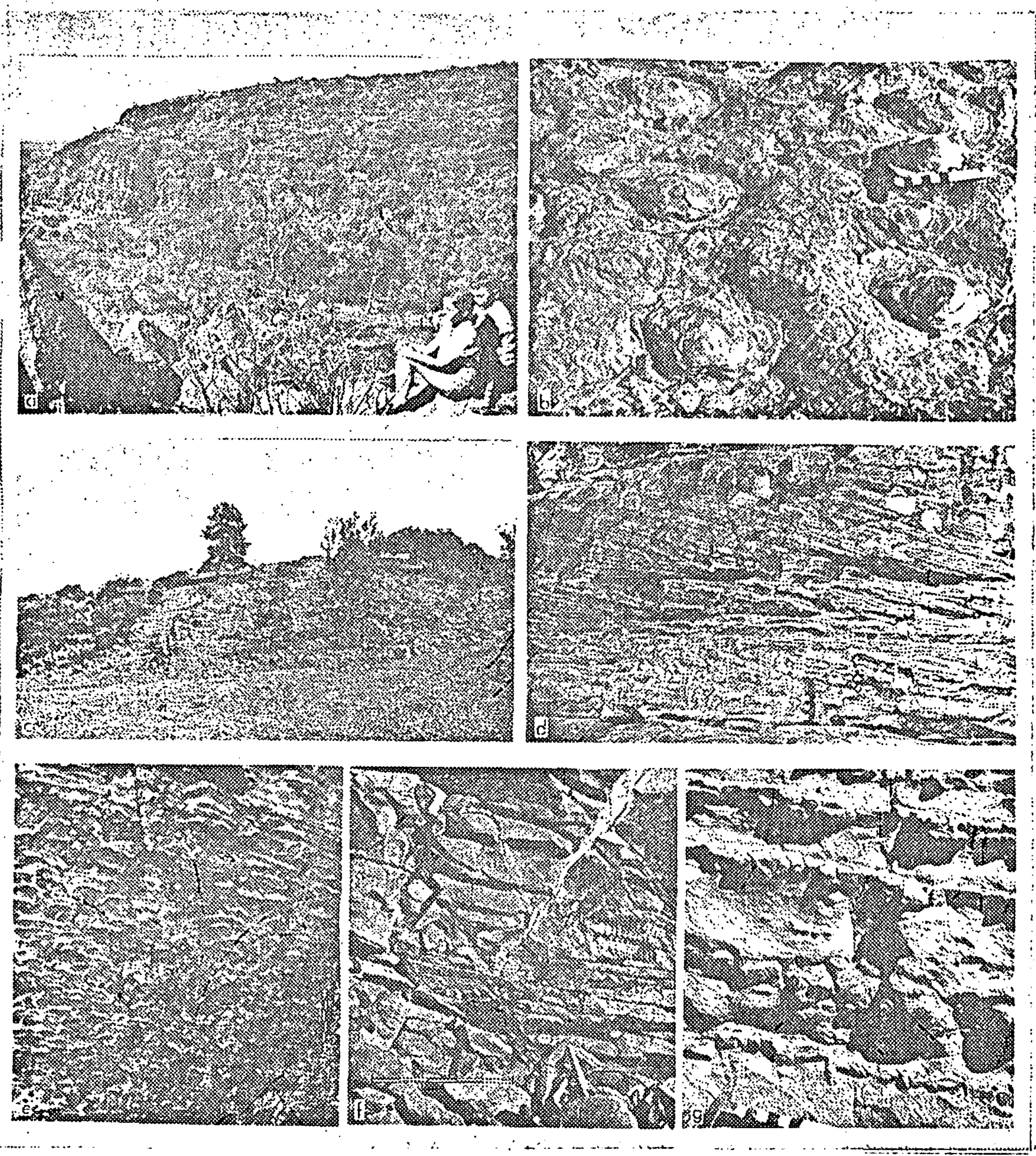

Fig. 3 Lower Cambrian sediments (Hawker Group) of Flinders Ranges. 3a; thickly bedded to massive Wilkawillina Limestone at Moro Gorge, south-west of Wertaloona Homestead; - eastern hinge - zone.
3b; cone-shaped algal bisquitesin Andamooka Limestone, Yarrawurta Cliff; - Stuart stable shelf.
3c; thin bands of Wilkawillina Limestone interbedded with shaley Parara facies (poor outcrops) at Angepena. Picture showsabout same stratigraphic interval as shown in 3a.
3d; angular current beds in Bunkers Sandstone, Billy Creek section,
3e; typical Parara Limestone, Angepena section. Shale - portions show up by light weathering colours.
3f; Oraparinna Shale with large, paradoxide trilobite, Billy Creek section.
3g; dark silty shale with bands of nodular limestones, an intermediate facies between 3f and g, atdDonkey Water section.

All scales are in inches (author's photographs)

A portion of the ground material was dissolved in acid and the liquid - and solid hydrocarbons which were liberated by solution were extracted by solvents. The solvent extract consisted of a cream, semi-solid, unsaponifiable hydrocarbon of the consistency of grease, completely liquified by slight warming. The yield of semi-solid hydrocarbons of the sample was 0.09%."

Small amounts of dark, semi-solid hydrocarbons and 26°API crude were also recovered from a vugular, dolomitic facies of the Wilkawillina Limestone in the Santos Well Wilkatana No. 1 (Fig. 4).

Contrasting with the massive Wilkawillina Limestone is the facies of the PARARA LIMESTONE which consists of dark grey, microcrystalline carbonate nodules about 3 - 7 cm in diameter, which are embedded in black, calcareous shale (Fig. 3e). Bands of dark green to black, calcareous, micromicaceous shales are occasionally interbedded. The Parara Limestone is the dominant facies in the central portion of the Cambrian basin where this unit reaches several thousand feet in thickness. Laterally, this facies may change into a predominant shale sequence with occasional carbonate nodules as for instance in the Angepena Section (Figs. 3c and 3g).

Insert Fig. 3

The BUNKERS SANDSTONE is restricted to the eastern margin of the Flinders Ranges. The unit consists of white, medium grained, generally well sorted quartz sandstone, which reaches a thickness of 600 feet in the type area (Daily, 1956). The sandstone is generally concavely current bedded with tangential toe-sets but angular current bedding is also common (Fig. 3d). Mostly the sandstone is cemented by a siliceous matrix but intermittent intervals show fair to good porosity. To the northeast of the type area, as for instance at Mt. Frome, the equivalent of the Bunkers Sandstone becomes calcareous and pebbly. Dalgarno (1964) describes intertongueing of the Bunkers Sandstone with both Parara Limestone and Oraparinna Shale.

The ORAPARINNA SHALE is a dark olive green, firm to splintery shale, sometimes silty and micromicaceous, and generally thinly bedded. In some localities the formation contains a varied trilobite fauna and some brachiopods (Fig. 3f). At the top of this unit there is a thinly laminated dolomite which Dalgarno (1964) includes in the overlying Billy Creek Formation. Sedimentologically this dolomite appears to be much closer related to the Oraparinna Shale and for the purpose of the present paper this unit was included in the Hawker Group. Towards the centre of the Cambrian basin (Donkey Waters, Nepabunna), the Oraparinna Shale changes into Parara-type facies by gradual increased participation of limestone nodules (see above and Figs. 3e to g). Interfingering of the Oraparinna Shale with the Narina Greywacke is reported by Dalgarno (1964).

The NARINA GREYWACKE occurs mainly in the central basin area, where it reaches a thickness in excess of 4,500 feet (Horwitz, 1962). The formation consists of grey siltstones and sandy greywacke with interbedded dolomites. There is no top to this unit and it is not known whether this formation was never deposited along the eastern margin of the basin or if it was eroded prior to the deposition of the Billy Creek Formation.

The sediments of the Hawker Group are overlain, either conformably or with erosional disconformity, by the upper Lower to lower Middle Cambrian Billy Creek Formation (Fig. 2).

Insert Fig. 4

LITHOFACIES

The present day distribution of Cambrian sediments in the Flinders Ranges is largely controlled by local structural configuration. Cambrian outcrops are situated on the flanks of the large anticlinal arch which forms the central Flinders Ranges or in local synclines. The fold axes of these synclines are generally north-south in the southern portion of the study area, changing to east-west trends in the northern portion, (Fig. 4). These latter latitudinal trends may possibly be ascribed to rotational movements of the Painter Block. Orogenic movements which caused the final deformation of the Adelaide Geosyncline commenced in late Cambrian time and appear to have been terminated by about the middle of the Ordovician (Thomson, 1965).

The folding of the Cambrian sediments undoubtedly will have resulted in some foreshortening. In the areas of meridionally trending fold axes this aspect was checked by constructing natural scale cross sections, and it was found that foreshortening in this area amounted to 2 to 2.5 miles. As the surface extension of most sections is equal to or greater than the amount of foreshortening, it is considered that the actual section positions are adequate to result in a representative picture. In the northern area, where rotational movements are suspected to have taken place, insufficient data are available to attempt a meaningful reconstruction of fold movements. Thus no corrections have been applied to the locations of sections in this area either, but distortions of contour lines thought to have been caused by these rotational movements are discussed wherever applicable. No significant changes of stratigraphic thickness caused by the deformation of the strata were detected.

The study presented in this paper is based on the evaluation of 22 measured surface sections of the Hawker Group. Section locations are identified on Figs. 4 and 5. Most of the sections evaluated represent the complete Hawker Group interval with reliable upper and lower stratigraphic boundaries. The only exceptions are a few sections in the central basin area where there is no top to the Narina Greywacke as for instance Donkey Water, Point Well, Nepabunna and Angepena.

The thickness distribution of the Hawker Group is shown by the isopach map, Fig. 5. Thicknesses shown represent the total stratigraphic interval from the base of the Parachilna Formation to the base of the Billy Creek Formation. The main features of this map are the rapid increase in thickness in the region of Donkey Water, the steep gradient on the southeastern flank of this trough, and widely spaced isopachs along the western part of the study area. The bunching of the contours in the northeastern portion of the area is almost certainly a post depositional feature, caused by late Cambrian - early Ordovician movements of the Painter Block. With the exception of this small portion, however, the author is confident that the isopachs approximate representative depositional trends.

Insert Fig. 5

Figure 6 shows the areal distribution of sand-size material within the Hawker Group. Sand-participation expressed in per cents of total section thickness shows a significant increase from west to east with a maximum of 18% in the southeastern portion of the study area, indicating an active source of terrigenous material to the southeast of the Flinders Ranges.

The facies variations of the Hawker Group are demonstrated by the three-component litho-facies map in Figure 7. As shown by the standard triangle in the lower right of figure 7, four facies associations are discernible. The belt west of the clastic ratio of $\frac{1}{4}$ is dominated by carbonate deposition. The area of maximum sedimentary thickness is characterised by a carbonate-shale association, whilst the eastern-most portion of the study area consists of carbonates with sand. An area of dominant shale deposition, identified by clastic ratios greater than 1 exists in the north of the study area.

Insert Figs. 6 and 7

From the data presented in the foregoing maps, the following palaeogeographic and environmental outlines are deduced: The belt west of the clastic ratio of $\frac{1}{4}$ is interpreted as an extensive stable shelf adjoining a low relief land mass which contributed very little clastic material. Cherty limestones, dolomites and algal limestones were the dominant rock types deposited along this shelf (Stuart Stable Shelf; Sprigg, 1952). The position of the shoreline during the Lower Cambrian therefore would have been located well to the west of Yarrawurta Cliff, the westernmost known outcrop of Hawker Group sediments. Maximum deposition of clean, biostromal Wilkawillina Limestone occurred along a hinge line, situated between the western stable shelf and the central basin area. The position of this hinge line is approximated by the $\frac{1}{4}$ clastic ratio line. An unstable, negative basin area with maximum sediment accumulation is indicated between the $\frac{1}{4}$ clastic ratio line and the sand/shale ratio line of 1. Spreading of the basin-width during the period of maximum downwarp in the central basin led to overlap of the Parara Limestone facies across the Wilkawillina Limestone deposited along the original hinge-zone. (Fig. 8).

The increasing sand content to the east of the sand/shale ratio 1 shows the proximity of a land mass to the south-east which was actively eroded and shed terrigenous material into the Lower Cambrian basin. This prediction is also strikingly demonstrated by the rapid westward decrease of sand-percentages shown in figure 6. Sand was deposited along the eastern shelf whilst the fine clastics were carried into the central basin. The most likely area which could have supplied the terrigenous material into the Cambrian basin is the Olary-Broken Hill Block (Figs. 1 and 9). This ancient, crystalline mass appears to have been a positive area during Cambrian time which shed its erosional debris into the Cambrian basins of the Flinders Ranges, but probably also southward, into the Cambrian Kanmantoo Trough. In this connection it may be of interest, that directional features in the Middle Cambrian sediments at Mt. Arrowsmith, also indicate a clastic source area to the south, i.e. in the direction of the Olary-Broken Hill Block, (Wopfner, 1966a).

The developments of Wilkawillina Limestone along the eastern margin of the Flinders Ranges, often quite sandy, bituminous and with occasional chert stringers, would have been formed along the hinge-zone between the negative basin and the eastern shelf. This hinge-zone would have been situated slightly east from the present eastern margin of the Flinders Ranges.

The small area of clastic ratios greater than 1 in the central northern part of the study area (Fig. 7) may reflect a salient of the Painter Block which supplied fine clastic material. This interpretation appears to be borne out by the presence of well-rounded mineral grains of apparent Mt. Painter provenance in the basal Cambrian sequence near Donkey Water (pers. com. C. Brooks, Kennecott Exploration (Aust.) Pty. Ltd.).

However, the dominant shale facies with minor, fine-grained sand-stringers of the Angepena area could also be interpreted as a distal basin area, in which case the influence of the Painter Block as an active source area would have been restricted to the basal Cambrian only. As sections in this area are incomplete, the answer to this question remains problematic.

Dalgarno (1964) has emphasised the influence of Precambrian diapiric structures on Lower Cambrian deposition. These structures which are a common feature of the Flinders Ranges (Coats, 1965b), certainly contributed clastic material during the early stages of Lower Cambrian sedimentation, as demonstrated by the course, often angular clastics incorporated into the basal Wilkawillina Limestone in the vicinity of diapiric structures; apparently these structures were still exposed to erosion during the early stages of the Lower Cambrian transgression, but became rapidly submerged as the foundation of the Cambrian basin progressed.

However, there is no evidence, that they had any prolonged or profound influence on the pattern of Lower Cambrian deposition.

The lithofacies study of the Hawker Group strongly supports the existence of a central, negative basin, or perhaps chain of basins, bounded by a stable western shelf and a sub-stable shelf to the east. Major intake of clastic material was from the southeast (Olary Block) and not, as previously thought, from the west. The configuration of the Lower Cambrian basin and the hypothetical facies distribution within it are illustrated by the schematic, latitudinal cross-section in figure 8. The concept of a bi-lateral shelf development, predicted from the results of this study, would, for the Cambrian part, contradict the theory of "unilateral outgrowth from the West Australian shield" and the existence of a continental terrace, as envisaged by Sprigg (1952).

Insert Fig. 8

Insert Fig. 9

CONCLUSIONS

In terms of Lower Cambrian petroleum prospects in the Frome Embayment the results of this study show that the most promising area is located along the southern and western portion of Lake Frome, where both sandstone reservoirs and "reef type" carbonate reservoirs may be expected in depth.

Although this hypothesis has yet to be proven or disproven by the drill, geophysical evidence in these parts of the Frome Embayment supports the predictions derived from this stratigraphic study. On Figure 9 isopachs of the Hawker Group in the Flinders Ranges have been combined with a Bouguer-gravity map of the Frome Embayment. In the western part of the Frome Embayment, the gravity contours show a subsurface continuation of the Lower Cambrian depositional trend, although apparently offset along the marginal fault system which separates the Flinders Ranges from the Frome Embayment. This would imply right hand strike slip displacement of the original Cambrian basin. However, the possibility of an original en echelon arrangement of several negative basins in early Cambrian time may also have to be considered.

Other thick sedimentary sequences are indicated to the southwest of Lake Frome, immediately to the east of the basinward dipping Cambrian sequence at Mt. Frome, and along the eastern shore of Lake Frome, between Frome Downs No. 3 and Cootabarlow No. 2 wells.

The gravity results presented on Fig. 9 are corroberated by aeromagnetic surveys and by seismic reflection data. In the area south and southwest of Lake Frome for instance, a thick, gently west-sloping sedimentary section has been outlined seismically, whilst a north-dipping section is indicated along the eastern shore of the lake.

In summary, the following points are emphasized:

(1) The widespread occurrence of hydrocarbons in Cambrian rocks of the Adelaide Geosyncline clearly demonstrates the presence of source rocks within the Lower Cambrian sequence of the Hawker Group.

(2) Potential reservoir rocks are present in the sandy intervals and increased sand/shale ratios may be expected in the southern portion of the Frome Embayment. In addition zones of secondary porosity can be expected within biostromal carbonate developments.

(3) Geophysical evidence indicates only gentle folding with some faulting of the pre-Mesozoic sediments of the Frome Embayment.

All these features add up to an attractive area for petroleum exploration whose value is enhanced further by the fact, that the pipeline from the Gidgealpa-Moomba gasfields

(Wopfner, 1966b; Martin 1967) will traverse the entire western portion of the Frome Embayment.

ACKNOWLEDGEMENTS

The author wishes to thank the Director of the South Australian Department of Mines for his permission to publish the results of this study.

Sincere appreciation is also recorded for the assistance given by Messrs. G.W. Krieg and J.D. Campbell, who, during the early stages of the project, measured several sections in the field and prepared preliminary isopach plans and cross-sections.

Additional sections were measured by the author but extensive use was made also of sections measured by the French Petroleum Company (Aust.) Pty. Ltd.

The permission of Delhi Australian Petroleum Ltd. to reproduce the Bouguer gravity map of the Frome Embayment in this paper is gratefully acknowledged.

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HW:CC
27.8.1968

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Fig. 1 Generalized geological map of Frome Embayment and structural contours of the base of the Cretaceous below sea level. Stratigraphic sections encountered in oil exploration and water wells are identified by letter symbols. (M= Mesozoic; P= Permian; O= Ordovician; C= Cambrian, P= Precambrian).