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By HARE & ASSOC

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BONAPARTE GULF BASIN
 OIL PERMIT NO. 3, NORTHERN TERRITORY
 INTERPRETATION OF GEOSEISMIC SURVEY, 1960
 BY: E.P. UTTING, B.Sc.
auvergne

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BONAPARTE GULF BASIN.

INTERPRETATION OF GEOSEISMIC SURVEY, 1960.

GENERAL SUMMARY.

The interpretation of the results of this seismic project presented many difficulties owing to the lack of reasonably continuous reflecting horizons, particularly in the most critical zone to the south of Spirit Hill.

Assumptions made by Geoseismic in producing an horizon suitable for contouring led to an erroneous picture which is discussed in the text herewith.

A similar degree of assumption has had to be applied by the writer in the present re-interpretation, but the assumptions have been controlled by the known surface geology. In view of the lack of readable unconformities in most sections, the methods of control used, although approximate, are considered valid.

The controlling horizon has been extended across the central faults of Spirit Hill by geological interpretation.

The structural and stratigraphic picture presented indicates that the prospects of sealed closure are not strong. Structural closure of the Spirit Hill Anticline occurs within a faulted zone two miles south of Spirit Hill, but this is at an horizon lower than the main shale beds and the strata involved are porous sandstones. The "semi-closure" indicated by Geoseismic either opens out to east in conformity with the basic structure, or to the east and, unless trapped in a suitable fault environment, thence south up the pitch of the Spirit Hill Anticline into the porous sandstones indicated.

Because of the lack of known sealed closure, and also for reasons of correlation, considerable attention has been given to the possibility of facies changes in the beds that underlie Spirit Hill Limestone, and to which the name Nigli Gap Sandstone has been re-applied.

There is quite a degree of possibility that these beds, together with the Spirit Hill Limestone into which they grade, are the equivalents of the Cockatoo Sandstone - Burt Range sequence of the western flank of the Burt Range Basin. If this is the case, the basinward equivalents of Nigli Gap Sandstone will merge into strata containing an increasing proportion of calcareous or dolomitic beds together with siltstone or shale, and the possibilities of fault or other traps below Spirit Hill Limestone will be increased. The type of facies change envisaged is already strongly indicated in the lower half of Spirit Hill No. 1 bore.

Amongst the recommendations made, two sites, "A" and "B", have been suggested for consideration as stratigraphic bores and, of these, site "A" is preferred.

A study of the seismic traverses to the north of Spirit Hill has been carried out but, as no defined closures are indicated in them, a detailed re-interpretation has not been made. Interesting features are the indication of a "nose" on the Pincombe buried ridge, the swing of the main basin axis to a north-east direction consistent with the gravity results, and the tendency for a "high" in the most north-eastern portion of the traverses.

NORTHERN TERRITORY
GEOLOGICAL SURVEY
Rebo/7

PLANS, DATA USED, REFERENCES

The following plans are presented:

- Plate 1. Burt Range Basin, Composite Plan, Scale 1 inch = 1 mile.
Copy of Plate 1 (Utting) 1958, with minor amendments
- Plate 2. Spirit Hill Area, Geology and Structure Contours. Scale
1 inch = 1415 feet approx.
- Plate 2A. Area South of Spirit Hill, Showing Structure Contours
Horizon 2, Overlay Sheet. Scale 1 inch = 1415 feet approx.
- Plate 3. Sections. Scale 1 inch = 1415 feet approx.

Data used.

Plate 2 is compiled directly from new airphotos (1961) by ...A. Lands and Survey Department.

It also makes extensive use of BMR. seismic sections (1957) and applies BMR. gravity contours taken at the same time.

References:

- TRAVES, D.M., (1955) The geology of the Ord-Victoria region, Northern Australia. BMR. Bull.27.
- UTTING, E.P., (1958) Progress geological report, Permit No. 3, Bonaparte Gulf Basin. Private report.

DISCUSSION OF GEOSEISMIC INTERPRETATION AND RESULTS.

The interpretation by Geoseismic was presented on a structure contour plan "Control for Lower Carboniferous", scale 1 inch = $\frac{1}{2}$ mile, dated 15-12-60.

The high-light of this plan is the near closure of the control contours between Traverses A and K, which, in view of the stratigraphy, would become a definite closure with the interpreted down-throw of faults f1 and f2, east block down. The "closure" is centred at Spirit Hill.

This conclusion is erroneous. It is based on the correlation of an arbitrary horizon between Traverses A and K (a gap of five miles) for which there is no justification, and in fact there may be 1,000 feet of vertical error.

The correlation of faults f1 and f2 across the same gap is completely hypothetical and their positions across Spirit Hill are not supported by geology. Their displacement (east block down) is the opposite of that indicated by geology and, if correct, would expose Spirit Hill Limestone, or beds below that horizon, across the western half of Spirit Hill, there is ample evidence to show that the beds there in fact over-lie the Spirit Hill Limestone horizon.

There seems little justification for interpreting f1 and f2 on the northern side of Spirit Hill as shown, although some faulting probably exists there. These faults do exist to the south of Spirit Hill but there are insufficient seismic data to show their location and disposition precisely.

There are also insufficient data to interpret the south-pitching nose shown between shot points K3 and K6.

The various reflection sections show a tendency for dips to increase slightly with depth in north-south section suggesting that a basement ridge may exist below Spirit Hill. This tendency becomes more evident below approximately 10,000 feet depth. Geoseismic's control contour has been influenced on the southern side of Spirit Hill by these deeper reflections, and is therefore considered to be misleading in over-emphasising the closure shown; a contour at a higher elevation (as drawn by the writer-Horizon 1) is considered to be more practical in indicating the structure at an horizon closer to the shale cover beds.

The possibility of the above-mentioned ridge is largely negated by the available east-west seismic sections which show westerly dips in the lower beds. The ridge effect is probably an "apparent" feature resulting from a slight arching in the strike of these beds.

Geoseismic has not attempted to trace unconformities or advise on the possibilities of their existence or otherwise. The sections do not generally indicate them, but some interesting possibilities occur, one of which is at about 2,600 feet depth between shot points T1 and T6. This would correlate approximately mid-way between Horizons 1 and 2 of the writer, and could possibly represent either the base of the Cockatoo Sandstone or a lenticular zone in that formation (of the lensing out of Cockatoo Sandstone towards the north end of Pincombe Range - Plate 1).

In general the interpretation of Geoseismic is unsatisfactory in not taking some guidance from surface geology.

Because of the inconsistencies revealed, doubt is cast on the whole of the work to the north of Spirit Hill where no assistance is available from geological outcrops. A study of the traverses there shows that alternative interpretations or modifications can be made to the existing Geoseismic interpretation, but the extensive work that is necessary for this project has not been commenced because of lack of indication that a closed structure exists.

Note: Unfortunately, traverses that were recommended to the east and south of Spirit Hill, in order to throw further light on this matter, appear to have failed to produce results as no sections are supplied and no shot hole samples obtained. Recent air photos show that extensive line clearing was done east of Spirit Hill, but none to the south along and across the anticlinal axis as recommended. It is considered important to check whether the shooting was, in fact, carried out and if any improvements in the technique could give useable results.

INTERPRETATION.

Significant correlations can be made from the south of Spirit Hill through to Spirit Hill No.1 bore i.e. from shoreward to basinward environments of the strata (Section 1).

It will be seen that the Spirit Hill Limestone is a persistent horizon; Milligans Beds grade from sandstone to shales; Nigli Gap Sandstone* grades from sandstone to a sequence of more or less dolomitic sandstones and siltstones with frequent gradations to dolomitic limestone and dolomite.

The basic facts regarding these beds are shown on the accompanying table:

	<u>South end of Spirit Hill and southwards.</u>	<u>North end of Spirit Hill</u>	<u>Spirit Hill No.1</u>
<u>Milligans Beds</u>	Up to 500'	600' approx.	826' (with full thickness 1000')
	Sandstone	Sandstone and shale	Shale with minor sandstone
<u>Spirit Hill + Limestone</u>	400' ± Sandy dolomitic		At least 389' probably 608'. Dolomitic limestone with subsidiary shale. Minor sandstone.
<u>Underlying Beds*</u> (Nigli Gap Sandstone)	Possibly 2000' (+) Sandstone only in outcrops, Leptophloeum.		1024' to probable fault then further 500' to bottom of hole Sandstone, siltstone and several dolomitic horizons. Leptophloeum minor coaly indications and traces marine fossils.

Note *: The name Nigli Gap Sandstone was previously thought to be redundant as there were indications that it represented Enga Sandstone and Border Creek Sandstone. As discussed elsewhere in the text, it is advisable to re-introduce it, at least on a temporary bases.

*+: The beds that form this sequence may be the equivalents of the Cockatoo Sandstone - Burt Range Formation sequence.

In order to correlate the various strata across the central faults of Spirit Hill (Faults "A" and "B") and to the south, similar basinward gradations and thicknesses have been assumed. There is no other alternative to this procedure, which is admittedly approximate, but gives a working basis for stratigraphy and structure contours which may not be too far from a realistic picture.

Thus in the sections drawn (Plate 3):

- a. In the basinward localities, where seismic results are available in part, the key horizon selected from the seismic sections of both Geoseismic and BHR. (Horizon 1) is approx. 2000 feet below the top of Milligans Beds shale and 1000 feet below the top of Spirit Hill Limestone.
- b. Towards the basin-edge, i.e. the south-eastern portion of Spirit Hill where there are no seismic results, the horizon has been accepted as 700 feet below the top of Spirit Hill Limestone (from consideration of Section 1).
- c. Structure contours have been compiled on this basis from a close study of the seismic sections (including the use of a model) and from the geology (factual and inferred) in the areas where no seismic sections are available.

This work includes the reversal that occurs within sandstones in

southerly continuation of the Spirit Hill anticline and which is the only approach to complete closure that is available in the Spirit Hill area. Because of the occurrence there of several components of the Cockatoo Fault complex, the displacements of which cannot be gauged, the contours must be regarded as partly dia-grammatic. However they demonstrate the reversal and allow the expression of it to be matched with the seismic controlled "semi-high" to the west of Fault "A".

- d. A gap has been left in the contouring for about one mile to the east of shot hole K3. In this area the seismic sections show erratic dips and blank zones, and the southerly projections of Faults "A" and "B" can only be approximated. Additional faults may exist from K2 eastwards. Section 4 shows the sporadic nature of the reflections.
- e. Resulting from a and b it will be seen (Sections 3 and 4) that a vertical displacement of approximately 1200 feet, west block down, is indicated across Faults "A" and "B". It is possible that facies changes or the necessary approximations have over-emphasised the displacement, but this does not affect the important result of removing the main cover beds of shale from the blocks to the east of the faults.
- f. A lower controlling horizon (Horizon 2) has been drawn in the area of the seismic traverses to provide an indication of the variation of the structure contours with depth (Overlay Plate 2A, Sections 3 and 4). There is insufficient data to extend the contouring.

The horizon is at similar depth to that of the Geoseismic control and shows a stronger tendency to closure due partly to the influence of the "apparent" basal ridge to which reference has been made in the discussion of Geoseismic's interpretation.

It is quite possible that the horizon exists within the Proterozoic basement or close to its contact with the Palaeozoic. A minor "high" (possibly closed) is apparent on Section 4 and has been used to guide the location of a proposed stratigraphic drill hole.

DISCUSSION ON BEDS BELOW SPIRIT HILL LIMESTONE.

Correlation of the beds underlying Spirit Hill Limestone is of considerable importance to the stratigraphy of the area, both locally and regionally in the whole basin.

As seen in the reversal area, i.e. in the scarp where there are ample exposures, their nature is similar to the few outcrops that underlie Spirit Hill Limestone viz. cross-bedded fine to medium, rarely coarse grained sandstone with very minor grit and pebble beds and zones of "floating" pebbles. The recent discoveries of Leptophloeum in outcrop and in Spirit Hill No. 1 assist in allowing a reasonable correlation of these strata with the basinward locality of the drill hole.

It will be noted that the outcrops grade upwards into the sandy dolomitic limestones of Spirit Hill Limestone.

The beds were originally named Nigli Gap Sandstone (Traves 1955), being described as sandstone with rafted pebbles and conglomerates which, in the most southern development, overlap the Cockatoo Fault and rest unconformably on Precambrian rocks. Approximately 1000 feet of conglomerate is reported at the latter locality.

The recognition of this unit as a separate formation presented several difficulties in correlation after later palaeontological determinations suggested that Septimus and Spirit Hill Limestones were of equivalent age (refer Utting, 1958, pp7, 15). It meant that the formation was equivalent to Enga Sandstone at the base of which there is no unconformity. Accordingly, use of the name and sense of Nigli Gap Sandstone was suspended, and the sediments were regarded as partly Enga Sandstone, partly indeterminate, with Border Creek Sandstone in major areas that overlapped the Cockatoo Fault.

It is now necessary to consider the strong possibility of these problematical beds, plus the Spirit Hill Limestone, being equivalent to the Cockatoo Sandstone - Burt Range Formation sequence. For the purpose of this report it is proposed to refer them to their original name of Nigli Gap Sandstone.

Pertinent facts regarding this matter are as follows:

- a. There are only two definite sedimentary breaks in the region, viz., at the base of the Cockatoo Sandstone and the Border Creek Sandstone. Sufficient evidence is available to demonstrate that there is continuity of sedimentation between these horizons.
- b. The Cockatoo Sandstone unconformity is more strongly pronounced regionally than that of Border Creek Sandstone. For instance, along the western edge of the Burt Range Basin, Cockatoo Sandstone wedges out in a northerly direction from 3000 (+) feet thickness, to nil at a locality due west of Spirit Hill.

In contrast, the basal conglomerate of Border Creek Sandstone overlies the rather thin Point Spring Sandstone horizon at almost every known locality in the Burt Range and Carlton Basins. Except for a possible localised exception at the north end of Spirit Hill, the relationship can be regarded as a disconformity. It does represent, however, an appreciable time break as no faulting of consequence has yet been noted within Border Creek Sandstone, whereas all older beds show appreciable displacements.

- c. Cockatoo Sandstone as typically developed on the western side of the Burt Range Basin is cross-bedded, generally fine to medium grained, with occasional pebble beds. The writer has noted a limited conglomerate development near its base, and beds of unfossiliferous (dolomitic?) limestone, calcareous sandstone and shale within it. It is noteworthy that a specimen of *Leptophloeum* has been recorded in the type area.

The Nigli Gap sandstone has very similar characteristics but is generally coarser in grain size. In Spirit Hill No. 1 the correlated equivalents are finer in grain, contain considerable dolomitic limestone beds and an appreciable silt fraction. The sandstone is cross-bedded. *Leptophloeum* is present at the surface and in the drill hole.

Although, in its most southern occurrence, Nigli Gap Sandstone contains about 1000 feet of conglomerate which is far in excess of any known development in Cockatoo Sandstone and is more like the nature of Border Creek Sandstone, the strength of the unconformity and weight of other evidence quoted leans clearly in favour of correlation with Cockatoo Sandstone.

- d. Cockatoo Sandstone in the type locality grades upwards into Burt Range Formation limestones, siltstones and sandstones, the latter increasing in proportion towards the top of the formation. Enga Sandstone is the strongest and uppermost bed.

The succession of Burt Ra, Pm-Enga Sandstone which totals approximately 4000 feet thickness, thins appreciably around the southern rim of the basin and in the Amphitheatre area is probably no more than 600 feet thick. There the limestone, which probably represents the upper sections of the Burt Range Formation, has a marked lithological resemblance to the Spirit Hill Limestone (Utting, 1958) whereas earlier palaeontological evidence precluded correlation (Traves, 1955) it is understood Dr. G.A. Thomas has recently indicated that this is possible. It should also be noted that the sandstone (regarded as Enga Sandstone) that overlies the limestone at Amphitheatre is similar to Milligans Beds Sandstones at Spirit Hill.

It seems desirable, therefore, to accept the correlation at least on a temporary working basis, i.e., that 2400 (+) feet of sediments in the Wigli Gap Sandstone - Spirit Hill Limestone succession is the probable equivalent of a combined 7000 feet of Cockatoo Sandstone and Burt Range Formation on the south-western flank, and a lesser thickness on the north-western flank. It is probable that Cockatoo Sandstone is the more strongly represented in Wigli Gap Sandstone.

There is no real boundary between Cockatoo Sandstone and Burt Range Formation and the whole succession is one of varied lithologies. The existence of limestone within Cockatoo Sandstone has been noted. Facies changes of Burt Range Formation members occur along strike and are to be expected in dip basinwards. The gradation of Wigli Gap sandstone from dominantly sandstone in outcrop to mixed sandstone, siltstone, dolomite facies in Spirit Hill No. 1 bore is consistent with these characteristics, and it is reasonable to expect that the lower dolomites encountered in the bore are representatives of the limestones of Burt Range Formation, or possibly of those known within Cockatoo Sandstone.

CONCLUSIONS

1. The seismic results have assisted in throwing new light over a considerable part of the potential area of Permit No. 3, but has not covered it exclusively. Potential ground not covered is as follows:
 - a. A gravity "high" situated near the northern border of the Permit and which passes into the adjacent permit of A.A.O.
 - b. A possible "high" which was partly indicated in the most north-eastern of the seismic traverses but was not fully investigated.
2. In the more evident phase of exploration, i.e., the search for closed anticlinal structures, the present data suggest that the more potential ground exists from the southern portion of Spirit Hill to some three miles southward.
3. An almost certain structural closure occurs in the scarp approximately two miles south of Spirit Hill within the porous strata of Wigli Gap Sandstone. The closure is faulted and the many outcrops that are available show that there is no prospect of sealing cover beds.

4. The remainder of the Spirit Hill area is open to the east or south, as demonstrated by the structure contouring of Horizon 1, and in sections.

In the lower strata represented by Horizon 2, which could possibly be within basement Proterozoic sediments, there is a greater tendency for localised closures but the structure as a whole is open to the east. One small possible closure, for which full information is not available is in a basinward position near K1, where stratigraphic drilling is recommended.

5. The central faults "A" and "B" of Spirit Hill, regarding which limited data are available in outcrop owing to scree, cannot be identified precisely in the seismic sections, because of erratic reflections and blank zones.

However, there is ample evidence from geology, and the previous drilling of percussion holes, that the displacements across the faults are both west block down. This brings Nigli Gap Sandstone up against Milligans Beds Shales and thereby eliminates the most favourable seal that is known in the region.

6. The oil potential of the area is considerably reduced because of 4 and 5 and becomes dependent on the less obvious targets of fault and stratigraphic traps, of which little is known except as follows:

a. There is a considerable body of evidence that Nigli Gap Sandstone grades into a facies containing sandstones with substantial silty and dolomitic beds in which porosity and permeability are low. In the faulted areas a pattern for traps could therefore be present.

b. There may be unidentified faults in the vicinity of faults "A" and "B" extending as far west as shot point K3 and possibly further. Although these would complicate the position, they could also assist in providing a greater potential for fault traps.

7. The influence of artesian water on the oil potential is not clear but water did flow from the Spirit Hill Limestone in Spirit Hill No. 1 and it is likely that it will reduce the potential. The opening of the main structure to the east, into the faulted and porous surface facies of Nigli Gap Sandstone, will allow considerable ingress of water to the basin as a whole.

8. There is a necessity for a stratigraphic drill hole to provide further data on the various possibilities brought out in the present report. Two sites have been proposed:

Site "A": The stratigraphic and structural possibilities are as shown in Sections 2 and 4. The location is suitable to demonstrate the "basinward" characteristics and in addition there is a tendency towards closure. Consideration might be given to shifting it $\frac{1}{4}$ mile westwards to K1 in order to avoid a possible fault indication, but this would place it down-flank from the near "high" that is indicated.

The hole should be planned to 6000 feet depth, with the possibility of completion at 4000 feet.

Site "B": The hole would be of similar depth and would offer a similar stratigraphy with indications of partial closure at depth.

Site "A" is preferred because it suggests better structural possibilities which face towards the main portion of the basin, and the Milligans Beds Shales are expected to be thicker.

A further site has been considered on the Spirit Hill Anticline axis just north of the main outcrop of Leptophloeum (Fossil Locality 6). This would verify the shorewards facies of Nigli Gap Sandstone and indicate the depth of Proterozoic. The hole has not been recommended as the other sites offer more useful data.

9. Gravity results have been proved to be of value in the basin as a whole and the few contours that are available to the immediate south of Spirit Hill support the present interpretation.

As these were derived from readings along the widely spaced BMR. traverses it is probable that a closer net could be of considerable help in verifying the structure of area.

RECOMMENDATIONS

1. Geoseismic should be asked to comment on the aspect of lack of reflections and to advise if any improvement could be made in their methods, which provided little improvement on the BMR. results.

2. As very few shot hole samples were obtained south of Spirit Hill, the hole localities should be inspected at an early date and the cuttings recorded.

If any shooting was carried out along the cleared lines to the east of Spirit Hill, an indication of the locations should be obtained in order to collect samples of the cuttings.

3. In the lack of seismic reflections in the critical area south of Spirit Hill, consideration should be given to a detailed gravity survey.

The survey should be carried out between the -2000' contour of Horizon 1 and the main scarp to the east, and from BMR. Traverse "E" northwards to include the plain on the eastern side of Spirit Hill and the indentation in towards fossil locality 7.

It is suggested that the readings be made at $\frac{1}{2}$ mile intervals, with the prospect of closing to $\frac{1}{4}$ mile in some localities if warranted. In this connection interesting trial data may be obtainable from a traverse just south of Spirit Hill across the line of faults "A" and "B".

4. The drilling of a stratigraphic hole at site "A" is recommended, the depth to be planned to 6000 feet with a possibility of termination at shallower depth, say 4000 feet.

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