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UBJECT: REVIEW OF GEOLOGICAL AND GEOPHYSICAL INFORMATION, GOSSE'S BLUFF, NORTHERN TERRITORY.

UTHOR: R.O. Brunschweiler, R.B. Leslie and K.A. Richards.

959.

REVIEW OF GEOLOGICAL AND GEOPHYSICAL INFORMATION
GOSSE'S BLUFF, NORTHERN TERRITORY

by

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Melbourne
December, 1959

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INTRODUCTION

Separate detailed geological investigations of the Gosse's Bluff structure were carried out first by Brunnschweiler and later by Leslie in 1959. A gravity and magnetic survey of the feature was made by Richards in 1958. The three surveys resulted in differing views as to the cause of Gosse's Bluff and there was some apparent geological contradiction in the surface mapping.

The three authors recently had extensive discussions on the reasons for these differences and attempted to reach agreement on as many phases as possible. The following report summarises the results and conclusions of these discussions.

STRATIGRAPHY

Treatment of this matter in Brunnschweiler, 1959 (1), was of necessity rather brief and unrelated to the findings of recent Frome-Broken Hill geological surveys.

With revision, the original mapping of Brunnschweiler is essentially unchanged in so far as boundaries of the various lithologic units are concerned. However, some amendment is required with respect to the nomenclature he used under the following headings:

(1) Mareenie Sandstone

Brunnschweiler (1959) did not attempt elucidation of the stratigraphy of the rim formations or those surrounding Gosse's Bluff. It is agreed that this would entail several weeks' additional field work. Knowledge gained in the course of Frome-Broken Hill regional surveys does, however, allow more detailed subdivision of the rocks involved in the rim structure.

Only the innermost whitish sandstones of the rim can now be regarded as equivalent to the ?Ordovician Mareenie Sandstone as known elsewhere.

The overlying reddish sandstones, siltstones and impure fragmental sandstones are considered by Frome geologists to be equivalent to the Pertnjara Formation. Several unconformities occur within the Pertnjara Formation and it is possible that continuous tectonic movement occurred during deposition of this thick clastic sequence. It is unnecessary, therefore, to treat the gently folded conglomeratic sequence to the north of the Areyonga Road (Plate I, Brunnschweiler, 1959) as a separate formation.

Plant fossils discovered in the Pertnjara Formation at Tempe Downs indicate a Carboniferous or Permian age. The structural condition of this formation throughout the basin indicates that strong orogenic forces have affected this part of Australia during late Palaeozoic or early Mesozoic time.

(2) Gosse Shale and Luther Limestone

Beds 5 - 8 of Brunnschweiler (1959, Pl. 1) make up together what is widely known as the Walker Creek Formation. Since subdivision into smaller units is possible this sequence could perhaps be renamed Walker Creek Group, and the smaller units classed as formations. At Haast

Bluff, Frome-Broken Hill geologists mapped a limestone horizon almost at the top of the sequence having lithology and faunal content identical with Brunnschweiler's Luther Limestone.

(3) Stokes Formation

From a consideration of the lithology, together with the evidence of small conulariid fossils ("Dingo Paws"), beds 2 -4 (Plate 1) of the Stokes Formation in Brunnschweiler (1959) are now considered to represent the Stairway Formation (normally called Stairway Sandstone) which is the next older sequence.

At Gosse's Bluff the Stairway Formation displays a peculiar facies variation. It contains numerous oolitic and sandy limestone beds as opposed to the normal fine grained sandstones and indicates a special shallow water environment. Although minor limestones are known to occur in the Stairway Formation elsewhere (e,g. Areyonga) such a complete facies change appears a peculiarity of the Gosse's Bluff area.

It is agreed that this stratigraphic peculiarity probably indicates abnormal conditions in the Gosse's Bluff area at the time of deposition of the Ordovician Stairway Formation.

Oldest Beds Exposed at Gosse's Bluff

Leslie considers that some Ordovician Horn Valley Formation may be present in the central portion of the structure. However, Brunnschweiler was convinced that the Horn Valley Formation does not crop out.

It is agreed that nowhere within the bluff has indisputable fossil evidence indicating presence of Horn Valley Formation been found. However, since the Stairway Formation is well developed in the central area it can be surmised that the Horn Valley Formation is not far beneath the surface.

Whether it crops out or not makes little difference to structural interpretation.

Pyroclastic Rock South and Southwest of Gosse's Bluff

At the request of Leslie, further petrological studies were made on rocks from the Mt. Pyroclast area. This work, which was carried out by the same petrologists, confirmed the original conclusions (Appendix II, Brunnschweiler, 1959) as to their pyroclastic origin.

It has been suggested (N. L. Falcon) that some analogy may be possible with certain pseudo-volcanic rocks associated with evaporite plugs in the petroliferous regions of Iran (McLintock, 1932, (2)). These rocks are metamorphic and have been produced by the burning of hydrocarbons. Whilst they contain interstitial glass and minerals which one usually associates with volcanic rocks, and resemble volcanics in their slaggy, lava-like appearance, their total chemical composition is completely outside the range normal for igneous suites. In addition, these rocks contain minerals of the evaporite family, mainly gypsum. They are considered to have originally been limestones.

The Mt. Pyroclast rocks are of Carboniferous or later age and have been almost completely silicified. They show no indication of the presence of evaporites, while the zeolites present belong to that family found only in igneous rocks. Some concentrations of coarsely crystalline calcite occur and blocks of quartzite and dark shales (possibly from Pioneer or Pertatataka Formation) and limestones (possibly Cambrian) are included in the brecciated zone.

In making an analogy with the pseudo-volcanics of Iran it must be realised that whereas the original rocks involved in the latter were limestones, the country rocks at Mt. Pyroclast are siltstones, sandstones and coarser clastics. Further, there is no knowledge of any other igneous activity of this age elsewhere in the Amadeus region.

Despite the findings of the petrological specialists, Leslie is not convinced that the Mt. Pyroclast suite is of igneous origin. Brunnschweiler considers the Mt. Pyroclast suite is too dissimilar to allow significant analogy with the pseudo-volcanics of Iran. Positive determination of their origin may provide an important clue to understanding the Gosse's Bluff region. Further studies, both geological and geophysical, are necessary before anything more can be said about the origin of these unusual rocks.

In the event of this suite being pseudo-volcanic and due to the burning of hydrocarbons as in Iran, then in the interests of the search for both evaporites and petroleum, more detailed investigation of the rocks and their occurrence would appear warranted.

STRUCTURE

1. Faulting of Rim Formation

Due to lack of stratigraphic control the detailed structure of the rim is still only vaguely known. Two opinions exist among the authors regarding the amount and extent of faulting.

Leslie considers that there is a southward divergent fault system radiating from the north-centre portion of the inner core (see Plate 1). The relative displacement of the rim formation is not as great except in the central portion of the southern rim where displacement appears to correspond to the indentation caused by the overturning of the southern core formation. He considers the major movement took place during a later orogenic phase but probably followed pre-existing lines of weakness. The major fault traces are considered to cross the entire structure, i.e. over rim and centre.

Brunnschweiler (1959, Plate II) while also indicating faulting in the rim structure, regards it as subordinate to the folding and essentially due to late phases of under-thrusting from the south.

These two views are not as irreconcilable as might appear. The authors agree that really strong fracturing is only apparent in the southern half of the rim, especially westward of the meridian of Cairn VI. Through the western and northern rim, the sequences are quite continuous. These areas have, for the most part, been checked in this respect by Brunnschweiler in the field. Brunnschweiler considers that some transcurrent slip-folding occurs in the eastern rim although the fault traces, inferred from aerial photographs, cannot be recognised as such in the field.

This leaves the southern rim to be discussed. In the southeastern corner of the bluff there is good evidence of very tight folding in the rim. Since the fold axes trend meridionally they give the impression of a slicing-by-faults across the rim. On the steep northern flank of the valley which cuts east-west into the outer part of the rim tight folding can be seen. However, in the absence of stratigraphic control, it cannot be flatly denied that there is no faulting at all. Yet it is most unlikely that it cuts across the whole width of the rim; the trends around the outside of the southeastern rim portion are undisturbed.

Severe fracturing is evident in the southwestern rim. North-south trending structure abuts against east-west trends in two or three places. Overturning is evident and this may be caused by underthrusting from the south. Again, however, it should be noticed that the outermost zone of the rim is far less affected by the fracturing than its inner zones. Brunnschweiler concluded from this that the south rim fracture pattern is due entirely to late-phase underthrusting. This, he admits, is not necessarily so. In any case, the authors agree that the breakup of the rim structure through the southern half is more pronounced than the map Plate I in Brunnschweiler (1959) suggests. On the other hand there is as yet no field evidence that the breakup is as extensive as is suggested by Leslie.

It is agreed that the present fracture pattern originally could have arisen from concentric and radial evaporite tectonics, but subsequent forces have obliterated the original pattern. In other words, even if fracturing were as extensive as suggested by Leslie, it is not of a type commonly found in salt plugs.

It is also agreed that underthrusting from the south (or upthrusting from the north against a subsurface resistant body) is all too evident in the southern rim areas. The overturning and southward imbricating in the southern portion of the bluff's central area point to this too.

2. Comparable Structures elswhere in the region

Some 12 to 15 miles northeast of Gosse's Bluff is a peculiar structure in the otherwise uncomplicated western MacDonnell Ranges. A sketch taken from aerial photographs is found in Plate 2. The structure may perhaps be described as an overturned diapir, which has been eroded and exposed in cross section. It is referred to by Frome-Broken Hill geologists as the Boomerang Valley structure.

The central portion of the structure is composed of strongly contorted Precambrian dolomite (Bitter Springs Limestone). The dolomite contains some gypsum and displays abundant slickensiding and flow structures. Its shape, if the plan is considered as a cross section, is not dissimilar to the shape of known evaporite plugs. The Pioneer, Pertatataka, and Arumbera Formations have been uprighted parallel to the western edge of the plug and to the east, fault features occur analogous to those observed around salt plugs.

The Pertaoorrta and younger formations arch gently across the older rocks which form the core of the structure and it seems probable that these older formations were eroded prior to Pertaoorrta sedimentation. Gentle upward arching of the younger sediments was apparently synchronous with sedimentation and there is a noticeable thinning in several units as they pass across the structure. This is particularly pronounced in the case of the Mareenie Sandstone in which a lower member occurring to the east wedges out against the structure. Later faulting affects both the Pertaoorrta Formation and Pacoota Sandstone.

An essential difference between the Boomerang Valley structure and Gosse's Bluff is the fact that in the latter, Carboniferous beds have been apparently pierced whereas at Boomerang Valley piercement did not continue after the early Cambrian.

About four miles north of the Palmer River and adjacent to the Alice Springs-Adelaide road (Nallesnum Hills) is a closed north-south trending anticlinal structure some $2\frac{1}{2}$ to 3 miles long and about $1\frac{1}{2}$ to 2 miles wide. The structure involves rocks of the Pertatataka Formation, and some Pioneer Formation may be present within the core. The quartzitic sandstones which form the rim have near vertical dips and on the eastern side are overturned. The structure is situated within a strongly faulted and folded zone and the rim itself is broken in several places by strong fault movements.

It is quite reasonable to explain this structure as due to folding alone.

From observations made adjacent to the Nallesnum structure it is fairly certain that all sediments from Pertatataka Formation to Pertnjara Formation, with the exception of Pacoota Sandstone and possibly Arumbera Formation, were deposited over the area and have since been eroded. The succession above the Pertatataka is estimated as some 5000 feet thickness and it is interesting to contemplate the configuration of those sediments which correspond to the Gosse's Bluff structure, prior to erosion. It is conceivable that we might expect a structure similar to that at Gosse's Bluff. There would, of course, be no reason to suspect a negative gravity anomaly with this uneroded structure.

The Boomerang Valley, Gosse's Bluff and Nallesnum structures, together with areas of structural complication in the Krichauff Range and Tempe Downs areas, are situated along a general northwest-southeast trend which is reflected on isopachous maps of the area. In the case of the Stairway Formation a pronounced thinning of sedimentation is apparent along this zone.

3. Bearing of Comparable Structures on Tectonic History of Gosse's Bluff

A structural analogy between Gosse's Bluff and Boomerang Valley can confidently be made. This would imply an initial diapiric history for both, with a difference in the effects of subsequent tectonics and erosion. However, the indisputable fact is that the Boomerang Valley structure proves that the Bitter Springs Limestone can and has acted as a plastic formation capable of giving rise to a diapiric structure.

Abnormal shallow water sedimentation occurred at Gosse's Bluff at least during the deposition of the Stairway Formation. This can be compared with the similar effects in the overlying sequence at Boomerang Valley during Cambro-Ordovician times, although both may not have been completely synchronous in time or extent.

Without bias towards any particular rock type beneath Gosse's Bluff, it is difficult to conclude that one single event could have produced the structure as it stands today.

There are only two conceivable ways in which the Gosse's Bluff structure could have been caused by a single phase movement. Firstly, if it were a result of intrusion, either igneous or sedimentary, then the invading plug must have pushed a great thickness of the sedimentary section in the form of a very large cap ahead of it. It has been shown by other writers (Travis and McDowell, 1955 (3)) that this is not known to occur anywhere in the world. Even if this had happened at Gosse's Bluff it is inconceivable that it would have resulted in the present structure.

Secondly, the structure could be postulated as being a well developed dome resulting from normal compressional folding. This poses difficulty in obtaining a suitable system of forces, raises the query as to why only one structure of this type is present and is refuted by analogy to the known diapiric nature of Boomerang Valley.

Having eliminated the single cause theory there remains a two-or-more phase theory to consider. It has often been suggested that Gosse's Bluff might represent a collapsed evaporite diapir. This would envisage that the plastic mass or at least its cap rock, had at one stage reached almost to the top of the present rim before sinking back, a minimum distance of 600 feet. It could not have overflowed since the centre of the structure is not sufficiently disturbed. Smooth and gradual retreat of the plug, so as to leave the core coherent, would pose a problem as complex as the ones we have already dealt with.

The depositional environment of formations above the Stairway Formation at Gosse's Bluff is similar to that of the same formations in the northern region of the Amadeus Basin. Therefore, whatever the final structure is due to, it must be regarded as an event which took place well after the close of Pertnjara sedimentation. The nature of the deforming forces is of necessity speculative. However, there is great temptation to associate it with the cause of the overturned southern rim zone and with Mt. Pyroclast. It must be considered quite reasonable that forces acting from the north against previously arched beds, and being resisted in the south by an igneous plug at Mt. Pyroclast, could give rise to the Gosse's Bluff structure. This theory is attractive because it poses only one direction of force, associates the structure with Mt. Pyroclast and takes care of the overturned southern rim zone. Other theories can be advanced and no doubt offer possible explanations. However, at this stage little more can be said, other than that it is considered no single cause could have produced the structure. It is the result of several superimposed tectonic events, one or more of which were diapiric in nature.

RELATION OF GEOLOGICAL AND GRAVITY FEATURES

The Bouguer gravity map of Gosse's Bluff and surrounding area is shown on Plate 4. It has been slightly altered from that shown in the original report (Richards. 1958 (4)). The strong positive nose south of the bluff is now shown as a positive closure. This is more in line with the strange rock units of Mt. Pyroclast and, in any case, is probably the more correct contouring procedure. The overall pattern is unaffected by the change, the gravity picture still being divisible into four groups as follows.

The interpretation of the positive anomaly in the centre of the bluff (Richards, 1958 (4)) has not been altered by the recent geological investigations. It could be due to the sediments inside the rim, to a possible cap rock or both. However, the fact that the most positive gravity value occurs where surface mapping placed the oldest outcropping sediments is significant in relating the geology to the gravity values.

The negative gradient across the rim indicates a steep-sided, plug-like feature with its top probably less than 2000 feet below the surface. (See Richards (4) for quantitative considerations). It also indicates that this body has a density slightly less than the average density of either the whole, or portion, of the section from Pertaoorrta Formation to Pertnjara Formation. The original interpretation was the obvious one, a salt dome, and must still be considered a possibility. However, it could also be interpreted as being due to some other rock type, such as the plastic Bitter Springs dolomite at Boomerang Valley, especially since that particular outcrop contains a fair percentage of gypsum. The authors agree that the possibility of this lower density body being an igneous plug of rhyolitic or trachytic character is rather remote. The average density of the Pertaoorrta Formation-Pertnjara Formation sedimentary section at Gosse's Bluff is difficult to estimate. Surface sample determinations suggest a value of 2.4 to 2.5 gm/cc would be a maximum figure. Thus the rock constituent of the plug-like feature would almost certainly have to have a maximum possible density of 2.4 gm/cc. It is doubtful if an igneous rock could fulfil this requirement. In any case, to the authors' knowledge, it would be the first igneous subsurface mass on record to produce a marked gravity anomaly of the type which is characteristic of salt domes the world over. The exact position of this negative gradient along the geologically most significant southern rim, is not known. There is not even 100% certainty as to its existence. The contours have been inferred by analogy to the pattern across the two traverses to the north, where the rim was crossed (see Richards, 1958 (4)) for alternative contour plan. From the known gravity values several widely different shapes could be proposed for the plug-like feature. This, coupled with the lack of information on the exact whereabouts of the negative gradient (if any) across the southern rim, makes any geophysical estimate of the lateral extent and position of the top of the low density body very questionable.

The gravity closures and nosings to the immediate east, north and west of Gosse's Bluff are consistent with the structural picture suggested on Plate 7 by Brunnschweiler (1959). They were interpreted originally as being typical rim features of a salt dome. Their correspondence with geological mapping further suggests that at least part of the geological section is behaving quite normally gravimetrically. That is, anticlines are giving highs and synclines lows. The positive anomaly south of the bluff agrees with the presence of an igneous body. The gravity control here is very sparse and no other statement is possible, except to say that the area is generally positive in a gravity sense. However, the fact that it is positive, is a strong argument against a similar igneous type rock occurring beneath Gosse's Bluff itself.

There is still no definite geological information available to discount or reinforce any of the interpretations originally set out by Richards to explain the broad circular shaped negative gradient around Gosse's Bluff. Recent geological work around the margins of the area tends to question the possibility of a thickening from all directions towards Gosse's Bluff. This information could be misleading due to the total lack of thickness data in the actual area where the gradient occurs. It is thought this gradient must have a great deal of significance, stratigraphically, in relation to the Gosse's Bluff structure. Any information assisting in its correct interpretation would be most important.

CONCLUSIONS

Reasonable agreement exists between the geophysical characteristics of the Gosse's Bluff area and the present interpretation of the structural geology.

The combined data indicate that Gosse's Bluff is a multiphased structure which was diapiric at some early stage of its development. The structure contains a subsurface core of significantly lesser average density than the surrounding sediments.

Gravimetric information strongly supports the presence of a plastic sedimentary core rather than a solid igneous plug, especially in view of the positive anomaly in the vicinity of Mt. Pyroclast. It is not sufficiently selective, however, to postulate a salt core although it is known that salt would produce the existing gravity picture.

Structural characteristics of Gosse's Bluff are such that interpretation of it as a simple post-Carboniferous diapir is inadequate. The authors have no knowledge of any evaporite dome having similar structural features.

A comparable multiphased structure occurs nearby in the Amadeus Basin at Boomerang Valley. This structure has a core of Precambrian carbonate rocks which contain gypsum, and shows evidence of having undergone plastic flow. Analogy to Gosse's Bluff is possible subject to a difference in timing and subsequent tectonics.

No density determinations are available with respect to the carbonate core at Boomerang Valley, however, considering its high plasticity it must be admitted that diapiric phases at Gosse's Bluff could have occurred without the presence of an economically interesting evaporite mass.

Pseudomorphs after halite and secondary gypsum are not uncommon within the sediments of the Amadeus Basin. However, there is no evidence of the former presence of any any large evaporite bodies.

From the evidence and theories put forward, it is obvious that much of the history of Gosse's Bluff remains uncertain. While not disputing the validity of anything written above, the authors are still not in complete agreement on the degree of probability that salt is the underlying cause. Brunnschweiler thinks that this degree of probability is low and favours a more solid core. Leslie and Richards think that salt is the most probable, but acknowledge the evidence for the other possibilities.

More extensive geological and geophysical investigations may solve some outstanding points of doubt, but it is considered that only by drilling can it be shown whether the low density values beneath Gosse's Bluff are due to evaporites.

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December, 1959

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LEGEND

- PERTNJARA FORMATION (Lower Sst member only)
- MAREENIE SANDSTONE
- GOSSE SHALE } WALKER Ch Fm
- LUTHER LIMESTONE } WALKER Ch Fm
- STAIRWAY FORMATION
- ? HORN VALLEY FORMATION (Possibly repetition of Luther Limestone)

Areas of ALLUVIUM indicated by stippling

- DIP
- DIP VERTICAL
- DIP OVERTURNED
- TREND OF BEDDING (Inferred from photos)
- APPROXIMATE GEOLOGICAL BOUNDARY
- FRACTURE or FAULT (Largely inferred from photos)

Note: This sketch is based on the original outcrop map by R.O. Brunnschweiler as amended following field examination and photo interpretation.

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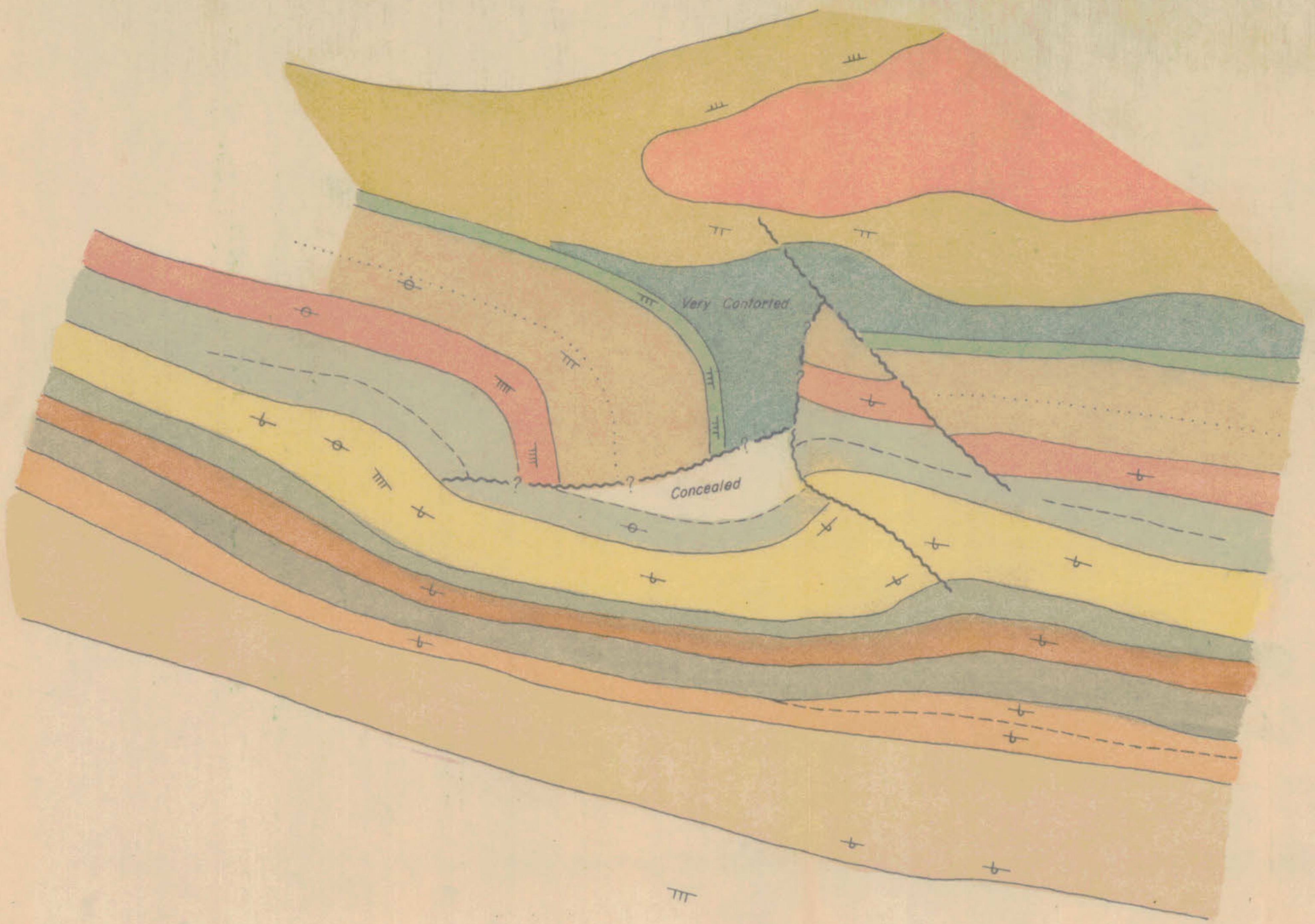
GOSSES BLUFF, N.T.
GENERALISED GEOLOGICAL SKETCH SHOWING INFERRED FRACTURE PATTERN.

CR 59/2

Scale 1" = 1000 feet	R.B. LESLIE Nov 1959	PLATE 1



Note Photo – interpretation based on brief field examination.

LEGEND

- PERTNJARA Fm.
- MAREENIE Sst
- WALKER Ck. Fm.
- STAIRWAY Fm.
- HORN VALLEY Fm.
- PACOOTA Sst.
- PERTAOORRTA Fm.
- ARUMBERA Fm.
- PERTATATAKA Fm.
- PIONEER Fm
- BITTER SPRINGS Lst.
- HEAVITREE Qte.
- ARCHAEAN

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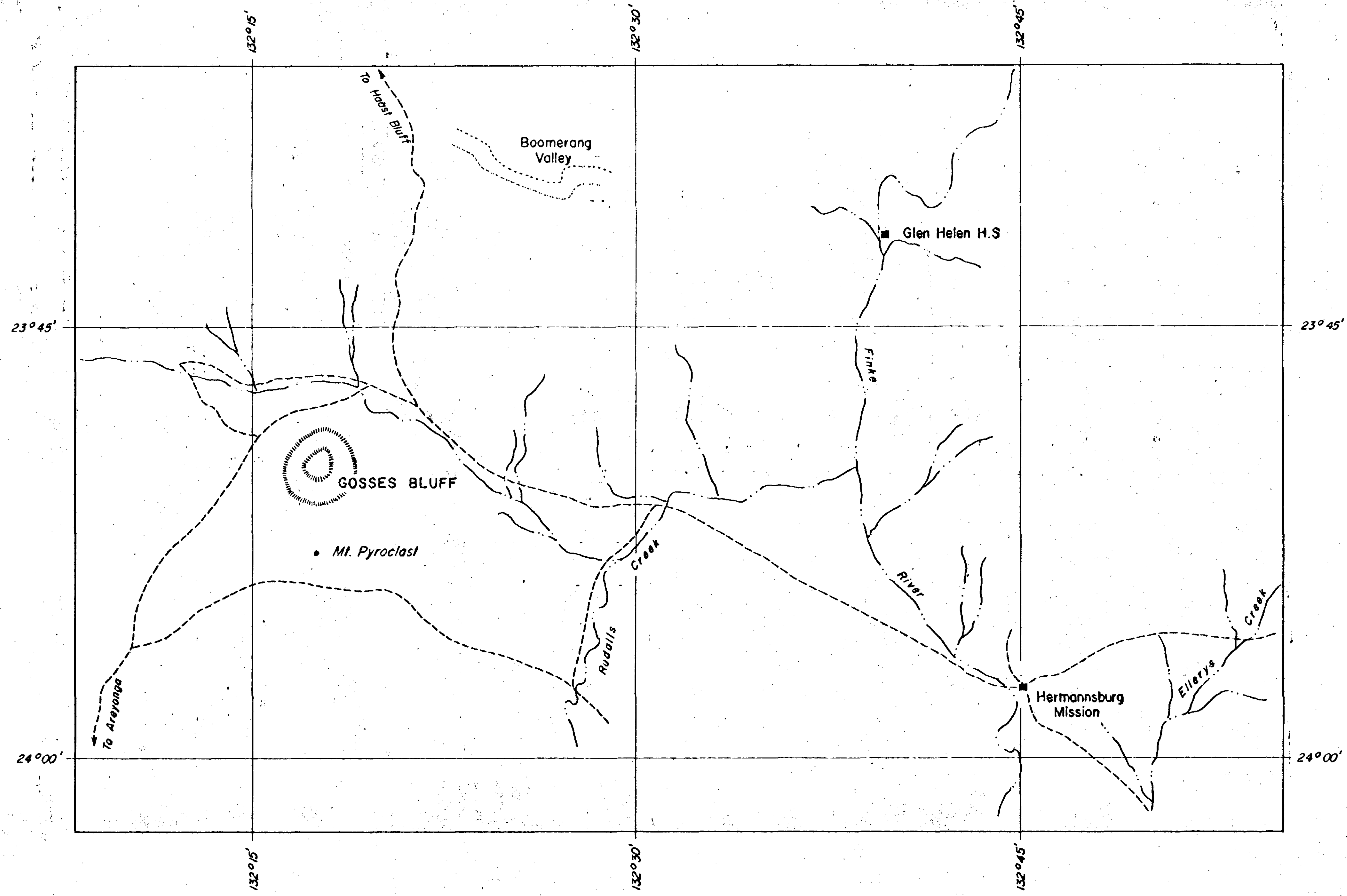
GOSSES BLUFF, N.T.
GENERALISED GEOLOGICAL SKETCH OF BOOMERANG VALLEY AREA

Scale 1" = 1 mile	R. B. LESLIE Nov 1959	PLATE 2



LOCALITY MAP OF GOSSES BLUFF

Scale : 1" = 4 Miles

PLATE 3

CR 59/2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GOSSES BLUFF, N.T.
REVISED BOUGUER GRAVITY MAP
PLATE 4
K.A. RICHARDS.
SCALE: 1 INCH = 1 MILE
NOV. 1959
CR 59/2
Bouguer Gravity Value in milligals.
Number of Gravity Station.
Contour interval 0·5 milligals.
Approximate axis between positive and negative gradients
Mt. Pyroclast
A
B
23°45'
132°15'
132°30'