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# Geology of the Outer Zone of the Gosses Bluff Crypto-Explosion Structure

by

*Andrew Y. Glikson*

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# I. INTRODUCTION

## 1. Earlier studies

The Gosses Bluff structure, situated in Central Australia about one hundred miles west of Alice Springs, has created considerable geological interest since 1956, when it was mapped by Prichard and Quinlan (1962) as part of a regional survey of the southern half of the Hermannsburg 1:250,000 Sheet area. These authors considered Gosses Bluff to be of diapiric origin. Brunnschweiler (1959) mapped the structure in connection with oil explorations and suggested that the structure resulted from the intrusion of a buried igneous plug. The structure was further investigated by seismic, gravity, and air-borne magnetic surveys carried out by oil companies and by the BMR (Richards, 1958; Lonsdale and Flavelle, 1963; Moss, 1964; Young and Shelley, 1966). Gosses Bluff has been drilled at its centre to a depth of 4535 feet by Exoil (N.T.) Pty Ltd (Pemberton and Planalp, 1965).

The discovery of shatter-cones at Gosses Bluff by Crook in 1964 led to the concept of its origin through crypto-explosion (Crook and Cook, 1966). Mapping on the scale of 1 inch per mile and scout drilling carried out by the BMR (Cook, 1966; 1968) yielded further evidence supporting an origin through crypto-explosion, and possibly through impact by an extra-terrestrial missile. Following the publication of Crook and Cook's concept, the Astrogeology Branch of the USGS became interested in the structure, and suggested the initiation of a joint USGS-BMR study of Gosses Bluff. The first phase of this project was carried out by Milton and Brett during 1967, and included the mapping of the central structure on the scale of 1:4000. The second stage took place in 1968, and included shatter-cone measurements by Milton, and mapping of the outer zone of Gosses Bluff* by the author, accompanied by shallow drilling on the outer zone (Appendix I).
Currently detailed gravity seismic and aeromagnetic surveys are being carried out by the BMR. The Department of Interior is currently surveying a grid laid out for the detailed gravity survey, and has completed

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*The outer zone of Gosses Bluff is defined as the poorly exposed circular belt of deformed strata which surrounds the central cliff ring.

the ground control which will enable the USGS to prepare a topographical map of the area from existing aerial photographs.

The present report is concerned with the mapping and the drilling of the outer zone,as well as with the implications of the results on the origin of the Gosses Bluff structure as a whole. It is based on field work carried between June and September, 1968, including supervision of the scout drilling (Appendix I). While suggesting an interpretation for the sequence of events which resulted in the present structural pattern, further conclusions will have to await the completion of the geophysical surveys of the Bluff.

## 2. Physiography

The Gosses Bluff structure is morphologically expressed as a ring of cliffs about 2.5 miles in diameter, and rising about 800 feet above the Missionary Plain which, in the Gosses Bluff area, lies about 2300 feet above sea level. The cliff ring surrounds a central depression about 1.5 miles in diameter, drained by a single creek which breaches the cliffs on the northeastern flank (Fig.2). The cliff-ring morphology of Gosses Bluff constitutes a reflection of the structure and the lithology of the resistant sandstone units, and does not reflect the original extent of the structure. Thus, the cliff ring stands up by virtue of the erosion of the Stokes Siltstone and Parke Siltstone on the inside and the outside respectively, whereas the Gosses Bluff structure extends several miles beyond the cliff-ring. The circular structurally-disturbed zone external to the cliff ring will be referred to as the Outer Zone.

The cliff-ring is encirced by an annular pediment with an extensive development of travertine crusts which shows as a white collar on the Gemini photograph (Fig.1). North of the Bluff the pediment merges into the southward-sloping pediment of the western Macdonnell Ranges, which consists of low terraces truncating sub-horizontal beds of the Brewer Conglomerate, and is dissected by streams emerging from the foothills in the north. In the other directions the Gosses Bluff pediment merges with a ring of alluvial flats encircled by low-lying dune country,

Fig. 1. - Gemini IV photo of a part of the northern margin of the Amadeus Basin. The photograph shows parts of the Burt Plain (B), Arunta Precambrian basement complex (A), western Macdonnell Ranges (M), the Waterhouse Range (W), Gardiner Range (G), and Gosses Bluff (GB).

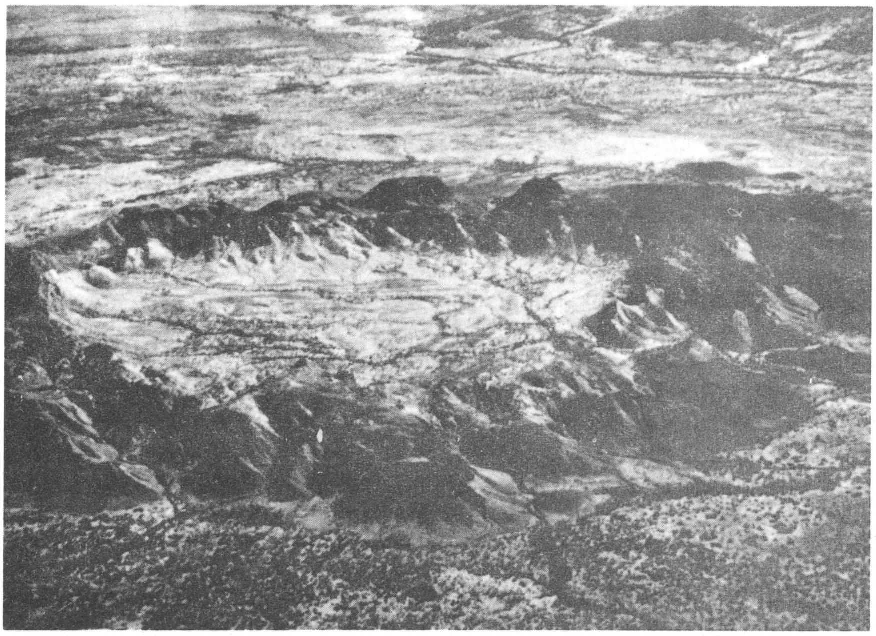

Fig. 2. - The central cliff ring of Gosses Bluff. An aerial view taken from the south-east.

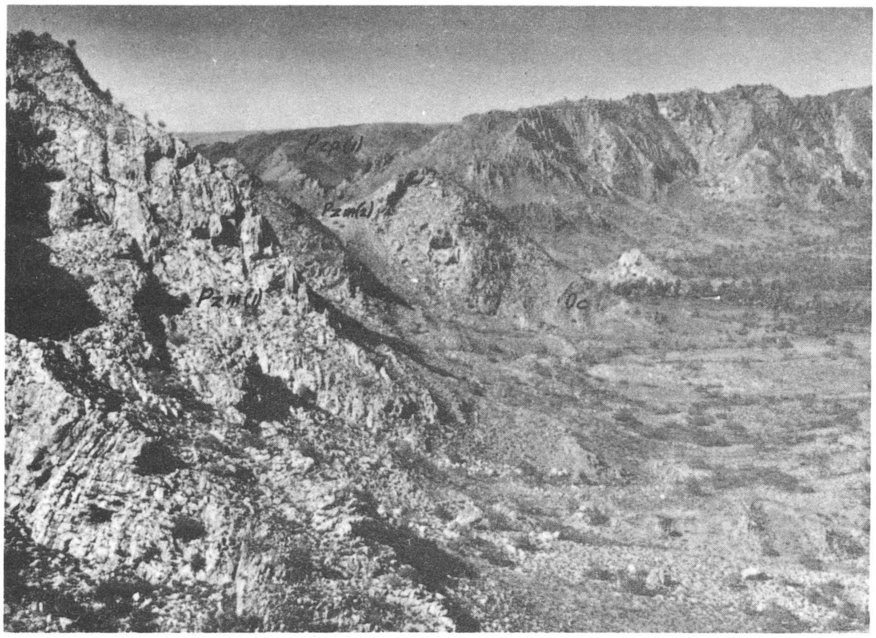

Fig. 3. - A part of the central depression of Gosses Bluff, looking from the north. The cliffs are formed by the lower unit of the Mereenie Sandstone (Pzml). The soft zone at the foot of the cliffs is the Carmichael Sandstone (Oc). A ridge of the lower sandstone unit of the Pertnjara Group can be seen in the background (Pzpl).

displaying a NNE-trending linear pattern.

The alluvial flats and the creek courses are marked by tall gum trees, the dunes are sparsely vegetated by low shrubs, and the travertine is typically covered by spinifex. Animal life in the area includes a prolific rabbit population, kangaroos, dingos, native cats, mice, and wild camels and horses. The area constitutes a marginal part of the Hermannsburg mission lands, and is bounded on the west by the lands of the Petermann Ranges aboriginal reserve. In view of the growing interest in Gosses Bluff, the Northern Territory Administration plans to declare the area a reserve.

## II. STRATIGRAPHY

The general sequence exposed at Gosses Bluff was described by Cook (1966) as follows.

| | | |
|---|---|---|
| Larapinta Group (Ordovician) | Brewer Conglomerate | Several thousand ft |
| | Hermannsburg Sandstone | 1000-2000 ft |
| | Upper part of Parke Siltstone | 100- 200 ft |
| | Middle sandstone unit within Parke Siltstone | 1000-1500 ft |
| | Lower part of Parke Siltstone | 200 ft |
| Pertnjara Group (Devonian-Carboniferous) | Mereenie Sandstone (Silurian-Devonian) | 1000-1500 ft |
| | Carmichael Sandstone | 500-1500 ft |
| | Upper part of Stokes Siltstone | |
| | Lower part of Stokes Siltstone | 500+ ft |
| | Upper part of Stairway Sandstone | |

Milton (pers. comm.) divided the Mereenie Sandstone into two units, and confirmed its Devonian age through the discovery of a fossil fish on the boundary between these sub-units. According to Milton's mapping the lower part of the Parke Siltstone is very poorly developed and not exposed on the bluff, thus casting some doubts as to the validity of the definition of a lower Parke Siltstone unit. Drilling at the Tyler (Magellan) No.1 Well, which penetrated horizontal strata

8.5 miles northeast of the centre of Gosses Bluff, encountered the following units*

| | |
|---|---|
| Brewer Conglomerate | 4350 ft |
| Hermannsburg Sandstone | 2780 ft |
| Parke Siltstone | 160 ft |
| Mereenie Sandstone | 2475 ft |

The low degree of exposure of the outer zone of Gosses Bluff and its structural complexity render even a rough estimate of the thickness of the various units impossible. This is clearly shown by the fact that the thicknesses encountered at the Tyler No.1 well are appreciably smaller than those which could be implied from the apparent width of the corresponding lithological belts around Gosses Bluff. These relationships indicate that, similar to the structural pattern of the central ring, the blocks of the outer zone are laterally imbricated in an en echelon pattern, which results in the duplication of units across the strike, and in a consequent thickening of the entire section. Thus, notwithstanding the possibility of facies and thickness changes between Gosses Bluff and Tyler No.1, the section encountered in the latter site is considered as a more reliable guide for the actual thicknesses of the units underlying the outer zone than any estimates within the deformed zone itself.

In comparing the sequence as described by Cook (1966) with the sequence encountered at Tyler No.1, it is apparent that the Mereenie Sandstone on the Bluff is thinner than at Tyler No.1, and that only one siltstone unit can be recognized in the latter. This supports the observation that lithologically the Mereenie Sandstone is practically continuous with the middle sandstone unit of the Parke Siltstone, as defined by Cook (1968). However, in view of the designation of the brown sandstone of the outer cliff ring of Gosses Bluff as belonging to the lower part of the Pertnjara Group by both Cook (1966, 1968) and Milton (pers. comm.), its classification as the uppermost part of the Mereenie Sandstone, although warranted on lithological grounds, will

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*Information released by Magellan Petroleum (N.T.) Pty Ltd.

result in further confusion. It must be stressed, however, that very likely the upper part of the unit defined at Tyler No.1 as Mereenie Sandstone, is equivalent to what has been defined as the lower part of the Pertnjara Group at Gosses Bluff.

Because of the above considerations, the following division of the Pertnjara Group is used in the present report:

1. Lower Sandstone of the Pertnjara Group (outer cliff ring) - Pzp(1)
2. Parke Siltstone (outer zone) - Pzp(2)
3. Hermannsburg Sandstone (outer zone) - Pzp(3)
4. Brewer Conglomerate (outer zone) - Pzp(4)

In the following, each of the units underlying the outer zone of Gosses Bluff will be briefly described.

<u>Parke Siltstone</u>. This unit is intermittently exposed over a one mile wide belt immediately surrounding the cliff ring of Gosses Bluff. This unit consists of interbedded sandstones, siltstones and shales, with the pelitic sediments constituting about one third of the sequence. The sandstones are brown and less commonly greenish in colour. Medium-grained sandstone predominates, but fine-grained varieties are present. In thin-section the quartz grains are subrounded and densely packed, with an argillaceous or calcareous cement. The siltstone and shale horizons range from a few inches to many feet in thickness. The shale is usually green, but oxidised brown shales occurring along the boundaries of green shale horizons or as independent layers are very common. The transitions from sandstone to shale are abrupt, and little grading has been observed. Mud-flake conglomerates within sandstone units are widespread. Because of the relative proximity of the Parke Siltstone unit to the centre of the structure, the sandstones and the shales are abundantly shatter-coned,or exhibit rhombohedral fracture patterns (section V). Mineralogical examination of breccia from Hermannsburg (BMR) No.1, believed to have been derived from the Parke Siltstone, disclosed the occurrence of minor zircon, phosphate, tourmaline, rutile,

apatite, chlorite amphibole, epidote and garnet (AMDEL report MP614-67).

Hermannsburg Sandstone. This unit is relatively better exposed than the other units underlying the outer zone, and constitutes a belt of low hills and shallow ridges encircling the bluff at an approximate distance of 1-2 miles from the cliff ring. The Parke Siltstone-Hermannsburg Sandstone boundary is gradational. The Hermannsburg Sandstone consists of cross-bedded and banded medium-grained and coarse-grained sandstones, gritstones and conglomeratic horizons. The coarser-grained sediments are particularly abundant at median stratigraphic levels, and individual beds can be traced over hundreds of feet. On the surface the sandstones are usually brown, but in drill cores white, grey, greenish and red sandstones have been also observed. In thin-section the sandstones display subangular to subrounded quartz grains cemented by argillaceous and calcareous matrices. Feldspar grains, lithic clasts and weathered detrital mica are common. Haematite staining is common in rocks collected from immediately below the weathering zone.

Brewer Conglomerate. The Brewer Conglomerate is exposed north and northeast of Gosses Bluff as flat-lying terraces flanked by rounded foothills on the north. The transition from the Hermannsburg Sandstone is achieved by means of a gradual increase in the abundance of conglomeratic horizons and pebbly sandstones. The Brewer Conglomerate consists of beds and lenses of pebble and boulder conglomerate interspersed with quartzose, feldspathic, and in places micaceous coarse-grained sandstones and gritstones. The sandstones are commonly cross-bedded, with the foreset beds dipping at angles up to 35 degrees. Some pebbly sandstone horizons contain large boulders isolated in sandstone matrix. The pebbles consist of a wide range of rock types, including variegated quartzite, gneiss, amphibolite, limestone, stromatolitic limestone, and scolithus sandstone. Evidently, most of the sequence presently exposed in the western Macdonnell Ranges, has been exposed contemporaneously with the deposition of the Brewer Conglomerate.

## III. STRUCTURE

### 1. Geophysical evidence

Gosses Bluff is situated near the northern margin of the Amadeus Basin, at the centre of the Missionary Syncline which is defined between the western Macdonnell Ranges flexure in the north and the Gardiner Range thrust Fault in the south. Seismic data (Geophysical Associates, 1965) show that the Bluff is located on the axis of a northeast-trending anticline which runs obliquely to the axis of the Missionary Syncline. A drill-hole (Tyler No.1) has been sunk on the axis of this anticline 8.5 miles northeast of Gosses Bluff by Magellan Petroleum.

Air-borne magnetic survey of the region (Young and Shelley, 1966) and section measurements in the western Macdonnell Ranges, show that the depth to the basement in the Gosses Bluff area is about 30,000 feet. A magnetic survey by Richards (1958) shows a positive magnetic anomaly about 1 mile east of Gosses Bluff. Preliminary results of a recent BMR air-borne magnetic survey indicate negative anomalies associated with the southwestern cliffs of the central structure, the western part of the outer zone, and in the Mount Pyroclast area.

The gravity Bouguer anomaly pattern of the central structure given in Richards (1958) shows a strong annular gravity low around the cliff ring, and a weak gravity high coinciding with the central depression. The current gravity survey carried out by the BMR confirmed these features. These anomalies are superimposed on a general southeast to northwest gradient, and may represent the breccia troughs around the Bluff, and a higher density of the sandstones drilled at Gosses Bluff No.1 (Exoil) reported by Cook (1966). The seismic information obtained in a BMR survey (Moss, 1964) and by Geophysical Associates, indicates that the Gosses Bluff structure coincides with a circular area 15 miles in diameter which yields poor seismic records, and is suggestive of the existence of a mild rim syncline around the bluff at depth below 12,000 feet. The deformed zone is underlain by strata dipping at a very low angle to the north. The area of poor record probably results in part of the extensive brecciation and shatter-cone fracturing within the deformed zone. The depth of the shatter-coned zone at the centre of the structure as determined in Gosses Bluff No.1 (Exoil) is 3000 feet, whereas the maximum radius of the shatter-coned zone as determined on the surface is 3.5 miles. The area of poor seismic records is therefore considerably more extensive than the highly fractured and brecciated zone. It is likely therefore that the poor record area, which broadly corresponds to the deformed zone as a whole, issues from the steep attitudes of the strata, as well as from the chaotic block structure which are typical of the Gosses Bluff area.

## 2. Boundaries of the Gosses Bluff structure

The mapping of the outer zone and the shallow drilling afford an approximate delineation of the deformed zone. . The outermost zones of deformed strata have been observed east and northwest of the bluff, as follows:

(1) Outcrops of highly disturbed beds of Brewer Conglomerate occur 7 miles due east of the centre of Gosses Bluff(loc.J14*).

(2) Steeply dipping beds of Brewer Conglomerate occur 5 miles northwest of the centre (loc.F3-F4).

(3) Steeply dipping beds of sandstone were cored at Hermannsburg (BMR) No.4, 4.9 miles west-northwest of the centre (loc.H3).

(4) Moderately dipping strata of sandstone and shale were cored at Hermannsburgh (BMR) No.17, located 7.5 miles southwest of the centre (loc.M1). Hermannsburg (BMR) No.12 drilled due southwest of this hole, penetrated horizontal beds.

The northern boundary of the deformed zone appears to be located somewhat closer to the centre of the structure than the eastern and southwestern boundaries. Thus, horizontal beds of Brewer Conglomerate crop out approximately 6 miles north of the centre of Gosses Bluff (loc.C7), and mildly dipping strata were drilled at Hermannsburg (BMR)

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*Refers to map reference grid.

No.21 and 22. In the northeast, the margin of the deformed zone occurs between Hermannsburg (BMR) No.26, where steeply dipping strata were cored, and loc.E.10, where horizontal and sub-horizontal beds were exposed. The boundary in this area is thus situated about 6 miles from the centre. It appears, therefore, that the radius of the deformed circular zone of Gosses Bluff ranges between 6 and 7 miles, with the longer diameter oriented about east-west. However, this conclusion must await confirmation by geophysical surveys.

Contrary to earlier views, and as far as can be assessed on the basis of surface geology and the drilling, the boundaries of the deformed zone are abrupt. There appears to be no gradual change from the steeply dipping strata of the Gosses Bluff structure into the horizontal to sub-horizontal strata of the Missionary Plain. In at least two places vertical and overturned beds were observed to persist to the limit of the structure (locations J14 and F3-F4).

Sub-horizontal beds of Brewer Conglomerate are exposed at numerous localities over the Macdonnell Ranges pediment north of Gosses Bluff. The detailed structural pattern of this area is masked by the steep-angled cross-bedding and primary sedimentary dips,coupled with the small size of the exposures.

## 3. Structure of the Outer Zone

Because of the low degree of exposure within the outer zone, the detailed structure of this area is largely unknown. Nevertheless, surface mapping of the isolated outcrops of this area, coupled with the shallow drilling programme, yielded a considerable amount of information on the general structural pattern of the outer zone.

Most bedding planes measured on the outer zone have a steep dip and strike at approximately tangential or nearly tangential directions with respect to the circular cliff ring. These attitudes indicate that the generally concentric structural pattern reflected by the cliff ring of Gosses Bluff persists within the outer zone. Whether individual blocks characterized by relatively uniform strike grade into one another

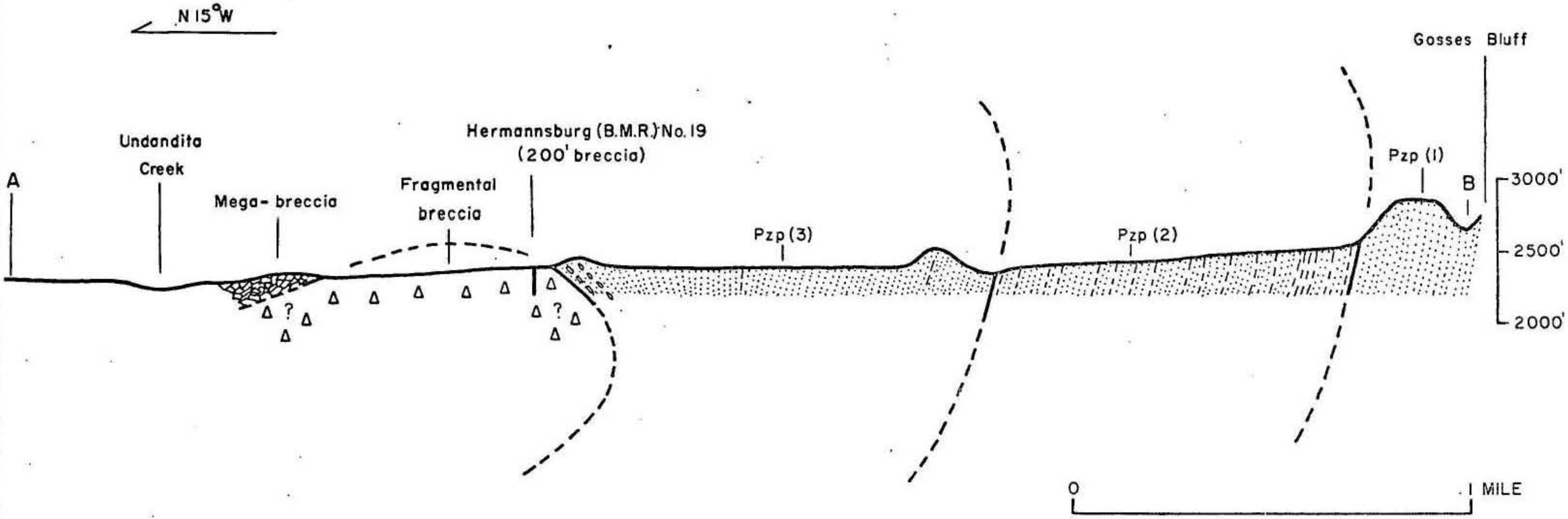

Fig. 4 Diagrammatic cross-section through the northern part of the outer zone of Gosses Bluff

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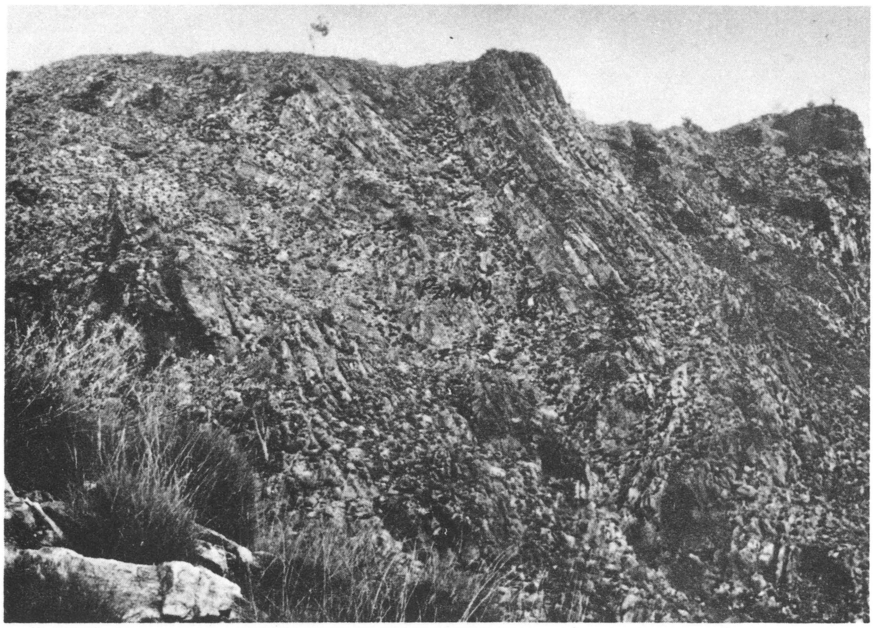


Fig. 5. - A transition from steeply dipping to overturned strata of lower Mereenie Sandstone within the cliff ring of Gosses Bluff. The flat top represents relics of a pre-existing peneplain.

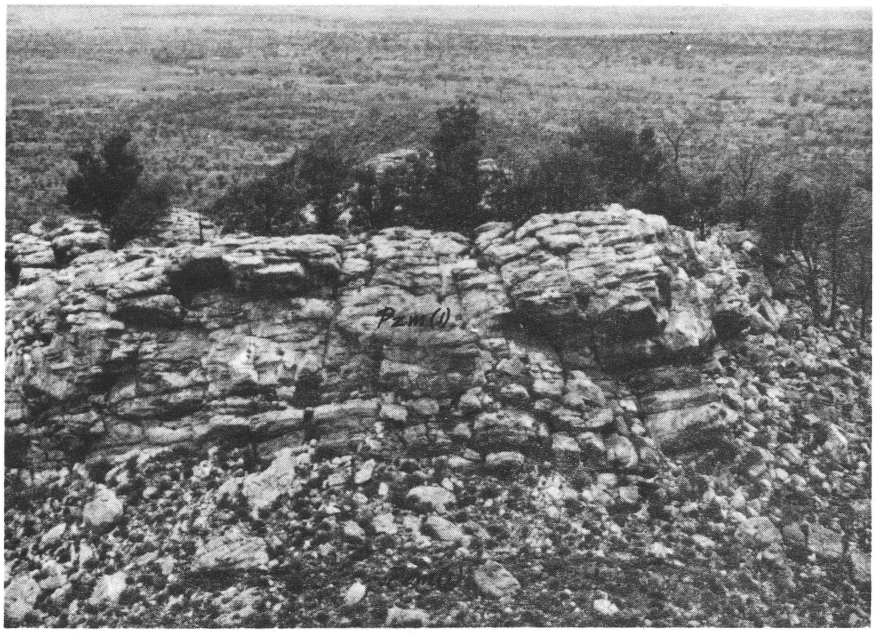


Fig. 6. - An overturned block of lower Mereenie Sandstone, resting on red sandstone horizon which represents a transitional zone into the upper Mereenie Sandstone. The red sandstone rests on steeply dipping Pertnjara Sandstone, not shown in this picture.

through steep axial flexures, or are separated by faults, could not be assessed. In the central structure, faulting is more important than flexuring, and this condition may apply to the outer zone as well. This view is supported by the common occurrence of abrupt changes in dip and strike in several areas of the outer zone (e.g. loc.G8, loc. K7, and the NE corner of loc. F8). Large-scale flexuring has been observed only around loc.F7, where beds of Hermannsburg Sandstone curve northward along a meridional axis of symmetry which may represent a major fault line which strikes in continuation with the north-south symmetry axis of the central structure.

As determined on the basis of cross-bedding orientation, the strata at the outer zone usually face outward from the centre. The dips are mostly subvertical to vertical, and commonly overturned. The dips within small areas may vary appreciably, implying the occurrence of folding and/or faulting, the details of which are mostly unknown. No consistent orientation of fold axes could be deduced. Some of the roots of overturned and imbricated bedrock segments are flexured on horizontal axes (Figs 4,5), whereas slight changes in the strike of some large blocks indicate steeply plunging fold axes.

## IV. BRECCIAS

Fragmental breccia, quartzitic breccia, flow-breccia and mega-breccia constitute a suite uniquely associated with the Gosses Bluff structure. The distribution of the breccias with respect to the structure as a whole will be considered in the following sections. In the following, the petrography of the breccia and the relationships of the various breccia types with each other will be considered first.

### 1. Fragmental breccia

These breccias were described in detail by Cook (1966, 1968) from both surface exposures and drill cores. The present study indicates that the breccias correspond in composition to the parent rocks with which they are commonly associated in space. Thus, the breccias occurring within the central structure consist of white quartzite sandstone derived from the lower unit of the Mereenie Sandstone, and less commonly from the Stairway Sandstone (Milton, pers. comm.). On the outer zone, the breccias which occur around Hermannsburgh (BMR) No.1 (loc. H5) abound in green and brown shale fragments, petrographically identical with the shale of the Parke Siltstone which constitutes the wall of the breccia trough in that area. Similarly, breccias occurring at Hermannsburg (BMR) No.19 (loc. F6) are composed of fragments of sandstone, gritstone, and conglomerate derived from the Hermannsburg Sandstone, which is exposed along the southern walls of the breccia zone. It is evident that the breccias are derived from the disintegration of the bedrock units with which they are associated in space, and are therefore subautochthonous, rather than allochthonous in origin.

The textures of the fragmental breccias, first described by Cook (1966), are characterized by the following general features:

(1) A high degree of angularity of the fragments
(2) Complete absence of sorting
(3) The common occurrence of shatter-cones in the fragments, as contrasted with their absence from the matrix.
(4) The occasional occurrence of preferred orientation of the fragments, and the development of flow deformation texture in shale-rich breccias (Figs 8,11).

The occurrence of flow deformations in the fragmental breccia testifies to the high pressures to which the breccia was subjected. The source of the pressure may be interpreted in terms of the lateral compression induced by advancing bedrock walls, and vertical pressures by over-riding bedrock plates. The latter plates, largely disintegrated into mega-breccia, collapsed over the finer-grained fragmental breccia, which was subsequently squeezed into joints in the overlying blocks (Figs 8, 9, 10).

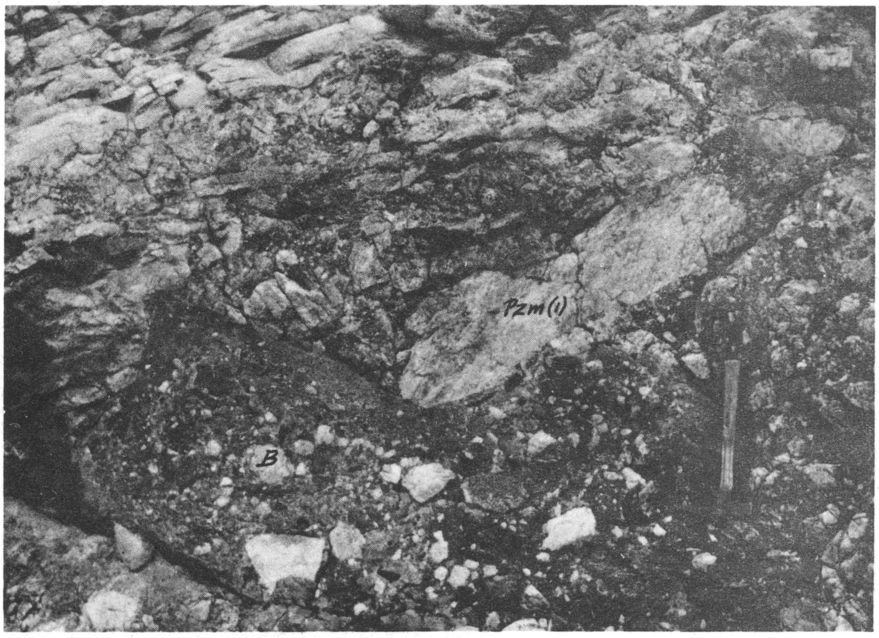


Fig. 7. - Fragmental breccia overlain by an overturned block of the lower unit of the Mereenie Sandstone. The breccia wedge which penetrates the base of the sandstone block may represent an incipient intrusion of the breccia (NW part of loc. J8).

Fig. 8. - Fragmental breccia (B) intruded into overturned blocks of Hermannsburg Sandstone (Pzp3). The northern breccia trough of the outer zone of Gosses Bluff (SE part of loc. F5).

Fig. 9. - Veins of breccia injected into fractures in Hermannsburg Sandstone. The northern breccia trough of the outer zone (SE part of loc. F5).

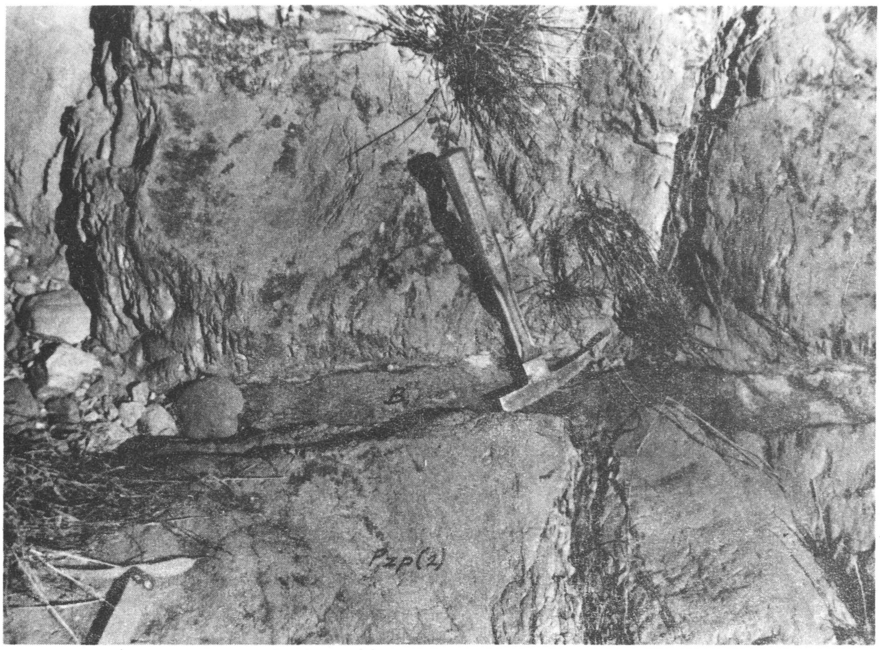


Fig. 10. - A dyke of micro-breccia intruded into sandstone of the Parke Siltstone (Eastern part of loc. H5).

The common retention of angular shale fragments in the breccias testifies against a sedimentary origin or later sedimentary remobilization of the breccia, which was suggested by some workers (Quinlan, pers.comm.). The matrix of the breccias comprises micro-fragments embedded in pulverised rock material, and which are mineralogically identical with the coarser fragments. Sedimentary features such as graded bedding or cross-bedding are absent.

### 2. Quartzitic breccia

Quartzitic breccia occurs beneath the Mount Pyroclast flow-breccia and as isolated outcrops at several localities around the bluff. The quartzitic breccia represents a thoroughly recrystallized equivalent of the fragmental breccia, and consequently forms a highly indurated rock. The outcrops of the quartzitic breccia are typically deep brown, and blocky (Fig.12). Shatter-coning of the fragments is more pronounced than in the fragmental breccia. Shale fragments are black to grey, of a uniform appearance, and are usually weathered out on exposed rock surfaces. A typical outcrop of quartzitic breccia is displayed in Fig.12.

The quartzitic aspect of the breccia could be ascribed to secondary silicification. There appears to be evidence, however, that the recrystallization resulted from heating associated with the explosion, as follows:

(1) In the southern breccia zone quartzitic breccias consistently occur beneath flow-breccias, and above fragmental breccias, and are thus presumably representative of the heated transition zone between the melted and normal breccias (Fig.13).

(2) No quartzitic bedrock similar to the quartzitic breccias was observed. Would the quartzitic aspect of the breccia be a result of secondary silicification, the same process could be expected to affect parts of the bedrock as well.

Isolated fragments and blocks of quartzitic breccia may occur as inclusions in partly melted flow-breccia. In these cases, the fragments and the blocks may be subrounded, probably as the result of marginal melting.

Fig. 11. - Fragmental breccia, cropping out near Hermannsburg (BMR) No. 1 well (SW part of loc. H5), showing deformed blocks of banded siltstone, set in finer fragmental breccia.

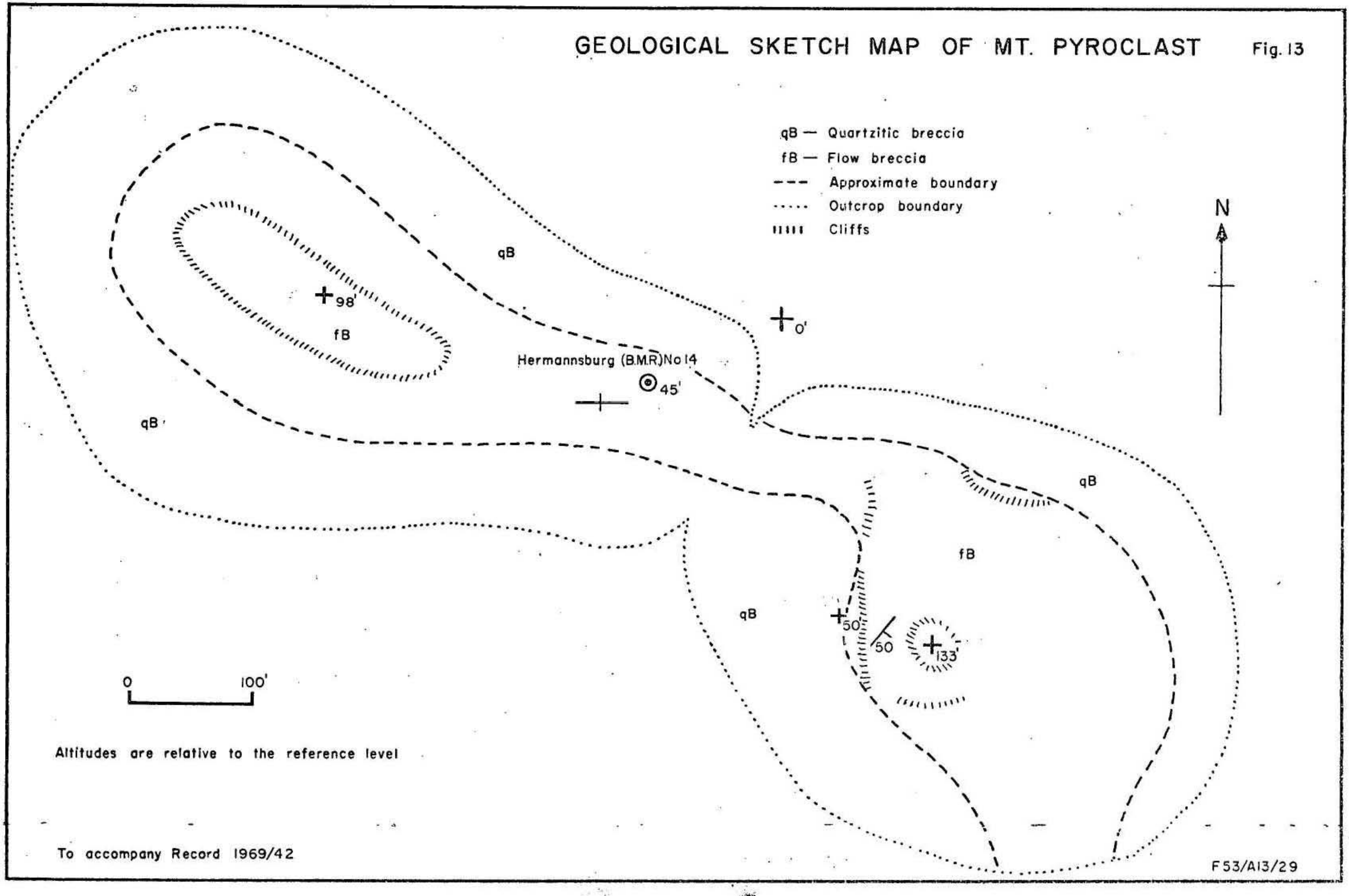
Fig. 12. - Quartzitic breccia. Angular fragments of recrystallized sandstone are set in an indurated micro-brecciated matrix. The recrystallisation is believed to have resulted from heating of the breccia. Exposure near Mt. Pyroclast (loc. L6).

### 3. Flow-breccia

The flow-breccia is certainly the most significant rock type associated with the Gosses Bluff structure, and appears to be representative of the shock-melted breccia from the immediate vicinity of the explosion. The best outcrops of flow-breccia occur at Mount Pyroclast (loc.L6-M6), but similar rocks were observed at a couple of hills northeast and northwest of Mount Pyroclast (localities K7-K8, L5-L6). Altogether three holes were sunk into flow-breccia (Hermannsburg Nos 13, 14, 31), providing continuous cores for detailed examinations.

As indicated by the sketch map of Mount Pyroclast (Fig.13), the flow-breccia invariably overlies quartzitic breccia. The exposed contact between these breccias occurs between 40 and 80 feet above the base of Mount Pyroclast. Drilling at the saddle between the two peaks of Mount Pyroclast, however, went through 45 feet of flow-breccia (approximately to the base level of the hill), showing that the flow-breccia overlies the quartzitic breccia along a highly irregular contact. The occurrence of quartzitic breccia at the bottom of the hole indicates that the flow-breccia constitutes an upper layer, rather than a dyke, which differs from the view of Brunnschweiler (1959).

In outcrop the flow-breccia consists of partly melted fragments of recrystallized quartzitic sandstones, baked mudstone, and lumps of devitrified silica glass embedded in a flow-banded matrix of devitrified silica glass (Figs 14, 15, 16, 17, 18, 19, 20). The quartzitic fragments may retain some of the primary bedding features. They are white to grey, with the typical brown and red colours of the sandstones of the Pertnjara Group being completely absent. This phenomenon may presumably be ascribed to a partial reduction of ferric iron into ferrous iron upon heating. A rare type of rounded fragments, conspicuous by virtue of their black colour and internal concentric pattern resulting in a zonation of the opaque, has been observed. The representative specimen is a ferruginous quartzite with 13.4 per cent ferric oxide and 2.75 per cent manganese oxide (A.M.D.E.L. Report No.AN1471-69). As the specimen came from a fresh outcrop, it is unlikely that its composition has been



GEOLOGICAL SKETCH MAP OF MT. PYROCLAST Fig. 13

Altitudes are relative to the reference level

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Fig. 14. - Shock-melted flow-breccia at Mt. Pyroclast (SE part of loc. L6). Note the flow in the left part of the picture.

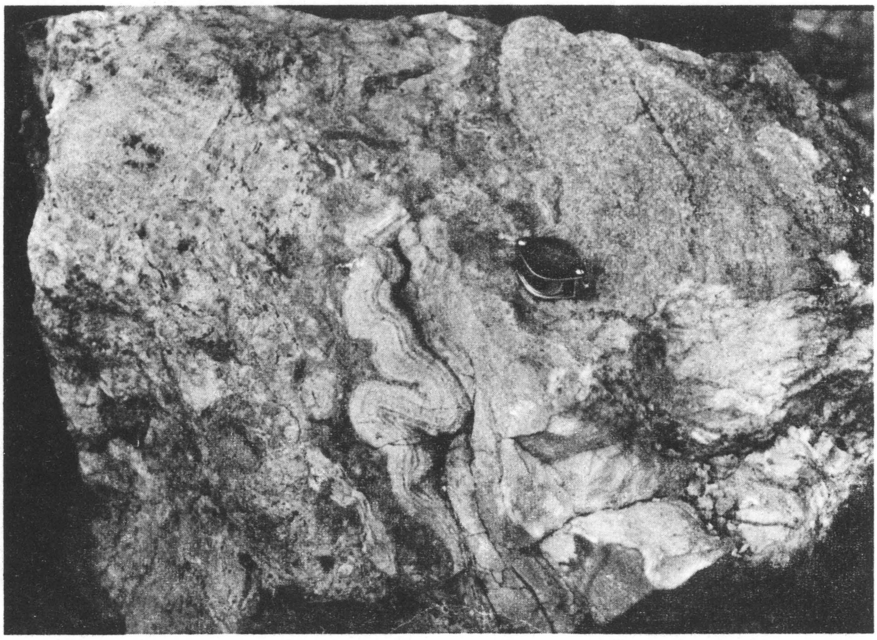

Fig. 15. - A ptygmatically folded flow of melted sandstone. Mt. Pyroclast. (SE part of loc. L6).

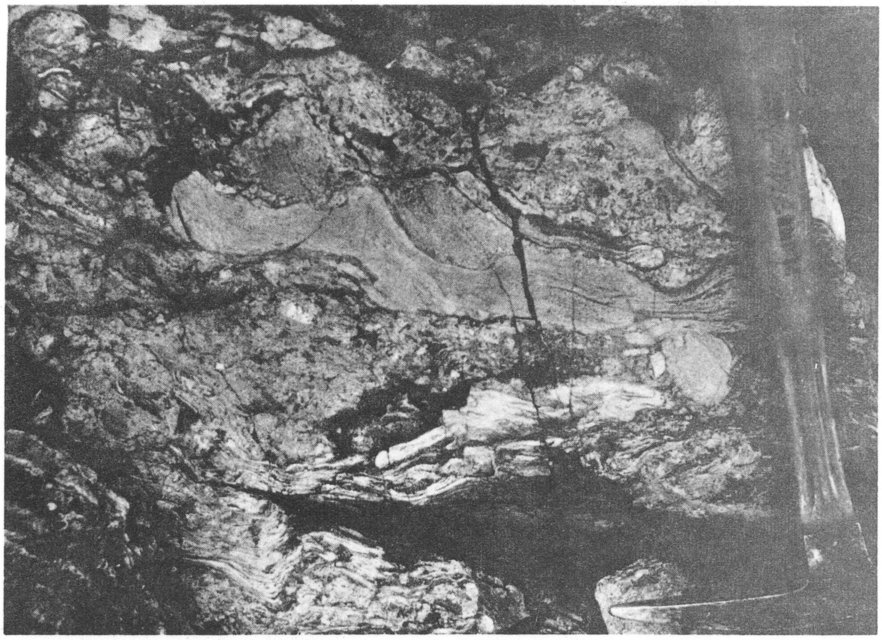

Fig. 16. - Flow structures in shock-melted flow-breccia, Mt. Pyroclast (SE part of loc. L6).

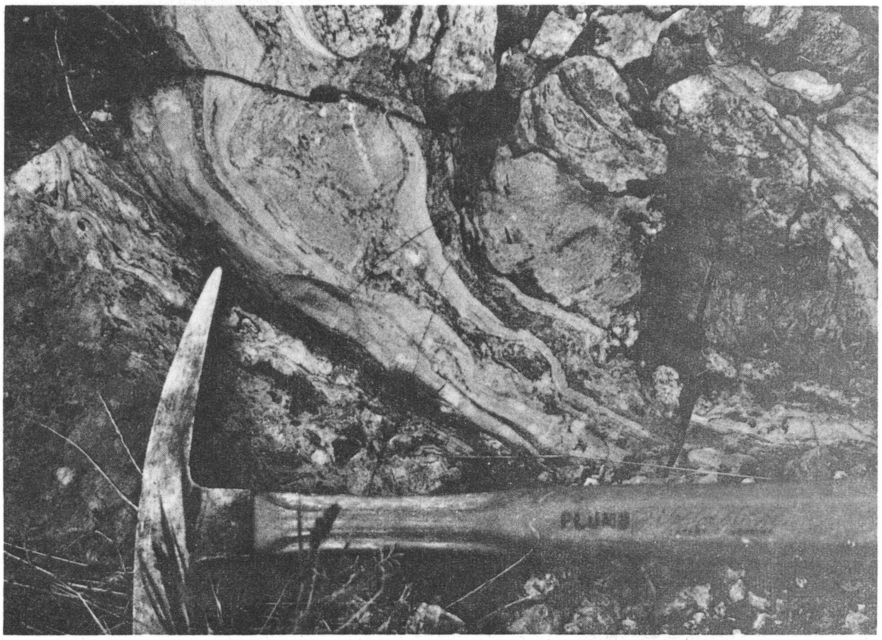

Fig. 17. - Flow structures in shock-melted flow-breccia. Mt. Pyroclast, (SE part of loc. L6).

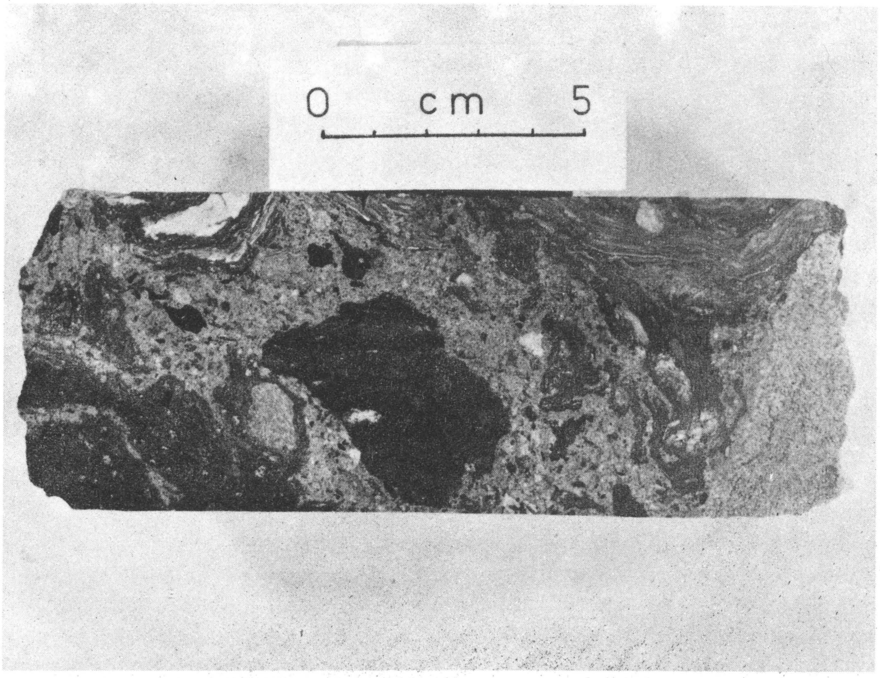

Fig. 18. - Flow-breccia with mudstone fragments (black) and sandstone fragments (white), embedded in a micro-brecciated matrix of devitrified silica glass. Drill core from Hermannsburg (BMR) No. 13, depth; 21'4".

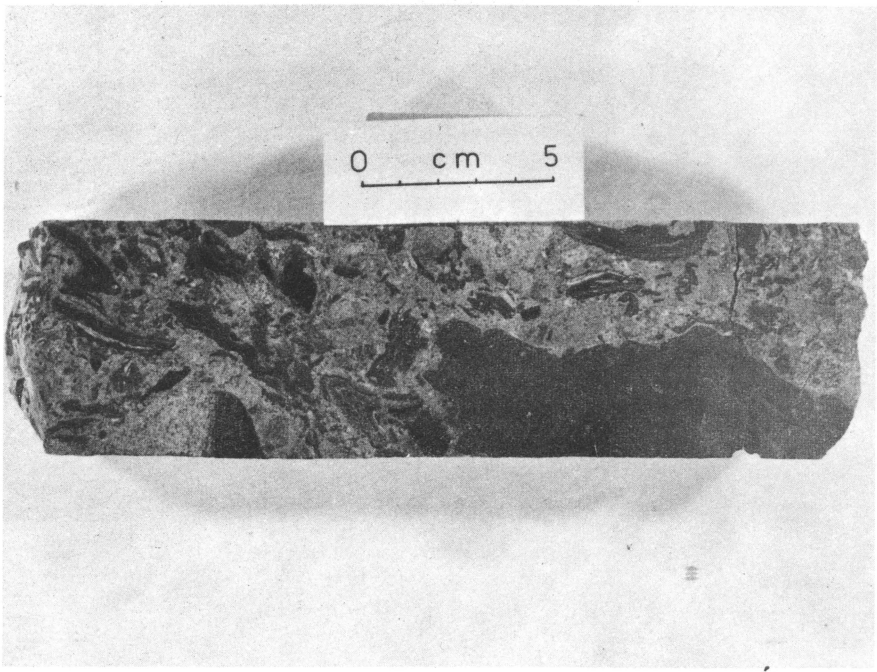

Fig. 19. - Flow-breccia, showing drawn-out mudstone fragments embedded in a finely brecciated matrix of devitrified silica glass. Drill core from Hermannsburg (BMR) No. 13, depth; 22'11".

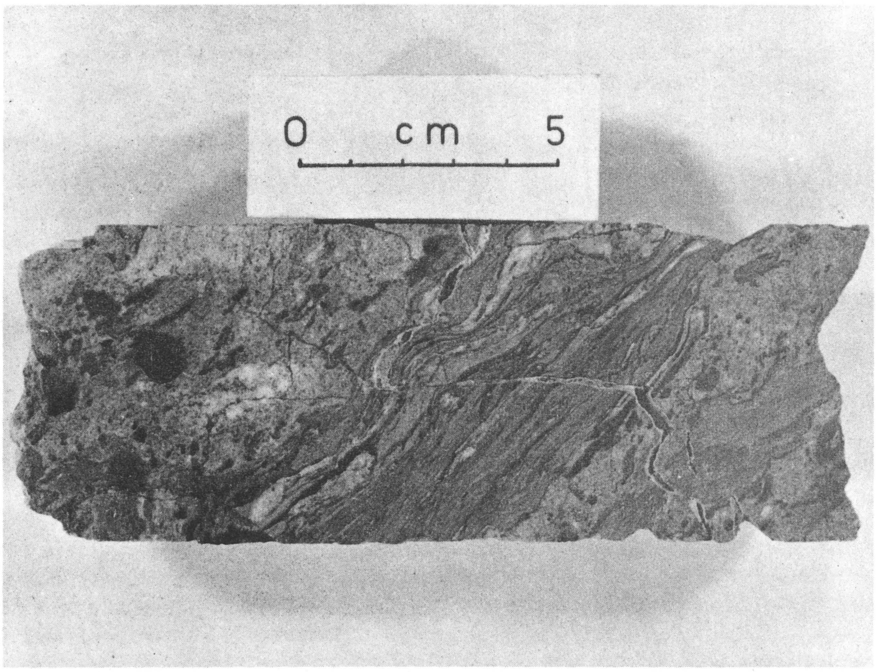

Fig. 20. - Flow-breccia, showing banded flows of devitrified silica glass, interspersed with brecciated matrix of mudstone fragments, sandstone fragments, and fragments of devitrified glass. Drill core from Hermannsburg (BMR) No. 13; depth, 9'11".

severely modified by weathering. One possibility is that the fragment represents a pre-existing lateritic crust, parts of which were incorporated in the breccia.

The devitrified glass flows are heterogeneously structured, with porous spongy masses of recrystallized silica alternating with ptygmatic flows of porcellaneous silica (Fig.15,20). The spongy masses abound in cavities which are commonly filled with zeolites (heulandite and laumontite, Cook, 1966), and in small druses of white and rose quartz. In outcrop the porous silica exhibits soft bulbous surfaces and poorly developed flow-banding. The porcellaneous silica, on the other hand, constitutes a dense compact light-coloured rock, with the flow banding very well developed. The flow bands may consist of dark and light-coloured laminae, presumably testifying to compositional segregation associated with the melting (Fig.20). Individual flows range from a few inches to many feet in length. The prevalent orientation of the flow structures varies in different sectors of Mount Pyroclast, but is usually steep to vertical. Thus the flowage planes are subvertical near Hermannsburg (BMR) No.14, and dip southeastward near the eastern peak of Mount Pyroclast. Observation of the cores of Hermannsburg (BMR) No.13 and No.14 also show a steep to vertical orientation of the flows.

Petrographic descriptions of thin-sections of the breccia were carried out by Schmerber (in Cook, 1966). The devitrified silica glass consists of cryptocrystalline to microcrystalline aggregates of quartz, accompanied by accessory opaques, feldspar, and mica. Breccia fragments may display multiple lamellar fracturing in the quartz grains, which are embedded in sericitic, calcareous, or haematitic matrices.

### 4. Mega-breccia

The chaotic structural picture of the northern part of the outer zone was pointed out by Cook (1966), who interpreted the structure in terms of dense faulting and the development of a mega-breccia, rather than of folding. The present study confirmed Cook's conclusion, and indicates that the blocks, which are up to several hundred feet in size, are separated from one another by narrow zones of fragmental breccia. The common association of quartzitic breccia with the mega-breccia, point to its original proximity to the centre of the explosion. No systematic orientation of the blocks has been observed. In many cases the blocks are overturned and overlie fragmental breccia (Figs 7,8). The mega-breccia of the northern part of the outer zone corresponds in composition to the Hermannsburg Sandstone, from which it has been derived by means of the disintegration of overturned bedrock plates.

## 5. Breccia troughs

The distribution and outline of the breccia troughs are significant for the understanding of the structure and the origin of Gosses Bluff. The geological mapping and the drilling can afford only a partial delineation of the breccia zones. It is hoped, however, that a more complete picture will be obtained from the detailed gravity and seismic surveys accomplished by the BMR. Earlier workers considered the breccia as the dominant rock type underlying the outer zone, and attributed the poor seismic record obtained in this zone to this factor (Crook and Cook, 1966; Cook, 1966, 1968). The mapping and drilling carried out in 1968 indicate that,as in the central structure, the breccia of the outer zone occupies trhoughs separated by zones of solid bedrock. On the outer zone the ratio of bedrock to breccia, as determined on the basis of the surface outcrop, is very roughly 5 to 1. This figure, however, might be misleading in view of the differential lithological control of the degree of exposure of the various rock types.

Although breccia occurrences were recorded in most sectors of the outer zone, the major outcrops occur to the north, northwest, and south of the central structure. These outcrops delineate the major breccia belts as follows:

The northwestern breccia zone:- This zone extends from loc.F8 in the east to loc.I4 in the west (refer to the enclosed geological map). It is approximately 5.5 miles long, and up to 1.5 miles wide. The trend is approximately parallel to the tangential strike of adjacent bedrock plates, except at its centre, where it cuts across the strike (around the eastern part of loc. G5).

While some isolated breccia outcrops lie directly on exposed bedrock surfaces (e.g. at loc.H4), drilling in the more continuous parts of the northern breccia zone failed to reach solid bedrock. Thus, Hermannsburg (BMR) No.1 and Hermannsburg (BMR) No.19 went through 500 and 200 feet of breccia respectively, without reaching the floor of the trough. As in the central structure, therefore, the breccia of the outer zone appears to lie with an irregular contact over the bedrock.

The southern breccia zone:- The flow-breccia and quartzitic breccia which crop out at Mount Pyroclast and several other localities south of the central structure, appear to represent a more or less continuous breccia zone whose minimum dimensions are 3 x 1.5 miles. Drilling within this zone penetrated 160 feet of breccia (Hermannsburg (BMR) No.13 and 47 feet of breccia (Hermannsburg (BMR) No.14) without reaching bedrock. At Hermannsburg (BMR) No.31, on the other hand, bedrock was reached at a depth of 33 feet. Wherever the relationships between the various breccia types could be assessed, the flow-breccia was observed to lie with an irregular contact over the quartzitic breccia, which in turn overlies fragmental breccia.

Isolated outcrops of breccia occur at several other localities within the outer zone. As testified by surface exposures at loc.F5, much of the breccia occurs beneath large blocks of overturned bedrock (Fig.8). In some areas a clue to the occurrence of buried breccia piles underneath bedrock plates is provided by breccia veins and dykes intruded into the bedrock plates (Figs 9,10).

## 6. Relationships between bedrock and breccia

Mapping of the central structure by Milton showed that much of the breccia associated with that zone occurs within concentric strike valleys hundreds of feet below the tops of adjacent bedrock ridges. Since little erosional redistribution of the breccia is evident, it appears that the emplacement of the breccia in the troughs is an original feature. This supposition is supported by the mode of occurrence of breccia in the outer zone, where the existence of deep troughs is demonstrated by the drilling. Fig. 4 displays a cross-section across the northern part of the northwestern breccia trough in the outer zone. The fragmental breccia in the trough is bordered to the south by overturned bedrock dipping toward the bluff, and by mega-breccia to the north. Both the bedrock and the mega-breccia consist of gritstones and fine conglomerates. In interpreting the structure of the area, it appears very likely that the mega-breccia represents the disintegrated fronts of overturned bedrock plates whose roots are represented by the bedrock ridge to the south of the breccia trough (Fig.4). If this view is correct, the mega-breccia should be underlain by fragmental breccia, which is supported by the relationships displayed by outcrops at loc.F3 (southern part), as shown in Fig.8.

The applicability of the above structural interpretation for the northwestern **breccia** belt as a whole is indicated by the consistently different nature of the southern and northern boundaries along the troughs. The southern boundary, wherever it has been observed, is characterized by a sharp transition between bedrock and fragmental breccia (e.g., at loc. H5-15, F6-F7). The northern boundary, on the other hand, shows a gradual transition from fragmental breccia into mega-breccia and densely faulted bedrock (e.g. northern part of loc.G5).

Isolated outcrops of breccia directly overlying bedrock outside the troughs were examined at several localities (e.g. locations H4, F10, J5). In one place only could the relationships between the flow-breccia and bedrock be observed. At and near Hermannsburg (BMR) No.31, located at the eastern part of loc.K7, the flow-breccia appears to grade into fragmental breccia which overlies densely faulted steeply dipping bedrock.

## V. SHATTER-CONES

Shatter-coning is considered a fracture pattern unique to large-scale astroblemes, and is ascribed to high velocity shock resulting from impact (Dietz, 1965). It is the widespread occurrence of shatter-cones at Gosses Bluff which led Creek to the crypto-explosion concept. Shatter-cones are developed to varying degrees in most lithological units of the central structure. The largest cones, with axes several feet long, are developed in the upper unit of the Mereenie Sandstone (Fig.21). Medium-sized shatter-cones occur in the sandstones of the Pertnjara Group (Fig.22), whereas small shatter-cones with axes only a few inches long were observed in shale of the Parke Siltstone. Certain units, like the lower Mereenie Sandstone and the Hermannsburg Sandstone, may be devoid of shatter-cones. Instead, these units may display a development of two sets of fractures imparting a rhombohedral aspect to the rock surfaces (Fig.23). These fractures are also well developed in association with shatter-cones, where they constitute the framework pattern according to which the shatter-cones are developed.

In the outer zone, shatter-coning has been observed at several outcrops and in drill cores at distances up to about 2 miles from the cliff ring. The shatter-cones are developed in sandstones, gritstones, conglomerates and shales, and are rather difficult to discern on weathered surfaces, even where their presence has been confirmed in nearby drill holes. The striated surfaces of the shatter-cones are often associated with thin veneers of green clay, and with calcareous crusts, which are considered to have been deposited from percolating ground water.

Dietz (1967), on the basis of a visit to Gosses Bluff, pointed out that the axes of the shatter-cones are generally directed toward a pre-existing focus at the centre of the Bluff. Comprehensive measurements of shatter-cone orientation in the central structure and the outer zone were carried out by Milton. The results show that upon rotation of the bedrock plates to their original horizontal position, performed on a stereographic projection, the shatter-cone axes point to a focus with a hypocentre very close to the centre of the structure, and at an elevation equivalent to a stratigraphic position somewhere

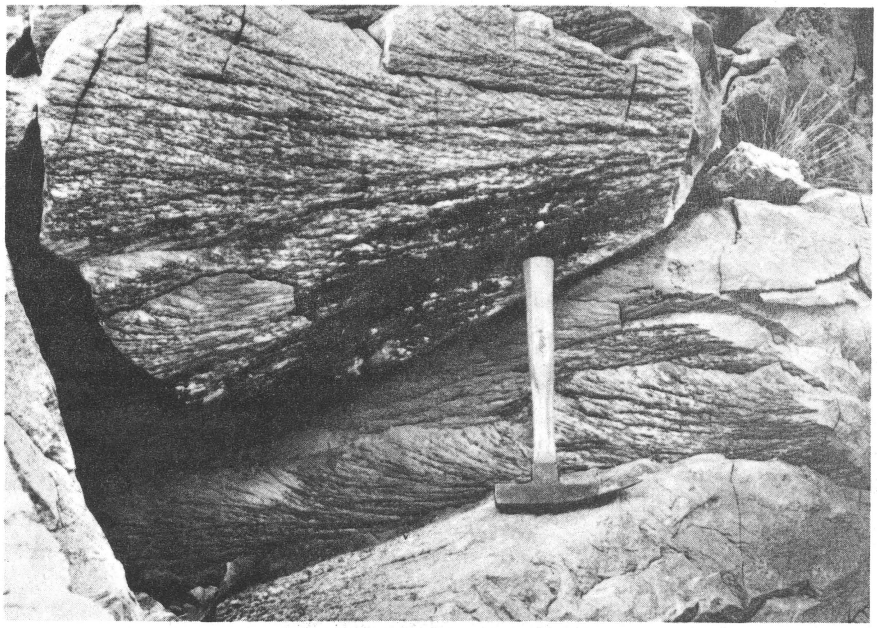

Fig. 21. - Shatter-cones developed in the upper unit of the Mereenie Sandstone (NW part of loc. J8).

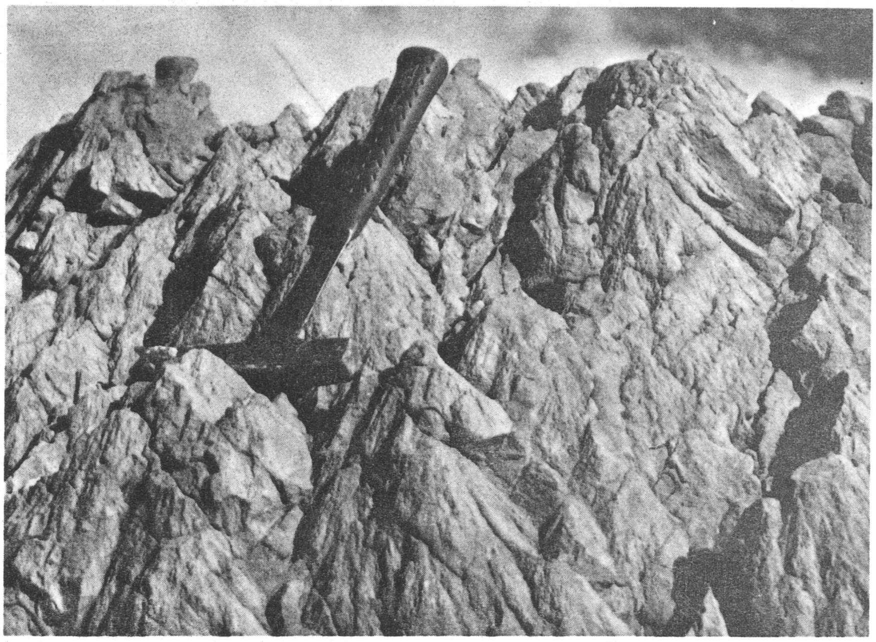

Fig. 22. - Shatter-cones developed in the lower sandstone unit of the Pertnjara Group (northern part of loc. J8).

Fig. 23. - Rhombohedral fracture system developed in sandstone of the Parke Siltstone (loc. H5).

between 3000 and 6000 feet above the contact of the lower sandstone of the Pertnjara Group and the Parke Siltstone (Milton, pers. comm.).

## VI. ORIGIN OF GOSSES BLUFF

### 1. The impact hypothesis

In spite of the considerable amount of structural, geophysical and petrographic information now available, the origin of the Gosses Bluff structure is still considered controversial by many geologists. Interpretations of the structure in terms of a diapir (Prichard and Quinlan, 1962; McNaughton, et al., 1968), igneous plug (Brunnschweiler, 1959), cryptovolcanic structure (Cook, in Crook and Cook, 1966), mud-volcano (Ranneft, pers. comm.), and astrobleme (Crook, in Crook and Cook, 1966), have been suggested. The merits and weaknesses of the various interpretations have been extensively discussed by Crook and Cook (1966) and by Cook (1966,1968), and are summarized in Table 1, where the explanations for each of the features of Gosses Bluff in terms of the various theories are compared. It is apparent from this comparison that the astrobleme theory has much to commend it. The similarity of Gosses Bluff to crypto-explosion structures such as the Sierra Madera structure, Wells Creek structure, Ries Crater, Vredefort Ring, and others, is evident from the centripetal sense of deformation, the extensive development of brecciation, occurrence of fusion breccias, shatter-cones, and strain lamellae in quartz (Cook, 1966). The strikingly consistent association of these features in crypto-explosion structures indicates a common origin. Consequently, the problem of the origin of Gosses Bluff cannot be considered separately from the question of the significance of the entire class of structures of its type.

The main difficulty in proving the impact hypothesis with respect to crypto-explosion structures is the usual absence of material of extra-terrestrial origin. This absence could be interpreted in terms of a complete vaporization of a solid missile, or alternatively in terms of a comet impact (Crook, 1967). The first possibility is supported by the discovery of iron-nickel globules in the shock-melted glass of

Table 1 - A comparison between the principal hypotheses related to the origin of Gosses Bluff.

| | Igneous-plug hypothesis (Brunnschweiler, 1959) | Diapir hypothesis (McNaughton et al, 1968) | Cryptovolcanic hypothesis (Crook and Cook, 1966) | Mud-volcanoe hypothesis (Ranneft, in press) | Astrobleme hypothesis (Crook and Cook, 1966) |
|---|---|---|---|---|---|
| Centripetal sense of deformation | not explained | May occur in diapirs | not explained | not explained | characteristic of crypto-explosion structures |
| Overturning and imbrication of blocks | not explained | Possible in diapirs | possible | possible | Adequately explained |
| Breccia troughs | not explained | Would be unusual in diapirs | possible | possible | Explained as breccia caught between deformed bed rock plates |
| Flow-breccia | Interpreted as contact effect | not explained | Explained as contact effects | Interpreted by Ranneft (in Press) as due to surface burning of emanated hydrocarbons | Explained as due to shock melting of the sandstones |
| Shatter-cones | not explained | not explained | Absent in circular structures of undoubted volcanic origin | not explained | Explained as due to high-velocity impact and/or due to explosion |
| Strain lamellae in quartz | not explained | not explained | Not detected in association with volcanic features | not explained | Explained as due to shock |
| Correspondence to geophysical evidence | A granitic plug could explain the gravity low | Explains the gravity low. Corresponds to the available seismic data (Moss, 1964) | The gravity low could be explained as reflecting an acid igneous body | Would explain the gravity low | The gravity low may reflect the low density of the shatter-coned and brecciated zone |
| Advantages | | Corresponds rather well to the geophysical data | Explains the location of Gosses Bluff on the axis of the NE-trending anticline | Explains the location of Gosses Bluff on the axis of the NE-trending anticline | Explains most of the features of Gosses Bluff |
| Weaknesses | No igneous activity of phanerozoic age is recorded in the area | Does not explain the shatter cones, flow-breccia and quartz lamellation | No phanerozoic volcanic activity is known in the region | No central vent is present. Shatter cones, flow-breccias and quartz lamellations were not observed in association with mud volcanoes | No meteoritic material has been discovered. Does not explain the location of the structure on the NE-trending anticline |

the Ries crater in Bavaria (Shoemaker and Chao, 1961). The experimental approach to the problem shows that features such as shatter-cones, strain lamellae in quartz, conversion of quartz and feldspar into glass without melting, and the formation of high-pressure polymorphs of quartz (coesite and stishovite) - can only be produced by instantaneously applied extremely high pressures, like those produced by nuclear explosions. Dietz (1959) has calculated that the energy of volcanic explosions falls short of the scale necessary to account for the above features. This conclusion is supported by the apparent absence of shatter-cones from circular features of undoubted volcanic origin. On the other hand, the energy released by high-velocity impact is more than sufficient to account for the features associated with crypto-explosion structures. Furthermore, that the origin of the explosion was not subterranean is indicated by the decrease of the degree of disturbance with increasing stratigraphic depth. It is therefore generally agreed that the astrobleme hypothesis, implying a relatively shallow explosion focus, explains best the known features of crypto-explosion structures of the Gosses Bluff type.

## 2. Sequence of events

A proposed sequence of events which led to the formation of Gosses Bluff is shown in fig.24. The earliest effect of the impact must have been the development of shatter-cone fracturing of the horizontal beds of the Missionary Syncline, over an aureole at least 2 miles in radius, since a sequence over 10,000 feet thick is affected by shatter-coning. The focus of the shatter-cone system, as determined by Milton (pers. comm.), was located between 3000 and 6000 feet above the base of the Parke Siltstone, and was therefore between 1500 and 4500 feet below the ground level, assuming that the present uppermost stratigraphical level of the Brewer Conglomerate roughly coincides with the stratigraphic top at the time of the impact. If this conclusion is correct, it follows that the shatter-coning developed from the impact and/or the explosion in depth, rather than upon the initial contact of the missile with the ground. In any case, the development of shatter-cone fracturing preceded brecciation, as is evident from the occurrence of shatter-cones in breccia fragments, and their absence from the matrices.

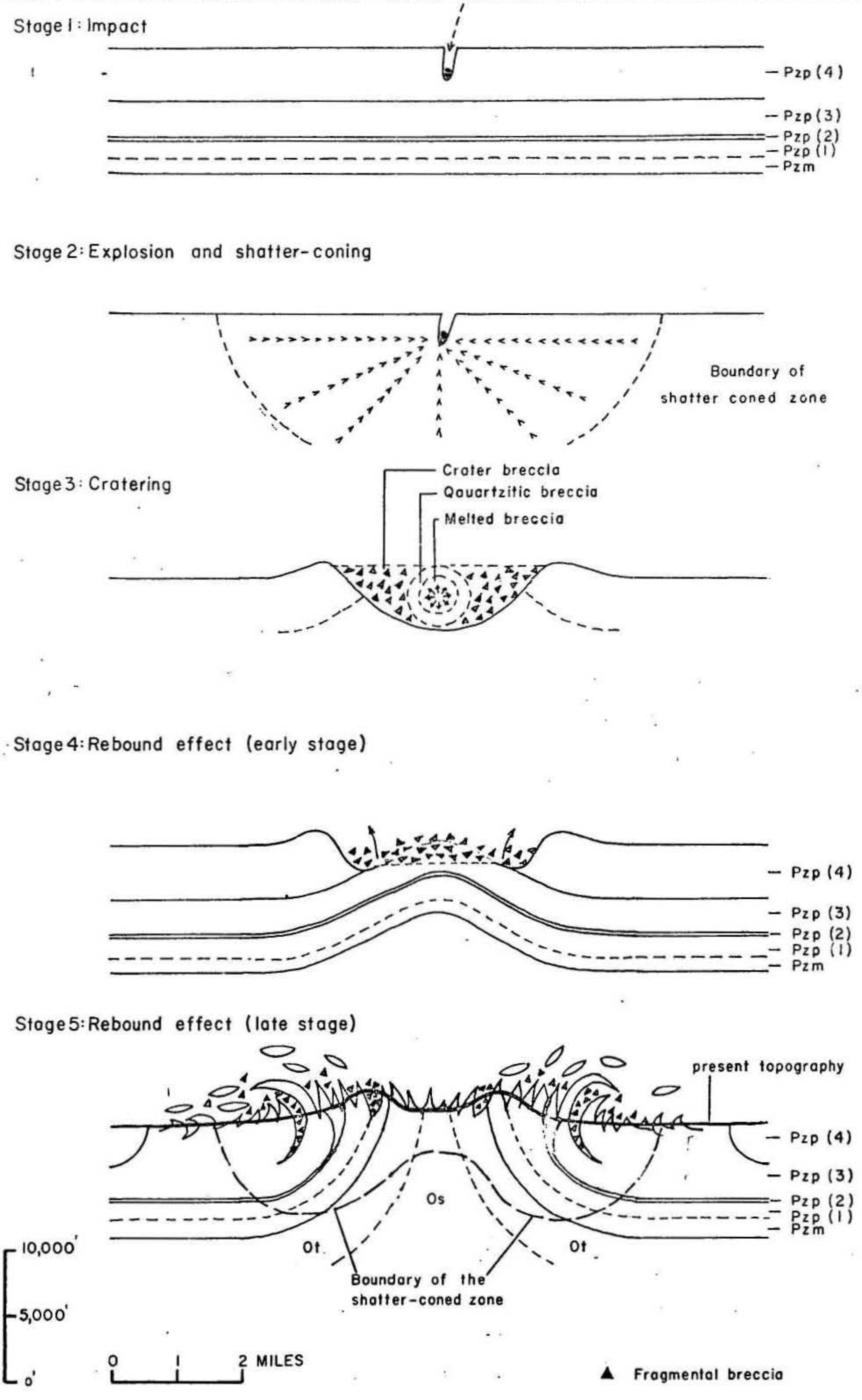

Fig.21 Schematic representation of the formation of the Gosses Bluff Structure

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The penetration and stopping of the missile resulted in a transfer of kinetic energy into heat, which resulted in both the vaporization of the missile and the melting of the rocks in its immediate vicinity. The large-scale volume changes associated with these processes resulted in an explosion, which must have produced a breccia-filled crater. The crater breccia must have consisted mainly of fragments of the uppermost formation, that is, of Brewer Conglomerate fragments. That such breccias have not been disclosed to date, however, may imply that the existing breccias are not remnants of a crater breccia. The fragmental breccias of Gosses Bluff are closely associated in space with bedrock segments from which they have been derived (Section IV, 6), and therefore were probably formed through disintegration of bedrock associated with the rebound effect (see below). On the other hand, the consistent occurrence of upward transition from fragmental breccia into quartzitic breccia and into flow-breccia, suggests that the breccia retained its primary position with respect to the heat source. This apparent anomaly can perhaps be understood if the Mount Pyroclast breccias were considered as erratic masses of breccia ejected by the explosion, and which landed subsequent to the formation of the structure. If this is so, the upward sequence: fragmental breccia-quartzitic breccia-flow-breccia, may reflect the zonation of breccia types in the contact aureole surrounding the missile (Fig.24). Upon explosion, the fragmental breccia would have been thrown out first, the heated breccia next, and the melted breccia last - which, upon landing, would have resulted in the sequence observed at Mount Pyroclast. This hypothesis may be supported by the highly irregular boundaries between the various breccia types (section IV). If this interpretation is correct, the non-occurrence of fragments of the Brewer Conglomerate at Mount Pyroclast indicates that the melted aureole developed at least partly within breccia derived from stratigraphically lower units. This implies either a penetration of the missile into these levels, or a partial rebound preceding the explosion.

The explosion resulted in the formation of a vacuum, followed by a rebound effect to which Gosses Bluff owes its existence. The formation of a central uplift has been simulated in chemical-explosive cratering in Canada and elsewhere. As indicated by the structural pattern of the Sierra Madera crypto-explosion structure (Wilshire and Howard, 1968), as well as by that of the Gosses Bluff structure, the rebound effect caused inward and upward movement of the blocks. At Gosses Bluff a centripetal sense of deformation is demonstrated by the en echelon pattern of the fault-bounded blocks constituting the central ring (Milton, pers. comm.). At its final stages, however, the upward movement must have been followed by a centrifugal rebound, as indicated by the imbricated overturned bedrock plates both within the central structure and in the outer zone. These movements were accompanied by the formation of great volumes of breccia, subsequently caught in gaps between the bedrock plates from which they were formed. The disintegration of ejected and imbricated bedrock plates resulted in the formation of mega-breccia. The high pressures to which the breccia were subjected are reflected by deformation patterns in shale-rich breccias, as well as by the development of dykes and veins of breccia, forcefully injected into overlying bedrock plates.

## 3. Age of the impact

The time interval within which the Gosses Bluff event occurred is defined by the age of the Brewer Conglomerate, which was involved in the deformation, and by the erosion surfaces which truncate the top of the central structure. As the age of the Brewer Conglomerate is probably Carboniferous (Wells et al., 1968), and that of the erosion surfaces is either early Tertiary or Mesozoic (Mabbutt, pers. comm.), the time interval in which the event which formed Gosses Bluff could have occurred is over 200 million years. Since the Brewer Conglomerate is a syn-orogenic deposit, it is likely that the event post-dated the Alice Springs orogenesis (Wells et al., 1968), and that the Missionary Syncline already existed at that stage. A more precise dating of the event could be attempted by means of isotope dating of the Mount Pyroclast flow-breccia. Palaeomagnetic dating of this breccia would be difficult in view of the scanty information on changes in the magnetic field during the late Palaeozoic and the Mesozoic. Possibly fission-track analysis of heated zircon and apatite incorporated in the quartzitic breccia will provide further information on the age problem.

## 4. Comparison with other crypto-explosion structures

Though to date over 50 craters, astroblemes, and crypto-explosion structures were recorded, only a few structures matching Gosses Bluff have been described. This fact can be understood, considering that Gosses Bluff is representative of the eroded roots of a crypto-explosion structure, whereas most other structures are either younger, and therefore not as deeply eroded, or are poorly exposed owing to post-explosion sedimentation. A list of meteorite impact structures and crypto-explosion structures, and the various features displayed by the associated rocks, is given by Short and Bunch (1966) (Table 2).

The crypto-explosion structure bearing the closest similarity to Gosses Bluff is the Sierra Madera structure in Texas (Wilshire and Howard, 1968). Both structures display a deformation pattern implying centripetal and upward movement, both have shatter-cones, breccias, breccia dykes and strain lamellae in quartz. The Sierra Madera structure, however, is smaller than Gosses Bluff, with a total diameter of about 7.5 miles, and a well defined rim syncline. Deformation patterns of the type prevailing at Gosses Bluff were also described from the Wells Creek basin in Tennessee (Wilson and Stearns, 1967) and the Vredefort Ring in South Africa (Manton, 1965). In the latter case, the rebound effect caused the cold emplacement of a solid granitic core, 25 miles in diameter. The granitic plug is enveloped by a 15 mile wide collar of overturned sediments representing an uplift of about 10 miles from the basement. A rim syncline is well developed around the Vredefort Ring.

Perhaps the best known crypto-explosion structure is the Rieskessel in Bavaria. The occurrence of high-pressure polymorphs of quartz, iron-nickel globules in the glass of shock-melted breccia, and of shatter-cones in the nearby Steinheim basin, indicates the genetic significance of shatter-cones as the products of impact.

## Table 2

## A WORLDWIDE INVENTORY OF FEATURES CHARACTERISTIC OF ROCKS ASSOCIATED WITH PRESUMED METEORITE IMPACT STRUCTURES

(Short and Bunch, 1966)

| STRUCTURES | UNITED STATES | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1. BARRINGER [METEOR] CRATER (ARIZON | 2. CROOKED CREEK (MISSOURI) | 3. DECATURVILLE (MISSOURI) | 4. FLYNN CREEK (TENNESSEE) | 5. GLASFORD (ILLINOIS) | 6. HOWELL (TENNESSEE) | 7. JEPTHA KNOB (KENTUCKY) | 8. KENTLAND (INDIANA) | 9. MANSON (IOWA) | 10. MIDDLESBORO (KENTUCKY) | 11. ODESSA (TEXAS) | 12. SERPENT MOUND (OHIO) | 13. SIERRA MADERA (TEXAS) | 14. WELLS CREEK (TENNESSEE) |
| CRATER DIAMETER (KILOMETERS) | 1.2 | 4.4+ | 4.4+ | 3.2+ | 4.4+ | 2.4+ | 3.5+ | 5.8+ | 31. | 5.8+ | 0.15(a) | 6.4 | 12. | 14. |
| **GENERAL CHARACTERISTICS** | | | | | | | | | | | | | | |
| STRUCTURE STUDIED BY FIELD AND/OR LABORATORY METHODS | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| STRUCTURE HAS BEEN CORE DRILLED | | | ● | ● | ● | ● | | | ● | | ● | | ● | ● |
| GEOPHYSICAL STUDIES: 1. GRAVITY | ● | | | ● | | | ● | | ● | | | ● | ● | ● |
| 2. MAGNETICS | ● | | | ● | | ● | ● | | ● | | ● | ● | ● | |
| 3. SEISMIC | ● | | | | | | | | | | | | ● | |
| SAMPLES AVAILABLE TO INVESTIGATORS | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| PUBLISHED REPORTS ON STRUCTURE ARE AVAILABLE | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | | ● | ● |
| PHOTOMICROGRAPHS OF ROCK THIN SECTIONS | ● | ● | ● | ● | ● | | ● | ● | ● | ● | ● | | ● | ● |
| ESTIMATED AGE: A. PRECAMBRIAN B. LOWER PALEOZOIC C. UPPER PALEOZOIC D. MESOZOIC E. CENOZOIC F. PLEISTOCENE-RECENT | F | BC | B | B | B | B | B | B | DE | CD | F | CD | D | CD |
| RIM AND/OR CRATER DEPRESSION STILL VISIBLE | ● | ● | ● | ● | | | | | | ● | ● | | | ● |
| STRUCTURAL UNITS STRONGLY DEFORMED | ● | ● | ● | ● | | ● | ● | ● | | ● | ● | ● | ● | ● |
| PRINCIPAL LITHOLOGIES: 1. SANDSTONE | ● | ● | ● | | ● | | | ● | | ● | ● | | ● | |
| 2. CARBONATES | ● | ● | ● | ● | | ● | ● | ● | | ● | ● | ● | ● | ● |
| 3. GRANITIC ROCKS | | | | | | | | | ● | | | | | |
| 4. VOLCANIC ROCKS | | | | | | | | | | | | | | |
| 5. METAMORPHIC ROCKS | | | | | | | | | ● | | | | | |
| 6. SOIL OR ALLUVIUM | | | | | | | | | | | | | | |
| ASSOCIATED "IGNEOUS" ROCKS OF POSSIBLE IMPACT ORIGIN | | | | | | | | | | | | | | |
| MEGABRECCIAS PRESENT (BLOCKS 1 FOOT OR LARGER) | ● | ● | ● | ● | | ● | ● | ● | | | | ● | | ● |
| SINTERED OR FUSED GLASS FRAGMENTS | ● | | | | | | | | ● | | | | | |
| INJECTION BRECCIA VEINS | ● | | | ● | | ● | ● | ● | | | | | | ● |
| SHATTER CONES | | ● | ● | ● | | | | ● | | ● | | ● | ● | ● |
| ASSOCIATED METEORITIC MATERIAL: 1. METEORITE FRAGMENTS | ● | | | | | | | | | | ● | | | |
| 2. Ni-Fe SPHERULES IN GLASS | ● | | | | | | | | | | | | | |
| HIGH-TEMPERATURE OR HIGH-PRESSURE PHASES: 1. COESITE/STISHOVITE | ● | | | | | | | ● | | | | | | |
| 2. LECHATELIERITE | ● | | | | | | | ● | | | | | | |
| 3. MASKELYNITE | | | | | | | | | | | | | | |
| X-RAY STUDIES OF SHOCKED MATERIALS | ● | | ● | ● | | | | ● | | | ● | | ● | |
| **PETROGRAPHIC FEATURES** (SYMBOLS DESIGNATE THE PARTICULAR MINERAL THAT DISPLAYS THE FEATURES) (A. QUARTZ; B. FELDSPARS; C. MICAS; D. CARBONATES; E. PYROXENES AND AMPHIBOLES) | | | | | | | | | | | | | | |
| MICROBRECCIAS (SOME OF "SUEVITE" TYPE) | ● | | ● | ● | | ● | ● | ● | ● | | ● | | | |
| "PSEUDOTACHYLITE" | | | | | | | | | | | | | | |
| RECRYSTALLIZATION | | ● | ● | ● | | | ● | ● | ● | | | | | ● |
| FUSED GLASS (FRAGMENTS OR MATRIX) | ● | | | | | | | | ● | | | | | |
| DECOMPOSED REFRACTORY MINERALS IN GLASS | ● | | | | | | | | | | | | | |
| DISORDERED MINERALS (INCLUDING THETOMORPHS) | ● | | | | | | | | ● | | | | | |
| PATCHY OR ANOMALOUS EXTINCTION | A | | | D | | | | A | AB | A | A | | | |
| SHOCK-INDUCED TWINNING | | | | D | | | | | | | | | | D |
| SHOCK-INDUCED CLEAVAGE | AB | | | D | | | | A | | | | | | |
| BASAL DEFORMATION LAMELLAE IN QUARTZ | ● | | | | | | | | | ● | | | | |
| ONE OR MULTIPLE SETS OF "PLANAR FEATURES" IN QUARTZ | ● | ● | | ● | | | | | ● | ● | | | ● | ● |
| MICROFRACTURES, NOT ASSOCIATED WITH CRYSTALLOGRAPHIC PLANES | ● | | | D | | | | | | | ● | | ● | |
| MICROSHEARING OF GRAINS | ● | | | D | | | | | | ● | ● | | | |
| KINK BANDING | ● | | | | | | | | | A | | | | |
| MEASUREMENTS OF C-AXIS, LAMELLAE, OR FRACTURE ORIENTATION | ● | | | ● | | | | | A<br>BC | ● | ● | | | |
| | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. |

| STRUCTURES | CANADA | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 15. BRENT (ONTARIO) | 16. CARSWELL LAKE (SASKATCHEWAN) | 17. CLEARWATER LAKES (QUEBEC) | 18. DEEP BAY (SASKATCHEWAN) | 19. HOLLEFORD (ONTARIO) | 20. LAC COUTURE (QUEBEC) | 21. LA MALBAIE (QUEBEC) | 22. MANICOUAGAN (QUEBEC) | 23. NEW QUEBEC (QUEBEC) | 24. NICHOLSON LAKE (N.W. TERRITORIES) | 25. PILOT LAKE (N.W. TERRITORIES) | 26. STEEN RIVER (ALBERTA) | 27. SUDBURY (ONTARIO) | 28. WEST HAWK LAKE (MANITOBA) |
| CRATER DIAMETER (KILOMETERS) | 3.5 | 34. | 30.(b) | 11.+ | 2.5 | 15.+ | 37. | 61.+ | 3.4 | 9.1+ | 6.7+ | (c) | 60.+(d) | 2.7 |
| **GENERAL CHARACTERISTICS** | | | | | | | | | | | | | | |
| STRUCTURE STUDIED BY FIELD AND/OR LABORATORY METHODS | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| STRUCTURE HAS BEEN CORE DRILLED | ● | | ● | ● | ● | | | | | | | ● | ● | ● |
| GEOPHYSICAL STUDIES: 1. GRAVITY | ● | ● | ● | ● | ● | | | ● | ● | ● | | ● | | ● |
| 2. MAGNETICS | ● | ● | ● | ● | ● | | | | | | | | ● | ● |
| 3. SEISMIC | ● | | ● | ● | ● | | | ● | | | | ● | ● | |
| SAMPLES AVAILABLE TO INVESTIGATORS | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| PUBLISHED REPORTS ON STRUCTURE ARE AVAILABLE | ● | ● | ● | ● | ● | ● | | ● | ● | ● | ● | ● | ● | ● |
| PHOTOMICROGRAPHS OF ROCK THIN SECTIONS | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| ESTIMATED AGE: A. PRECAMBRIAN B. LOWER PALEOZOIC C. UPPER PALEOZOIC D. MESOZOIC E. CENOZOIC F. PLEISTOCENE-RECENT | B | A | C | C | AB | AC | B | BC | F | B | C | D | A | D |
| RIM AND/OR CRATER DEPRESSION STILL VISIBLE | ● | | ● | ● | ● | ● | | ● | ● | | ● | | | ● |
| STRUCTURAL UNITS STRONGLY DEFORMED | ● | ● | ● | | ● | ● | | ● | ● | | | | | |
| PRINCIPAL LITHOLOGIES: 1. SANDSTONE | | ● | | | | | | | | | | | ● | |
| 2. CARBONATES | | ● | | | | | ● | | | ● | | | | |
| 3. GRANITIC ROCKS | ● | | ● | ● | ● | ● | | ● | ● | ● | ● | ● | ● | |
| 4. VOLCANIC ROCKS | | | | | | | | ● | | | | | | |
| 5. METAMORPHIC ROCKS | ● | ● | ● | ● | ● | ● | ● | ● | | ● | | ● | ● | ● |
| 6. SOIL OR ALLUVIUM | | | | | | | | | | | | | | |
| ASSOCIATED "IGNEOUS" ROCKS OF POSSIBLE IMPACT ORIGIN | ● | | ● | | | | | ● | | ● | | | | |
| MEGABRECCIAS PRESENT (BLOCKS 1 FOOT OR LARGER) | ● | | ● | | ● | | ● | ● | | ● | | | ● | ● |
| SINTERED OR FUSED GLASS FRAGMENTS | ● | | ● | | ● | ● | ● | ● | | ● | ● | ● | ● | ● |
| INJECTION BRECCIA VEINS | ● | ● | ● | | | | ● | ● | | ● | | ● | | ● |
| SHATTER CONES | | ● | ● | | | ● | | ● | | ● | | | ● | |
| ASSOCIATED METEORITIC MATERIAL: 1. METEORITE FRAGMENTS | | | | | | | | | | | | | | |
| 2. Ni-Fe SPHERULES IN GLASS | | | | | | | | | | | | | | |
| HIGH-TEMPERATURE OR HIGH-PRESSURE PHASES: 1. COESITE/STISHOVITE | | | | | ● | | | | | | | | | |
| 2. LECHATELIERITE | | | ● | | | | | | | | | | | |
| 3. MASKELYNITE | ● | | ● | | | | | ● | | | | | | ● |
| X-RAY STUDIES OF SHOCKED MATERIALS | ● | | ● | | ● | | | ● | | | | | ● | ● |
| **PETROGRAPHIC FEATURES** (SYMBOLS DESIGNATE THE PARTICULAR MINERAL THAT DISPLAYS THE FEATURES) (A. QUARTZ; B. FELDSPARS; C. MICAS; D. CARBONATES; E. PYROXENES AND AMPHIBOLES) | | | | | | | | | | | | | | |
| MICROBRECCIAS (SOME OF "SUEVITE" TYPE) | ● | | ● | | ● | ● | ● | ● | | ● | ● | ● | ● | ● |
| "PSEUDOTACHYLITE" | | | ● | | | | | ● | | | | | ● | |
| RECRYSTALLIZATION | ● | ● | ● | | | ● | ● | ● | | ● | ● | ● | ● | ● |
| FUSED GLASS (FRAGMENTS OR MATRIX) | ● | | ● | ● | | ● | ● | ● | | ● | ● | ● | ● | ● |
| DECOMPOSED REFRACTORY MINERALS IN GLASS | | | | | | | | | | | | | ● | |
| DISORDERED MINERALS (INCLUDING THETOMORPHS) | ● | | ● | | | | ● | ● | | | | ● | ● | ● |
| PATCHY OR ANOMALOUS EXTINCTION | AB | | AB | ● | A | ● | ● | B | A | | | AB | | A |
| SHOCK-INDUCED TWINNING | ● | | AB | | B | B | | ● | | | | | | D |
| SHOCK-INDUCED CLEAVAGE | AB | ● | AB | ● | AB | ● | | ● | ● | ● | ● | | | A |
| BASAL DEFORMATION LAMELLAE IN QUARTZ | ● | ● | ● | ● | | ● | ● | ● | ● | ● | ● | | ● | |
| ONE OR MULTIPLE SETS OF "PLANAR FEATURES" IN QUARTZ | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| MICROFRACTURES, NOT ASSOCIATED WITH CRYSTALLOGRAPHIC PLANES | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| MICROSHEARING OF GRAINS | | | | | ● | | ● | | | | | | ● | |
| KINK BANDING | ● | | AB | | A<br>BE | B | ● | | | ● | | | ● | C |
| MEASUREMENTS OF C-AXIS, LAMELLAE, OR FRACTURE ORIENTATION | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| | 15. | 16. | 17. | 18. | 19. | 20. | 21. | 22. | 23. | 24. | 25. | 26. | 27. | 28. |

| STRUCTURES | SOUTH AMERICA | | EUROPE | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 29. CAMPO DEL CIELO (ARGENTINA) | 30. MONTURAQUI (CHILE) | 31. CHASSENON [ROCHECHOUART] (FRANC | 32. KALLIJÄRV (ESTONIAN S.S.R.) | 33. KÖFELS (AUSTRIA) | 34. LAKE MIEN (SWEDEN) | 35. LAPPAJÅRVI (FINLAND) | 36. RIES KESSEL (W. GERMANY) | 37. STEINHEIM (W. GERMANY) |
| CRATER DIAMETER (KILOMETERS) | 0.1(e) | 0.5 | (f) | 0.1(g) | 4.8(h) | 6. | –5. | 24. | 2.8 |
| **GENERAL CHARACTERISTICS** | | | | | | | | | |
| STRUCTURE STUDIED BY FIELD AND/OR LABORATORY METHODS | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| STRUCTURE HAS BEEN CORE DRILLED | ● | | | | | | | ● | ● |
| GEOPHYSICAL STUDIES: 1. GRAVITY | | | | | | ● | | ● | ● |
| 2. MAGNETICS | | | | | | | | ● | ● |
| 3. SEISMIC | | | | | | | | ● | ● |
| SAMPLES AVAILABLE TO INVESTIGATORS | ● | ● | ● | | ● | ● | | ● | ● |
| PUBLISHED REPORTS ON STRUCTURE ARE AVAILABLE | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| PHOTOMICROGRAPHS OF ROCK THIN SECTIONS | | ● | ● | | ● | ● | | ● | ● |
| ESTIMATED AGE: A. PRECAMBRIAN B. LOWER PALEOZOIC C. UPPER PALEOZOIC D. MESOZOIC E. CENOZOIC F. PLEISTOCENE-RECENT | F | F | ? | F | ? | E | ? | E | E |
| RIM AND/OR CRATER DEPRESSION STILL VISIBLE | ● | ● | | ● | | ● | ● | ● | ● |
| STRUCTURAL UNITS STRONGLY DEFORMED | ● | | | | | | | ● | ● |
| PRINCIPAL LITHOLOGIES: 1. SANDSTONE | | | | | | | | | ● |
| 2. CARBONATES | | | | ● | | | | ● | ● |
| 3. GRANITIC ROCKS | | ● | ● | | ● | ● | ● | ● | |
| 4. VOLCANIC ROCKS | | | | | | ● | | | |
| 5. METAMORPHIC ROCKS | | | ● | | ● | ● | ● | ● | |
| 6. SOIL OR ALLUVIUM | ● | | | | | | | | |
| ASSOCIATED "IGNEOUS" ROCKS OF POSSIBLE IMPACT ORIGIN | | | | | | ● | | | |
| MEGABRECCIAS PRESENT (BLOCKS 1 FOOT OR LARGER) | | ● | | | | ● | | ● | ● |
| SINTERED OR FUSED GLASS FRAGMENTS | ● | ● | ● | ● | ● | ● | | ● | |
| INJECTION BRECCIA VEINS | | | ● | | | | | ● | |
| SHATTER CONES | | | | ● | | | | | ● |
| ASSOCIATED METEORITIC MATERIAL: 1. METEORITE FRAGMENTS | ● | | | ● | | | | | |
| 2. Ni-Fe SPHERULES IN GLASS | | ● | | | | | | ● | |
| HIGH-TEMPERATURE OR HIGH-PRESSURE PHASES: 1. COESITE/STISHOVITE | | | | | | ● | | ● | |
| 2. LECHATELIERITE | | | | | | | | ● | |
| 3. MASKELYNITE | | | | | | | | ● | |
| X-RAY STUDIES OF SHOCKED MATERIALS | | | | | | | | ● | ● |
| **PETROGRAPHIC FEATURES** (SYMBOLS DESIGNATE THE PARTICULAR MINERAL THAT DISPLAYS THE FEATURES) (A. QUARTZ; B. FELDSPARS; C. MICAS; D. CARBONATES; E. PYROXENES AND AMPHIBOLES) | | | | | | | | | |
| MICROBRECCIAS (SOME OF "SUEVITE" TYPE) | | ● | ● | | ● | ● | | ● | |
| "PSEUDOTACHYLITE" | | | | | | | | ● | |
| RECRYSTALLIZATION | | ● | ● | | | ● | | ● | |
| FUSED GLASS (FRAGMENTS OR MATRIX) | | ● | ● | | ● | ● | | ● | |
| DECOMPOSED REFRACTORY MINERALS IN GLASS | | | | | | | | ● | |
| DISORDERED MINERALS (INCLUDING THETOMORPHS) | | ● | ● | | ● | ● | | ● | |
| PATCHY OR ANOMALOUS EXTINCTION | | ● | A | | ● | AB | | AB | |
| SHOCK-INDUCED TWINNING | | | | | | | | | |
| SHOCK-INDUCED CLEAVAGE | | | | | ● | A | | ● | |
| BASAL DEFORMATION LAMELLAE IN QUARTZ | | | | | | | ● | ● | |
| ONE OR MULTIPLE SETS OF "PLANAR FEATURES" IN QUARTZ | | ● | ● | | ● | ● | ● | ● | ● |
| MICROFRACTURES, NOT ASSOCIATED WITH CRYSTALLOGRAPHIC PLANES | | ● | ● | | ● | | | ● | |
| MICROSHEARING OF GRAINS | | | | | | | | ● | |
| KINK BANDING | | | ● | | ● | C | | ● | |
| MEASUREMENTS OF C-AXIS, LAMELLAE, OR FRACTURE ORIENTATION | | ● | | | | A | ● | ● | |
| | 29. | 30. | 31. | 32. | 33. | 34. | 35. | 36. | 37. |

| STRUCTURES | AFRICA-ASIA | | | | | | | | | | AUSTRALIA | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 38. ASHANTI [LAKE BOSUMTWI] (GHANA) | 39. AOUELLOUL (MAURITANIA) | 40. LONAR LAKE (INDIA) | 41. PRETORIA SALT PAN (SOUTH AFRICA) | 42. RICHÂT (MAURITANIA) | 43. ROTER KAMM (S.W. AFRICA) | 44. SIKHOTE-ALIN (U.S.S.R.) | 45. TALEMZANE (ALGERIA) | 46. VREDEFORT (SOUTH AFRICA) | 47. WABAR (ARABIA) | 48. BOXHOLE (NORTHERN TERRITORY) | 49. DALGARANGA (WESTERN AUSTRALIA) | 50. GOSSES BLUFF (NORTHERN TERRITORY) | 51. HENBURY (NORTHERN TERRITORY) | 52. WOLF CREEK (WESTERN AUSTRALIA) |
| CRATER DIAMETER (KILOMETERS) | 11. | 0.25 | 1.8 | 1.1 | 50. | 2.4 | 0.03(i) | 1.9 | 40.+ | 0.1(j) | 0.15 | 0.02 | 19. | 0.20(k) | 0.83 |
| **GENERAL CHARACTERISTICS** | | | | | | | | | | | | | | | |
| STRUCTURE STUDIED BY FIELD AND/OR LABORATORY METHODS | ● | ● | ● | ● | ● | | ● | | ● | ● | ● | ● | ● | ● | ● |
| STRUCTURE HAS BEEN CORE DRILLED | | | ● | | | | | | | | | | ● | | |
| GEOPHYSICAL STUDIES: 1. GRAVITY | | | | ● | | | | | | | | | ● | | |
| 2. MAGNETICS | | | | | | | ● | | | | | | ● | ● | |
| 3. SEISMIC | | | | | | | | | | | | | ● | | |
| SAMPLES AVAILABLE TO INVESTIGATORS | ● | ● | ● | ● | ● | | | | ● | ● | ● | ● | ● | ● | ● |
| PUBLISHED REPORTS ON STRUCTURE ARE AVAILABLE | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| PHOTOMICROGRAPHS OF ROCK THIN SECTIONS | ● | ● | ● | ● | ● | | | | ● | ● | ● | ● | ● | ● | ● |
| ESTIMATED AGE: A. PRECAMBRIAN B. LOWER PALEOZOIC C. UPPER PALEOZOIC D. MESOZOIC E. CENOZOIC F. PLEISTOCENE-RECENT | EF | F | F | EF | C? | E | F | EF | AC | F | F | F | D | F | F |
| RIM AND/OR CRATER DEPRESSION STILL VISIBLE | ● | ● | ● | ● | | ● | ● | ● | | ● | ● | ● | ● | ● | ● |
| STRUCTURAL UNITS STRONGLY DEFORMED | ● | | ● | ● | | | | | ● | | | | ● | ● | ● |
| PRINCIPAL LITHOLOGIES: 1. SANDSTONE | | ● | | | ● | ● | | | ● | ● | | | ● | ● | ● |
| 2. CARBONATES | | | | ● | ● | | | ● | | | | | ● | | |
| 3. GRANITIC ROCKS | | | | ● | | | | | ● | | | | | | |
| 4. VOLCANIC ROCKS | | | ● | | | | | | | | | | | | |
| 5. METAMORPHIC ROCKS | ● | | | | | | | | ● | | ● | | | | |
| 6. SOIL OR ALLUVIUM | | | | | | | ● | | | | | | | ● | |
| ASSOCIATED "IGNEOUS" ROCKS OF POSSIBLE IMPACT ORIGIN | | | | | | | | | | | | | | | |
| MEGABRECCIAS PRESENT (BLOCKS 1 FOOT OR LARGER) | ● | | | ● | ? | | | | | | ● | ● | ● | ● | |
| SINTERED OR FUSED GLASS FRAGMENTS | ● | ● | | | | | | | | ● | | | ● | ● | |
| INJECTION BRECCIA VEINS | | | | | | | | | ● | | | | ● | | |
| SHATTER CONES | ● | | | | | | | | ● | | | | ● | | |
| ASSOCIATED METEORITIC MATERIAL: 1. METEORITE FRAGMENTS | | ● | | | | | ● | | | ● | ● | ● | | ● | ● |
| 2. Ni-Fe SPHERULES IN GLASS | ● | ● | | | | | | | | ● | | | | ● | |
| HIGH-TEMPERATURE OR HIGH-PRESSURE PHASES: 1. COESITE/STISHOVITE | ● | | | | | | | | | ● | | | | | |
| 2. LECHATELIERITE | | | | | | | | | | ● | | | | | |
| 3. MASKELYNITE | | | | | | | | | | | | | | | |
| X-RAY STUDIES OF SHOCKED MATERIALS | | ● | | | | | | | | ● | | | | | |
| **PETROGRAPHIC FEATURES** (SYMBOLS DESIGNATE THE PARTICULAR MINERAL THAT DISPLAYS THE FEATURES) (A. QUARTZ; B. FELDSPARS; C. MICAS; D. CARBONATES; E. PYROXENES AND AMPHIBOLES) | | | | | | | | | | | | | | | |
| MICROBRECCIAS (SOME OF "SUEVITE" TYPE) | ● | | | | | | | | | | | | ● | | |
| "PSEUDOTACHYLITE" | | | | | | | | | ● | | | | | | |
| RECRYSTALLIZATION | ● | | | | | | | | ● | | | | ● | | |
| FUSED GLASS (FRAGMENTS OR MATRIX) | ● | ● | | | | | | | | ● | | | ● | | |
| DECOMPOSED REFRACTORY MINERALS IN GLASS | ● | ● | | | | | | | | ● | | | | ● | |
| DISORDERED MINERALS (INCLUDING THETOMORPHS) | ● | | | | | | | | | A | | | ● | ● | |
| PATCHY OR ANOMALOUS EXTINCTION | ● | | | | | | | | | A | | | A | ● | |
| SHOCK-INDUCED TWINNING | | | | | | | | | | | | | | ● | |
| SHOCK-INDUCED CLEAVAGE | | | | | | | | | | ● | | | | | |
| BASAL DEFORMATION LAMELLAE IN QUARTZ | | | | | | | | | | | | | ● | | |
| ONE OR MULTIPLE SETS OF "PLANAR FEATURES" IN QUARTZ | ● | | | | | | | | ● | | | | ● | ● | |
| MICROFRACTURES, NOT ASSOCIATED WITH CRYSTALLOGRAPHIC PLANES | ● | | | | | | | | ● | ● | | | ● | ● | |
| MICROSHEARING OF GRAINS | | | | | | | | | ● | ● | | | ● | | |
| KINK BANDING | | | | | | | | | | | | | | | |
| MEASUREMENTS OF C-AXIS, LAMELLAE, OR FRACTURE ORIENTATION | ● | | | | | | | | ● | ● | | | ● | ● | |
| | 38. | 39. | 40. | 41. | 42. | 43. | 44. | 45. | 46. | 47. | 48. | 49. | 50. | 51. | 52. |

Footnotes to crater diameters. (a) (Odessa, Texas) Largest of three craters. (b) (Clearwater Lakes, Quebec) Largest of two craters; second crater 26 km in diameter. (c) (Steen River, Alberta) Subsurface structure, diameter unknown, indicated by geophysical anomaly approximately 10 by 30 km. (d) (Sudbury, Ontario) Present structure is elliptical, approximately 60 by 27 km. (e) (Campo del Cielo, Argentina) Largest of 12 known craters. (f) (Chassenon, France) Diameter unknown. A minimum diameter of 10 km estimated on basis of presently known distribution of fallback breccia. (g) (Kaalijärv, Estonian S.S.R.) Largest of 7 craters. (h) (Köfels, Austria) Estimated diameter. No definite circular feature is topographically visible. (i) (Sikhote-Alin, U.S.S.R.) Largest of 122 craters. (j) (Wabar, Arabia) Largest of two craters. (k) (Henbury, Australia) Largest of 13 craters.

Recently, a large crypto-explosion structure was discovered near Charlevoix, 65 miles northeast of Quebec (Rondot, 1968). The circular structure, 35 miles in diameter, is developed in intrusive rocks and high-grade metamorphic rocks, and comprises a central uplift surrounded by an annular graben. Shatter-cones, dykes of pseudotachylite, breccias, and planar features in quartz are well developed.

In comparing Gosses Bluff with the above structures, the following points are pertinent:

(1) Neither a rim syncline nor a central uplift can be differentiated at the structural level exposed at Gosses Bluff, with the highly deformed and overturned strata persisting right to the edge of the structure. The possible existence of a rim syncline at depth, suggested by the seismic surveys, has yet to be confirmed by further detailed seismic work.

(2) No circular faults have been so far disclosed at Gosses Bluff.

(3) No high-pressure polymorphs of quartz or remnants of extra-terrestrial material were disclosed at Gosses Bluff.

(4) The pattern of deformation, occurrence of shatter-cones, flow-breccias and strain lamellae in quartz, are the main features which Gosses Bluff shares with crypto-explosion structures of probable origin by impact of an extra-terrestrial missile.

## 5. Post-impact morphological evolution

With the absence of stratified sediments younger than the Brewer Conglomerate at Gosses Bluff, surface deposits and erosional surfaces constitute the only evidence at hand for the study of its post-impact evolution. Three erosional surfaces have been recognized in the Gosses Bluff area, as follows:-

(1) Relict plateau surfaces truncating the central uplift at an elevation of about 800 feet above the level of the Missionary Plain.

(2) A circular pediment sloping gently from the base of the cliff ring, and extensively coated by travertine crusts.

(3) The Macdonnell Ranges pediment, sloping gently southward from the base of the foothills of the Macdonnell Ranges, and coming into contact with the Gosses Bluff pediment along the Rudalls Creek.

The surface deposits in the Gosses Bluff area are classified under the following categories:

(1) Travertine crusts
(2) Older alluvial terraces
(3) Younger alluvial terraces
(4) Scree slopes (colluvium)
(5) Alluvial flats
(6) Aeolian deposits

The relict erosional surfaces at the top of the bluff were correlated with similar surfaces occurring at similar levels over the Macdonnell Ranges (Mabbutt, pers. comm.). Evidence for an early drainage system is afforded by the creek which drains the central depression of Gosses Bluff, and which has its uppermost extension on the western rim of the cliff ring (Milton, pers. comm.). The continuation of the erosive processes resulted in the accentuation of the cliff-ring morphology by means of the removal of the soft shales of the Stokes Siltstone from the centre, and the formation of the circular pediment around the cliff ring. These developments were conceivably contemporaneous with the formation of the Macdonnell Ranges pediment, which north of Gosses Bluff is developed mainly through the truncation of flat-lying beds of Brewer Conglomerate. The pediment is covered by relict alluvial terraces (Upper terrace) and by pebble drift, and is eroded by southward directed streams which open into narrow valleys occupied by lower-level alluvial terraces (lower terrace). The bulk of the pebbles of both the upper and lower terraces represent retransported pebbles of the Brewer Conglomerate, and are characterized, therefore, by a similar range of composition. The pebbles of the upper terrace commonly display yellowish weathering crusts, and may be cemented by travertine. Both features were not observed in conjunction with the lower terraces.

The cliff ring of Gosses Bluff is surrounded by scree slopes into which the radial gulleys which drain the circular ridge are entrenched. The colluvium comprises only sandstone pebbles derived from the Pertnjara and Mereenie Formations, and can therefore be easily distinguished from the upper and lower terraces of the Macdonnell Ranges pediment. The pebble drift of the Macdonnell Ranges pediment may in places cover portions of the Gosses Bluff pediment, which suggests that these pediments were continuous before the development of the present drainage system. In summarizing the morphological evolution of the area, the following sequence of events is conceived:

(1) Development of a regional peneplain
(2) Regional elevation, erosion, and the formation of the pediments and of the upper terraces
(3) A dry period, formation of travertine, and development of dunes
(4) Rejuvenated erosion associated with regional uplift and with the onset of more humid climatic conditions, resulting in the present drainage system and the lower terraces.

## VII. SUMMARY AND CONCLUSIONS

The field study of the outer zone of Gosses Bluff, coupled with the shallow drilling programme within this zone, brought forward the following evidence:

(1) The outer zone consists of concentric to sub-radial troughs of breccia, separated by extensive zones of steeply dipping and overturned bedrock.

(2) The structure of the outer zone is essentially the same as that of the central cliff ring, the differences being mainly in scale rather than in the pattern of deformation

(3) The diameter of the Gosses Bluff structure ranges between 12 and 14 miles. The deformed zone appears to have sharp boundaries with the little disturbed strata of the Missionary Syncline.

(4) The depth and narrowness of the breccia troughs indicate that the formation of the structure was associated with the opening of gaps, probably along fault planes. Some of these breccia troughs were subsequently buried under overturned bedrock plates

(5) The Mount Pyroclast flow-breccia rests with an irregular contact on heat-affected quartzitic breccia, which in turn rests on fragmental breccia

(6) The absence of breccia derived from the Brewer Conglomerate remains a problem to be explained.

Though the past and the current surveys have provided abundant information on the Gosses Bluff structure, and though in the light of present knowledge the impact hypothesis appears the most likely explanation, the details of the event which created the structure are still little understood. The complete story will probably never be uncovered. It is hoped, however, that the seismic, gravity, and air-borne magnetic surveys, when correlated with the geological results, will afford a clearer picture of the Gosses Bluff structure.

## ACKNOWLEDGEMENTS

I am grateful to Mr J.N. Casey, Dr P.J. Cook, Mr W.B. Dallwitz, Mr D. Guppy and Mr J. Perry for their useful comments. I would also like to thank other members of the BMR who helped in various ways in the Gosses Bluff Survey, and in the preparation of this report.

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AMDEL Report AN314/67 - Chemical analyses of samples from Gosses Bluff.

AMDEL Report MP614/67 - Mineralogical examination of eleven samples from Gosses Bluff.

AMDEL Report AN1471/69 - Chemical analysis of a fragment from Mount Pyroclast.

AMDEL Report MP1471/69 - Petrography of a fragment from Mount Pyroclast.

# APPENDIX I

## Shallow drilling at the outer zone of Gosses Bluff

A shallow drilling programme was undertaken during June and July, 1968, at the outer zone of Gosses Bluff by the BMR drilling team No. 4, directed by N. Lodwick, and using a Foxhole mobile rig. The drilling was supervised by A.Y. Glikson and D.J. Milton. The principal aims were to define the limits of the structural disturbance, to elucidate structural details within the poorly exposed outer zone, and to provide cores for laboratory studies. Altogether 23 holes were sunk, totalling 1565 feet, of which 348 feet were cored. The results of the drilling are discussed in the text of this record.

1

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

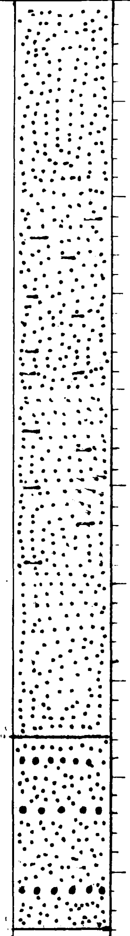
# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses BluFF Joint BMR-USGS study

HOLE NO Hbúrg (BMR) 9 ANGLE Vertical BEARING ELEVATION ~ 2300'

LOCATION Gosses BluFF FOUR MILE SF53-13 LATITUDE K LONGITUDE 3

TOTAL DEPTH 48' DEPTH TO WATER TABLE



| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | SQ | Q |
| 0 | | | | | | | | | | | | | Medium-grained red, brown and white sandstone | | 1 | | |
| 10 | | | | | | | | | | | | | Grey and white sandstone and shaly sandstone | | 2 | | |
| 20 | | | | | | | | | | | | | White, grey, and light brown shaly sandstone | | 3 | | |
| 30 | | | | | | | | | | | | | light brown sandstone | | 4 | | |
| 40 | | | 2.5" | 1 | 9'5" | 55°-60° | | | | | | | medium- to coarse-grained ~~white and~~ brown sandstone. Horizons of grit, with quartzite Fragments. | | | | |
| 50 | | | | | | | | | | | | | | | | | |
| 60 | | | | | | | | | | | | | | | | | |
| 70 | | | | | | | | | | | | | | | | | |

DRILL Foxhole

DRILLER N. Ladwick

COMMENCED 1. 6. 1968

COMPLETED 1. 6. 1968

REMARKS

- Drilling with air

LOGGED A. Glikson

SAMPLED A. Glikson

ASSAYED

SHEET 1 OF 1

Record 1969/142

M(PS)7b N/K

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

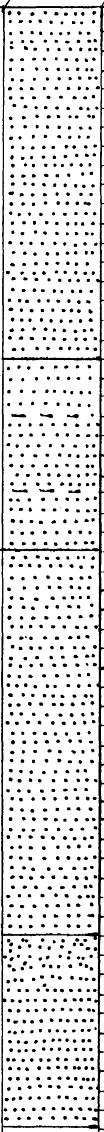
# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project

HOLE NO H'burg (BMR) 10 ANGLE Vertical BEARING ELEVATION ~ 2300'

LOCATION Gosses Bluff FOUR MILE SF 53-13 LATITUDE K LONGITUDE 2

TOTAL DEPTH 58' DEPTH TO WATER TABLE



| WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % P2O5 SQ | % P2O5 Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Red sand | | 1 | | |
| | | | | | | | | | | | | White to light-brown medium-grained sandstone | | 2 | | |
| | | 2.5" | 1 | 9'5" | 20°-30° | | | | | | | White medium-grained sandstone with thin bands of red sandstone. Thin shale intercalations | | | | |
| | | | | | | | | | | | | Light grey to light brown fine- to medium-grained sandstone | | 3 | 1 | |
| | | | | | | | | | | | | " | | 4 | | |
| | | 2.5" | 2 | 9'5" | 20°-30° | | | | | | | Off-white to light-brown medium to coarse-grained sandstone. Brown s.s. bands. Pockets of gritstone. | | | | |

0 10 20 30 40 50 60 70

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED 3.6.1968

COMPLETED 3.6.1968

REMARKS

Upwards facing

Drilling with air

LOGGED A. Glikson

SAMPLED A. Glikson

ASSAYED

SHEET 1 OF 1

Record 1969/42

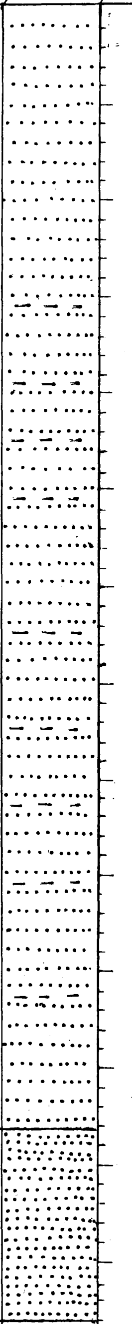
M(Pf)7b N.L.K

3

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS study
HOLE NO H'burg (BMR) 11 ANGLE vertical BEARING ELEVATION ~2300'
LOCATION Gosses Bluff FOUR MILE SF 53-13 LATITUDE L LONGITUDE 1
TOTAL DEPTH 68' DEPTH TO WATER TABLE



| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | | | | | Red sand | | 1 | | |
| 10 | | | | | | | | | | | | | Red-brown sandstone and argillaceous sandstone | | 2 | | |
| 20 | | | | | | | | | | | | | " | | 3 | | |
| 30 | | | | | | | | | | | | | Fine-grained red-brown argillaceous sandstone | | 4 | | |
| 40 | | | | | | | | | | | | | " | | 5 | | |
| 50 | | | | | | | | | | | | | Fine grained red-brown argillaceous sandstone, with some grey horizons. | | 6 | | |
| 60 | | | 2.5" | 1 | 9'2" | 60°-70° | | | | | | | Uniform red-brown fine-grained to medium-grained sandstone. Horizons of grey medium-grained to coarse gr. s.s. | | | | |
| 70 | | | | | | | | | | | | | | | | | |

DRILL Foxhole
DRILLER N. Lodwick
COMMENCED 3.6.1968
COMPLETED 3.6.1968

REMARKS

Drilling with air

LOGGED A. Glikson
SAMPLED A. Glikson
ASSAYED
SHEET 1 OF 1

Record 1969/42

M(Pf)7b N.L.K

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

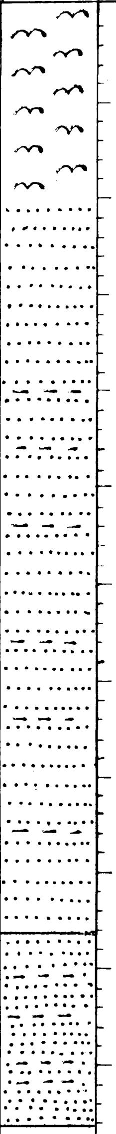
# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS study.

HOLE NO H'burg (BMR) 12 ANGLE vertical BEARING ELEVATION ~2300'

LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE LONGITUDE

TOTAL DEPTH 58' DEPTH TO WATER TABLE



| Depth | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0–10 | | | | | | | | | | | | | Red soil | | 1 | | |
| 10–20 | | | | | | | | | | | | | Red-brown fine-grained sandstone, with fragments of travertine | | 2 | | |
| 20–30 | | | | | | | | | | | | | Light-brown fine-grained to medium-grained S.S., and grey shale chips. | | 3 | | |
| 30–40 | | | | | | | | | | | | | Light brown S.S., and grey shale chips. | | 4 | | |
| 40–48 | | | | | | | | | | | | | light brown sandstone | | 5 | | |
| 48–58 | | | 2.5" | 1 | 9'4" | | | | | | | | Red fine-grained to medium-grained sandstones. White sandstone intercalations. Thin bands of argillaceous S.S. | | | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED 3.6.1968

COMPLETED 3.6.1168

REMARKS

Located on the Areyonga road, 1 mile southwest of H'burg (BMR) No. 17 well.

LOGGED A. Glikson

SAMPLED A. Glikson

ASSAYED

SHEET 1 OF 1

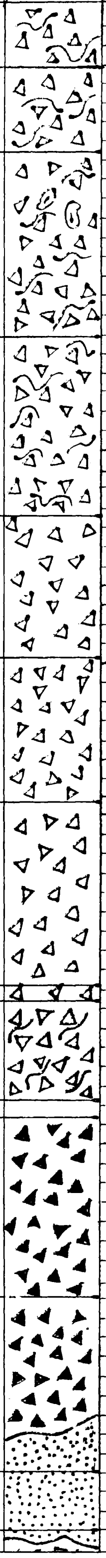
Record 1969/142

M(Pf)7b N.L.K.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS study
HOLE NO H. urg (BMR) 13 ANGLE Vertical BEARING ELEVATION ~2300'
LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE L LONGITUDE 6
TOTAL DEPTH 158' 1" DEPTH TO WATER TABLE



| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | | | | | Flow-breccia | | 1 | | |
| | | | 2.5" | 1 | 4' | | | | | | | | Flow-breccia: Devitrified brecciated silica glass. | | | | |
| 10 | | | " | 2 | 8'11" | | | | | | | | Flow-breccia: Devitrified brecciated silica glass, mudstone fragments, and s.s. fragments. | | | | |
| 20 | | | " | 3 | 9'5" | | | | | | | | Flow-breccia: Mudstone, sandstone and devitrified silica-glass fragments, set in devitrified silica glass. | | | | |
| 30 | | | " | 4 | 7' | | | | | | | | Brecciated and partly melted white sandstone | | | | |
| 40 | | | " | 5 | 7'8" | | | | | | | | White to yellow sandstone and devitrified silica glass fragments, aphanitic matrix. | | | | |
| 50 | | | " | 6 | 9'4" | | | | | | | | Fragments of sandstone and shale, embedded in a relatively well indurated sandy to devitrified glassy matrix | | | | |
| | | | " | 7 | 5" | | | | | | | | | | | | |
| | | | " | 8 | 4'5" | | | | | | | | Flow-textured breccia, with yellowish matrix and green clay. | | | | |
| 60 | | | " | 9 | 9'6" | | | | | | | | Quartzitic breccia. Silicified sandstone fragments set in a well-indurated matrix. | | | | |
| 70 | | | " | 10 | 8'9" | | | | | | | | Quartzitic breccia, including silicified s.s. fragments, and mudstone chips. | | | | |
| 80 | | | " | 11 | 3' | | | | | | | | Quartzite block | | | | |

DRILL Foxmole
DRILLER N. McLuick
COMMENCED 4.6.1968
COMPLETED 12.6.1968

REMARKS
The fragments may be shatterconed. The flow-banding is usually vertical or steep. Drilling with air

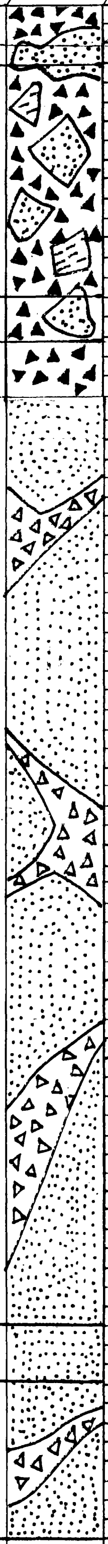
LOGGED A. Glikson
SAMPLED A. Glikson
ASSAYED
SHEET 1 OF 2

Record 1969/42

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS study
HOLE NO H'burg (BMR) 13 ANGLE vertical BEARING ELEVATION ~2800'
LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE L LONGITUDE 6
TOTAL DEPTH 158'9" DEPTH TO WATER TABLE



| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 | | | " | 12 | 2'11" | | | | | | | | Quartzite blocks and quartzitic breccia. | | 1 | | |
| | | | | | | | | | | | | | Quartzite Fragments | | 2 | | |
| 90 | | | | | | | | | | | | | Quartzite and mudstone Fragments | | 3 | | |
| | | | " | 13 | 2'2" | | | | | | | | Quartzitic breccia | | | | |
| 100 | | | | | | | | | | | | | Quartzite Fragments | | | | |
| | | | | | | | | | | | | | Grey sandstone | | 4 | | |
| 110 | | | | | | | | | | | | | " | | 5 | | |
| 120 | | | | | | | | | | | | | " | | 6 | | |
| | | | | | | | | | | | | | Quartzitic sandstone | | 7 | | |
| 130 | | | | | | | | | | | | | Soft grey sandstone | | 8 | | |
| 140 | | | | | | | | | | | | | Brown sandstone | | 9 | | |
| 150 | | | 2.5 | 14 | 2'6" | | | | | | | | Soft red-brown sandstone | | | | |
| | | | " | 15 | 8'3" | | | | | | | | Blocks of sandstone intervened by breccia zones | | | | |
| 160 | | | | | | | | | | | | | | | | | |

DRILL Foxhole
DRILLER N. Lodwick
COMMENCED 4.6.1968
COMPLETED 12.6.1968

REMARKS
Drilling with air

LOGGED A. Glikson
SAMPLED A. Glikson
ASSAYED
SHEET 2 OF 2

Record 1969/42

M(PF)7b N.L.K

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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

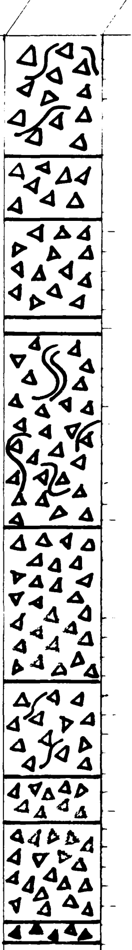
# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, joint BMR · USGS study

HOLE NO H'burg (BMR) 14 ANGLE Vertical BEARING ELEVATION ~ 2300'

LOCATION Gosses Bluff FOUR MILE SF 53-13 LATITUDE L LONGITUDE 6

TOTAL DEPTH 47' DEPTH TO WATER TABLE



| Depth | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | | | | | Flow-breccia | | 1 | |
| | | | 2,5" | 1 | 2'6" | | | | | | | | Flow-breccia | | | |
| 10 | | | " | 2 | 4'6" | | | | | | | | glassy breccia. | | | |
| | | | " | 3 | 10" | | | | | | | | | | | |
| 20 | | | " | 4 | 9'5" | | | | | | | | Flow-breccia. white a yellow s.s. Fragments and mudstone Fragments set in melted sandstone Flows | | | |
| 30 | | | " | 5 | 7'11" | | | | | | | | Well indurated Flow-breccia | | | |
| | | | " | 6 | 4'8" | | | | | | | | Flow-breccia | | | |
| 40 | | | " | 7 | 2'6" | | | | | | | | Flow-breccia | | | |
| | | | " | 8 | 5' | | | | | | | | Flow-breccia | | | |
| | | | " | 9 | 1'3" | | | | | | | | Quartzitic breccia | | | |
| 50 | | | | | | | | | | | | | | | | |
| 60 | | | | | | | | | | | | | | | | |
| 70 | | | | | | | | | | | | | | | | |
| 80 | | | | | | | | | | | | | | | | |

DRILL Failing

DRILLER N. Lodwick

COMMENCED 13. 5. 1968

COMPLETED 18. 5. 1968

REMARKS

The Flow banding is subvertical to vertical

Location: Mt. Pyroclast. Airdrilling

Record 1969/142

LOGGED A. Glikson

SAMPLED A. Glikson

ASSAYED

SHEET 1 OF 1

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project

HOLE NO H'burg (BMR) 15 ANGLE Vertical BEARING ELEVATION ~ 2300'

LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE K LONGITUDE 6

TOTAL DEPTH 67' DEPTH TO WATER TABLE

| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | | | | | Soft, fine-grained silty sandstone | | 1 | | |
| 10 | | | | | | | | | | | | | Brown fine-grained to medium-grained sandstone | | 2 | | |
| 20 | | | 2.5" | 1 | 5' | 20° | | | | | | | Fine-grained red argillaceous massive sandstone | | | | |
| | | | | | | | | | | | | | Brown medium-grained sandstone | | 3 | | |
| 30 | | | | | | | | | | | | | | | 4 | | |
| 40 | | | | | | | | | | | | | Light brown sandstone, brown mudstone intercalations. | | 5 | | |
| 50 | | | | | | | | | | | | | Light brown medium-grained sandstone | | 6 | | |
| 60 | | | "2.5" | 2 | 5' | 20° | | | | | | | Argillaceous sandstone and sandy shale. | | | | |
| 70 | | | | | | | | | | | | | | | | | |
| 80 | | | | | | | | | | | | | | | | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED 19.6.1968

COMPLETED 19.6.1968

REMARKS

Shatter cones and small-scale faulting are present.

LOGGED A. Glikson

SAMPLED A. Glikson

ASSAYED

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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

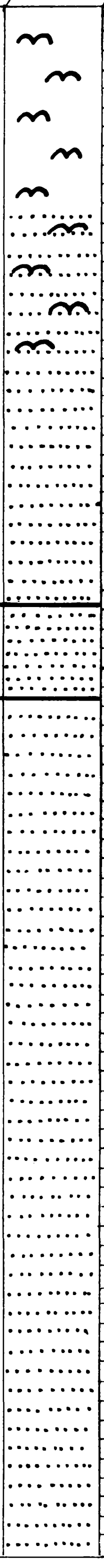
# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS study

HOLE NO H'burg (BMR) 16 ANGLE Vertical BEARING ELEVATION ~2300'

LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE N LONGITUDE 6

TOTAL DEPTH 98'6" DEPTH TO WATER TABLE



| WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Red soil | | 1 | | |
| | | | | | | | | | | | | Red soil and brown sandstone chips | | 2 | | |
| | | | | | | | | | | | | Fine-grained brown sandstone | | 3 | | |
| | | 2'5" | 1 | 4'3" | 62° | | | | | | | massive fine- to medium-grained red-brown sandstone | | | | |
| | | | | | | | | | | | | light brown fine-grained to medium-grained sandstone | | 4 | | |
| | | | | | | | | | | | | " | | 5 | | |
| | | | | | | | | | | | | " | | 6 | | |
| | | | | | | | | | | | | Red brown medium-grained sandstone | | 7 | | |
| | | | | | | | | | | | | Brown and grey medium-grained sandstone | | 8 | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED 19.6.1968

COMPLETED 19.6.1968

REMARKS

The sandstones are weakly calcareous.

Drilling with air

LOGGED A. Glikson

SAMPLED A. Glikson

ASSAYED

SHEET 1 OF 2

Record 1969/42

M(Pf)7b N.L.K

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS study

HOLE NO H'burg (BMR) 16 ANGLE Vertical BEARING ELEVATION N 2300'

LOCATION Gosses Bluff FOUR MILE SF 53-13 LATITUDE N LONGITUDE 6

TOTAL DEPTH 98'6" DEPTH TO WATER TABLE

| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 | | | | | | | | | | | | | | | 8 | | |
| | | | | | | | | | | | | | " | | 9 | | |
| 90 | | | | | | | | | | | | | | | | | |
| | | | 2'5" | 2 | 5' | 62° | | | | | | | Banded brown white and grey S.S. Pebbly sandstone. | | | | |
| 100 | | | | | | | | | | | | | | | | | |
| 110 | | | | | | | | | | | | | | | | | |
| 120 | | | | | | | | | | | | | | | | | |
| 130 | | | | | | | | | | | | | | | | | |
| 140 | | | | | | | | | | | | | | | | | |
| 150 | | | | | | | | | | | | | | | | | |
| 160 | | | | | | | | | | | | | | | | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED 19.6.1968

COMPLETED 19.6.1968

REMARKS

The sandstones are weakly calcareous.

Drilling with air

LOGGED A. Glikson

SAMPLED A. Glikson

ASSAYED

SHEET 2 OF 2

Record 1969/42

M(Pf)7b NLK

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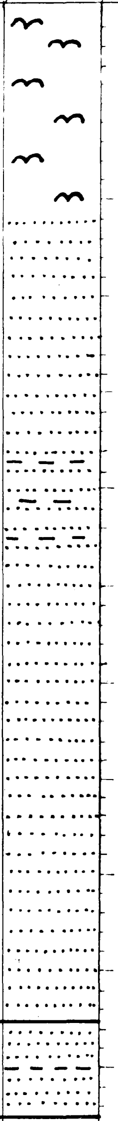
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, joint BMR-USGS study
HOLE NO H'burg (BMR) 17 ANGLE Vertical BEARING ELEVATION ~2300'
LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE M LONGITUDE 1
TOTAL DEPTH 57'6" DEPTH TO WATER TABLE



| WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Red soil | | 1 | | |
| | | | | | | | | | | | | Brown medium-grained sandstone, and travertine chips | | 2 | | |
| | | | | | | | | | | | | Brown fine-grained to medium-grained argillaceous sandstone. | | 3 | | |
| | | | | | | | | | | | | Brown fine-grained sandstone | | 4 | | |
| | | | | | | | | | | | | Brown and grey sandstone | | 5 | | |
| | | 2.5" | 1 | 5' | 22° | | | | | | | Banded brown to grey m.g. to c.g. s.s and argillaceous s.s. | | | | |

0
10
20
30
40
50
60
70
80

DRILL Foxhole
DRILLER N. Lodwick
COMMENCED 20.6.1968
COMPLETED 20.6.1968

REMARKS
The sandstones are slightly calcareous.
Facing upwards. Drilling with air

LOGGED A. Glikson
SAMPLED A. Glikson
ASSAYED
SHEET 1 OF 1

Record 1969/42

M(Pf)7b NLK

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project

HOLE NO H'burg (BMR) 18 ANGLE Vertical BEARING ELEVATION ~2300'

LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE F LONGITUDE 6

TOTAL DEPTH 22' DEPTH TO WATER TABLE

| WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Brown c.g. sandstone | | 1 | |
| | | | | | | | | | | | | Light brown sandstone | | 2 | |
| | | 2.5" | 1 | 2'1" | 70° | | | | | | | Brown to grey c.g. sandstone | | | |

0 10 20 30 40 50 60 70 80

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED 20.6.1968

COMPLETED 20.6.1968

REMARKS

Abundant shatter cones

Drilling with air

Record 1969/42

LOGGED A. Glikson

SAMPLED A. Glikson

ASSAYED

SHEET 1 OF 1

M(Pf)7b NLK

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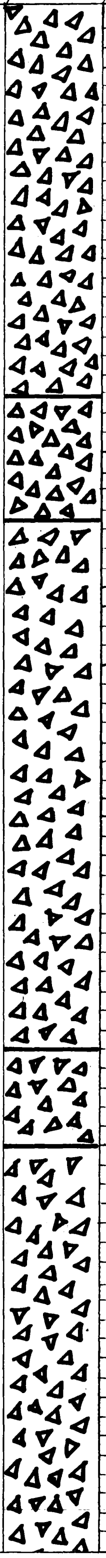
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project
HOLE NO H'burg (BMR) 19 ANGLE vertical BEARING ELEVATION ~2300'
LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE F LONGITUDE 6
TOTAL DEPTH 208'8" DEPTH TO WATER TABLE



| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | | | | | Exposed Breccia | | 1 | | |
| 10 | | | | | | | | | | | | | Brown and green sandstone, mudstone, and gritstone cuttings. Travertine chips. | | 2 | | |
| 20 | | | 2.5" | 1 | 5'7" | | | | | | | | Fragmental breccia. Fragments of s.s., mudstone, gritstone, and F.g. conglomerate | | | | |
| 30 | | | | | | | | | | | | | | | 3 | | |
| 40 | | | | | | | | | | | | | Brown and green sandstone, mudstone, and gritstone chips. Pebble chips, representing conglomerates | | 4 | | |
| 50 | | | | | | | | | | | | | | | 5 | | |
| | | | 2.5" | 2 | 4'8" | | | | | | | | Fragmental breccia, with fragments over 1" in size. | | | | |
| 60 | | | | | | | | | | | | | Brown and green sandstone, mudstone and gritstone. Pebble chips represent conglomerates. | | 6 | | |
| 70 | | | | | | | | | | | | | | | 7 | | |
| | | | | | | | | | | | | | ″ | | 8 | | |
| 80 | | | | | | | | | | | | | | | | | |

DRILL Foxhole
DRILLER N. Lodwick
COMMENCED 21.6.1968
COMPLETED 25.6.1968

REMARKS Drilling with air
Fragment sizes in the cores are usually below 1 inch. The fragments may be shatter-coned.

LOGGED A. Glikson
SAMPLED A. Glikson
ASSAYED
SHEET 1 OF 3

Record 1969/42

M(Pf)7b N.L.K.

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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project
HOLE NO. H'burg (BMR) 19 ANGLE vertical BEARING ELEVATION ~2300'
LOCATION Gosses Bluff FOUR MILE SF 53-13 LATITUDE F LONGITUDE 6
TOTAL DEPTH 208'8" DEPTH TO WATER TABLE

| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 | | | | | | | | | Δ | | | | " | | 8 | | |
| 90 | | | | | | | | | Δ | | | | " | | 9 | | |
| 100 | | | | | | | | | Δ | | | | Brown and green s.s., mudstone and conglomerate chips. | | 10 | | |
| 110 | | | 2.5" | 3 | 4'9" | | | | Δ | | | | Fragmental breccia | | | | |
| | | | | | | | | | Δ | | | | | | 11 | | |
| 120 | | | | | | | | | Δ | | | | | | 12 | | |
| 130 | | | | | | | | | Δ | | | | Brown and green s.s., mudstone, gritstone, and conglomerate chips. | | 13 | | |
| 140 | | | | | | | | | Δ | | | | | | 14 | | |
| | | | 2.5" | 4 | 3'11" | | | | Δ | | | | Fragmental breccia | | | | |
| 150 | | | | | | | | | Δ | | | | Fragmental breccia | | 15 | | |
| 160 | | | | | | | | | Δ | | | | " | | 16 | | |

DRILL Foxhole
DRILLER N. Lodwick
COMMENCED 21.6.1968
COMPLETED 25.6.1968

REMARKS
Core of Fragmental breccia was taken between 208' - 208'8" (bottom of hole).
Drilling with air

LOGGED A. Glikson
SAMPLED A. Glikson
ASSAYED
SHEET 2 OF 3

Record 1969/42

M(Pf)7b N.L

5.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project

HOLE NO H'burg (BMR) 19 ANGLE Vertical BEARING ELEVATION N 2300'

LOCATION Gosses Bluff FOUR MILE SF 53-13 LATITUDE F LONGITUDE 6

TOTAL DEPTH 208' 8" DEPTH TO WATER TABLE

| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 160 | | | | | | | | | | | | | 〃 | | 16 | | |
| 170 | | | | | | | | | | | | | 〃 | | 17 | | |
| 180 | | | | | | | | | | | | | 〃 | | 18 | | |
| 190 | | | | | | | | | | | | | 〃 | | 19 | | |
| 200 | | | | | | | | | | | | | 〃 | | 20 | | |
| | | 2.5 | 5 | 7" | | | | | | | | | Fragmental breccia | | | | |
| 210 | | | | | | | | | | | | | | | | | |
| 220 | | | | | | | | | | | | | | | | | |
| 230 | | | | | | | | | | | | | | | | | |
| 240 | | | | | | | | | | | | | | | | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED 21.6.1968

COMPLETED 25.6.1968

REMARKS

Core of Fragmental breccia was taken between 208' - 208' 8" (bottom of hole)

Drilling with air

LOGGED A. Glikson

SAMPLED A. Glikson

ASSAYED

SHEET 3 OF 3

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

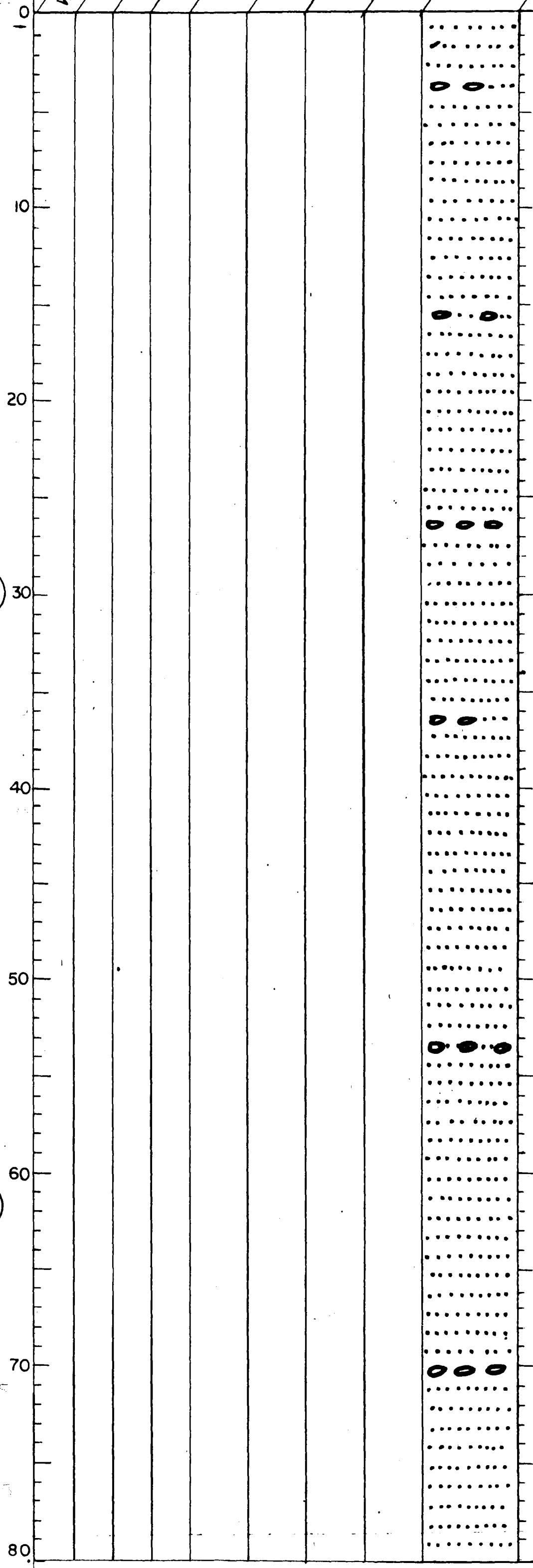
# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR- USGS project

HOLE NO H'burg (BMR) 20 ANGLE vertical BEARING ELEVATION ~ 2300'

LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE F LONGITUDE 6

TOTAL DEPTH 120' DEPTH TO WATER TABLE



| WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Brown and green sandstone, gritstone, conglomerate chips. | | 1 | | |
| | | | | | | | | | | | | " | | 2 | | |
| | | | | | | | | | | | | " | | 3 | | |
| | | | | | | | | | | | | " | | 4 | | |
| | | | | | | | | | | | | " | | 5 | | |
| | | | | | | | | | | | | " | | 6 | | |
| | | | | | | | | | | | | " | | 7 | | |
| | | | | | | | | | | | | " | | 8 | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED 26.6.1968

COMPLETED 28.6.1968

REMARKS

Drilling with air

LOGGED A. Glikson

SAMPLED A. Glikson

ASSAYED

SHEET 1 OF 2

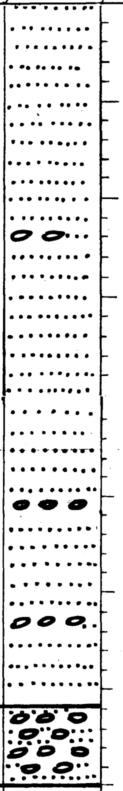
Record 1969/42

M(Pf)7b N.L.K.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project
HOLE NO H'burg (BMR) 20 ANGLE Vertical BEARING ELEVATION ~ 2300'
LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE F LONGITUDE 6
TOTAL DEPTH 120' DEPTH TO WATER TABLE

| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 | | | | | | | | |  | | | | | | 8 | | |
| | | | | | | | | | | | | | " | | 9 | | |
| | | | | | | | | | | | | | " | | | | |
| 100 | | | | | | | | | | | | | | | 10 | | |
| 110 | | | | | | | | | | | | | Conglomerate, gritstone, sandstone. | | 11 | | |
| | | | 2.5" | 1 | 4' | 40° | | | | | | | Conglomerate, gritstone and coarse | | | | |
| 120 | | | | | | | | | | | | | | | | | |
| 130 | | | | | | | | | | | | | | | | | |
| 140 | | | | | | | | | | | | | | | | | |
| 150 | | | | | | | | | | | | | | | | | |
| 160 | | | | | | | | | | | | | | | | | |

DRILL Foxhole
DRILLER N. Lodwick
COMMENCED 26.6.68
COMPLETED 28.6.68

REMARKS

Drilling with air

LOGGED A. Glikson
SAMPLED A. Glikson
ASSAYED
SHEET 2 OF 2

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

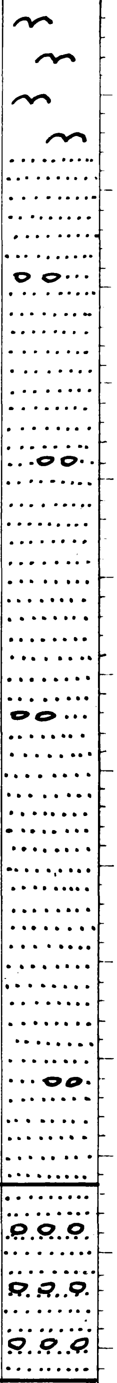
# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project

HOLE NO H'burg (BMR) 21 ANGLE Vertical BEARING ELEVATION ~2300'

LOCATION Gosses Bluff FOUR MILE SF 53-13 LATITUDE E LONGITUDE 7

TOTAL DEPTH 71'6" DEPTH TO WATER TABLE



| WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Red soil, travertine, and sandstone chips. | | 1 | | |
| | | | | | | | | | | | | Grey to light brown coarse-grained sandstone and gritstone chips | | 2 | | |
| | | | | | | | | | | | | Grey to brown medium-grained sandstone chips | | 3 | | |
| | | | | | | | | | | | | " | | 4 | | |
| | | | | | | | | | | | | " | | 5 | | |
| | | | | | | | | | | | | " | | 6 | | |
| | | 2.5" | 1 | 4'11" | 25° | | | | | | | Coarse-grained sandstone and gritstone. Isolated quartzite pebbles. | | | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED 8.7.1968

COMPLETED 8.7.1968

REMARKS

The sandstones are weakly calcareous.
Poorly-defined shatter cones.
Drilling with mud

LOGGED A. Glikson

SAMPLED A. Glikson

ASSAYED

SHEET 1 OF 1

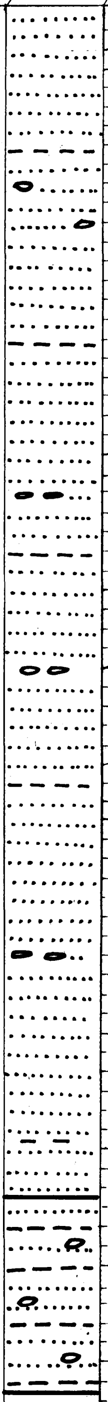
Record 1969/42

M(Pf)7b NLK

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, joint BMR-USGS project
HOLE NO H'burg (BMR) 22 ANGLE vertical BEARING ELEVATION ~ 2300'
LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE D LONGITUDE 7
TOTAL DEPTH 71' DEPTH TO WATER TABLE



| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | | | | | Argillaceous sandstone and siltstone. some gritstone and pebble chips. | | 1 | | |
| 10 | | | | | | | | | | | | | " | | 2 | | |
| 20 | | | | | | | | | | | | | " | | 3 | | |
| 30 | | | | | | | | | | | | | " | | 4 | | |
| 40 | | | | | | | | | | | | | " | | 5 | | |
| 50 | | | | | | | | | | | | | " | | 6 | | |
| 60<br>70 | | | 2.5" | 1 | 9'2" | 20° | | | | | | | Brown and green sandstone, gritstone, pebbly sandstone. Shale and mudstone pockets and horizons. | | | | |
| 80 | | | | | | | | | | | | | | | | | |

DRILL Foxhole
DRILLER N. Lodwick
COMMENCED 9.7.1968
COMPLETED 9.7.1968

REMARKS
The sandstone is slightly calcareous
Drilling with mud

LOGGED A. Glikson
SAMPLED A. Glikson
ASSAYED
SHEET 1 OF 1

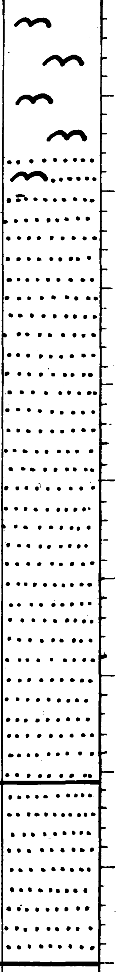
Record 1969/42

M(Pf)7b N.L.K.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project
HOLE NO A'burg (BMR) 23 ANGLE vertical BEARING . ELEVATION ~ 2300'
LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE J LONGITUDE 9
TOTAL DEPTH 50' DEPTH TO WATER TABLE -



| WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Red soil | | 1 | | |
| | | | | | | | | | | | | Brown sandstone chips | | 2 | | |
| | | | | | | | | | | | | Brown to grey medium-grained sandstone | | 3 | | |
| | | | | | | | | | | | | " | | 4 | | |
| | | 2.5" | 1 | 8'2" | | | | | | | | Brown medium-grained and some coarse-grained sandstone. Bedding is little developed. | | | | |

DRILL Foxhole
DRILLER N. Lodwick
COMMENCED 11.7.1968
COMPLETED 11.7.1968

REMARKS
Abundant shatter-cones

Drilling with mud

LOGGED A. Glikson
SAMPLED A. Glikson
ASSAYED
SHEET 1 OF 1

Record 1969/42

M(Pf)7b N.L.K

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project

HOLE NO H'burg (BMR) 24 ANGLE vertical BEARING ELEVATION ~2300'

LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE D LONGITUDE 7

TOTAL DEPTH 90'6" DEPTH TO WATER TABLE

0 10 20 30 40 50 60 70 80

| WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Alluvium<br>Brown medium-grained sandstone, and siltstone. | | 1 | | |
| | | | | | | | | | | | | " | | 2 | | |
| | | | | | | | | | | | | " | | 3 | | |
| | | | | | | | | | | | | " | | 4 | | |
| | | 2.5" | 1 | 4'10" | 45° | | | | | | | Massive, brown and green medium-grained sandstone, and argillaceous sandstone | | | | |
| | | | | | | | | | | | | Brown and green sandstone and siltstone | | 5 | | |
| | | | | | | | | | | | | " | | 6 | | |
| | | | | | | | | | | | | " | | 7 | | |
| | | | | | | | | | | | | " | | 8 | | |
| | | | | | | | | | | | | " | | 9 | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED 12.7.1968

COMPLETED 12.7.1968

REMARKS

The sandstone is slightly calcareous

Drilling with mud

LOGGED A. Glikson

SAMPLED A. Glikson

ASSAYED

SHEET 1 OF 2

Record 1969/42

M(Pf)7b N.L.K.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project

HOLE NO. H'burg (BMR) 24 ANGLE Vertical BEARING ELEVATION N 2300'

LOCATION Gosses Bluff FOUR MILE SF 53-13 LATITUDE D LONGITUDE 7

TOTAL DEPTH 90' 6" DEPTH TO WATER TABLE

| DEPTH | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 | | | | | | | | | | | | | " | | 9 | | |
| 90 | | | 2.5" | 2 | 3'7" | 45° | | | | | | | Brown medium-grained sandstone, brown shale. | | | | |
| 100 | | | | | | | | | | | | | | | | | |
| 110 | | | | | | | | | | | | | | | | | |
| 120 | | | | | | | | | | | | | | | | | |
| 130 | | | | | | | | | | | | | | | | | |
| 140 | | | | | | | | | | | | | | | | | |
| 150 | | | | | | | | | | | | | | | | | |
| 160 | | | | | | | | | | | | | | | | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED 12-7-1968

COMPLETED 12-7-1968

REMARKS

The sandstone is slightly calcareous.

Drilling with mud.

LOGGED A. Glikson

SAMPLED A. Glikson

ASSAYED

SHEET 2 OF 2

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

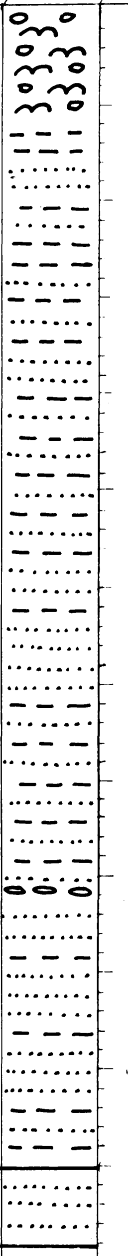
# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, joint BMR-USGS project

HOLE NO H'burg (BMR) 25 ANGLE vertical BEARING ELEVATION ~2300'

LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE D LONGITUDE 9

TOTAL DEPTH 64' DEPTH TO WATER TABLE



| WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Terrace conglomerate | | 1 | | |
| | | | | | | | | | | | | Blue-green clay | | 2 | | |
| | | | | | | | | | | | | Soft purple sandstone, and blue-green clay | | 3 | | |
| | | | | | | | | | | | | Sandy clay | | 4 | | |
| | | | | | | | | | | | | Soft purple clayey sandstone | | 5 | | |
| | | | | | | | | | | | | grit and conglomerate | | 6 | | |
| | | | | | | | | | | | | Soft purple clayey sandstone | | 7 | | |
| | | | | | | | | | | | | gritstone | | 8 | | |
| | | | | | | | | | | | | Purple sandstone | | 9 | | |
| | | 2.5" | 1 | 3' | | | | | | | | Massive variegated soft sandstone. | | | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED July, 1968

COMPLETED July, 1968

REMARKS

No bedding is apparant.

Drilling with mud

LOGGED D. Milton

SAMPLED D. Milton

ASSAYED

SHEET 1 OF 1

Record 1969/42

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

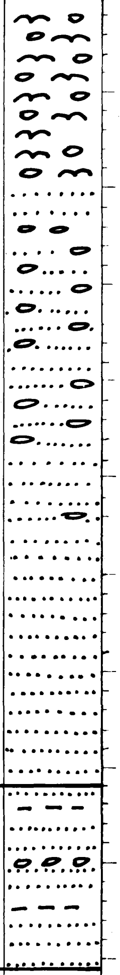
# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project

HOLE NO. H'burg (BMR) 26 ANGLE Vertical BEARING ELEVATION ~2300'

LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE E LONGITUDE 9

TOTAL DEPTH 50'5" DEPTH TO WATER TABLE



| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | | | | | Gravel | | 1 | | |
| 10 | | | | | | | | | | | | | Purplish-grey pebbly grit | | 2 | | |
| 20 | | | | | | | | | | | | | Purplish-grey sandstone | | 3 | | |
| 30 | | | | | | | | | | | | | " | | 4 | | |
| 40 | | | 2.5" | 1 | 9'5" | 75° | | | | | | | Grey to light brown coarse-grained sandstone and grit-stone. Fine-grained conglomerates, thin shale beds. | | | | |
| 50 | | | | | | | | | | | | | | | | | |
| 60 | | | | | | | | | | | | | | | | | |
| 70 | | | | | | | | | | | | | | | | | |
| 80 | | | | | | | | | | | | | | | | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED July, 1968

COMPLETED July, 1968

REMARKS

The sandstones are calcareous

Drilling with mud.

LOGGED D. Milton

SAMPLED D. Milton

ASSAYED

SHEET 1 OF 1

25

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

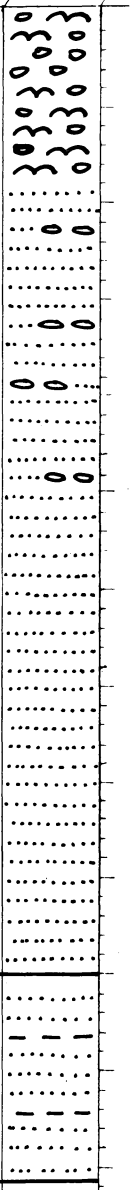
# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project

HOLE NO H'burg (BMR) 27 ANGLE vertical BEARING ELEVATION ~2300'

LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE E LONGITUDE 9

TOTAL DEPTH 60'5" DEPTH TO WATER TABLE



| WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Red sandy soil | | 1 | | |
| | | | | | | | | | | | | Gravel | | 2 | | |
| | | | | | | | | | | | | Soft grey green pebbly s.s. | | 3 | | |
| | | | | | | | | | | | | " | | 4 | | |
| | | | | | | | | | | | | Soft grey sandstones | | 5 | | |
| | | 2.5" | 1 | 9'5" | 40° | | | | | | | Grey to light green coarse-grained sandstone, gritstone and thin shale beds. Little bedding is apparant | | | | |

0
10
20
30
40
50
60
70
80

DRILL Foxhole
DRILLER N. Lodwick
COMMENCED July, 1968
COMPLETED July, 1968

REMARKS
The sandstones are calcareous

Drilling with mud

LOGGED D. Milton
SAMPLED D. Milton
ASSAYED
SHEET 1 OF 1

Record 1969/42

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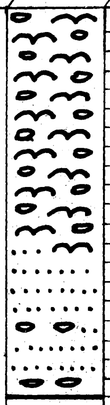
# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, joint BMR-USGS project

HOLE NO H'burg (BMR) 28 ANGLE Vertical BEARING ELEVATION ~2300'

LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE G LONGITUDE 11

TOTAL DEPTH 20' DEPTH TO WATER TABLE



| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | | | | | Alluvium and gravel | | 1 | | |
| 10 | | | | | | | | | | | | | Red coarse-grained sandstone. Travertine chips. Pebble chips. | | 2 | | |
| 20 | | | | | | | | | | | | | | | | | |
| 30 | | | | | | | | | | | | | | | | | |
| 40 | | | | | | | | | | | | | | | | | |
| 50 | | | | | | | | | | | | | | | | | |
| 60 | | | | | | | | | | | | | | | | | |
| 70 | | | | | | | | | | | | | | | | | |
| 80 | | | | | | | | | | | | | | | | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED July, 1968

COMPLETED July, 1968

REMARKS

No core taken

Drilling with mud.

LOGGED D. Milton

SAMPLED D. Milton

ASSAYED

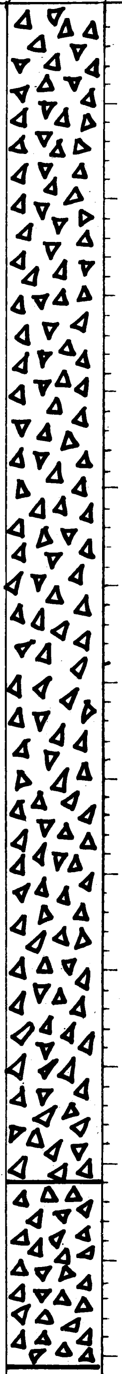
SHEET 1 OF 1

Record 1969/42

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT: Gosses Bluff, joint BMR-USGS project
HOLE NO: H'burg (BMR) 29 ANGLE: vertical BEARING: ELEVATION: ~ 2300'
LOCATION: Gosses Bluff FOUR MILE: SF53-13 LATITUDE: H LONGITUDE: 4
TOTAL DEPTH: 70'5" DEPTH TO WATER TABLE:



| WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Sandy soil and travertine | | 1 | | |
| | | | | | | | | | | | | Soft, fine- to medium-grained red brown sandstone, and minor red shale chips. | | 2 | | |
| | | | | | | | | | | | | " | | 3 | | |
| | | | | | | | | | | | | " | | 4 | | |
| | | | | | | | | | | | | " | | 5 | | |
| | | | | | | | | | | | | " | | 6 | | |
| | | 2.5" | 1 | 9'5" | | | | | | | | Fragmental breccia. Angular sandstone fragments brown and green siltstone fragments, in sandy matrix | | | | |

DRILL: Foxhole
DRILLER: N. Lodwick
COMMENCED: July, 1968
COMPLETED: July, 1968

REMARKS
Breccia fragments may be shatter coned.
Drilled with mud.

LOGGED: D. Milton
SAMPLED: D. Milton
ASSAYED:
SHEET 1 OF 1

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS project

HOLE NO H'burg (BMR) 30 ANGLE vertical BEARING ELEVATION ~2300'

LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE H LONGITUDE 5

TOTAL DEPTH 60' DEPTH TO WATER TABLE

| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | % $P_2O_5$ Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | △△△ | | | | Sand | | 1 | | |
| | | | | | | | | | △△△ | | | | Travertinised sand soil | | 2 | | |
| 10 | | | | | | | | | △△△ | | | | Fragments of shale, Fine-grained sandstone. | | 3 | | |
| 20 | | | | | | | | | △△△ | | | | " | | 4 | | |
| 30 | | | | | | | | | △△△ | | | | " | | 5 | | |
| 40 | | | | | | | | | △△△ | | | | " | | 6 | | |
| 50 | | | 2.5" | 1 | 9'6" | | | | △△△ | | | | Fragmental breccia. saudstone, siltstone, and shale fragments in sandy matrix. | | | | |
| 60 | | | | | | | | | | | | | | | | | |
| 70 | | | | | | | | | | | | | | | | | |
| 80 | | | | | | | | | | | | | | | | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED July, 1968

COMPLETED July, 1968

REMARKS

The fragments are shatter-coned.

Drilling with mud

LOGGED D. Milton

SAMPLED D. Milton

ASSAYED

SHEET 1 OF 1

Record 1969/42

M(Pf)7b N.L.K

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

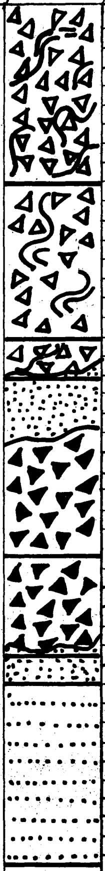
# GEOLOGICAL LOG OF DRILL HOLE

PROJECT Gosses Bluff, Joint BMR-USGS study

HOLE NO H'burg(BMR)31 ANGLE vertical BEARING ELEVATION ~2300'

LOCATION Gosses Bluff FOUR MILE SF53-13 LATITUDE K LONGITUDE 7

TOTAL DEPTH 44'5" DEPTH TO WATER TABLE



| | WEATHERING | CASING | CORE SIZE | LIFTS | CORE RECOVERY | DIP | FOSSILS | BEDDING | GRAPHIC LOG | FOOTAGE | COLOUR | TEXTURE | LITHOLOGY | SAMPLE INTERVAL | SAMPLE NUMBER | % $P_2O_5$ SQ | Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | | | | | White and grey fragments of devitrified silica glass | | 1 | | |
| 10 | | | 2.5" | 1 | 8' | | | | | | | | Flow-breccia. Fragments of sandstone, mudstone, and silica rock (devitrified glass). | | | | |
| | | | " | 2 | 1'9" | | | | | | | | Flow-breccia | | | | |
| 20 | | | 2.5" | 3 | 9'5" | | | | | | | | A block of white quartzitic breccia. Quartzitic breccia, with quartzite and shale fragments | | | | |
| 30 | | | 2.5" | 4 | 4'6" | | | | | | | | Quartzitic breccia. Shatter-coned fragments. | | | | |
| | | | " | 5 | 6' | | | | | | | | Sandstone and shale | | | | |
| 40 | | | 2.5" | 6 | 9'5" | 40° | | | | | | | Sandstone and shale. horizons of mud-flake conglomerate. Cross-bedding and slumping | | | | |
| 50 | | | | | | | | | | | | | | | | | |
| 60 | | | | | | | | | | | | | | | | | |
| 70 | | | | | | | | | | | | | | | | | |
| 80 | | | | | | | | | | | | | | | | | |

DRILL Foxhole

DRILLER N. Lodwick

COMMENCED July, 1968

COMPLETED July, 1968

REMARKS

Drilling with mud

LOGGED D. Milton

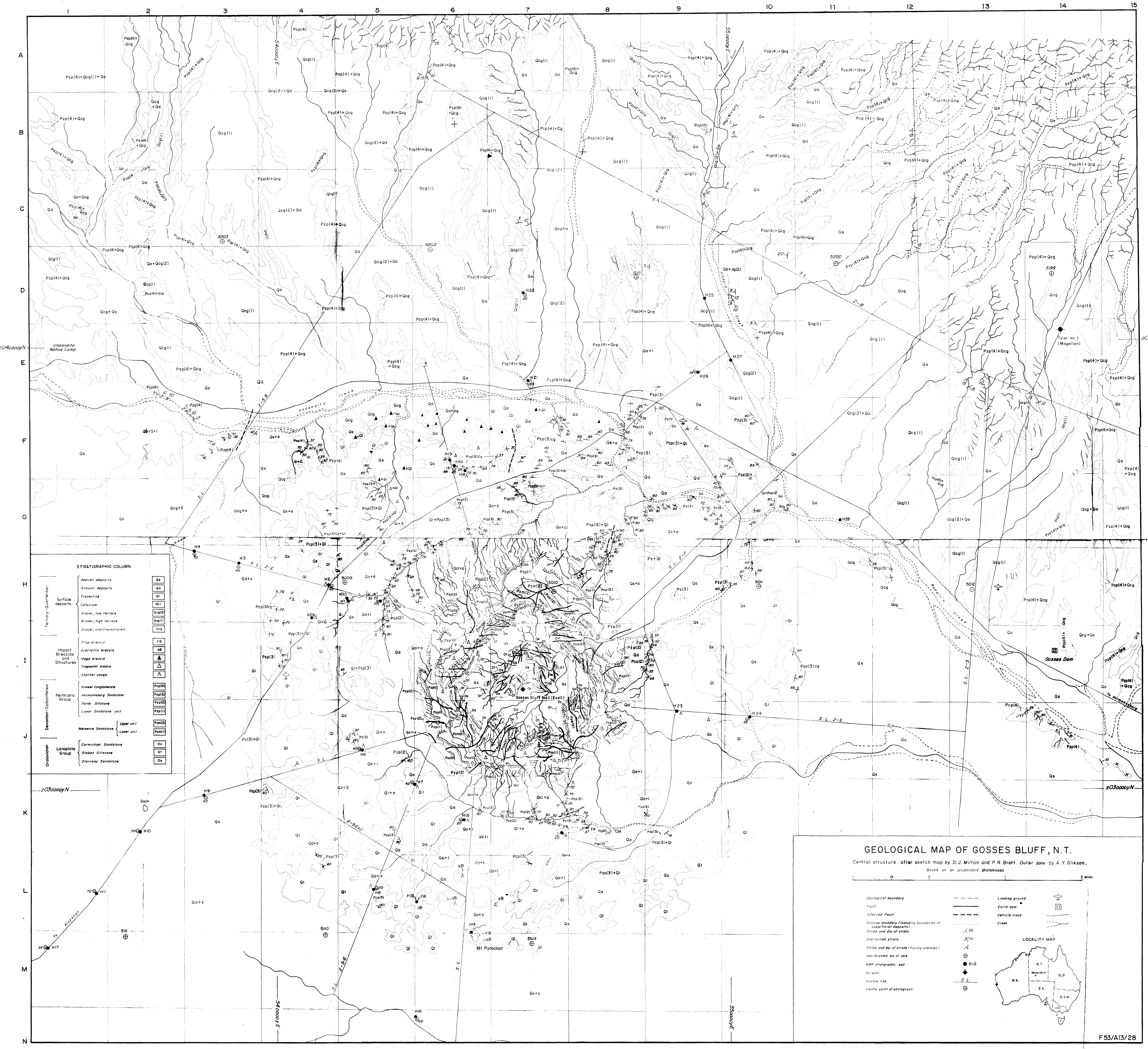
SAMPLED D. Milton

ASSAYED

SHEET 1 OF 1

Record 1969/42

M(PS)7b N/K



# GEOLOGICAL MAP OF GOSSES BLUFF, N.T.

Central structure: after sketch map by D.J. Milton and P.R. Brett. Outer zone by A.Y. Glikson.

Based on an uncontrolled photomosaic.

**STRATIGRAPHIC COLUMN**

| | | | |
|---|---|---|---|
| Tertiary-Quaternary | Surface deposits | Aeolian deposits | Qs |
| | | Alluvial deposits | Qa |
| | | Travertine | Ql |
| | | Colluvium | Qcl |
| | | Gravel, low terrace | Qcg(2) |
| | | Gravel, high terrace | Qcg(1) |
| | | Gravel, undifferentiated | Qcg |
| | Impact Breccias and Structures | Flow-breccia | FB |
| | | Quartzitic breccia | qB |
| | | Mega breccia | ▲ |
| | | Fragmental breccia | △ |
| | | Shatter cones | Λ |
| Devonian-Carboniferous | Pertnjara Group | Brewer Conglomerate | Pzp(4) |
| | | Hermannsburg Sandstone | Pzp(3) |
| | | Parke Siltstone | Pzp(2) |
| | | Lower Sandstone unit | Pzp(1) |
| | Mereenie Sandstone | Upper unit | Pzm(2) |
| | | Lower unit | Pzm(1) |
| Ordovician | Larapinta Group | Carmichael Sandstone | Oc |
| | | Stokes Siltstone | Ot |
| | | Stairway Sandstone | Os |