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PROBABLE SALT DOME AT WOOLNOUGH HILLS, CANNING BASIN, WESTERN AUSTRALIA

by

J.J. Veevers & A.T. Wells

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SUMMARY

A dome of Cretaceous and probable Permian sediments, about 2 miles across, is exposed in the southern part of the Canning Basin, at the north-western corner of the Warri 4-mile Sheet area. Two arcs of Cretaceous cuestas lie concentrically round an inner ring of hills 50 feet high, of probable Permian age, with a mound of brecciated dolomite at the centre. Sheared gypsum crops out 250 yards south-east of the dolomite. Only one theory of origin appears to explain all the observed features: this is that the sediments were arched up by an intrusive plug of rock salt to form a salt dome with a central area of cap rock. The economic implications of this theory - that rock salt, and possibly petroleum and sulphur, occur in the dome - can be tested by drilling only.

INTRODUCTION

Location of area

The hills situated at the north-western corner of the Warri 4-mile Sheet area (G51/4), Western Australia, are here named Woolnough Hills*, after the late W. G. Woolnough, who contributed greatly to the advancement of the geology of Western Australia. The geographical co-ordinates are 24°06'S, 124°32'E (Figure 1) and the air photographs covering the area are Morris (F51/16) Run 16/5045, 5046. Woolnough

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* This proposed name has been submitted to the Lands and Surveys Department, Western Australia, for approval.

Hills lie immediately north of the southern limit of air-photograph cover of the Canning Basin. The area is situated within the Gibson Desert, 370 miles south-east of Marble Bar, and 250 miles west-north-west of Giles Meteorological Station; the nearest points of settlement are Jiggalong Mission, 240 miles to the west, and Carnegie Homestead, 200 miles to the South-west.

Previous Work

A preliminary interpretation by J. N. Casey of the air photographs of Woolnough Hills, intended solely as a guide for future field work, showed a dome of Precambrian rocks overlain by Permian rocks to the north and east. B. H. Stinear and A. T. Wells (geologists), and S. Waterlander (geophysicist) visited the structure in June 1956, as part of a reconnaissance of the southern part of the Canning Basin. The structure was considered to be a Permian and Cretaceous dome with a core of Upper Proterozoic dolomite. One measurement of gravity was made within the dome. In October, 1958, J. J. Veevers examined the air photographs of the Woolnough Hills as part of a general investigation of the Precambrian rocks at the edge of the Basin, and suspected that the structure was a salt dome. The further study of all available information is given below.

REGIONAL GEOLOGY

A broad belt of thin horizontal Cretaceous rocks lies in the southern part of the Canning Basin. It is more than 100 miles wide and 150 miles from its northern edge to the limit of air-photograph cover (Figure 1). Woolnough Hills lie about 40 miles east of the south-western corner of this belt.

The thickest measured section of Cretaceous rocks in the region (as seen at a single outcrop) is 45 feet at Bejah Hill, 30 miles north-west of Woolnough Hills. The peak of Bejah Hill is about 250 feet above the nearest Permian outcrops, and since the strata here are horizontal, this is the best estimate of thickness of the Cretaceous rocks. As Woolnough Hills lie along the southern limit of air-photograph cover, the geology immediately to the south is unknown.

Relief within the region underlain by Cretaceous rocks is low; rises of pisolitic rubbly ironstone and clay, and rare outcrops of rocks, are lightly incised by dry radial streams, along which mulga bush is concentrated; the streams pass into broad flat sandy valleys covered with spinifex. Maximum relief is 45 feet. Breakaways (scarp-retreats) are uncommon, and where formed are generally cut into ironstone caps; consequently fresh outcropping rock is also uncommon. On 4-mile air-photograph mosaics, the sand-covered valleys in the Cretaceous region form a minutely dendritic pattern, best seen on the Morris 4-mile Sheet. The most notable single feature of the Cretaceous terrain is the almost complete absence of sand dunes, which are ubiquitous in the Permian and Jurassic terrains.

The Cretaceous rocks consist of partly silicified white massive claystone (porcellanite), which at many places encloses a thin bed of medium-grained purplish porous sandstone containing numerous worm tracks. The nearest good rock exposure visited, 18 miles north of Woolnough Hills, has this lithology.

The evidence for the Cretaceous age of these rocks is presented by Traves et al. (1956, pp. 28-30).

The nearest known outcrops of Permian rocks are near Bejah Hill. They are identified by lithology and photo-pattern; not until Helen Hill, 60 miles farther north-west, can Permian rocks be dated by fossils. The Permian outcrops consist of horizontal medium to coarse-grained pebbly quartz sandstone, interbedded with fine conglomerate and, in some places, thin siltstone. They crop out as isolated rises, commonly capped by pisolitic ironstone, in fields of seif dunes, and have a smooth dark photo-pattern. Fluvioglacial rocks like those of the Permian Paterson Formation crop out 50 miles west of Bejah Hill at Cromer Cone. Beds of sand

and clay with erratics up to three feet across are interbedded with laminated and massive sandstone.

A plant-bearing Jurassic sequence of coarse sandstone, fine conglomerate, and current-bedded sandstone occupies the eastern margin of Runton Range (Figure 1) and transgresses Permian rocks to rest directly on Lower Proterozoic metamorphic rocks. Farther east, Jurassic rocks are absent, and the Cretaceous directly overlies the Permian.

STRATIGRAPHY OF WOOLNOUGH HILLS

Two units of clastic sedimentary rocks may be recognized at Woolnough Hills (Figure 2): a poorly outcropping sheet of fine-grained rocks, mainly claystone (porcellanite) and fine siltstone, which by lithology, photo-pattern, and continuity to the north with fossiliferous rocks, are identified as Cretaceous, underlain, probably disconformably, by an inlier of interbedded quartz siltstone, sandstone and sedimentary breccia, at least 1,000 feet thick. The inlier (see Figure 4 for thickest measured section) is lithologically distinct from the Cretaceous rocks of the region, and is therefore almost certainly older. In lithology the inlier agrees well with the Permian rocks west of Bejah Hill, with which, therefore, it is identified.

The nearest outcrops of Jurassic rocks, at Runton Range, are coarser grained, more friable, and contain fragments of schist and granite.

At least two other rock units occur at Woolnough Hills, a dolomite, and a gypsum rock.

Dolomite is exposed in a hillock 15 feet high within the central mound of the structure (M5, Figure 2). The hillock consists of several blocks, the largest of which is 5 feet high and6 feet across (Figure 5). Recent or sub-Recent weathering has introduced vein-fillings of siliceous ironstone, but the well-banded, strongly brecciated structure of the dolomite is still preserved. In the right-hand side of the larger block shown in Figure 5, the banding is crenulated along incipient shears. The banding in the rest of the block is not folded. There is nothing to indicate whether the banding is original bedding or subsequent shearing. Brecciation is intense, and the breccia fragments range in size from 3 feet across (the angular block seen in the lower right-hand corner of Figure 5) to half an inch. The banding of this block lies at right-angles to that of the main block.

A deeply weathered specimen consists of

41.7% $MgCO_3$
38.4% $CaCO_3$
14.1% insoluble in 1 N HCl

Polished surfaces of the dolomite are blue-grey. The rock has a granoblastic texture of dolomite anhedra. Grain diameters range from 0.005 to 0.03 mm., with average diameter 0.015 mm. In places, thin veins of calcite and fine-grained quartz, lined with an unidentified botryoidal mineral (possibly gypsum) with R.I. less than that of balsam, cross the dolomite.

An isolated area of crystalline gypsum occurs at M6a in a dry creek bed, 250 yards south-east of the central, dolomitic outcrop. Polished surfaces show a schistose structure. Under the microscope the grains are seen to be 2 to 5 mm. long, and 1 to 4 times as long as broad. Grains are aligned parallel in finer-grained areas. Interfingering, optically parallel grains show strain extinction, and some contain bubbles of unidentified material elongated along the schistosity. Accessory minerals, consisting of quartz, possible detrital chlorite, an unidentified mineral of high refractive index and low birefringence, and argillaceous material, form less than 1% of the rock. There are no carbonates.

STRUCTURE OF WOOLNOUGH HILLS

The structure of Woolnough Hills contrasts sharply with that of the surrounding country. The steepest dip in the Permian and Mesozoic rocks of the region is 2°, without visible trend: the steepest measured dip at Woolnough Hills is 15°, in a dome.

As the section shows (Figure 2), the structure is a dissected dome of Cretaceous and probable Permian rocks with a postulated core of rock salt capped by outcropping dolomite and gypsum. In other words, the postulated structure is a salt dome. Topographically, the dome is expressed as an inner discontinuous ring of low hills (figures 3 and 6), composed of probable Permian rocks, up to 50 feet high and 4,500 feet in diameter, enclosing a saucer-shaped depression, covered with rubble, clay soil, and powdery travertine, dotted with low rises, and with a mound at the centre. In the southern part, two outer arcs of low-dipping Cretaceous cuestas are separated from each other, and from the ring of inner hills, by dry streams which follow the strike. Drainage is lightly impressed except at the southern part of the structure where shallow water-courses of the inner basin unite into a trunk which cuts radially across the ring of hills and the two arcs of cuestas. All other watercourses arise at the periphery of the inner ring of hills and flow radially outwards over Cretaceous rocks. The elevation (1,375 feet) of the central mound is the same as that of the country surrounding the structure.

Two measurements of dip were observed in the field: 10° to 15° at M4f (figure 2) and 8° at M4a-e. The other dips shown on figure 2 were interpreted from air photographs. All rocks dip outwards, except the dolomite and gypsum, which have no consistent dips. The ring of Permian hills is almost perfectly circular, but the group of Cretaceous cuestas has an oval outline, with long axis north-south. This oval area of disturbed strata is 2.2 miles long and 1.8 miles wide. Outside this oval, the Cretaceous rocks are horizontal.

Numerous small faults, denoted by short displacements of strike, have been interpreted from the air photographs; most of them are marked by watercourses and lines of trees and shrubs, and most are radial. All but two of the fault traces are confined to the area of probable Permian rocks, and most are concentrated in the northern half of the dome. The traces of faults were not examined in the field.

The single Bouguer gravity measurement at the dome does not differ appreciably from measurements made at 5-mile intervals in the area to the north.

ORIGIN OF THE DOME

Two lines of argument indicate that the dome was formed by an intrusion of salt.

(a) The structure, size and topography of the dome argree with descriptions of American Gulf Coast salt domes, among which the Butler or West Point Salt Dome of Texas, recognized as 'one of the most symmetrical and best defined, both geologically and topographically, of the North American salt domes' (DeGolyer, 1919, p.647) is the closest. According to DeGolyer (p.651), the West Point Dome 'topographically .....consists essentially of an almost circular mound surrounded by a ring-shaped valley, and this in turn is bounded on its outer margin by high hills having steep faces toward the valley and long dip slopes away from it. This topography is so expressive that one would be justified in classifying this as a salt dome on the basis of topographic evidence alone'. Powers (1920) estimates the central core of the dome to be circular in plan and 6,000 feet in diameter, the diameter of the area of disturbed strata surrounding the core about 2½ miles, and the minimum amount of uplift at the centre of the dome 1,200 feet. Comparative estimates of the postulated Woolnough Hills salt dome are:

Diameter of core 2,200 feet

Diameter of area of disturbed strata	2 miles
Minimum amount of uplift at centre of dome	1,000 feet

The main differences between the West Point Salt Dome and the Woolnough Hills structure are:

Much wider core in West Point Dome;

steeper dips around periphery of West Point Dome (25^{o}-80^{o}).

These differences are well shown by a comparison of hypothetical sections of the two domes (figure 2 of this paper and figure 2 of Powers, 1920, p.130). In the West Point Dome, the salt is a few hundred feet beneath the centre, and is covered by a thin discontinuous cap of limestone. 'The salt core and cap rock are probably overlain by sand and clay to which no age can be assigned'.

(b) The occurrence of dolomite and gypsum within the central mound of the dome supports the postulate of a salt dome. The dolomite and gypsum may be:

(1) Superficial deposits of Recent or sub-Recent age. The brecciation of the dolomite, and the flowage of the gypsum rule out this theory.

(2) The lowest exposed parts of a conformable sedimentary succession. Gypsum occurs in the Noonkanbah Formation, anhydrite and dolomite in the Anderson Formation, and dolomite in the Devonian and Ordovician successions of the Fitzroy Basin. Dolomite occurs in the Upper Proterozoic rocks along the margin of the Canning Basin. This theory also fails to account for the localized brecciation and shearing in the dolomite and gypsum.

(3) The surface of an inlying hill of pre-Permian rocks. (see p. 111, for a consideration of the theory that the Woolnough Hills dome developed over a buried hill).

(4) Remnants of deep-seated beds rafted upwards by an intrusive salt plug. In possible support of this

(as opposed to 5 below) is the fine lamination (laminae less than 1 mm. thick) of one of the dolomite samples, and the coarser banding seen as the outcrop (figure 5), both of which may represent normal sedimentary bedding.

(5) The insoluble residue of the upper, dissolved part of a salt plug. Gypsum, as the hydration product of anhydrite, is a characteristic constituent of cap rock of practically all salt domes. Its form in cap rocks is described by Taylor (1938, p.76): 'Immediately after the completion of hydration, the gypsum consists of many small interlocking crystals that retain the outlines of the replaced anhydrite grains....These small crystals gradually coalesce to form large irregularly interlocking crystals, with relatively large areas of the same optical orientation where shear planes are closely adjacent'. This fits the description of the gypsum from Woolnough Hills (figure 9a and b).

Calcite is the main carbonate in cap rock, but, as Taylor (1938, p.92) has noted, 'the less common minerals of the residues, particularly the dolomite and quartz, are locally concentrated along some of the narrow bands that show the effect of shearing'. This fits the description of the dolomite from Woolnough Hills. According to this theory, the banding in the dolomite is caused by shearing. If the unidentified botryoidal mineral found lining quartz veins in the dolomite is gypsum, as its few observable characters suggest, this would support the residue theory. To quote once again from Taylor (1938, p.59): 'Cap rock is a very heterogenous mass, particularly in its upper portion, that has been subjected to intensive faulting and brecciation. High-angle shearing, and the incorporation of breccia fragments from the surrounding sediments and from the overlying parts of the cap rock, characterize the calcite cap rock in particular'.

ALTERNATIVE THEORIES

IGNEOUS THEORY

Laccolith or stock intrusion

Domes produced by the intrusion of laccoliths or stocks have been well known since Gilbert's description of the Henry Mountains of Utah. These and other examples are readily identified as laccolithic domes because they have been sufficiently dissected to expose the central core of igneous rock. Such a structure which has not been sufficiently dissected to reveal the igneous core might resemble the Woolnough Hills dome in size and shape, but the absence of any signs of metamorphism, and failure to account for the occurrence of dolomite and gypsum, must rule out this theory.

Cryptovolcanic Structure

A cryptovolcanic structure is thought to be produced by the sudden release of volcanic gases at depth. Charateristic features, as summarized by Thornbury (1954, p.212), are: 'a nearly circular outline, a central uplifted portion which is usually marked by pronounced faulting; shattering and brecciation; and an absence of exposure of igneous rocks. A typical cryptovolcanic dome is two to three miles in diameter'. This theory also fails to explain the occurrence of dolomite and gypsum at Woolnough Hills.

No structures comparable with the Woolnough Hills dome, even on a smaller scale, are associated with intrusions of Fitzroy Lamproite (Guppy et al., 1958, p.71) in the Permian areas of the Fitzroy Basin.

Buried Hill Theory

A postulated hill over which the dome sediments were draped would have the following features:

(a) shape and size: obtuse, conical, with relief of at least 1,000 feet;

(b) composition: brecciated sedimentary rocks, including gypsum rock and dolomite, at least at top of hill;

(c) in view of the dips as high as 15° in the flanking sediments, the exhumed hill of resistant rock should stand high above present plain level;

(d) dolomite fragments should be present in the flanking sediments;

(e) slump structures in flanking sediments.

None of these features is found at Woolnough Hills; no dolomite is found in the 'flanking' sediments, which are not slumped; the core of the dome is topographically lower than the 'flanking' sediments; and a conical hill 1,000 feet high is not likely to form by the erosion of sedimentary rocks including brecciated dolomite and gypsum.

Lateral Crustal Deformation

Lateral crustal deformation fails to explain the isolated occurrence of the dome within a region of horizontal, undisturbed strata.

AGE OF THE DOME

The age of the dome cannot be estimated exactly. The youngest rocks involved in the domal folding are Cretaceous, probably Lower Cretaceous. The Permian and Cretaceous rocks are probably disconformable and it is inferred that all significant folding and subsequent erosion of the dome took place after the Cretaceous. The upper age limit of the folding must be inferred from an estimate of the time required to form the dome and reduce it by erosion to its present topography. On these grounds, an estimate of late Tertiary could be made.

AGE OF POSTULATED SALT BED

The age of the postulated 'mother' salt bed must be Permian or older. The only known evaporites in the Palaeozoic succession of the Canning Basin occur in the

Anderson Formation (Carboniferous) penetrated in Wapet Grant Range Bore No. 1 (McWhae et al., 1958, p.50). Incrustations of salt on relatively fresh faces of Permian outcrops are common in the north-eastern part of the Basin. In the Basin, salt is concentrated in salt lakes, and numerous bores and wells produce salty water. All these surface occurrences may be attributed to salt occluded in normal marine sediments.

CONCLUSIONS

Of the several possible theories of origin of the Woolnough Hills dome, only one accounts for all the observed features. This is the theory that a plug of rock salt rose from a deep-seated source of bedded rock salt to form a salt dome. Three economic deposits are associated with salt domes: petroleum, sulphur, and rock salt. None of these deposits would be expected to appear at the surface and only by drilling could they be detected. Only a minority of the known, tested salt domes have yielded either sulphur or petroleum, and fewer still have yielded both.

ACKNOWLEDGMENTS

Photographs of features in the Woolnough Hills area were taken by B. H. Stinear. The air photograph is reproduced by courtesy of the R.A.A.F.

Petrographical information of the samples was supplied by W. B. Dallwitz.

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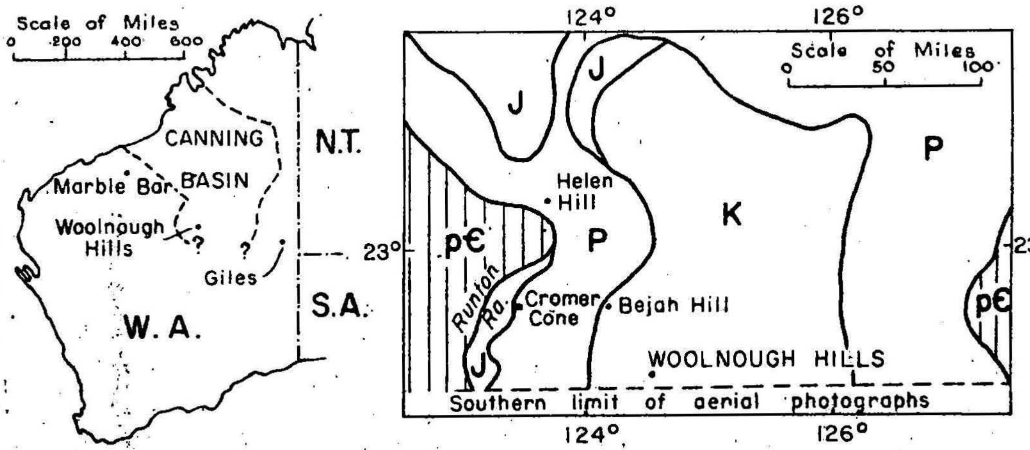
LOCALITY MAP AND REGIONAL GEOLOGY OF WOOLNOUGH HILLS

Fig1

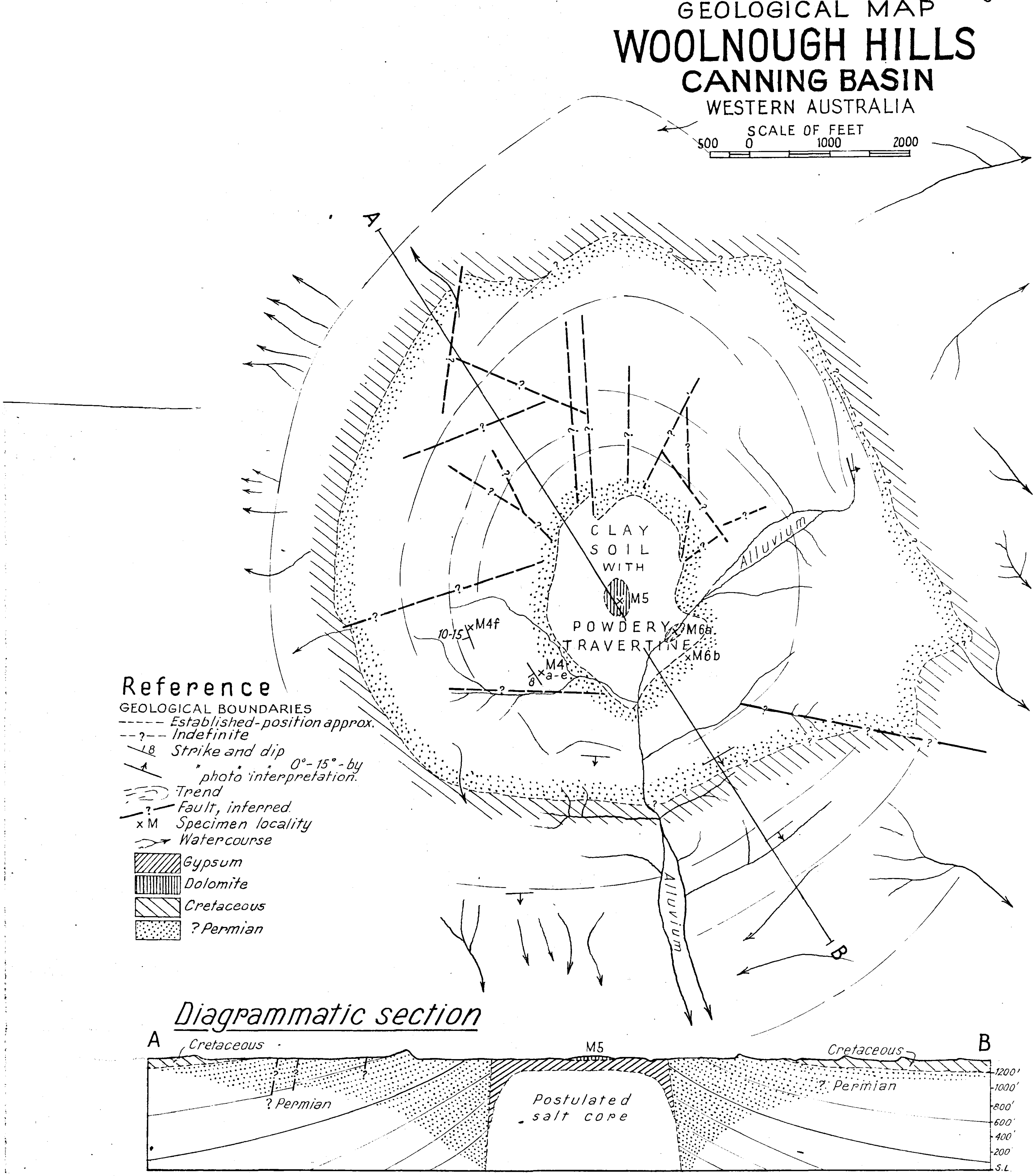
Reference

K	*Cretaceous*	P	*Permian*
J	*Jurassic*	p€	*Precambrian*



Bureau of Mineral Resources, Geology & Geophysics. Nov., 1958. **WA 4-160** F.J.R.

Fig 2



Bureau of Mineral Resources, Geology & Geophysics Nov. 1958

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a REDUCE "a-c" (10") to a-b (5") b c

FIGURE 3

Air-photograph of Woolnough Hills

FIGURE 4

(not included - see BMR report)

FIGURE 5

Folded and brecciated dolomite (M.5) in central mound at Woolnough Hills.

FIGURE 6

Panoramic view of Woolnough Hills
(not included - see BMR. Report)

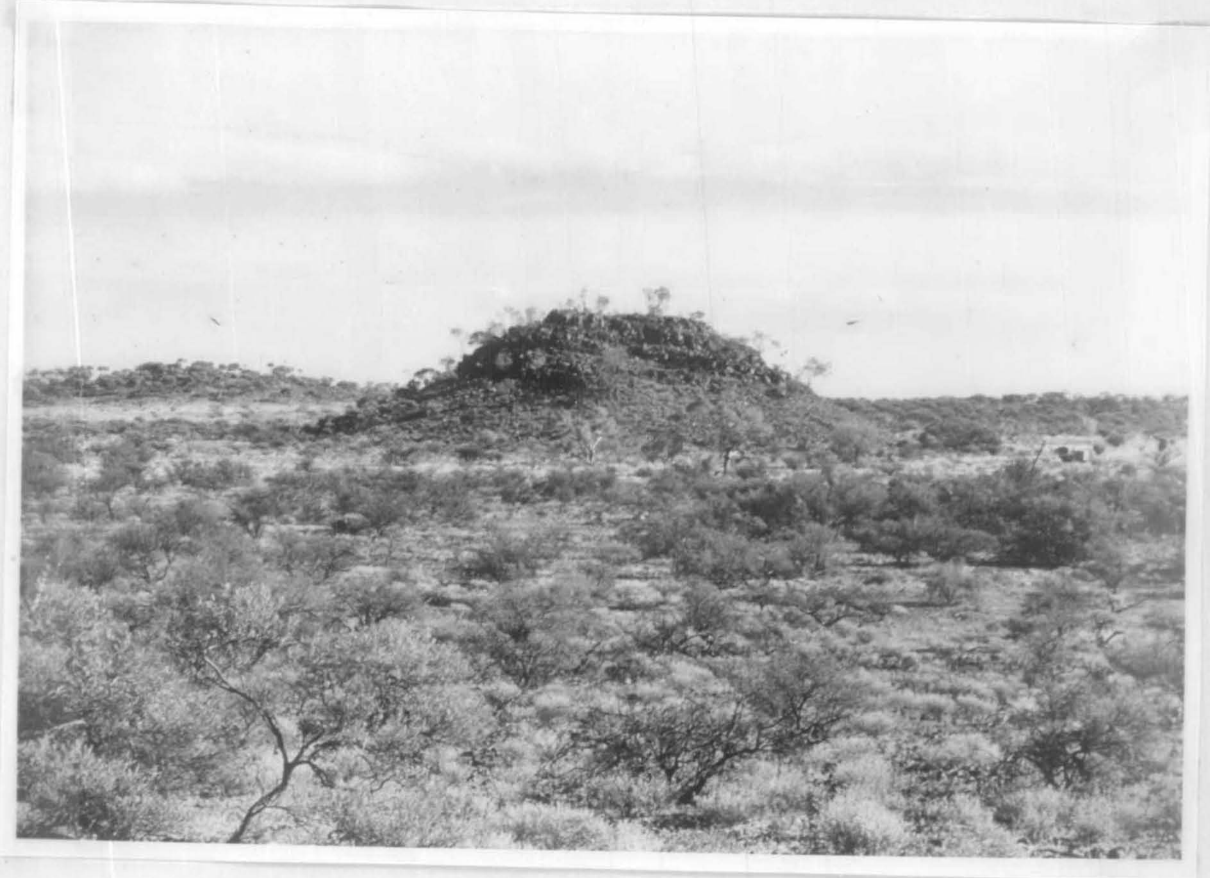

FIGURE 7
View looking south at conical hill (M4a-c) of probable Permian sediments.

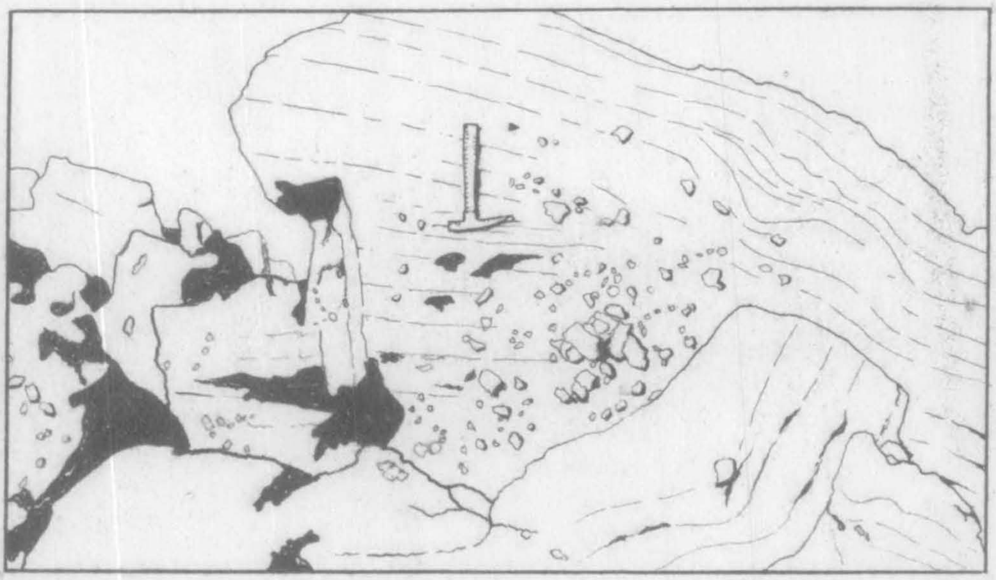

FIGURE 8

Line ~~of~~ drawing of Figure 5.

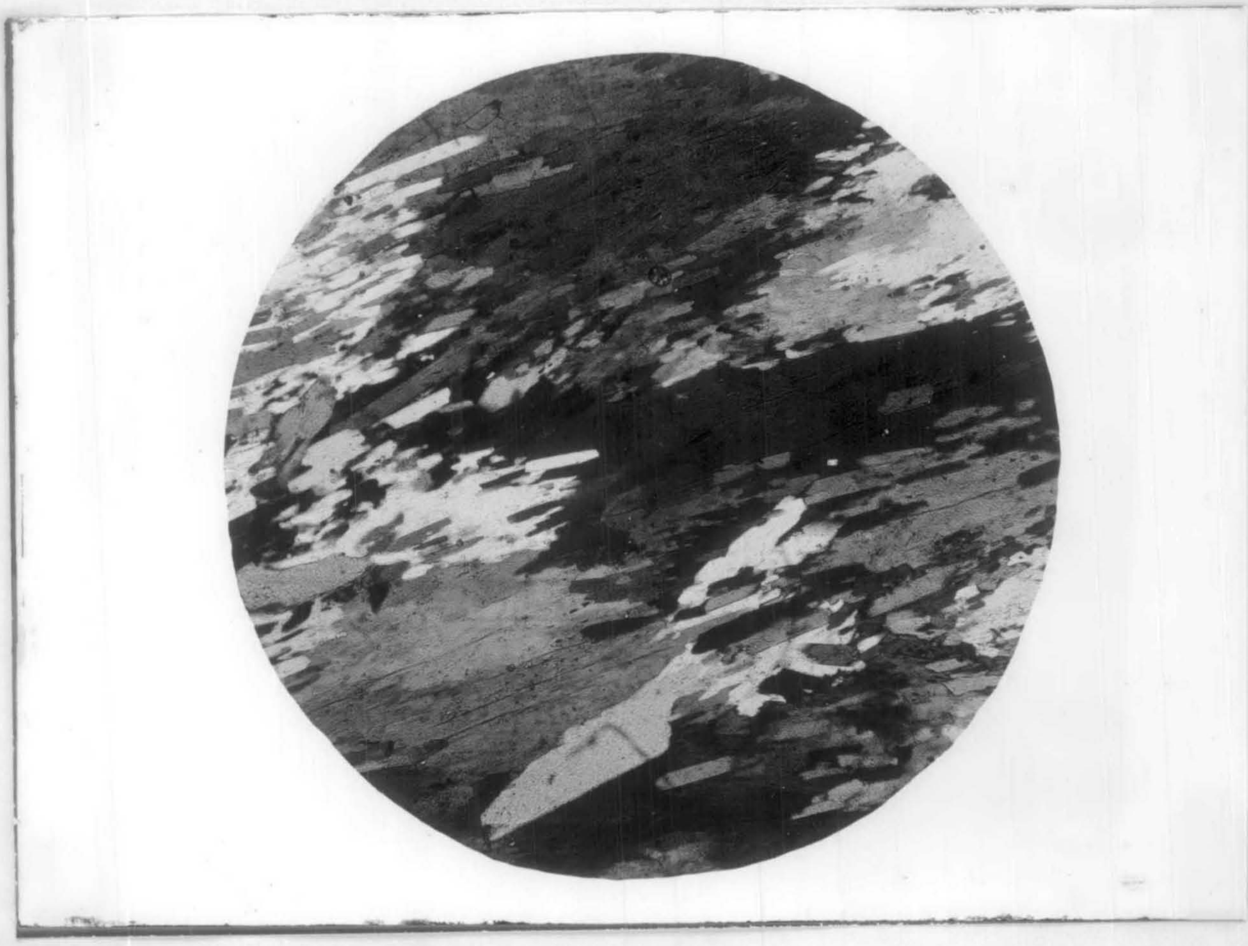

FIGURE 9A

Sample M6a X-nicols, X28

Interfingering elongated grains of gypsum.

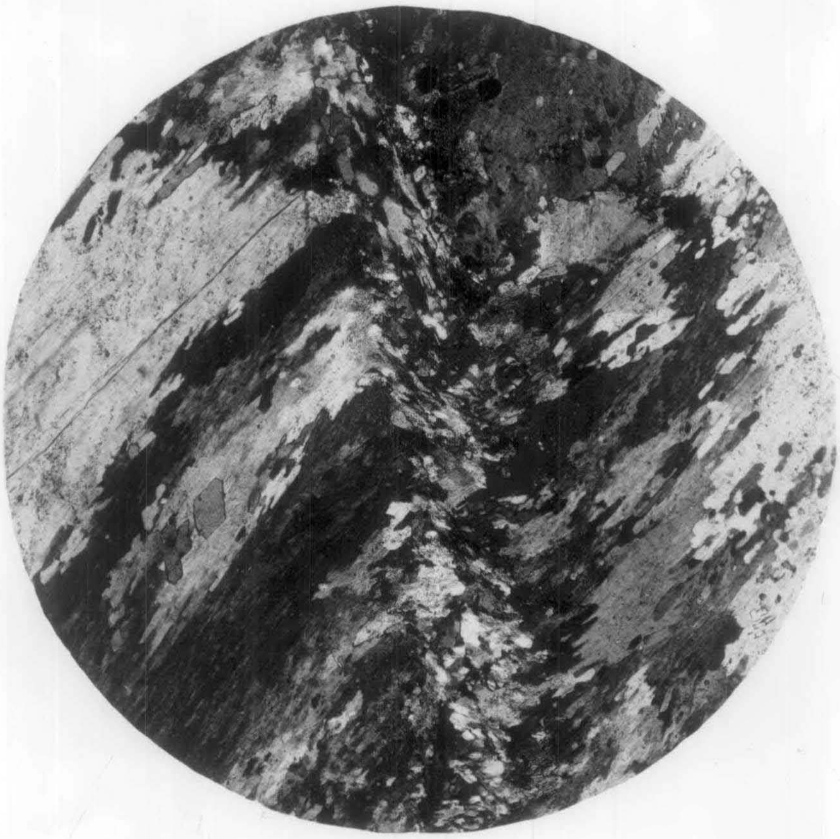

FIGURE 9B

Sample M6a X-nicols, X28
Small cross-shear in schistose gypsum.

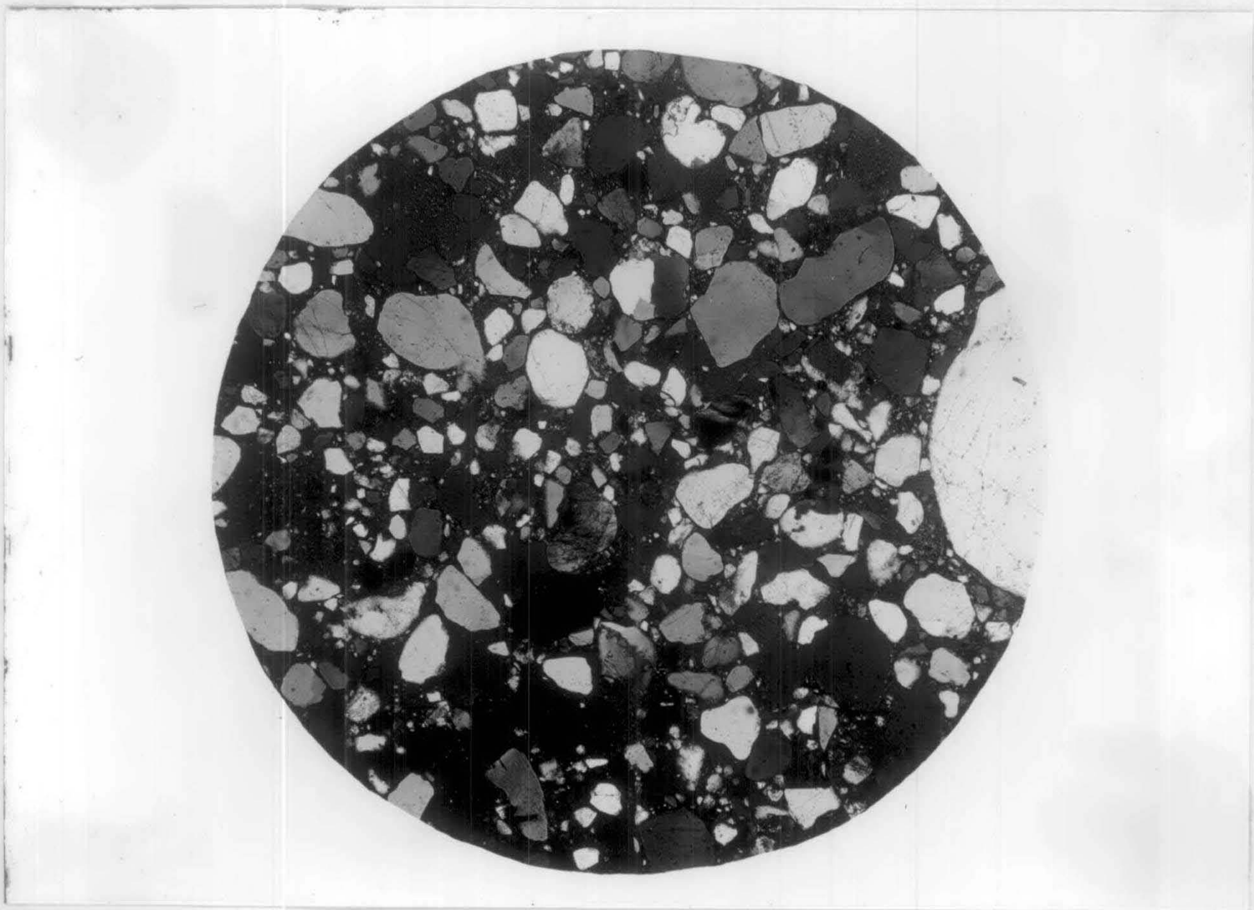

FIGURE 10

Sample M4f

Subrounded grains in probable Permian argillaceous quartz sandstone.