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Geology of the McMurray Formation

PART I

Foraminifera of the Upper McMurray and Basal Clearwater Formations

by

G. B. MELLON AND J. H. WALL

PART II

Heavy Minerals of the McMurray Formation

by

G. B. MELLON

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FOREWORD

The Research Council of Alberta, for many years, has been actively connected with projects relating to the McMurray oil-sand deposits of the lower Athabasca River area in Alberta. The bulk of this research has taken the form of investigations into the composition of the oil and modes of extraction, and has indicated that economic exploitation of the deposits should be feasible in the not too distant future. In anticipation of increasing oil-sand development, the Research Council of Alberta is publishing the following report dealing with geological aspects of the McMurray formation.

These studies on the petrology and microfaunal assemblages of the McMurray formation were initiated by the Research Council of Alberta. Mr. Mellon was awarded a postgraduate Shell Oil fellowship at the University of Alberta to complete the analysis of the McMurray lithological collections. The Socony-Vacuum Oil Company provided an almost complete core from their Oil Sands Well No. 27. Mr. H. Benthim, formerly the Athabasca Oil Sands Project geologist at McMurray, Alberta, supplied additional pertinent data.

Technical assistance and advice has been received from the staff of the Research Council of Alberta and from the Department of Geology at the University of Alberta.

Part I

Foraminifera of the Upper McMurray and Basal Clearwater Formations

ABSTRACT

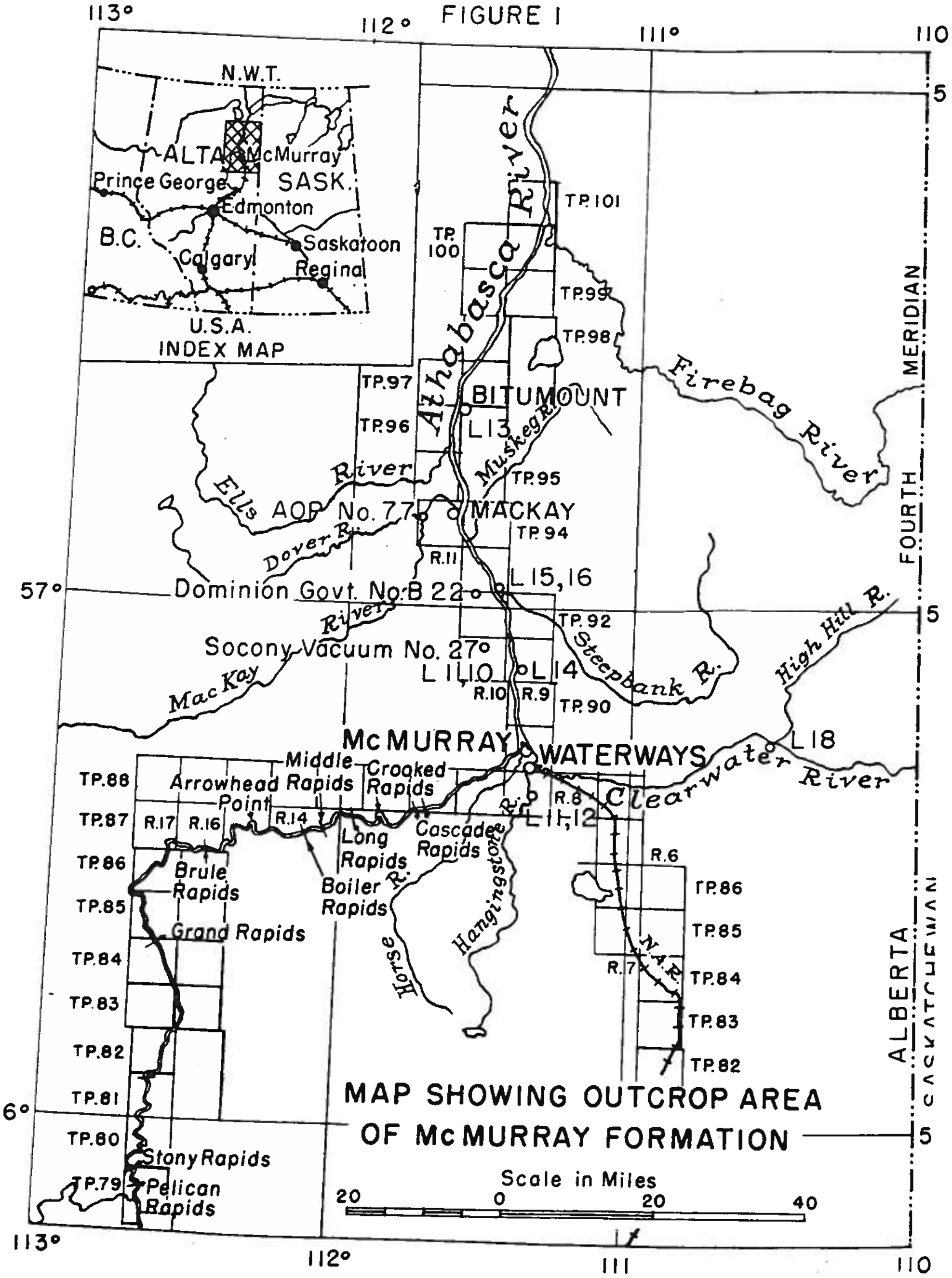
Fifteen species and subspecies of Foraminifera—of which twelve are new—from the upper part of the McMurray formation and the basal part of the Clearwater formation in the lower Athabasca River area of northeastern Alberta are figured and described. These faunas are correlated with foraminiferal assemblages from the Cummings member of the Mannville formation of east-central Alberta and from the upper part of the Loon River formation of the Peace River area of northwestern Alberta. The suites are dated Middle Albian in age (late Lower Cretaceous). Environment of deposition appears to have been brackish lagoonal and shallow marine.

INTRODUCTION

The basal sands of the Cretaceous sequence in western Canada are included in various formations of diverse ages. The basal formation of the Lower Cretaceous series in the lower Athabasca River area of northeastern Alberta is the McMurray oil sand. In the type area of the McMurray formation, the upper part is transitional to the overlying Clearwater shale and yields a microfauna of Middle Albian age. The faunal spectrum reveals arenaceous Foraminifera in the upper McMurray belonging to the genera *Haplophragmoides, Miliammina, Trochammina,* and *Verneuilinoides?* giving way to a dominantly calcareous suite in the succeeding Clearwater strata. Outside of brief mention of an undescribed foraminiferal suite within the McMurray formation by Hume (1947, p. 304) and Wickenden (1951A, p. 40), no previous publication deals with the fossil Foraminifera of the Upper McMurray and basal Clearwater formations.

Early geological work of a reconnaissance nature by Bell (1884), McConnell (1893), and McLearn (1917), and the more recent investigations by various oil company geologists, have furnished paleontological collections. Formal studies of the megafossils of the McMurray and overlying Clearwater formations were carried out by Whiteaves (1892), McLearn (1919, 1931, 1933, 1945) and Russell (1932). A complete summary of the various general geological aspects of the McMurray formation is contained in the "Proceedings, Athabasca Oil Sands Conference", published by the Government of Alberta in 1951.

FIGURE I



MAP SHOWING OUTCROP AREA OF McMURRAY FORMATION

THE McMURRAY FORMATION

The name "McMurray" was introduced by McLearn (1917) for the basal Cretaceous oil-bearing sands outcropping along the lower Athabasca river. The general section along the lower Athabasca river from Grand Rapids to Bitumount is as follows (McLearn, 1917; Wickenden, 1949):

	Thickness, feet
Grand Rapids formation—sandstone, siltstone, some minor shale	360
Clearwater formation—soft, grey or black marine shale with minor glauconitic sandstone beds, glauconitic sandstone at base	275
McMurray formation—massive to thick, cross-bedded, bitumen-impregnated sands, shaley and thinner-bedded at the top	200
Unconformity	
Waterways formation (Devonian)—fossiliferous limestone and shaley limestone.	

The McMurray formation outcrops along the lower Athabasca river and its tributaries from Boiler Rapids, west of the town of McMurray, to several miles north of Bitumount (see Fig. 1). It rests unconformably upon the Waterways limestone, which Warren and Stelck (1950) consider to be early Upper Devonian in age, while the upper limit of the McMurray is set at the base of a green, glauconitic sandstone, above which the *Lemuroceras* fauna of the Clearwater shale appears (McLearn, 1917). The contact between the Clearwater and McMurray formations marks an abrupt change in depositional environment, but, as will be discussed later, there is no time-break at the boundary of the two formations. Furthermore, there is no valid evidence for postulating a hiatus within the McMurray formation itself.

In outcrop along the Athabasca river, the McMurray formation varies from about 150 to 200 feet in thickness, although data from numerous boreholes on both sides of the river show that the formation may vary considerably in thickness over very short distances owing to the uneven surface of the underlying Waterways limestone. The formation consists of beds of unconsolidated to very friable quartz sand, with bitumen acting as a binding agent in many areas. The lower part of the formation is massive to thick-bedded, and cross-bedded on a very large scale, while the upper 50 feet or so tends to be thinner-bedded with the intercalation of silt and clay lenses and laminae between and within the sand beds. Conglomerate is rare, both at the base and within the formation, but the basal beds may become a coarse-grained grit, grading upwards into finer-grained sands. Boreholes and outcrop data show that usually several feet of residual clay and sand separate the McMurray formation proper from the underlying limestone.

The petrology of the formation, particularly the heavy mineral content, is discussed in Part II.

MEGAFOSSILS

Well-preserved tree trunks and wood (Gordon, 1932) have been found in the McMurray formation, but no respresentative flora has yet been reported. Laminae of a *Ginkgo* and a few other plant fragments have been collected by Mellon from a small outcrop on the Athabasca river between MacKay and Bitumount. This outcrop is in the lower half of the McMurray formation.

Russell (1932) described a small fauna (referred to hereafter as the *Elliptio biornatus fauna*) from near the top of the McMurray formation on the Hangingstone river, which contained the following species:

Unio (Elliptio) biornatus Russell
Murraia naiadiformis Russell
Viviparus murraiensis Russell
Lioplacodes bituminis Russell
Goniobasis? multicarinata Russell
Melania multorbis Russell
Melampus athabascensis Russell

Russell (1932, p. 7.) stated that the fauna was "predominantly composed of non-marine genera, and reckoning by individuals, is overwhelmingly of fresh-water habitat. However, there are several forms present suggesting brackish water or even marine conditions . . . . It is suggested, on the basis of the molluscan fauna, and subject to revision in the light of field evidence, that the McMurray formation was developed under estuarine or near estuarine conditions."

Russell (1932, p. 1) noted that a small marine faunule occurs near the top of the McMurray formation. This fauna had been previously mentioned by McLearn (1931) as occuring in the transition beds between the Clearwater and McMurray formations above the *Elliptio biornatus* fauna. It carries the brackish pelecypod *Astarte natosini* McLearn.

The megafauna of the overlying Clearwater shale has been described by Whiteaves (1892) and McLearn (1919, 1931, 1933) and consists of the following forms:

Beudanticeras affine (Whiteaves)
Beudanticeras glabrum (Whiteaves)
Lemuroceras mcconnelli (Whiteaves)
Lemuroceras cf. *belli* McLearn
Gastroplites cf. *canadensis?* (Whiteaves)
Entolium irenense McLearn
Pecten alcesianus McLearn
Camptonectes matonabbei McLearn
Brachidontes athabaskensis McLearn
Nucula athabaskensis McLearn

Inoceramus dowlingi McLearn
Arctica limpidiana McLearn
Thracia kissoumi McLearn
Yoldia kissoumi McLearn
Goniomya matonabbei McLearn
Psilomya peterpondi McLearn
Psilomya elongatissima McLearn
Protocardia alcesiana McLearn
Onestia onestae (McLearn)
Tellina dowlingi McLearn
Turnus lacombi McLearn

The fauna of the Clearwater formation is distinctly marine in contrast to that of the underlying McMurray formation.

MICROFOSSILS OF THE McMURRAY FORMATION

Two distinct microfossil assemblages are present within the McMurray formation. There is a lower assemblage of non-marine appearance and an upper brackish fauna.

The elements collected from the lower part of the McMurray formation between the depths of 117 and 293 feet in the Socony-Vacuum Oil Sands Well No. 27 are as follows:

(a) Occasional poorly preserved non-marine ostracods, including the genus *Cypridea*,

(b) Rare sporitoid forms, together with much finely ground-up cuticle and carbonaceous material,

(c) Unidentifed arenaceous objects, probably organic.

A well-defined foraminiferal assemblage has been collected from the upper part of the McMurray formation between the depths of 101 and 117 feet in the Socony-Vacuum Oil Sands Well No. 27 and includes the following foraminiferal species:

Ammodiscus sp.
Haplophragmoides cf. *sluzari* n. sp.
Haplophragmoides sp.
Miliammina sproulei Nauss var. *gigantea* n. var.
Trochammina mcmurrayensis n. sp.
Trochammina? sp.
Verneuilinoides? sp.

The same fauna, except *Ammodiscus* sp. and *Trochammina?* sp., was also found in the core of the Athabasca Oil Sands Project Well No. 77 between the depths of 55 and 80 feet, immediately underlying shaley glauconitic sand.

No diagnostic microfossils have been obtained from the coarser oil-bearing sands. The fine-grained margins of the oil-sand deposit have received little attention to date. However, an assemblage of Foraminifera was recoved in the Mildred-Ruth Lakes area Well B22 (Hume, 1947, p. 304) from a 17-foot bed of shale laying above a coal seam, 102 feet above the base of the McMurray formation.

The position of this shale tongue appears to be relatively lower than the shale containing the microfauna described from the Socony-Vacuum Oil Sands Well No. 27.

MICROFOSSILS OF THE BASAL CLEARWATER FORMATION

The basal glauconitic sand of the Clearwater formation did not yield any microfauna in the Socony-Vacuum well. However, from the basal 19 feet of the shale, immediately overlying the sand, a prolific fauna was obtained which includes the following suite:

Ostracoda
- *Cytheridea* (*sensu lato*) sp.

Foraminifera
- *Ammobaculites humei* Nauss
- *Ammodiscus* sp.
- *Bathysiphon* sp.
- *Discorbis norrisi* n. sp.
- *Globulina lacrima* Reuss var. *canadensis* n. var.
- *Haplophragmoides gigas* Cushman var. *minor* Nauss
- *Haplophragmoides sluzari* n. sp.
- *Lenticulina bayrocki* n. sp.
- *Leptodermella?* sp.
- *Marginulinopsis collinsi* n. sp.
- *Marginulinopsis collinsi* var.
- *Miliammina subelliptica* n. sp.
- *Nodosaria* aff. *proboscidea* Reuss
- *Pseudonodosaria clearwaterensis* n. sp.
- *Quadrimorphina albertensis* n. sp.
- *Saracenaria trollopei* n. sp.
- *Saracenaria trollopei* var.
- *Saracenaria* sp.
- *Tritaxia athabascensis* n. sp.
- *Verneuilinoides?* sp.

This fauna has a widespread distribution and provides a datum of reference for correlation.

AGE AND CORRELATIONS

The affinities of the microfauna obtained from the upper part of the McMurray formation are very close to those found in the basal Clearwater formation. A commonly occurring species of *Verneuilinoides?* is present in both the upper McMurray and basal Clearwater formations, while species of the genus *Haplophragmoides* show only varietal differences.

The basal Clearwater microfaunas are compared most readily with forms previously described from the Cummings member of the Mannville formation of east-central Alberta(Nauss, 1947) and with described forms from the Gault formation of Europe. The

Gault is Albian (later Lower Cretaceous) in age. The ammonites of the Clearwater formation (*Lemuroceras, Beudanticeras*) are Middle Albian in age. The age of the upper McMurray Foraminifera may be regarded, therefore, as early Middle Albian.

Several ammonite "zones" may be recognized from the Lower Cretaceous marine sequence of northern Alberta and northeastern British Columbia. Starting from the top of the Lower Cretaceous, these "zones" may be generically outlined in descending order as the *Neogastroplites* zone, the *Gastroplites* zone, the *Lemuroceras* zone and the *Cleoniceras* zone. The stratigraphic interval covered by these faunas spans the Upper Albian, the Middle Albian, and, in part, the uppermost Lower Albian substages. The lower part of the Middle Albian substage shows the following descending succession of species (C. R. Stelck, pers. comm.):

Lemuroceras mcconnelli
Lemuroceras irenense
Lemuroceras indicum
Cleoniceras cf. *subbayleyi*

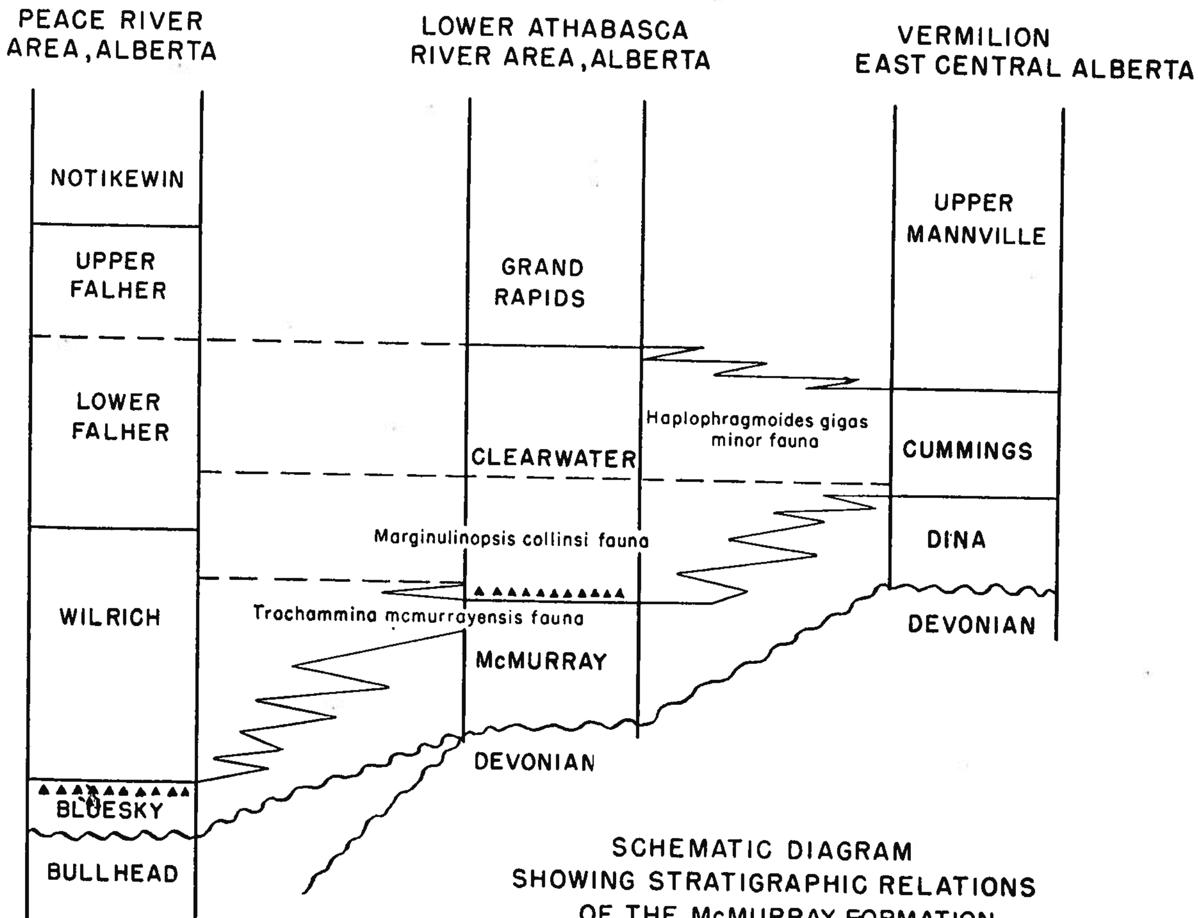
Of the above, only the *Lemuroceras mcconnelli* faunal suites are present in Clearwater shale collections housed in the University of Alberta. This would indicate that the *Unio* (*Elliptio*) *biornatus* fauna of the upper McMurray formation is slightly earlier and probably represents the brackish facies equivalent of the marine *L. indicum* fauna, approximately. On this basis, the upper part of the McMurray formation would belong to the lower part of the Middle Albian substage of the Lower Cretaceous.

The upper part of the McMurray formation and the basal Clearwater beds of the Athabasca River area may be correlated, through their microfaunas, with part of the Loon River formation of the Peace River drainage. In the terminology set up by Workman et al. (1954), correlative beds would belong to the lower part of the Falher member of the Spirit River formation of the Peace River region of Alberta. Along the Peace river in northeastern British Columbia, the upper part of the McMurray formation and the basal Clearwater beds are represented by the lower part of the Moosebar formation. A similar correlation may be made, through the microfauna, with the lower part of the Moosebar formation along Hasler and Crassier creeks in the Pine River area (Stelck, 1950).

The close association of the microfauna in the Cummings member of the Mannville formation in east-central Alberta to the microfauna found in the lower Clearwater formation gives an indicated correlation of the top of the McMurray formation with the Dina member of the Mannville formation (see Fig. 3).

Marine equivalents to the upper part of the McMurray formation are present over most of the Arctic slope as the ammonite *Lemuroceras* is found in the Garbutt formation on the Liard River drainage, northeastern British Columbia; in the Sans Sault group of the

FIG. 3



SCHEMATIC DIAGRAM
SHOWING STRATIGRAPHIC RELATIONS
OF THE McMURRAY FORMATION.

▲▲▲▲▲▲ glauconite

Mackenzie river, Northwest Territories (Hume, 1954); from unnamed shales of the Peel River drainage in northern Yukon; and in the upper part of the Torok formation in northern Alaska (Payne, 1951).

Apparently, the McMurray formation of type area marked a southern near-shore facies of the Arctic flooding of the early Middle Albian sea, and the Dina member of the Mannville formation marks a slightly later southern margin to the continuing inundation of that time.

ECOLOGY

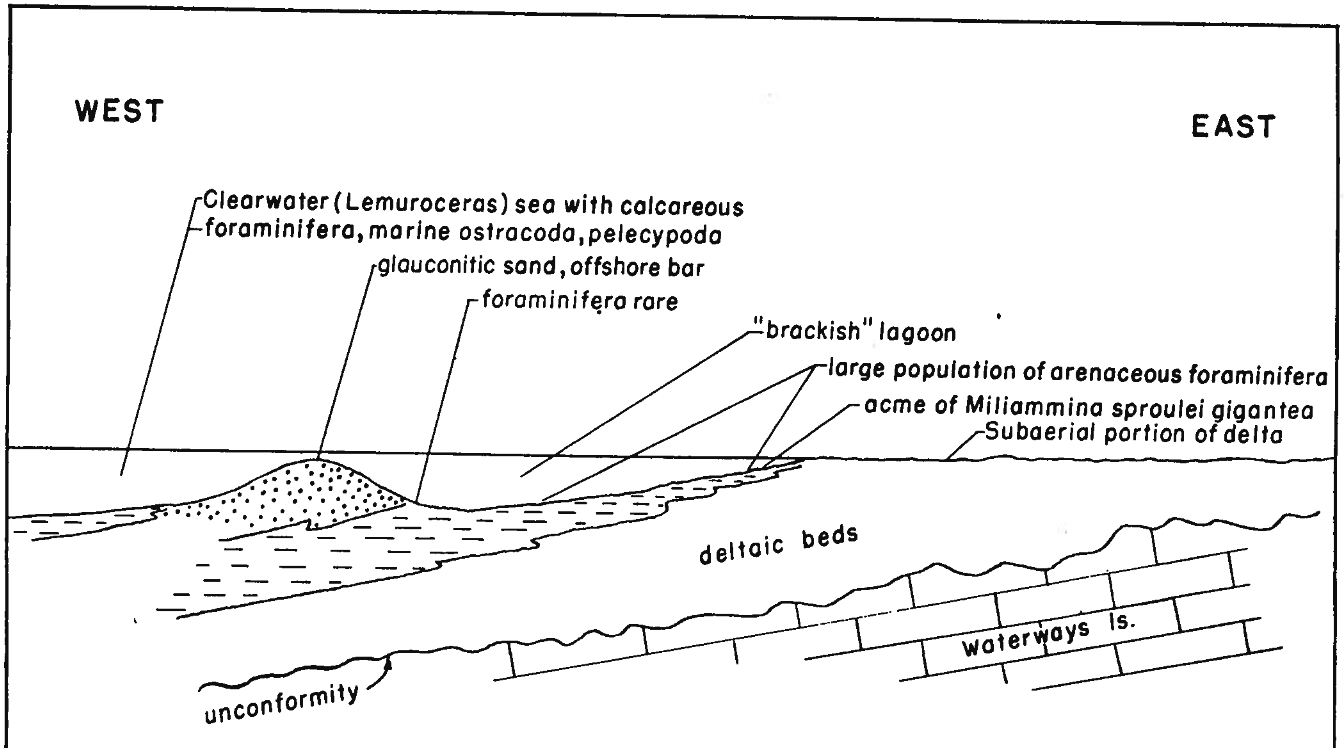
The transgressional inundation of the Middle Albian sea is reflected in the shift from the arenaceous microfaunal assemblage recovered from the upper McMurray formation to the calcareous microfauna found in the basal Clearwater formation.

The detailed work of Phleger (1954, 1955) on the foraminiferal assemblages of the Mississippi Sound area has been the guide in interpreting the ecology of the two foraminiferal suites found in the Socony-Vacuum Oil Sands Well No. 27. Phleger divides his faunas into four geographic and ecologic facies, but the main distinction is between an open-gulf facies of calcareous Foraminifera and a sound or "lagoonal" facies of arenaceous Foraminifera, separated from each other by a barrier of low offshore islands. The waters of the open gulf are thus prevented from invading the less saline waters of the Mississippi Sound by both the barrier of offshore islands and the high runoff of fresh water from the adjoining mainland. In similar fashion, the glauconite sand of the basal Clearwater formation provided the barrier which prevented the normal saline water of the onlapping Clearwater sea from contaminating the shallow brackish water adjacent to the so-called McMurray "delta" (see Fig. 4).

The foraminiferal assemblage from the upper part of the McMurray formation is very similar to the Recent assemblage found by Phleger in marshes adjacent to the mainland. *Trochammina comprimata* Cushman and Bronnimann and *Miliammina fusca* (H. B. Brady), both abundant in the Mississippi marshes, have their counterparts in the McMurray formation in *Trochammina mcmurrayensis* n. sp. and *Miliammina sproulei* Nauss var. *gigantea* n. var. The partly calcareous microfauna from the basal Clearwater shales is thought to be analogous to Phleger's open-gulf fauna.

Although the microfauna present in the lower part of the McMurray formation is poorly preserved, certain ecological deductions may be drawn. The ostracod *Cypridea,* which occurs in the lower McMurray formation, occupies a fresh to brackish water habitat in contrast to the marine genus *Cytheridea* occurring in the base of the Clearwater formation. The presence of numerous comminuted plant remains is usually considered indicative of a fresh to brackish water environment.

FIGURE 4



DIAGRAMMATIC SKETCH TO SHOW RELATION OF FAUNAL ASSEMBLAGES TO DEPOSITIONAL ENVIRONMENT DURING ONLAP OF CLEARWATER SEA OVER SUBMERGING McMURRAY DELTA.

FORMAL DESCRIPTIONS

Order *Foraminifera*

Genus AMMOBACULITES Cushman, 1910

AMMOBACULITES HUMEI Nauss

Plate 1, figure 18

Ammobaculites humei Nauss, 1947, Jour. Paleontology, vol. 21, p. 333, pl. 48, fig. 1.

Test usually somewhat flattened in fossilization, early portion close-coiled and comprised of five or six equal chambers, later portion consisting of up to six chambers in straight uniserial arrangement; chambers increasing slightly in diameter as added, the ultimate chamber tending to be pyriform; sutures partly obscured, depressed, at right angles to the long axis of the test; wall coarsely arenaceous, of angular quartz grains up to 0.08 mm. but averaging about 0.04 mm., with a small amount of cement, giving an uneven finish to the test; aperture, a terminal central opening; colour white.

Length of plesiotype: 0.9 mm., diameter of coiled portion 0.36 mm.

Plesiotype locality: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 81 feet, 20 to 28 feet above the base of the Clearwater formation.

Plesiotype: Univ. of Alberta Pal. Type Coll.

Horizon: This is a rather common species in the basal shales of the Clearwater formation.

Remarks: Considerable variation exists in this species regarding the size of the uncoiled portion, and the number of chambers in the uncoiled portion, which varies from two to six.

A. humei was originally described by Nauss from the Cummings member of the Mannville formation of east-central Alberta. Martin (1954) reported this species from the upper part of the Clearwater formation in type section on the Athabasca river. Wickenden's (1951B) *Ammobaculites* sp. A from the lower Falher member of the Spirit River formation seems identical to this form.

Genus DISCORBIS Lamarck, 1804

DISCORBIS NORRISI Mellon and Wall, n. sp.

Plate 2, figures 9, 10, 11

Test small to medium, trochoid, dorsal side convex, ventral side tending to be concave and umbilicate, periphery subacute; umbilical area obscured with extraneous shelly material; test of three whorls, six to seven chambers in final whorl of adult specimens; chambers, all visible on dorsal side, those of ultimate whorl and occasionally of penultimate whorl visible ventrally, gradually enlarging, final one somewhat inflated ventrally; sutures fairly distinct, arcuate, flush to slightly raised; wall calcareous, hyaline, medium perforate; aperture, a low arch at the ventral margin of the ultimate chamber, near the periphery; colour light brown.

Maximum diameter of paratype: 0.27 mm.; thickness 0.09 mm.

Paratype locality: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 81 feet, 20 to 28 feet above the base of the Clearwater formation.

Holotype: Univ. of Alberta Pal. Type Coll., to be figured in a forthcoming publication.

Paratypes: The figured paratype, apparently a juvenile specimen, unfortunately was lost. Similar paratypes in the Univ. of Alberta Pal. Type Coll.

Horizon: Rare in the basal shales of the Clearwater formation.

Remarks: This species is present in the central part of the Clearwater formation, type section (Martin, 1954). It occurs also in the upper part of the Loon River formation exposed along the lower Peace river (Trollope, 1951). The species is probably identical to *Anomalina* sp. of Wickenden (1951B, pl. IA, figs. 34, 35) from the lower Falher.

Name: After Dr. A. W. Norris, geologist, Geological Survey of Canada.

Genus GLOBULINA d'Orbigny, 1839

GLOBULINA LACRIMA CANADENSIS Mellon and Wall, n. var.

Plate 2, figure 6

Globulina sp. Wickenden, 1951, Geol. Surv. Canada Paper 51-16, p. 40, pl. IA, fig. 27.

Test small, tear-shaped, circular in cross-section, generally of three or four chambers which extend almost back to the base; sides and base concave, never straight; sutures distinct, flush, seldom slightly depressed; wall very thin, smooth, calcareous, finely perforate; apertural end extended, with radiate aperture and small apertural chamber; colourless to white opaque.

Length of holotype: 0.31 mm.; width 0.2 mm.

Holotype locality: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 81 feet, 20 to 28 feet above the base of the Clearwater formation.

Holotype: Univ. of Alberta Pal. Type Coll.

Horizon: Rare to occasional in the basal shales of the Clearwater formation.

Remarks: This form is similar to *Globulina lacrima* Reuss recorded by Cushman from the Upper Cretaceous of Texas, except that the Texas form is larger and tends to have straight sides. The type material of Reuss from the Upper Cretaceous of Germany ranges in size from 0.75 to 1.0 mm. and hence is considerably larger than the basal Clearwater variety.

Locally, this variety is identical to Wickenden's *Globulina* sp. from the middle part of the Falher member of the Spirit River formation. It is present in the central part of the Clearwater formation, type section (Martin, 1954), and is found in the lower part of the Moosebar formation of northeastern British Columbia (Stelck, 1950).

Genus HAPLOPHRAGMOIDES Cushman, 1910

HAPLOPHRAGMOIDES GIGAS MINOR Nauss

Plate 1, figure 10

Haplophragmoides gigas minor Nauss, 1947, Jour. Paleontology, vol. 21, p. 338, pl. 49, fig. 10.

Test of medium size, compressed, usually somewhat flattened in fossilization, planispiral, involute with some umbilical development; periphery angular, the thickest part of the test about the umbilical margin; chambers gradually increasing in size, six to ten being visible in the ultimate whorl; sutures sigmoidal, distinct, very slightly depressed, marked in flattened specimens by thickened ridges along traces of the intercameral walls; wall finely arenaceous with much cement, giving a generally smooth or glazed exterior surface; aperture a low arch at the base of the terminal face.

Maximum diameter of plesiotype: 0.5 mm.

Plesiotype locality: Socony-Vacuum Oil Sands well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 81 feet, 20 to 28 feet above the base of the Clearwater formation.

Plesiotype: Univ. of Alberta Pal. Type Coll.

Horizon: Common in the basal shales of the Clearwater formation.

Remarks: This variety is usually somewhat deformed in fossilization, making identification difficult. However, the Clearwater form seems to be definitely the same as topotypes of *H. gigas* Cushman var. *minor* Nauss from the Cummings member of the Mannville formation.

Martin (1954) records the occurrence of this form in the middle and upper part of the Clearwater formation, type section.

HAPLOPHRAGMOIDES SLUZARI Mellon and Wall, n. sp.

Plate 1, figure 15

Adult test medium to large size, compressed, planispiral, slightly evolute, periphery broadly rounded; chambers tending to be indistinct, gradually increasing in size, seven to twelve in ultimate whorl (average about nine and one-half); sutures thickened, straight, flush, indistinct, their positions sometimes denoted by traces of the intercameral walls; umbilicus shallow and usually filled, generally showing a portion of the earlier whorl; wall arenaceous, of fine clear quartz grains set in a brownish cement, giving an even but not glazed exterior surface; aperture a low arch at the base of the terminal face.

Maximum diameter of holotype: 0.7 mm.

Holotype locality: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 81 feet, 20 to 28 feet above the base of the Clearwater formation.

Holotype: Univ. of Alberta Pal. Type Coll.

Horizon: Common in the basal shales of the Clearwater formation.

Remarks: This species is distinguished mainly by its relatively large size, and its tendency to become slightly evolute, thus showing a portion of the preceding whorl. Other features are less distinct, and specimens tend to be more or less flattened. There appears to be some variation in wall structure, with many individual variants having somewhat coarser grains and less cement, thus appearing not so smoothly finished as the holotype.

This species is present in the central and upper part of the Clearwater formation, type section (Martin, 1954). *Haplophragmoides* sp. A of Wickenden (1951B, pl. IA, fig. 3) from the lower and middle parts of the Falher member is similar to *H. sluzari*.

Name: After R. D. Sluzar, geologist, Imperial Oil Limited, Edmonton.

HAPLOPHRAGMOIDES cf. H. SLUZARI

Plate 1, figures 11, 12

Test of small to medium size, compressed, planispiral, involute; periphery broadly rounded, the test being slightly thicker about the umbilical margin; umbilicus shallow but distinct; chambers of approximately equal size, rather indistinct but made more noticeable by flattening of the test, seven or eight in the ultimate whorl; sutures rather indistinct, slighly arcuate, their positions being emphasized by the strength of the intercameral walls; wall arenaceous, of fine clear quartz grains set in a matrix of opaque, brownish material; aperture an arch at the base of the septal face; colour light brown.

Maximum diameter of figured specimen: 0.5 mm.; thickness 0.17 mm.

Locality of figured specimen: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, at a depth of 117 feet, 16 feet below the top of the McMurray formation.

Holotype: Univ. of Alberta Pal. Type Coll.

Horizon: Rare in the upper part of the McMurray formation.

Remarks: This form seems closely related to *H. sluzari* from the overlying basal Clearwater shales, and appears almost identical to those variant forms of the species which have less cement and a rather uneven finish.

HAPLOPHRAGMOIDES sp.

Plate 1, figures 7, 8, 9

Test variable in size, planispiral, involute, compressed, periphery broadly rounded; chambers indistinct, sometimes made more distinct by crushing, six or seven in ultimate whorl; sutures and umbilicus generally indistinct; wall coarsely arenaceous with large, clear, subangular quartz grains up to 0.1 mm. in diameter but averaging about 0.03 or 0.04 mm., set in a variable amount of matrix of finer brownish material, often with small, black carbonaceous fragments adhering to the outer surface; aperture an arch at the base of the terminal face.

Maximum diameter of specimen (fig. 7): 0.5 mm.; thickness of same specimen (fig. 8): 0.15 mm.

Maximum diameter of specimen (fig. 9); 0.6 mm.

Locality of figured specimens: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 106 and 107 feet, 5 to 6 feet below the top of the McMurray formation.

Figured specimens: Univ. of Alberta Pal. Type Coll.

Horizon: Occasional in the uppermost part of the McMurray formation, immediately underlying the glauconite sand.

Remarks: This form is similar in some respects, particularly in wall structure, to *H. collyra* Nauss var. *bullocki* Stelck and Wall from the Upper Cretaceous Kaskapau formation of the Peace River area. However, the McMurray form is more compressed, has fainter sutures, and appears rather square in outline, whereas the periphery of the Kaskapau variety tends to be circular. Due to the general lack of diagnostic characters in the McMurray form, no specific name is being assigned to it.

Genus LENTICULINA Lamarck, 1804

LENTICULINA BAYROCKI Mellon and Wall, n. sp.

Plate 2, figure 7, 8

Lenticulina sp. Wickenden, 1951, Geol. Surv. Canada Paper 51-16, p. 37, pl. IA, figs. 12, 13.

Adult test medium size, compressed, planispiral, or becoming slightly trochoid thus showing the earlier chambers on one side only; peripheral margin distinct, bordered by a rim; test, a spherical proloculus with twelve or thirteen subsequent chambers, eight or nine in the last whorl; chambers distinct, gradually increasing in size, last one or two chambers very slightly inflated; sutures distinct, thickened, arcuate, slightly raised except ultimate one which is depressed; wall calcareous, finely perforate; aperture radiate, a small round opening on the terminal face at the peripheral angle; colour white.

Maximum diameter of holotype: 0.74 mm.; thickness 0.3 mm.

Holotype locality: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 81 feet, 20 to 28 feet above the base of the Clearwater formation.

Holotype: Univ. of Alberta Pal. Type Coll.

Horizon: Rare in the basal shales of the Clearwater formation.

Remarks: The basal Clearwater species figured here is somewhat similar to the "forme typique" of *Cristellaria gaultina* Berthelin from the Albian of France, except that the French species has developed a distinct flange which is lacking in the Clearwater species. The latter is therefore described as a new species on the basis that it lacks a flange, and the adult test may tend to become slighly trochoid in the manner of those forms described under the generic name *"Darbyella"*.

Locally, this form is identical to Wickenden's *Lenticulina* sp. from the lower Falher. It is also present in the central and upper parts of the Clearwater formation, type section (Martin, 1954).

Name: Afer L. A. Bayrock, geologist, Research Council of Alberta, Edmonton.

Genus MARGINULINOPSIS Silvestri, 1904

MARGINULINOPSIS COLLINSI Mellon and Wall, n. sp.

Plate 2, figures 1, 2

Marginulina sp. A Wickenden, (*pars*), 1951, Geol. Surv. Canada Paper 51-16, p. 37, pl. IA, figs. 14, 16 (*non* 15).

Adult test of medium size, coiled portion compressed with five or six visible chambers, uncoiled portion of three chambers and becoming ovoid in cross-section; chambers distinct, particularly in uncoiled portion, last three chambers tending to become slightly inflated; sutures distinct, becoming depressed in uncoiled portion; generally about twelve longitudinal costae running uninterruptedly across the sutures from the last one or two chambers of the coiled portion to about one-quarter of the way up the terminal chamber, sometimes splaying out as they cross the last suture; wall calcareous, perforate, hyaline or opaque; aperture radiate, at the outer peripheral angle.

Length of holotype: 0.7 mm.; diameter of coiled portion 0.32 mm.

Locality of holotype: Socony-Vacuum Oil Sands Well No. 27 in

Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 81 feet, 20 to 28 feet above the top of the Clearwater formation.

Holotype: Univ. of Alberta Pal. Type Coll.

Horizon: Occasional in the basal shales of the Clearwater formation.

Remarks: This species seems related to several European forms from the Lower Cretaceous, its similarity to *Cristellaria* (*Marginulina*) *mülleri* Reuss being probably the closest. In the latter species, however, there appears to be no early coiled portion.

Locally, this form is identical in part to *Marginulina* sp. A of Wickenden (1951B) from the Falher. It is present in the central part of the Clearwater formation, type section (Martin, 1954), and is found in the lower part of the Moosebar formation of northeastern British Columbia (Stelck, 1950).

Name: After George A. Collins, geologist, Research Council of Alberta, Edmonton.

MARGINULINOPSIS COLLINSI Variety

Plate 2, figures 3, 4

This varietal form differs from the species *s.s.* in being more slender and elongate, although still oval to nearly circular in cross-section. The early coiled portion of the variety is keeled (this feature is not clearly shown on the figured specimen).

Length of figured specimen: 0.7 mm.; diameter of coiled portion 0.2 mm.

Locality of figured specimen: same as for the species *s.s.*

Figured specimen: Univ. of Alberta Pal. Type Coll.

Horizon: same as for the species *s.s*

Genus MILIAMMINA Heron-Allen and Earland, 1930

MILIAMMINA SPROULEI GIGANTEA Mellon and Wall, n. var.

Plate 1, figure 1

Test variable in size, ranging from about 0.5 mm. to 1.2 mm. in length, usually badly flattened in fossilization; chambers tubular, irregular, distinct, usually four visible on one side and three on the other; sutures depressed and distinct; wall of very fine, white, opaque, arenaceous material, usually with considerable very fine carbonaceous (?) material adhering to the external surface imparting a greyish or dirty colour to the test; aperture a round opening at the end of the last chamber, on a short but distinct neck with an incipient phialine lip.

Length of holotype: 0.9 mm.; maximum width 0.42 mm.

Holotype locality: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, at a depth of 117 feet, 16 feet below the top of the McMurray formation.

Holotype: Univ. of Alberta Pal. Type Coll.

Horizon: Abundant in the upper part of the McMurray formation immediately overlying the non-marine part of the formation.

Remarks: This new varietal form is distinguished by its much larger average size and more robust chambers from Nauss' original species, described from the Cummings member of the Mannville formation of east-central Alberta.

The smaller specimens of the new variety appear similar to *Miliammina subelliptica* Mellon and Wall, n. sp. found in the overlying basal Clearwater shale, but the latter is more coarsely arenaceous and seems to have stronger, thicker walls.

MILIAMMINA SUBELLIPTICA Mellon and Wall, n. sp.

Plate 1, figure 6

Test broadly elliptical in outline, usually flattened in fossilization and hence compressed in cross-section; chambers tubular but sutures not readily evident, four chambers visible on one side and three on the other; sutures rather indistinct, their positions emphasized by flattening of the test; wall arenaceous, of fine clear quartz grains set in a matrix of very fine white material, giving a generally smooth but slightly fuzzy exterior finish; aperture a round opening at the end of the last chamber on a short but distinct neck; colour white.

Length of holotype: 0.64 mm.; maximum width 0.32 mm.

Holotype locality: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 81 feet, 20 to 28 feet above the base of the Clearwater formation.

Holotype: Univ. of Alberta Pal. Type Coll.

Horizon: Occasional to common in the basal shales of the Clearwater formation.

Remarks: Comparison of this species with specimens of *Miliammina sproulei* Nauss shows that the latter species has a more pronounced neck, is distinctly more elongate than elliptical, and has more slender chambers.

Miliammina manitobensis Wickenden is smaller, more rectangular in outline, and its sutures are more distinct.

Genus NODOSARIA Lamarck, 1812

NODOSARIA aff. N. PROBOSCIDEA Reuss

Plate 2, figure 5

Nodosaria proboscibea Reuss, 1851, Haidinger's Naturwiss, Abhl., vol. 4. pt. 1. p. 7, pl. 1, fig. 6.

Nodosaria proboscidea Reuss. Cushman 1946, U.S. Geol. Surv. Prof. Paper 206, p. 72, pl. 26, figs. 12, 13 (synonymy).

Nodosaria proboscidea Reuss. Frizzell, 1954, Texas Bureau of Econ. Geol. Rept. of Investigations No. 22, p. 91, pl. 10, figs. 33. 34.

Test small, tapering in juvenile specimens, sides more nearly parallel in the adult, circular in cross-section; chambers few, four in figured specimen, ultimate one considerably larger, inflated, cupola-shaped; sutures indistinct; six strong longitudinal ribs running from the base of the test uninterruptedly across the sutures well up onto the terminal face; wall smooth, calcareous, finely perforate; aperture terminal, central, apparently radiate on a small nipple-like protuberance.

Length of figured specimen: 0.35 mm.; diameter of ultimate chamber 0.16 mm.

Locality of figured specimen: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 81 feet, 20 to 28 feet above the base of the Clearwater formation.

Figured specimen: Univ. of Alberta Pal. Type Coll.

Horizon: Very rare, from the basal Clearwater shales.

Remarks: The figured specimen is apparently a juvenile form, the adult specimens being less tapering. This form appears rather similar to specimens from the Upper Cretaceous of Texas referred to *Nodosaria proboscidea* Reuss by Cushman (1946). The Clearwater form, however, does not possess such a prominent apertural neck as the Texas species, and its chambers and sutures are much less distinct. Reuss' type figure of the species from the Upper Cretaceous of Poland shows a very pronounced apertural beak and about twice as many costae as are observed on the Alberta and Texas specimens.

Wickenden (1951B, pl. I A, figs. 23, 24) figures a species of *Nodosaria* from the lower Falher, which probably is identical to the Clearwater form.

Genus PSEUDONODOSARIA Boomgaart, 1949

PSEUDONODOSARIA CLEARWATERENSIS Mellon and Wall, n. sp.

Plate 2, figures 15, 16, 17

Test elongate, circular in cross-section, tapering to sides nearly parallel; chambers few, embracing, distinct, tending to be slightly inflated; sutures distinct, straight, at right angles to the long axis of the test, depressed, especially in later chambers; wall smooth, calcareous, finely perforate; aperture terminal, central, radiate.

Length of holotype (fig. 17): 0.80 mm., maximum width 0.24 mm.

Length of paratype (fig. 15): 0.47 mm.; maximum width 0.22 mm.

Length of paratype (fig. 16): 0.58 mm.; maximum width 0.2 mm.

Locality of holotype and paratypes: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 92 feet, 9 to 28 feet above the base of the Clearwater formation.

Holotype and paratypes: Univ. of Alberta Pal. Type Coll.

Horizon: Rare in the basal shales of the Clearwater formation.

Remarks: Loeblich and Tappan (1955) have recently revised certain genera of glanduline Nodosariidae, suppressing Cushman's genus *Pseudoglandulina.* Examinations of the interior of the Clearwater species shows distinct overlapping of chambers and lack of an internal tube, thus assigning the species to the genus *Pseudonodosaria* Boomgaart.

Among the Clearwater specimens, there seem to be two types of test within the specific range. One type, exemplified by the holotype (fig. 17) and paratype (fig. 16), tapers only slightly and its chambers embrace gradually. The other type, exemplified by the paratype (fig. 15), tapers considerably backwards and its later chambers are more embracing.

This species appears somewhat similar to *Pseudonodosaria larva* (Carsey) from the Upper Cretaceous of Texas, but differs in having fewer chambers, the earlier ones not so closely appressed. The aperture in the Texas species is much more coarsely radiate than in the Alberta form.

Locally, this new species is present in the central part of the Clearwater formation, type section (Martin, 1954) and is found in the lower part of the Moosebar formation of northeastern British Columbia (Stelck, 1950).

Name: After the Clearwater river in northeastern Alberta.

Genus QUADRIMORPHINA Finlay, 1939

QUADRIMORPHINA ALBERTENSIS Mellon and Wall, n. sp.

Plate 2, figures 12, 13, 14

Quadrimorphina sp. Wickenden, 1951, Geol. Surv. Canada Paper 51-16, p. 42, pl. IA, fig. 36.

Test small, trochoid in a clockwise spiral, biconvex, tending to be globigerinoid; test with a very low spire of a proloculus and two or three whorls of four chambers each; chambers increase suddenly in size at the end of each whorl, last four noticeably inflated and sub-globular, all chambers visible from dorsal side and usually four visible from ventral side; sutures distinct, oblique, those of last whorl depressed; umbilicus closed; aperture a low arched slit be-

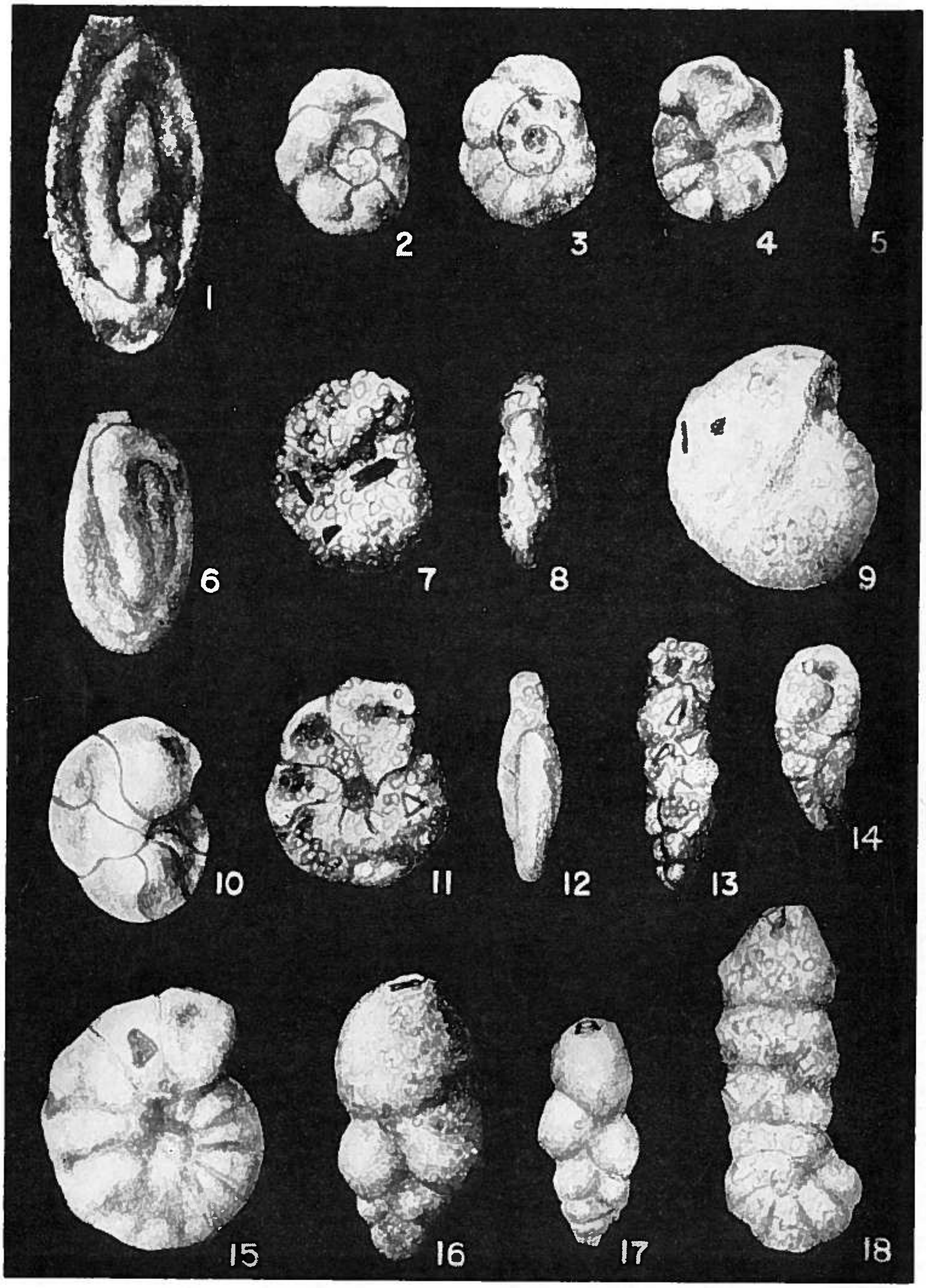


Plate 1—Upper McMurray and basal Clearwater Foraminifera.

EXPLANATION OF PLATE 1

Upper McMurray and Basal Clearwater Formations
Socony-Vacuum Oil Sands Well No. 27,
McMurray, Alberta, Canada
Magnification x55

Fig. 1: *Miliammina sproulei* Nauss var. *gigantea* Mellon and Wall, n. var., variety holotype, from McMurray formation .... (p. 21)

Figs. 2-5: *Trochammina mcmurrayensis* Mellon and Wall, n. sp., from McMurray formation; 2, paratype—dorsal view: 3, 4, 5, holotype—dorsal, ventral and peripheral views .... (p. 28)

Fig. 6: *Miliammina subelliptica* Mellon and Wall, n. sp. holotype, from basal Clearwater formation .... (p. 22)

Figs. 7-9: *Haplophragmoides* sp., from McMurray formation; 7, 8—side and peripheral views of a specimen; 9—side view of another specimen .... (p. 19)

Fig. 10: *Haplophragmoides gigas* Cushman var. *minor* Nauss, plesiotype, from basal Clearwater formation .... (p. 17)

Figs. 11, 12: *Haplophragmoides* cf. *sluzari* Mellon and Wall, McMurray formation; 11—side view, 12—peripheral view .... (p. 18)

Figs. 13, 14: *Verneuilinoides?* sp.; 13, specimen from McMurray formation; 14, specimen from basal Clearwater formation .... (p. 28)

Fig. 15: *Haplophragmoides sluzari* Mellon and Wall, n. sp., holotype from basal Clearwater formation .... (p. 17)

Figs. 16, 17: *Tritaxia athabascensis* Mellon and Wall, n. sp. from basal Clearwater formation; 16, holotype; 17, paratype .... (p. 27)

Fig. 18: *Ammobaculites humei* Nauss, plesiotype, from basal Clearwater formation .... (p. 15)

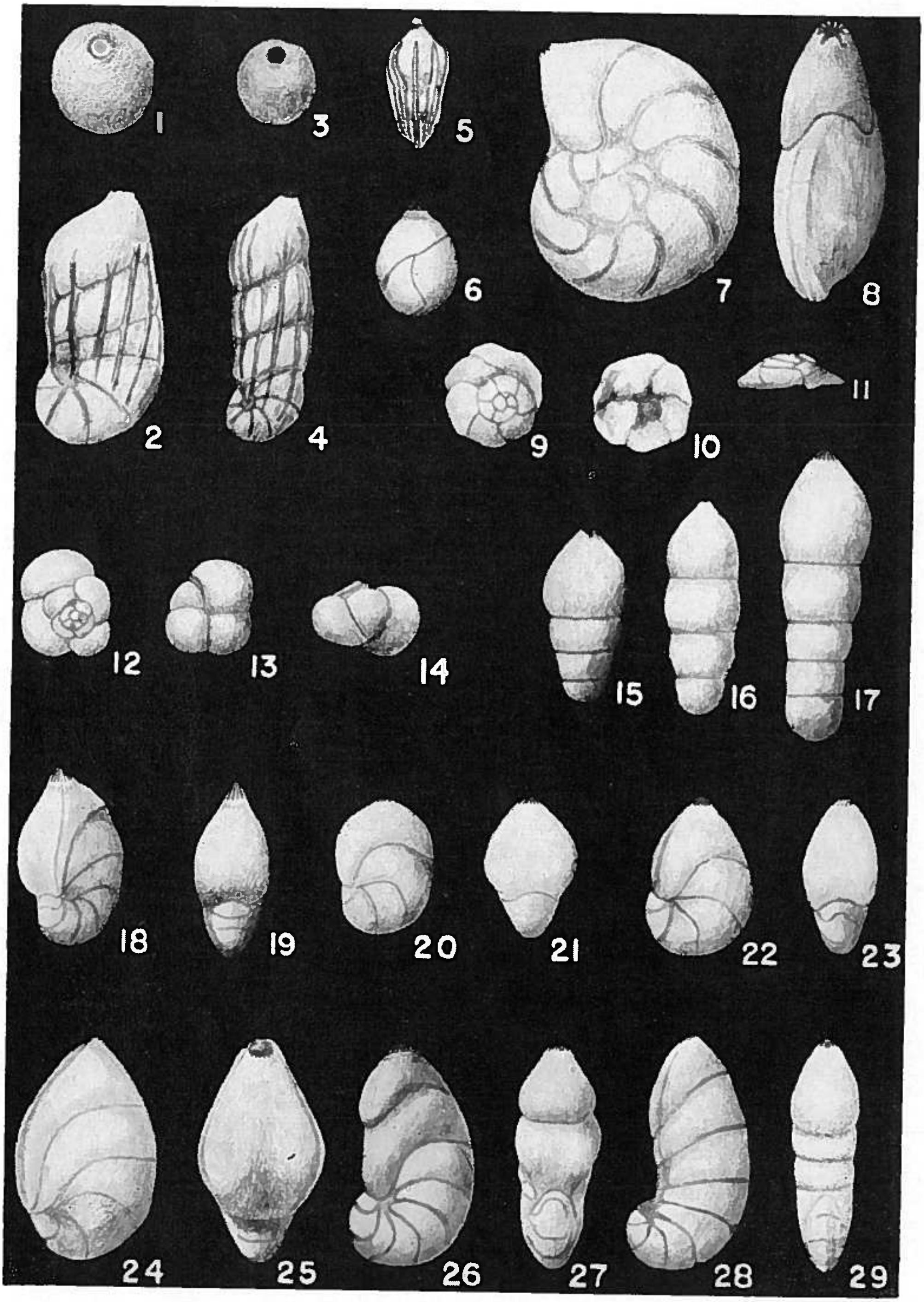


Plate 2—Basal Clearwater Foraminifera.

EXPLANATION OF PLATE 2

Basal Clearwater Formation
Socony-Vacuum Oil Sands Well No. 27,
McMurray, Alberta, Canada
Magnification x55

Figs. 1, 2: *Marginulinopsis collinsi* Mellon and Wall, n. sp., holotype; 1—apertural view, 2—side view .... (p. 20)

Figs. 3, 4: *Marginulinopsis collinsi* variety;3—apertural view, 4—side view .... (p. 21)

Fig. 5: *Nodosaria* aff. *proboscidea* Reuss .... (p. 23)

Fig. 6: *Globulina lacrima* Reuss var. *canadensis* Mellon and Wall, n. var., variety holotype .... (p. 16)

Figs. 7, 8: *Lenticulina bayrocki* Mellon and Wall, n. sp., holotype; 7—side view, 8—peripheral view .... (p. 19)

Figs. 9-11: *Discorbis norrisi* Mellon and Wall, n. sp., paratype; 9—dorsal view, 10—ventral view, 11—peripheral view .... (p. 15)

Figs. 12-14: *Quadrimorphina albertensis* Mellon and Wall, n. sp., holotype; 12—dorsal view, 13—ventral view, 14—peripheral view .... (p. 24)

Figs. 15-17: *Pseudonodosaria clearwaterensis* Mellon and Wall, n. sp.; 15, 16—paratypes, 17—holotype .... (p. 23)

Figs. 18-25: *Saracenaria* sp., side and peripheral views of four specimens .... (p. 28)

Figs. 26, 27: *Saracenaria trollopei* Mellon and Wall, n. sp., holotype; 26—side view, 27—peripheral view .... (p. 25)

Figs. 28, 29: *Saracenaria trollopei* variety; 28—side view, 29—peripheral view .... (p. 28)

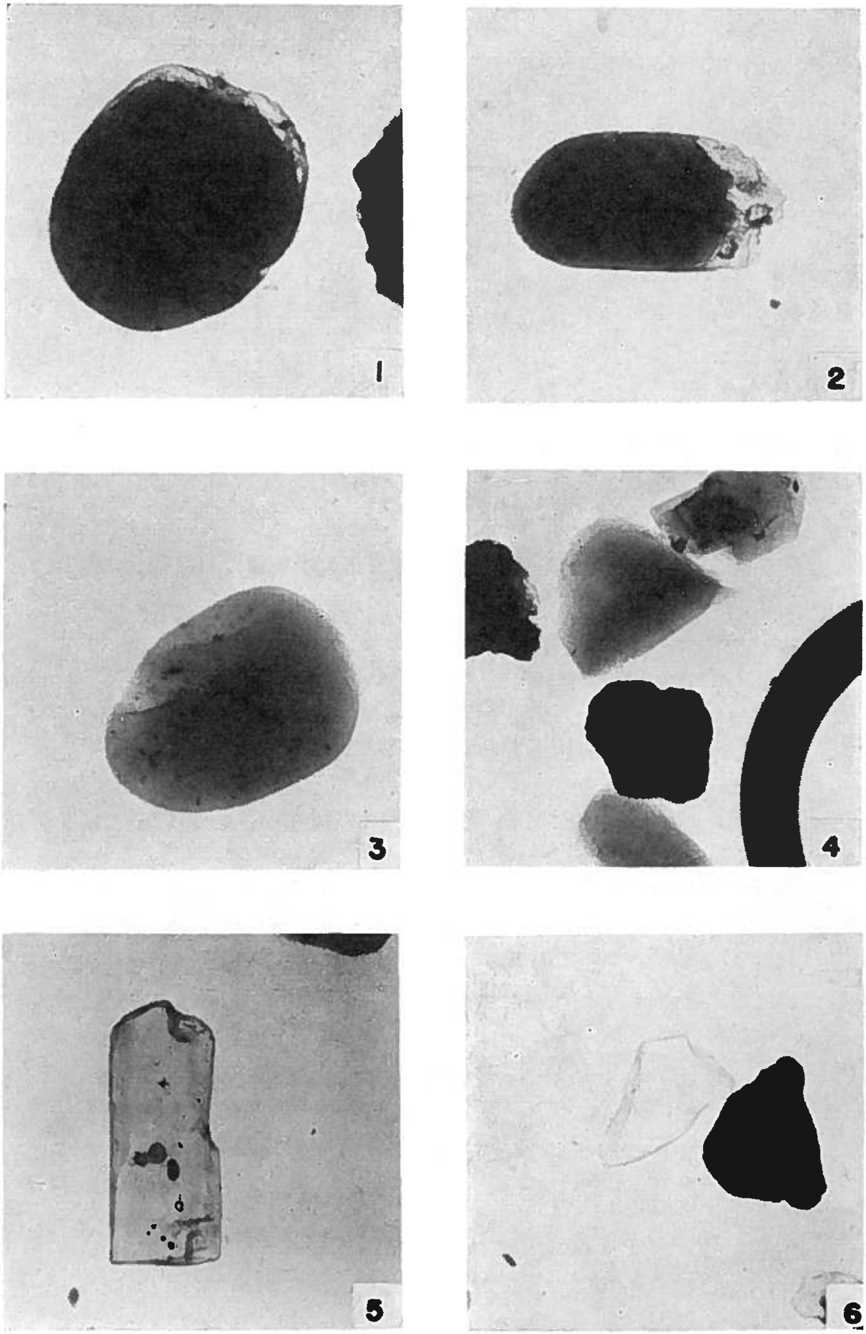


Plate 3—Heavy minerals of the McMurray formation.

EXPLANATION OF PLATE 3

Heavy Minerals of the McMurray Formation

Fig. 1: *Tourmaline* with abraded overgrowth; bituminous sand from the quarry at Bitumount .... (p. 33)

Fig. 2: *Tourmaline* with overgrowth; bituminous sand from the quarry at Bitumount .... (p. 33)

Fig. 3: Well-rounded, coffee-brown basal section of *tourmaline;* bituminous sand from the quarry at Bitumount .... (p. 33)

Fig. 4: Angular, brownish-green basal section of *tourmaline* and pink *tourmaline* prism; bituminous sand from the Socony-Vacuum Oil Sands Well No. 27 .... (p. 33)

Fig. 5: Pale brown, subhedral *tourmaline* prism; bituminous sand from the quarry at Bitumount .... (p. 33)

Fig. 6: *Apatite:* glauconite sand in the Socony-Vacuum Oil Sands Well No. 27 .... (p. 36)

EXPLANATION OF PLATE 4

Heavy Minerals of the McMurray Formation

Fig. 1: Two grains of inclusion-ridden *chloritoid:* bituminous sand from the Socony-Vacuum Oil Sands Well No. No. 27 .... (p. 35)

Fig. 2: Pleochroic, inclusion-free *chloritoid;* unimpregnated McMurray sand from the Clearwater river .... (p. 35)

Fig. 3: Rounded *staurolite:* unimpregnated McMurray sand from the Clearwater river .... (p. 34)

Fig. 4: *Garnet* and euhedral *zircon;* bituminous sand near the mouth of the Steepbank river .... (p. 34)

Fig. 5: *Garnet;* unimpregnated sand from the Clearwater river .... (p. 34)

Fig. 6: Concentration of *kyanite;* bituminous sand south of Bitumount .... (p. 35)

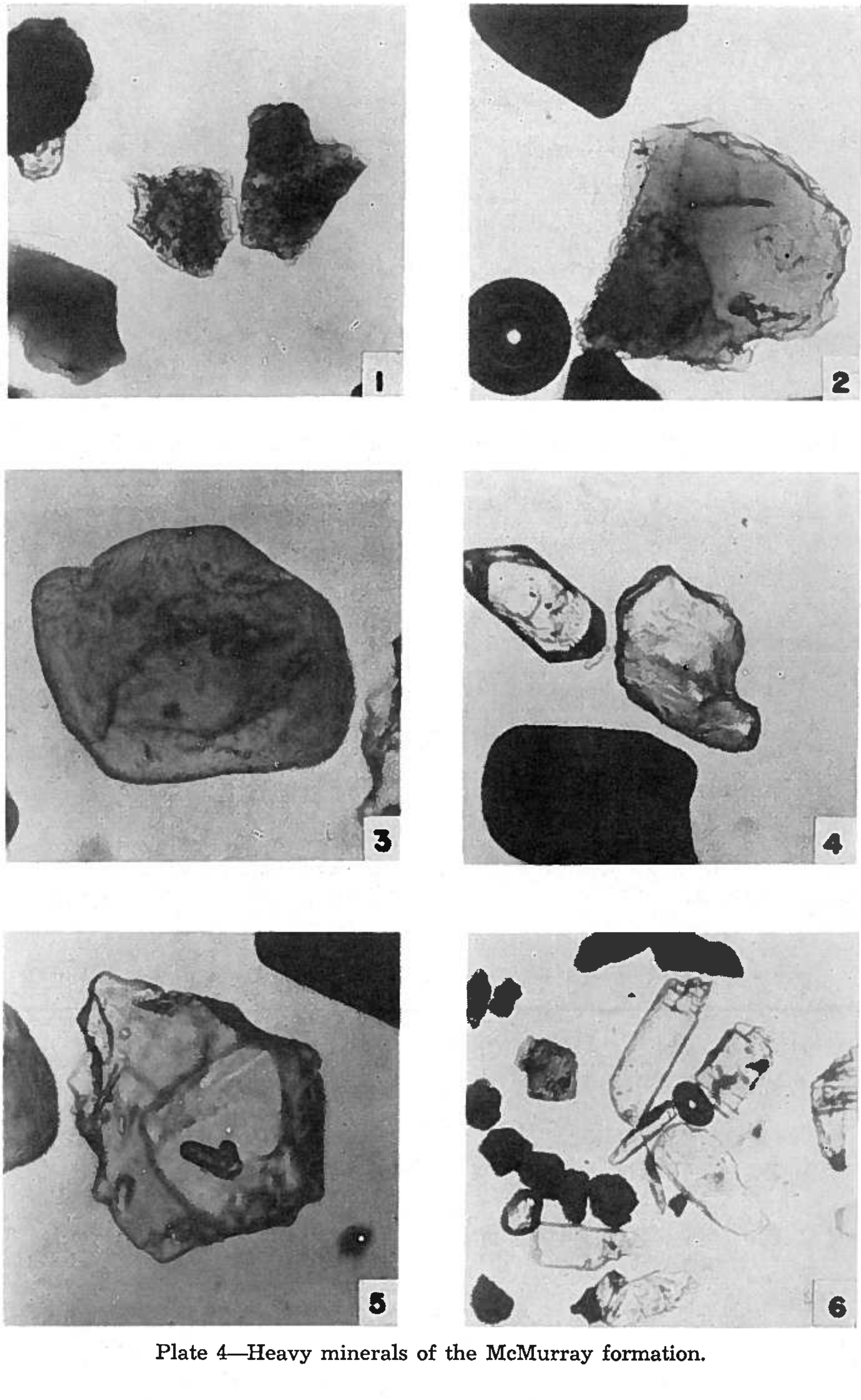


Plate 4—Heavy minerals of the McMurray formation.

tween the umbilicus and periphery, with a lip; wall calcareous, medium perforate, smooth and translucent; colour light brown.

Maximum diameter of holotype: 0.30 mm.; thickness 0.18 mm.

Holotype locality: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 81 feet, 20 to 28 feet above the base of the Clearwater formation.

Holotype: Univ. of Alberta. Type Coll.

Horizon: The species occurs occasionally in the basal shales of the Clearwater formation.

Remarks: This species is the second most-common calcareous form found in the Socony-Vacuum well. A certain amount of variation is present, particularly regarding the degree of inflation of the chambers of the ultimate whorl, the holotype being one of the more globigerinoid specimens.

The species is identical to Wickenden's *Quadrimorphina* sp. from the lower Falher. It is present in the central part of the Clearwater formation, type section (Martin, 1954), and is found in the lower part of the Moosebar formation of northeastern British Columbia (Stelck, 1950).

Genus SARACENARIA Defrance, 1824

SARACENARIA TROLLOPEI Mellon and Wall, n. sp.

Plate 2, figures 26, 27

Test of medium size, compressed, strongly curved on dorsal side, ventral side nearly straight, uncoiling with the penultimate chamber reaching back to the coiled portion; periphery narrowly rounded; chambers, four to six in coiled portion, two to three in uncoiled portion, chambers gradually increasing in size, those in uncoiled portion becoming slightly inflated and triangular in cross-section; sutures arcuate, distinct, flush or becoming slightly depressed in the uncoiled portion; wall calcareous, perforate; aperture radiate, at the peripheral angle on the terminal face.

Length of holotype: 0.6 mm.; maximum thickness 0.23 mm.; diameter of coiled portion 0.3 mm.

Holotype locality: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 81 feet, 20 to 28 feet above the base of the Clearwater formation.

Holotype: Univ. of Alberta Pal. Type Coll.

Horizon: Rare to occasional in the basal shales of the Clearwater formation.

Remarks: This species is present in the lower part of the Moosebar formation of northeastern British Columbia (Stelck, 1950).

Name: After Frederick H. Trollope, geologist, Socony-Vacuum Oil Company of Canada, Edmonton.

SARACENARIA TROLLOPEI Variety

Plate 2, figures 28, 29

Test of medium size, compressed, uncoiling, with dorsal side moderately convex and ventral side slightly concave; chambers, gradually increasing in size, five to six in coiled portion, four in uncoiled portion, last three slightly inflated, appearing rounded triangular in cross-section; sutures fairly distinct, arcuate, flush, except for final two which are slightly depressed; wall calcareous, hyaline, finely perforate; aperture radiate, at the peripheral angle.

Length of figured specimen: 0.63 mm.; maximum thickness 0.18 mm.; diameter of coiled portion 0.25 mm.

Locality of figured specimen: same as for the species *s.s.*

Figured specimen: Univ. of Alberta Pal. Type Coll.

Horizon: same as for the species *s.s.*

Remarks: This varietal form differs from the species *s.s.* in being more compressed, and in having a longer uncoiled portion in which the later chambers do not reach back to the coiled portion.

The varietal form bears some resemblance to *Cristellaria* (*Cristellaria*) *planiuscula* Reuss from the Lower Gault of North Germany, but the latter form is considerably smaller and its later chambers do not appear to be inflated. The coiled portion of the German species is smaller in proportion to the size of the entire test than in the Canadian form.

Locally, *Saracenaria* sp. B of Wickenden (1951B, pl. I A, fig 22) from the middle Falher is identical to this varietal form.

SARACENARIA sp.

Plate 2, figures 18 to 25

Test small to medium size, close-coiled, involute, later portion tending gradually to become inflated and more or less triangular in cross-section; periphery narrowly rounded but never acute, without a keel; chambers few, from four to seven visible, gradually increasing in length and breadth but rarely actually uncoiling (as shown in fig. 24); sutures distinct, flush, usually arcuate, ultimate one occasionally depressed; wall calcareous, perforate, hyaline or opaque; aperture radiate, at the peripheral angle on the terminal face, often on a small projecting cone.

Length of specimen (figs. 18, 19): 0.47 mm.; width of apertural face 0.2 mm.

Length of specimen (figs. 20, 21): 0.36 mm.; width of apertural face 0.25 mm.

Length of specimen (figs. 22, 23): 0.42 mm.; width of apertural face 0.2 mm.

Length of specimen (figs. 24, 25): 0.6 mm.; width of apertural face 0.33 mm.

Locality of figured specimens: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 92 feet, 9 to 28 feet above the base of the Clearwater formation.

Figured specimens: Univ. of Alberta Pal. Type Coll.

Horizon: Occasional in the basal shales of the Clearwater formation.

Remarks: This "species" contains forms which vary from more compressed *Lenticulina* types to *Saracenaria* types with a terminal face shaped like an equilateral triangle. Further variation is present in the degree of curvature of sutures, in the number of chambers and increase in size of succeeding chambers, but only rarely does the test actually begin to uncoil.

There are a number of species figured in the literature similar to the specimens figured here, one of the closest being *Lenticulina navicula* (d'Orbigny) Cushman and Jarvis from the Cretaceous of Trinidad. However, the Clearwater forms invariably lack the sharp keel of *Lenticulina navicula.*

Locally, a similar form is present in the central part of the Clearwater formation, type section (Martin, 1954).

Genus TRITAXIA Reuss, 1860

TRITAXIA ATHABASCENSIS Mellon and Wall, n. sp.

Plate 1, figures 16, 17

Test elongate, triserial, usually badly flattened in fossilization and tending to appear biserial (later chambers may be added biserially); chambers rapidly expanding, inflated, twelve to fifteen in number, those in early portion often barely visible; sutures indistinct in early portion, distinct and depressed in later whorls; wall of fine clear quartz grains set in white siliceous cement, giving a rather smooth finish to the exterior surface; aperture terminal, circular, at the end of a short but distinct neck, usually with a phialine lip; colour white.

Length of holotype (fig. 16): 0.75 mm.; maximum width 0.36 mm.

Length of paratype (fig. 17): 0.6 mm.; maximum width 0.25 mm.

Locality of holotype and paratype: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 73 and 81 feet, 20 to 28 feet above the base of the Clearwater formation.

Holotype and paratype: Univ. of Alberta Pal. Type Coll.

Horizon: Occasional to common in the basal shales of the Clearwater formation.

Remarks: This form is present in the central and upper parts of the Clearwater formation, type section (Martin, 1954).

Name: After the Athabasca river in northern Alberta.

Genus TROCHAMMINA Parker and Jones, 1859

TROCHAMMINA MCMURRAYENSIS Mellon and Wall, n. sp.

Plate 1, figures 2, 3, 4, 5

Test small, compressed, periphery angular and slightly lobate in more flattened specimens; test trochoid with obscure primary whorl followed by two distinct whorls; spire low and flush with dorsal surface of the ultimate whorl, but made noticeable by its distinctly darker colour; ventral surface concave with small but deep umbilicus; chambers gradually increasing in size, seven to nine visible in ultimate whorl, chambers usually scalloped on ventral side; sutures rather indistinct, oblique, slightly arcuate, their positions often emphasized by crushing or scalloping of chambers; wall finely arenaceous with much cement, giving a smooth finish to the exterior surface; aperture on ventral side, a notch on the margin of the ultimate chamber halfway between the umbilicus and the periphery, and extending into the former; colour light to dark brown, with the region of the spire being distinctly darker than the outer whorl.

Maximum diameter of holotype (fig. 3): 0.45 mm.

Maximum diameter of paratype (fig. 2): 0.45 mm.

Locality of holotype and paratype: Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, at a depth of 112 feet, 11 feet below the top of the McMurray formation.

Holotype and paratype: Univ. of Alberta Pal. Type Coll.

Horizon: Occasional in the uppermost part of the McMurray formation.

Remarks: This species is somewhat similar to *Trochammina webbi* Stelck and Wall from the Upper Cretaceous Kaskapau formation of the Peace River area. It differs from *Trochammina webbi* in not being as lobate, in having a smoother exterior finish, in its much deeper umbilicus, and in the location of the aperture.

Name: After the McMurray formation.

Genus VERNEUILINOIDES Loeblich and Tappen, 1949

VERNEUILINOIDES? sp.

Plate 1, figures 13, 14

Test small to medium in size, slightly tapering, twisted, rounded; test of five to six whorls of three chambers each, but occasionally biseriality is developed in adult stage; chambers in an ascending spiral, gradually increasing in size, slightly inflated; sutures depressed, but generally indistinct owing to crushing of the test or to the coarsely arenaceous character of the wall; wall arenaceous, of clear subangular quartz grains up to 0.1 mm. in size, but averaging much less in Clearwater specimens, grains set in siliceous reddish-brown cement, the amount of cement decreasing in later whorls; aperture a low arch at the inner margin of the base of the last-formed chamber; colour reddish-brown, often becoming white in the later whorls.

Length of specimen (fig. 13): 0.64 mm.; maximum width 0.18 mm.

Length of specimen (fig. 14): 0.47 mm.; maximum width 0.21 mm.

Locality of specimen (fig. 13): Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, at a depth of 112 feet, 11 feet below the top of the McMurray formation.

Locality of specimen (fig. 14): Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta, Canada, between depths of 81 and 89 feet, 12 to 20 feet above the base of the Clearwater formation.

Figured specimens: Univ. of Alberta Pal. Type Coll.

Horizon: This form occurs commonly to abundantly in the basal shales of the Clearwater formation, and in the upper part of the McMurray formation.

Remarks: The specimen (fig. 13), upon which the description is based, is somewhat similar to *Verneuilinoides cummingensis* (Nauss) from the Cummings member of the Mannville formation, except that the McMurray specimen is more coarsely arenaceous, some of the grains making up the wall being nearly equal to the size of the chambers. There is a tendency for biseriality to develop in the late stages of the McMurray form, a feature which is not observed in *V. cummingensis*.

Due to the unsatisfactory preservation of the material and the uncertainty regarding the taxonomic position of this form, no specific name has been assigned to it. The main significance of the "species" is its presence in both the upper part of the McMurray formation and the overlying Clearwater shales, thus indicating continuity of deposition across the boundary of the two formations.

PART II

Heavy Minerals of the McMurray Formation

ABSTRACT

Heavy mineral residues from sands of the McMurray formation show two distinct suites: (1) first-cycle minerals derived from an igneous-metamorphic terrane, and (2) second-cycle tourmaline and zircon derived from pre-existing sediments. "Unstable" minerals, such as amphiboles and pyroxenes, are absent or very rare. It follows that the source area of the McMurray sediments was a low-lying land to the east, made up in part of the igneous-metamorphic rocks of the Canadian Shield, and in part of a thin veneer of late Precambrian-early Palaeozoic sediments.

INTRODUCTION

The sediments of the McMurray formation constitute a distinct lithologic unit at the base of the Cretaceous sequence in northeastern Alberta. The formation consists of loosely consolidated quartzose sands, held together by their well-known bitumen content, although argillaceous beds are present in varying, and sometimes considerable, amounts. The McMurray formation is overlain conformably by the basal glauconite-quartz sand member of the Clearwater formation, and is underlain unconformably either by marine Devonian limestones of the Waterways formation or by residual clays of uncertain age that seem to have been developed on the eroded uneven surface of the Waterways formation. The apparent homogeneity of the McMurray formation is supported by the mineralogy of the sands.

The sands of the McMurray formation consist of 90 to 95% or more of pure quartz grains, and can therefore be classified under the "quartzose sandstone" category of Krynine (1948), or as "orthoquartzites" by Pettijohn's (1949) definition. It is possible that some of the sands could be called feldspathic, as examination of the light fraction from random outcrop and core samples shows a minor but persistent amount of orthoclase present in everyinstance. The average quartz-feldspar content of eleven samples is 96% quartz —4% feldspar, with the maximum amount of feldspar being 8% and the minimum amount being 2%.

Both the sands and shales of the McMurray formation from the Athabasca River area contain noticeable amounts of muscovite, and the white glittering flakes of the mineral are a conspicuous feature of most hand specimens. As the amount of muscovite varies with regard to locality and average grain size, no data on the exact amount of the mineral are available. Certainly enough muscovite is present in those sands examined by the writer to justify assigning them to the "quartz-muscovite sandstone" category of Dapples et al. (1948, p. 1931).

In summary, the sands of the McMurray formation consist mainly of quartz with minor amounts of orthoclase, muscovite, and heavy minerals. The strata may become argillaceous, particularly near the top of the formation, but do not in the type section area approach either the composition of an arkose or subgraywacke as defined by modern petrologists.

HEAVY MINERALS

Previous data on the heavy mineral petrology of the McMurray formation have been confined to casual comments, excepting Kupsch' (1954) paper on pockets of bituminous sands in glacial tills of northwestern Saskatchewan. Kupsch pointed out that the McMurray sands may be differentiated from glacial sands by means of heavy minerals, and listed several heavy mineral analyses of outcrop material and of ice-transported lenses of bituminous sand.

In this paper the notes on the petrology of the McMurray formation have been largely confined to a description of the non-opaque heavy minerals of the sand fraction. Eighteen outcrop and core samples (locations in Appendix) from the McMurray formation, chosen from different localities and at various depths within the formation, present a very consistent qualitative picture of the non-opaque heavy minerals of the sand fraction. The data show that the same major heavy mineral species are distributed laterally and vertically throughout the formation, although relative abundances of these minerals vary considerably from sample to sample.

The opaque heavy minerals include the usual assemblage of leucoxene, hematite, limonite, pyrite, and ilmenite or magnetite, but their precise identification is uncertain and they have little genetic significance. As the opaque minerals sometimes form as high as 80% or more of the heavy fraction, their abundance obscures the true percentage distribution of the non-opaque minerals which have much more genetic significance. Consequently, the opaque heavy minerals were disregarded in making the heavy mineral counts.

All of the heavy minerals examined by the writer were recovered from that portion of the sand fraction retained between the 100-mesh and 200-mesh sieves. The heavy minerals were separated from the light fraction using acetylene tetrabromoethane (sp. gr.=2,965), washed in acetone, and mounted in Aroclor (n=1.66). Three hundred non-opaque heavy mineral grains per sample were identified, and the relative abundances of the mineral species in each sample are tabulated in Table I.

A brief description of each of the major non-opaque heavy mineral species follows:

TABLE I

RELATIVE PERCENTAGES OF HEAVY MINERALS WITHIN THE McMURRAY SANDS

SAMPLE *	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Av.
Tourmaline	18	50	55	48	54	54	60	60	58	54	47	55	54	50	48	28	10	40	47
Zircon	3	9	5	9	1	6	4	8	8	13	8	3	9	21	11	15	41	20	11
Rutile		tr.			tr.			1		tr.	3	1	1	1	2	1	3	1	1
Garnet	52	14	4	6	3	2	8	7	3	4	5	6	4	8	6	18		8	9
Staurolite	5	8	12	11	3	5	12	8	11	15	9	9	14	9	18	14	12	21	11
Kyanite	4	6	6	3	3	4	5	3	6	8	3	4	2	8	4	12	31	5	6.5
Chloritoid	5	10	17	18	35	27	6	9	12	5	25	21	14	2	10	3		2	12
Apatite	11	2		2	1	1	1	1	tr.	1			1		tr.	2	tr.	1	1
Amphiboles																2			
Others	tr.			tr.				tr.			tr.				tr.	2			
Unidentified	2	1	1	2	1	1	3	2	2	tr.	1	1	1	2	1	2	2	1	1.5

* Location of samples in Appendix

Tourmaline

Tourmaline is, on the average, the most abundant non-opaque heavy mineral present. Although the mineral occurs in a number of shapes and colours, these properties seem to be of a generally gradational nature and do not easily lend themselves to precise classification. For very general descriptive purposes there are three main types of tourmaline present in the McMurray sands, using colour as a basis of classification:

(1) Very pale brown tourmaline grading into deeper brown or greenish brown grains, pleochroic to dark brown or black. Common.

(2) Very pale pink to distinctly reddish grains, pleochroic to greenish-black or black. Only the occasional pink grain is pleochroic to blue. Less common than type (1).

(3) Blue grains, pleochroic to darker blue. Rare.

Only near-basal sections, which show maximum absorption and minimum pleochroism, are visible on about 40% of the tourmaline grains. Brownish-green basal sections are most common, followed by black (almost opaque) ones. Orange or light brown basal sections are much less common, and blue ones are rare. The brownish-green or opaque grains could be confused with biotite or hornblende, but they invariably give a slightly off-centre uniaxial figure when tested.

The occurrence and significance of tourmaline as a detrital mineral has been discussed by Krynine (1946) who outlined five main sources of sedimentary tourmaline:

(1) Granitic tourmaline;

(2) Pegmatitic tourmaline;

(3) Tourmaline from metamorphic rocks;

(4) Sedimentary authigenic tourmaline, occurring as colourless overgrowths on detrital tourmaline grains;

(5) Reworked tourmaline from older sediments.

The first four sources include the various varieties of primary tourmaline, which upon the erosion of the parent rock, appear in sediments as first-cycle detrital grains. While authigenic tourmaline is usually easily recognized, granitic, pegmatitic and metamorphic tourmaline must be differentiated on the basis of colour and inclusions (Krynine, 1940, 1946). Reworked tourmaline is derived from the erosion of pre-existing sedimentary rocks, and must be differentiated from igneous or metamorphic varieties on the basis of grain morphology.

The tourmaline from the McMurray formation has helped considerably in determining the nature of the source area of the bituminous sands, for which purpose the mineral has been divided into two groups:

(1) Well-rounded grains, presumed to be second-cycle and derived from pre-existing sedimentary rocks,

(2) Subangular or angular grains, presumed to be first-cycle and derived from igneous and metamorphic rocks.

Although just how well-rounded a tourmaline grain must be to justify calling it second-cycle is a matter of personal opinion, examination of four samples indicates that a minimum of 30% of the tourmaline grains are sufficiently well-rounded to be classified as second-cycle. The remaining 70% of the grains, which vary from small idiomorphic crystals or angular fragments of larger crystals to subangular or subrounded grains, is thought to be first-cycle, and derived from the same source that provided the garnet, kyanite, staurolite, and other first-cycle minerals.

Authigenic tourmaline, occurring as colourless overgrowths on pre-existing tourmaline grains, is rare in the McMurray sands. Only a sample from the quarry at Bitumount showed any appreciable amount (6%), while one grain apiece was observed in four other samples. The overgrowths tend to be well-abraded, occurring on well-rounded pale brown or pinkish grains, and have undoubtedly passed through at least one cycle of erosion. The significance of this authigenic tourmaline is discussed later.

Zircon

Zircon is present in all samples that were examined, making up from 1% to 41% of the non-opaque heavy minerals. The mineral is almost always colourless, only the occasional yellow or purple grain being observed. Zoned zircon is rare. As in the case of tourmaline, small euhedra or subangular grains are more common than the well-rounded, presumably second-cycle, variety.

A rather peculiar feature of as much as one-third of the zircon present in some samples is the presence of a patchy, reddish, opague film clinging to the grains, partially obscuring them and making identification difficult. This film was not observed on any of the other non-opaque minerals, and the writer is not sure of its origin.

Garnet

Garnet is present in all but one of the samples examined, occurring as colourless, angular, often shard-like fragments, and is remarkably fresh in appearance. Pink garnet is extremely rare, only one or two grains being observed in the eighteen samples examined.

For some reason, garnet is the dominant non-opaque heavy mineral in a sample of the marine glauconite sand immediately overlying the McMurray formation. Moreover, the garnet is the glauconite sand tends to be pitted and etched, and is associated with a rather large amount of apatite. Unfortunately no other samples of the glauconite sand from other localities were available for study to test the lateral extent of this anomaly.

Staurolite

Staurolite is present in all samples which were examined, and constitutes from 3 to 21% of the non-opaque heavy minerals. The mineral is pale golden yellow, pleochroic to deep yellow or russet, and often shows a typical "swiss-cheese" structure. Although the grains are generally angular or subangular, the larger ones often show signs of abrasion and tend to be somewhat rounded. The occasional grain shows "hacksaw" terminations where the 010 cleavage is at right angles to the tube of the microscope.

Kyanite

Kyanite is present in most of the samples in small but persistent amounts, except in one instance where it constitutes 31% of the non-opaque heavy minerals. It occurs typically as clear lathe-like grains, completely free from any signs of alteration.

Chloritoid

A mineral identified as chloritoid comprises a conspicuous percentage of the non-opaque heavy minerals in a number of the samples and is absent only from one. As chloritoid is not commonly reported as a detrital mineral, a brief description of the mineral as found in the McMurray sands follows. It occurs as angular micaceous flakes in two general, but gradational, varieties:

(1) As greenish-blue, non-pleochroic flakes full of tiny, lineated, colourless inclusions; or marked by swarms of oval or round, black, opaque inclusions which are sometimes so abundant that the mineral is nearly opaque. Under crossed-nicols this variety presents a cryptocrystalline or "wispish" appearance, and not give an interference figure.

(2) About one-quarter of the chloritoid present occurs as almost inclusion-free flakes, markedly pleochroic from deep-blue to olive-green, or less commonly from very light blue to deeper blue. Under crossed-nicols this variety shows very low interference colours (grey or ultra-blue), and usually yields a biaxial positive figure. The isogyres are rather fuzzy and show strong dispersion. This pleochroic variety grades into the non-pleochroic, inclusion-ridden variety so that no definite line between the two types can be drawn.

The chloritoid from the McMurray formation matches almost exactly, the description given by Milner (1929, p. 158). The mineral could, however, be confused with certain varieties of chlorite except that the refractive index of chloritoid is much higher. The genetic significance of the two minerals is quite different, since chlorite is an alteration product of various ferromagnesian minerals while chloritoid is a primary metamorphic mineral found in low- to medium-rank metamorphic rocks.

Rutile

Rutile is a very minor constituent of the heavy mineral fraction. Generally, two or three grains of the mineral were observed in each sample.

Apatite

With the exception of a sample from the glauconite sand, apatite forms 2% or less of the non-opaque heavy mineral fraction. It is found as colourless, subangular or subrounded grains that possess a distinctive orange tinge about the edges. The mineral is further characterized by its low birefringence and by the uniaxial negative figure of the basal section.

Amphiboles

Amphiboles are extremely rare. Only a few grains of hornblende were observed in a sample from the basal beds of the McMurray formation near the mouth of the Steepbank river.

Miscellaneous

This category includes the few grains of epidote, sphene, zoisite, and sillimanite that were identified in the eighteen samples examined. Because of their rare occurrence within the samples, these minerals do not merit individual description. Several grains in each sample were not identified because of their altered condition or because of the lack of diagnostic properties.

EVALUATION OF THE HEAVY MINERAL DATA

In the light of the petrological evidence, it is obvious that igneous, metamorphic, and sedimentary rocks have contributed to the sediments of the McMurray formation. As the formation has been correlated in Part I of this paper with marine shales in the lower part of the Loon River formation, the only possible source area for the mineral aggregate in the bituminous sands would lie to the east on the area now referred to as the Canadian Shield. Chert and rock fragments are common features of those Cretaceous sandstones which received their sediments from the Cordilleran area to the west (Wickenden, 1951 A, p. 43). The absence of chert and rock fragments in the McMurray sands is further evidence for an eastern source.

Sproule (1951, p. 10) has suggested that the Athabasca formation (late Precambrian or early Palaeozoic), which supposedly covers a large area of northern Saskatchewan, contributed a large part of the sands to the McMurray formation. The Athabasca formation, in the type area south of Lake Athabasca, seems to consists almost entirely of flat-lying beds of almost pure quartz sandstones and conglomeratic sandstones (Alcock, 1936; Sproule, 1938), which lie unconformably upon a typical Precambrian complex of igneous, metamorphic and sedimentary rocks. The factors favouring the Athabasca formation as a source for the McMurray sands are (1) that it lies only a short distance to the east of the present outcrop area of the McMurray formation, and (2) that the McMurray sands, like those of the Athabasca formation, consist largely of quartz.

However, the accessory but persistent amounts of muscovite and orthoclase in the McMurray sands probably were not derived from the Athabasca orthoquartzites. These minerals could have been brought in from a minor, secondary source. The material from the latter would mix with and contaminate the pure quartz sands coming from the Athabasca formation. But the most convincing argument against the Athabasca formation as the major source for the McMurray sediments is found in the analyses of the heavy mineral residues from several samples of sandstone from the Athabasca formation (Mawdsley, 1954). In the latter, only very small amounts of well-rounded tourmaline, zircon and rutile are present, and the tourmaline grains from some of the samples possess large authigenic overgrowths which, most certainly, would have survived reworking. This is illustrated in that one-third of the tourmaline grains from Recent river sands along the Clearwater river, which drains part of the large outcrop area of the Athabasca formation, also possess very noticeable authigenic overgrowths, and yet such tourmaline is rare or non-existent in those samples of the McMurray sands examined by the writer. Actually, not enough data are available, particularly with regard to the regional lithology of the Athabasca formation, to be certain whether or not the Athabasca orthoquartzites did contribute to the sediments of the McMurray formation. The evidence at hand strongly suggests that the formation contributed only a very minor part of the McMurray sediments. Juxtaposition of the outcrop reas of the two formations at the present time does not necessarily mean that such a condition existed at the time of deposition of the McMurray sediments.

The heavy mineral assemblage from the McMurray formation can be divided into two groups:

(1) First-cycle minerals derived from an igneous-metamorphic terrane. This group includes all staurolite, kyanite, chloritoid, garnet and apatite, and approximately two-thirds of the tourmaline and zircon. The first four minerals are metamorphic, while the apatite, zircon and most of the tourmaline indicate an igneous source.

(2) Second-cycle minerals derived from pre-existing sedimentary rocks. This group includes about one-third of the tourmaline and zircon, and perhaps rutile.

The igneous and metamorphic rocks are found today in the Precambrian terranes of the Canadian Shield, while the sedimentary source rocks were probably Precambrian or early Palaeozoic sandstones, similar to those of the McMurry formation in that they were made up largely of pure quartz, rather than quartz with chert or rock fragments. Although the distribution of early Palaeozoic strata in McMurray time on what is now the Canadian Shield was probably considerably greater than at present, the evidence presented here shows that the Shield was not completely covered. But while the nature and general direction of the source rocks can be ascertained, just how far to the east they lay can only be surmised.

The absence of plagioclase, biotite, amphiboles and pyroxenes in the McMurray sands, which certainly must have been present in the original source area, suggests that the source area was a low relief and had undergone rather intense weathering prior to erosion and deposition of the weathered products as the McMurray sediments. As the McMurray formation rests on the Devonian limestones of the Waterways formation, that part of the Shield which contributed to the McMurray sediments must have been emergent during much of late Palaeozoic and early Mesozoic times. As a result, weathering of the source area over such a long period would remove most of the feldspar, along with the amphiboles, pyroxenes and biotite. This, of course, implies that kyanite, staurolite, chloritoid, garnet and apatite survived weathering processes, and were redeposited along with the more stable quartz, muscovite, tourmaline and zircon to form the McMurray sands. The stability of detrital minerals under weathering processes is at present somewhat debatable, and the presence of apatite may well indicate specialized weathering conditions.

CONCLUSIONS

The sediments of the McMurray formation constitute a petrologic unit. The formation was emplaced as a submerging delta. Deposition of the McMurray sediments began with the initial downwarp which brought the early Loon River sea into northern Alberta. Sources of the McMurray sediments was to the east, from a well-weathered area of low relief underlain by igneous, metamorphic and sedimentary rocks, *i.e.,* from the Canadian Shield. Sedimentation was rapid at first, allowing the McMurray strata to be deposited as a delta-like wedge on the eastern margin of this early sea; however, as the rate of subsidence of the delta overcame the rate of deposition, the late Loon River or Clearwater sea spread further east and south into Saskatchewan, drowning the delta and bringing McMurray sedimentation to a close.

APPENDIX

Location of Heavy Mineral Samples

(1) From the core of the Socony-Vacuum Oil Sands Well No. 27 in Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta. Fig. 2 indicates the sample locations at this well, as follows:

L 1 —glauconitic sandstone from the basal member of the Clearwater formation, at a depth of 95-96 feet.

L 2 —bituminous sand at 115 feet.

L 3 —bituminous sand at 132 feet.

L 4 —bituminous sand at 152 feet.

L 5 —bituminous sand at 175 feet.

L 6 —bituminous sand at 194 feet.

L 7 —bituminous sand at 217 feet.

L 8 —bituminous sand at 235 feet.

L 9 —bituminous sand at 252 feet.

L 10—bituminous sand at 282 feet.

(2) Outcrop samples:

L 11—bituminous sand from the upper part of the McMurray formation on the Hangingstone river.

L 12—bituminous sand near the base of the McMurray formation on the Hangingstone river.

L 13—bituminous sand from the quarry at Bitumount.

L 14—bituminous sand from the upper part of the McMurray formation on the Athabasca river, twelve miles north of McMurray.

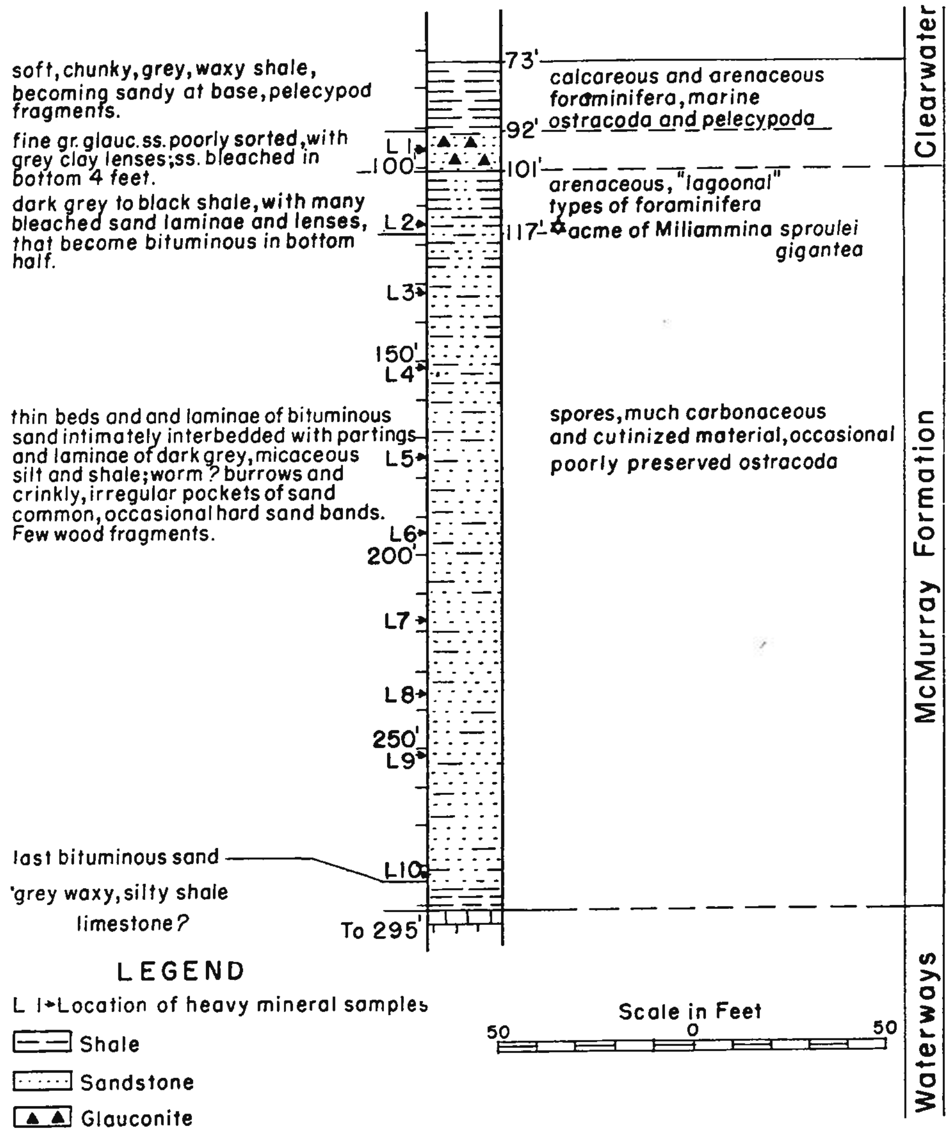
L 15—bituminous sand from the upper part of the McMurray formation near the mouth of the Steepbank river.

L 16—bituminous sand at the base of the McMurray formation, near the mouth of the Steepbank river.

L 17—rather clean sand from the lower? part of the McMurray formation on the Athabasca river between MacKay and Bitumount.

L 18—unimpregnated sand from the McMurray formation on the Clearwater river.

FIG. 2
LITHOLOGY AND FAUNAL ZONES OF THE SOCONY-VACUUM OIL SANDS WELL No. 27
Sec. 27, Tp. 91, Rge. 10, W. 4th Meridian, Alberta.



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