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DEPARTMENT OF ENERGY, MINES AND RESOURCES, OTTAWA

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PAPER 74-38

ILLUSTRATIONS OF CANADIAN FOSSILS

CRETACEOUS FORAMINIFERA FROM SASKATCHEWAN AND MANITOBA

B.R. North and W.G.E. Caldwell

1975

ERRATUM

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PLATE VII

Zones VIII to XVI, Campanian and Maestrichtian
Lea Park, Bearpaw and Eastend Formations, Pembina Member
of Vermilion River Formation, Riding Mountain Formation

Figures 1a, b, 2a, b: *Haplophragmoides* cf. *impensus* Martin, 1964. Figured specimens G.M.U.S. Pf 294, Central Canada Potash Co. mine shaft between 603 and 610 feet. x35 (103)

Figure 3: *Ammobaculites* sp. Figured specimen G.M.U.S. Pf 296, knoll on southern border of NW14-1-10W3 between elevations of 2,635 and 2,640 feet. x30 (146)

Figures 4a-c: *Trochamminoides* cf. *velascoensis* Cushman, 1926. Figured specimen G.M.U.S. Pf 297, Duval Corp. mine shaft between 1,002 and 1,012 feet. x50 (63)

Figures 5, 6: *Spiroplectammina* cf. *mordenensis* Wickenden, 1932. Figured specimens G.M.U.S. Pf 123, 124, Imperial Oil Structure test hole 67 at 95 feet. x65 (167)

Figures 7a, b: *Spiroplectammina semicomplanata* (Carsey), 1926. Hypotype G.M.U.S. Pf 125, Imperial Oil Structure test hole 168 at 250 feet. x80 (109)

Figures 8a, b: *Spiroplectammina* sp. Figured specimen G.M.U.S. Pf 298, Central Canada Potash Co. mine shaft between 1,027 and 1,034 feet. x80 (67)

Figures 9a,b: *Spiroplectammina sigmoidina* Lalicker, 1935. Hypotype G.M.U.S. Pf 299, Central Canada Potash Co. mine shaft between 969 and 974 feet. x80 (80)

Figure 10: *Pseudobolivina rollaensis* (Stelck and Wall), 1954. Hypotype G.M.U.S. Pf 247, Duval Corp. mine shaft between 1,112 and 1,122 feet. x100 (55)

Figures 11, 12, 13: *Pseudobolivina* sp. Figured specimens G.M.U.S. Pf 300 (fig. 11), APM Operators Elstow mine shaft between 335 and 348 feet; G.M.U.S. Pf 301 (fig. 12), small valley in SE7-1-10W3 between elevations of 2,523 and 2,526 feet; G.M.U.S. Pf 302 (fig. 13), Central Canada Potash Co. mine shaft between 627 and 635 feet. x75 (68)

Figures 14a-c: *Trochammina albertensis* Wickenden, 1932. Hypotype G.M.U.S. Pf 136, Geological Survey of Canada cored borehole 61-1 at 620 feet. x100 (128)

Figures 15a-c: *Trochammina globigeriniformis* (Parker and Jones), 1865. Hypotype G.M.U.S. Pf 138, Imperial Oil Structure test hole 67 at 75 feet. x100 (140)

Figures 16a-c, 17, 18a-c: *Trochammina* cf. *boehmi* Franke, 1928. Figured specimens G.M.U.S. Pf 303 to 305, valley west of ridge in NW11-1-10W3 between elevations of 2,827 and 2,832 feet. x45 (142)

Figures 19a-c: *Trochammina diagonis* (Carsey), 1926. Hypotype G.M.U.S. Pf 306, International Minerals and Chemical Corp. Gerald mine shaft between 228 and 236 feet. x35 (61)

Figures 20a-c: *Trochammina ribstonensis* Wickenden, 1932. Hypotype G.M.U.S. Pf 250, Central Canada Potash Co. between 1,178 and 1,183 feet. x100 (57)

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ABSTRACT

Sixteen foraminiferal faunas, composed collectively of nearly two hundred genera and species, can be distinguished in the Cretaceous System of Saskatchewan and Manitoba. These faunas are the basis of successive assemblage zones which can be traced from the Manitoba escarpment, through Saskatchewan, to the borderlands with Alberta.

The lowest four faunas, mainly Albian in age, are composed exclusively of arenaceous-walled, benthonic species. Their distribution provides evidence of increasing marine influence on Albian sedimentation and is in keeping with the long-postulated southward transgression of a "boreal" sea through the Canadian interior in Early Cretaceous time. The succeeding three faunas, late Cenomanian to Late Santonian in age, include the only ones dominated by pelagic species. Although widespread in distribution, these species seem to have invaded the Canadian interior from the south during episodes of widespread inundation following union of northward- and southward-transgressive seas to form the Western Interior seaway. The remaining nine faunas, Campanian to early Maestrichtian in age, are composed of varying proportions of arenaceous- and calcareous-walled, benthonic species. Particularly abundant and varied faunas mark times of westward transgression before and after the proto-Laramide movements of mid-Campanian time that resulted in an eastward spread of deltaic sediments from the site of the Rocky Mountains to beyond the mid-line of Saskatchewan. The Campanian-Maestrichtian faunas suggest a growing influence of Gulfian waters in the Canadian interior toward the close of the Late Cretaceous Epoch.

Together with the more refined molluscan range zones, the foraminiferal assemblage zones permit biostratigraphic analysis of rock sequences; these sequences being partly in different facies and ranging from 2,000 to 4,000 feet (609-1,219 m) in thickness. Well-preserved foraminifera are common, molluscs rare, in subsurface sections. Foraminifera, therefore, are a particularly useful means of correlation because, throughout the plains of Saskatchewan and Manitoba, the Cretaceous rocks are buried beneath remnants of a Tertiary cover and a mantle of Pleistocene drift.

RÉSUMÉ

Dans le système crétacé de la Saskatchewan et du Manitoba, on peut distinguer seize faunes de foraminifères, composées de presque deux cent genres et espèces. Ces faunes font la base de zones d'assemblages successives que l'on peut tracer de l'escarpement du Manitoba, à travers la Saskatchewan jusqu'à la région frontière avec l'Alberta.

Les quatre faunes inférieures, principalement d'âge albien, sont composées exclusivement d'espèces benthoniques arénacées. Leur distribution nous fourni l'évidence d'une influence marine croissante sur la sédimentation albienne et s'accorde bien avec la transgression vers le sud d'une mer "boréale" à travers l'intérieur canadien au crétacé inférieur, ceci longtemps posé en postulat. Les trois faunes suivantes, d'âge cénomanien supérieur à santonien supérieur, comptent les seules faunes dominées par des espèces pélagiques. Quoique de distribution répandue, ces espèces semblent avoir envahi l'intérieur canadien par le sud durant des épisodes d'inondation répandue faisant suite à l'union des mers transgressant vers le nord et vers le sud pour former la mer de l'intérieur ouest. Les neuf autres faunes, d'âge campanien à maestrichtien inférieur, sont composées de proportions variantes d'espèces benthoniques arénacées et calcaires. Des faunes particulièrement riches et variées indiquent des temps de transgression vers l'ouest avant et apres les mouvements proto-laramiens du temps mi-campanien, ce qui résulta dans le deploiement vers l'est de sédiments deltaïques à partir du site des Montagnes Rocheuses jusqu'au-delà la mi-Saskatchewan. Les faunes campaniennes-maestrichtiennes nous suggèrent une influence croissante des eaux golfiennes dans l'intérieur canadien vers la fin du crétacé supérieur.

Mises ensemble avec les zones d'étendue stratigraphique plus rafinées des mollusques, les zones d'assemblages des foraminifères nous permettent de faire l'analyse biostratigraphique de séquences de roches de 2,000 à 4,000 pieds (609-1,219 m) d'épaissuer et, en partie, de facies différents. Dans les sections souterraines les foraminifères bien préservés sont abondants et les mollusques sont rares. Les foraminifères sont donc particulièrement utiles pour la corrélation, car à travers les plaines de la Saskatchewan et du Manitoba, les roches crétacées sont enterrées sous les restants d'une couverture tertiaire et sous des dépôts pleistocènes.

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STRATIGRAPHICAL CONTEXT

Terrigenous clastic rocks of Cretaceous age are spread throughout southern Saskatchewan and much of southwestern Manitoba, where they form the bedrock foundation of a large, triangular segment of the Canadian Interior Platform. The Cretaceous rocks of Saskatchewan and Manitoba are continuous with those of Alberta, Montana, and North Dakota and, in wider context, are seen to be an integral part of the vast, North American, Western Interior, Cretaceous province. In northwestern Saskatchewan, basal beds of the Lower Cretaceous Series rest with gross unconformity on igneous and metamorphic rocks along the southern edge of the Canadian Precambrian Shield. Southward from northeastern Saskatchewan into Manitoba, the basal Lower Cretaceous beds overstep Ordovician, Silurian, and Devonian strata to rest on Jurassic rocks at the base of the Manitoba escarpment. Succeeding Lower and Upper Cretaceous beds are encountered southwestward across the plains, until ultimately the youngest disappear beneath a conformable Paleocene cover in the borderland with the United States (Fig. 1). Across Saskatchewan, the Cretaceous System varies in facies and thickness: the western sequence recalls that in Alberta, the eastern sequence that in Manitoba; and each has its own nomenclature derived from that applied in the adjacent province. The successions generally recognized in western Saskatchewan and in eastern Saskatchewan and Manitoba are shown in Figure 2, which also indicates how these successions are believed to relate to the standard section for the continental Western Interior, constructed from outcrops in the United States.

The Cretaceous rocks of Manitoba and Saskatchewan, where they are exposed, have yielded fairly abundant and varied molluscan faunas. Rapidly evolving stocks of ammonites and bivalves, in particular, form the basis of a zonal scheme that enables the rocks of the eastern Interior Platform to be correlated with the more complete and thicker sections in Alberta and the Northwest Territories, and also with the sections in the Western Interior of the United States (Jeletzky, 1968; 1970, p. 649-662). Unfortunately, the Cretaceous rocks of the Saskatchewan and Manitoba plains are poorly exposed; they are largely buried beneath patches of Paleogene and Neogene sediments and a blanket of Pleistocene deposits. Upper Campanian and Maestrichtian rocks crop out on the flanks of the Cypress Hills and in the valleys of the Frenchman, South Saskatchewan, and Qu'Appelle Rivers, but the older Neocomian to Santonian rocks are known almost entirely from boreholes (a number of which have been cored) and from mine shafts which, in recent years, have been sunk to the rich potash ores of Middle Devonian age preserved at depths in excess of 3,000 feet (914 m) (Price and Ball, 1971, 1973). Whereas the subsurface sections have yielded mainly crushed, fragmentary and, in other respects, poorly preserved molluscs, they are sources of well-preserved foraminifera, which not only occur with remarkable consistency throughout the marine part of the sections but, at certain levels, in great profusion. Compared to the molluscs, foraminifera have the advantage that they can be recovered with equal facility from both surface and subsurface sections (some allowance being made for leaching of the calcareous-walled varieties in deeply weathered exposures). They have a disadvantage in that most of the stocks evolved much more slowly; the zonal scheme based upon their distribution, therefore, is relatively crude; they are less useful for international correlation; and the ages of the zones generally have to be determined indirectly by first relating them to the molluscan zones. To some extent, the foraminifera and molluscs complement one another: molluscs have been recovered from rare beds apparently devoid of foraminifera; at many localities, foraminifera have been recovered from beds that, so far, have not yielded molluscs.

Due to the efforts of officers of the Geological Survey, the presence of foraminifera in the Cretaceous rocks of Manitoba and Saskatchewan and the usefulness of these fossils in stratigraphic studies have been known for many years. J.B. Tyrrell (1890) first recorded foraminifera and radiolarians from Manitoba; Cushman (1927) described some foraminifera from Saskatchewan that had been submitted to him by E.M. Kindle; and R.T.D. Wickenden (1932a, b, c; 1941; 1945; 1948; *in* Fraser *et al.*, 1935) described and used foraminifera in the course of his investigations of the rocks beneath the Great Plains.

Sixteen successive foraminiferal faunas, composed collectively of nearly two hundred species, now have been distinguished in the Cretaceous System of Saskatchewan and Manitoba. The faunas form the bases of sixteen assemblage zones but, until these zones can be compared more closely with those already established in Alberta, they are designated informally by successive Roman numerals (Fig. 3). Eleven of the sixteen assemblages have been established in sections encountered in eight potash mine shafts (or exploratory boreholes for such shafts) aligned west-northwest-east-southeast across Saskatchewan (1 to 8 in Fig. 1). The ages of the rocks in these sections range from possibly Neocomian to mid-Campanian. In two additional shaft sections currently under study,

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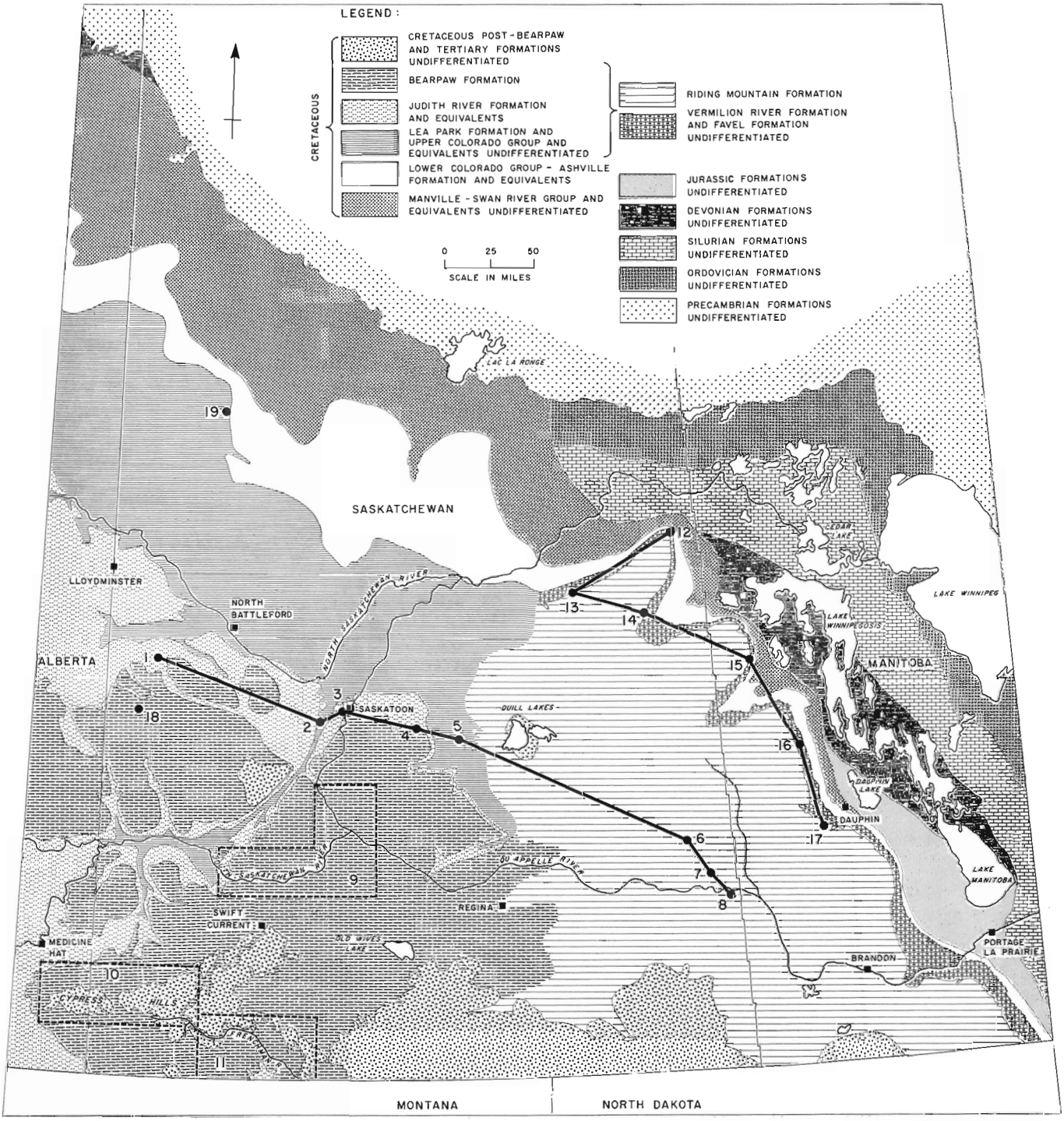

Figure 1. Geological map of adjacent parts of Saskatchewan and Manitoba showing the distribution of Cretaceous rocks and the locations of the principal borehole sections, mine-shaft sections, and areas of outcrop from which foraminiferal faunas have been recovered

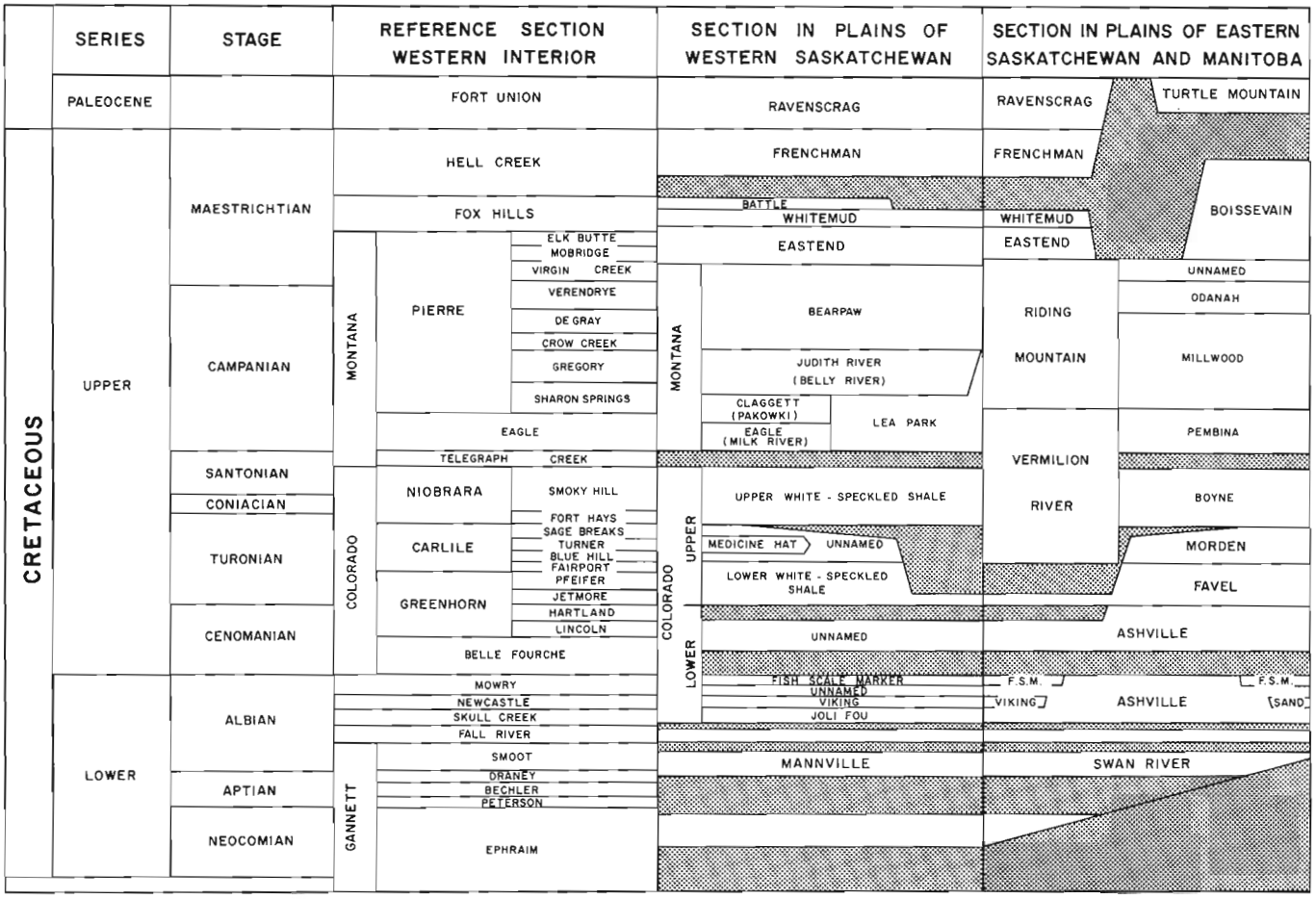

Figure 2. Tabular summary of the generalized Cretaceous sections in western Saskatchewan and in eastern Saskatchewan and Manitoba, with their relationship to the reference section for the Western Interior (McGookey *et al.*, 1972, Fig. 9) and to the international stages

the distribution of the assemblages seems consistent. The five remaining assemblages have been established in the late Campanian-early Maestrichtian Bearpaw Formation of the South Saskatchewan River valley (Caldwell, 1968; North and Caldwell, 1970), the Cypress Hills (Loranger and Gleddie, 1953), the Frenchman River valley (9, 10, and 11 respectively in Fig. 1), and in other parts of southwestern Saskatchewan in which the formation has been cored. Additional information on the composition and distribution of the foraminiferal faunas was obtained from a series of cored boreholes in the Manitoba-Saskatchewan borderland (Caldwell and North, 1966) and from isolated boreholes near Hearts Hill in the Battleford district (McLean, 1971, p. 84, Pl. 1F) and at Flotten Lake in the Meadow Lake district (12-17, 18, and 19 respectively in Fig. 1). Moreover, current studies by D.H. McNeil of the Department of Geological Sciences of the University of Saskatchewan indicate that many of the zones can be traced from the Pasquia Hills of east-central Saskatchewan southward along the Manitoba escarpment.

Most of the foraminiferal assemblages are dominated by benthonic species; of these, some are composed entirely of arenaceous-walled elements, others of mixtures of arenaceous- and calcareous-walled elements. Only two assemblages contain abundant pelagic species. Some of the higher assemblages have been described and illustrated by North and Caldwell (1964, 1970), and a summary of the composition and distribution of all sixteen assemblages has been given by North and Caldwell (in press).

The main events in the paleogeographical evolution of the North American Western Interior are well established: rapid transgression of a northern, cool, temperate sea by way of the District of Mackenzie and and prairie provinces into the heart of the continent; slower transgression of a southern, warmer, temperate sea from the Gulf of Mexico by way of the southern Rocky Mountain states; and confluence of these encroaching waters toward the close of the Early Cretaceous Epoch to form the Western Interior seaway, which remained an open strait almost to the end of the Cretaceous Period. The sequences in Saskatchewan and Manitoba

and the foraminiferal faunas they contain may be interpreted readily in terms of these events.

Sand, silt, and mud, now forming the Mannville Group, were deposited throughout much of Saskatchewan in Neocomian to Albian time. Initially, nonmarine beds formed a partial blanket on a geologically and topographically varied foundation. Following a period of uplift and erosion, the northern sea made its first incursion into Saskatchewan and, although forced to recede, then variably checked by progradation, it exerted an increasing influence on subsequent Mannville sedimentation. The youngest Mannville sediments, deposited after a further period of uplift and erosion, probably accumulated entirely under marine conditions. Farther east, in Manitoba, earliest Cretaceous depositional events are less well understood, but they are recorded in the Swan River Group, which is correlative with part of the Mannville Group.

The yield of foraminifera from the basal Cretaceous sandy and silty beds of the Mannville and Swan River Groups has been extremely poor. Assemblage I (Fig. 3) has been recovered only from a marine shale tongue low in the upper Mannville Group of west-central Saskatchewan -- probably an eastward extension of the shale from which Nauss (1947) recovered the assemblage in the Vermilion district of Alberta. Fuglem's (1970) report of many of the same and similar foraminiferal elements in shale tongues distributed through the upper Mannville Group in the Lloydminster district of Saskatchewan suggests that the oldest assemblage zone (I) has a greater stratigraphic span than that shown. His work also provides evidence of the increasing marine influence on later Mannville sedimentation.

Marine mud and silt were deposited over Saskatchewan and Manitoba through most of Late Albian to Late Santonian time, and these now are represented by the Colorado Group in western Saskatchewan and by the Ashville Group, Favel Formation, and part of the Vermilion River Group in eastern Saskatchewan and Manitoba. Although the Western Interior seaway achieved its maximum extent and probably all of Saskatchewan and Manitoba were inundated at this time, the depositional record in a large area of central Saskatchewan is incomplete. The sequence is broken by disconformities and paraconformities, which are explained most easily in terms of recurrent uplift along a broad, local axis extending southward into central Saskatchewan. The possibility that some of the unconformities are expressions of regional uplifts, however, is not to be excluded. The pre-Campanian sequences in Saskatchewan are anomalously thin; they are exceeded by overlying beds of Campanian age alone. In the past, this has been attributed to a slow rate of sedimentation on a marine platform far removed from contemporary shores -- an explanation that probably is valid but only partly so, for it now seems that the thinness of the pre-Campanian sequences also is to be explained in part by several episodes of erosion or non-deposition.

Foraminifera begin their consistent occurrence at the base of the lower Colorado Group and the Ashville Group, and three distinct faunal assemblages, II to IV, the lowest divisible into two sub-assemblages, characterize the lower Colorado and Ashville beds. Together with the fauna of the Mannville Group, they are composed entirely of northern ("boreal") elements or mixtures of northern and indigenous elements, all with agglutinated test walls (Pls. I-III); they compare well with the faunas described from equivalent rocks in the Arctic Slope of Alaska by Tappan (1962). Zones I to IV are mainly Albian in age. They reflect the influence of the north temperate sea as it transgressed through Saskatchewan on route to the interior of the United States.

Assemblages V to VII (Fig. 3, Pls. IV, V) are markedly different from Assemblages I to IV: not only are they composed predominantly of calcareous-walled species, the lowest is composed exclusively of, and the highest is dominated by, pelagic species. At some levels within the zones, the pelagic species are exceptionally abundant; nearly a thousand specimens may be recovered from a single 100-gram sample. The pelagic faunas, V and VII, occur in the calcareous, white-speckled shale of the Favel Formation and of the Boyne Member of the Vermilion River Formation, respectively, in Manitoba and eastern Saskatchewan and in the equivalent Lower and Upper White Speckled Shales, respectively, of the upper Colorado Group in western Saskatchewan. These shales form distinctive markers traceable throughout the Canadian Plains. The intervening non-calcareous shale of the Morden Member of the Vermilion River Formation and the equivalent shale within the upper Colorado Group contain few representatives of a limited, mixed, arenaceous- and calcareous-walled assemblage that is as contrasted paleontologically from the assemblages overlying and underlying it as the rocks containing it are contrasted lithologically. The presence of both pelagic assemblages (V and VII) in a single white-speckled shale formation in central Saskatchewan first drew attention to the disconformities responsible for condensation of the lower Upper Cretaceous sequence in this area. The pelagic faunas are widespread in the Western Interior of the United States, where they occur in the limestone and calcareous shale of parts of the Greenhorn and Niobrara Formations. They thrived during episodes of strong transgression in Turonian and Coniacian-Santonian times, when the Western Interior seaway achieved its greatest lateral extent, when the axial tract of the Western Interior basin was broad, and when the supply of terrigenous clastic detritus to the basin was diminished (Kauffman, 1969). Unlike the components of Assemblages I to IV, those of Assemblages V to VII are dominantly immigrants from the south -- Gulfian elements that spread northward following union of the northern and southern seas late in Early Cretaceous time.

During Campanian and Maestrichtian times, accelerating and intensifying Laramide movements in the eastern Cordillera had their effect on sedimentation as far east as western Saskatchewan, where there developed a sequence of intertongued eastward-thinning, marine and nonmarine sand and silt and westward-thinning, marine silt and clay. The Judith River (Belly River) Formation, for example, represents the distal portion of the most extensive of these wedges of coarser, terrigenous clastic detritus that developed following pulses of uplift. The sand and silt of the Judith River were mostly river-borne from the western mountains and deposited in an alluvial plain that, at maximum extent, reached beyond the mid-line

of Saskatchewan. In contrast, the succeeding Bearpaw Formation, for example, denotes a westward transgression of the sea during an ensuing phase of tectonic quiescence, its dominant silts and clays indicative of supply of the finer grades of detritus that characterized these transgressive events. Contemporaneously in eastern Saskatchewan and Manitoba, beyond the reach of sand influx from the west, mud accumulated continuously to form the unbroken shale sequence of the upper Vermilion River and Riding Mountain Formations. Final retreat of the Cretaceous sea from Saskatchewan is marked by the Eastend Formation, which records the transition from marine to nonmarine conditions, and also possibly by the less well known Boissevain Formation preserved at Turtle Mountain in Manitoba. Presence of the distal parts of coarser-grained, terrigenous clastic wedges distinguishes the Montana Group of western Saskatchewan from equivalent rocks of eastern Saskatchewan and Manitoba. The boundary between the western Montana facies (at maximum extent) and the eastern "Pierre facies" (as it might be called for convenience) is depicted in Figure 1.

Assemblages VIII to XVI (Pls. VI-XII) are found in the Campanian-Maestrichtian sequences of Saskatchewan and Manitoba -- sequences considerably thicker than those of pre-Campanian age and apparently unbroken by disconformities. Within the continuous shale of the Lea Park and Riding Mountain Formations particularly, the distribution spectrum of the foraminifera changes gradually, and boundaries between assemblage zones, based more on proportionate representation than on simply "presence" or "absence", are more difficult to draw (Fig. 3). In terms of foraminiferal distribution, the base of the Lea Park Formation (and, therefore, of the Montana Group) in western Saskatchewan and of the Pembina Member of the Vermilion River Formation in eastern Saskatchewan and Manitoba is quite distinct. There is a drastic change in the kind and quantity of the foraminifera, so much so as to suggest a definite break in sedimentation and, therefore, to support westward extension of the Late Santonian-Early Campanian disconformity, posulated for southeastern Saskatchewan by Williams and Baadsgaard (in press) on the basis of discrepant radiometric dates. Although Assemblage VIII is composed of a limited variety of arenaceous-walled elements, it does usher in the rich and varied, arenaceous- and calcareous-walled, benthonic faunas of Assemblages IX and X, found throughout the greater part of the Lea Park and Riding Mountain Formations. When the deltaic sediments of the Judith River Formation invaded western Saskatchewan in the aftermath of an early Laramide tectonic pulse, the foraminifera migrated eastward and southward with the receding sea, returning with it to invade the distal deltaic flats between phases of delta growth. Elements of Zone XI, for example, are found in the marine tongues of the Judith River Formation in the Battleford district (McLean, 1971, p. 84-86, Fig. 9, 15). With transgression of the Bearpaw sea over the Judith River alluvial plain, foraminifera re-established themselves in western Saskatchewan and reached a new peak in distribution and variety in mid-Bearpaw time (Zone XV). A few elements of the terminal assemblage, XVI, lived on in Saskatchewan while the basal, marine sands of the Eastend Formation were deposited. Others seem to have migrated southward into the Dakotas, where open-marine conditions continued (North and Caldwell, 1970, p. 74-76). Foraminifera disappeared from Saskatchewan and most of Manitoba as nonmarine environments came to prevail later in Maestrichtian time. The Campanian-Maestrichtian assemblages are composed of northern ("boreal"), southern (Gulfian), and some indigenous elements. Southern elements become increasingly dominant in upward sequence, particularly in the eastern deposits of the "Pierre facies". The mixture of northern and southern migrants is in keeping with a Western Interior strait open until Maestrichtian time.

Whereas the position of the western shorelines of the Cretaceous seas that covered the Canadian Interior Platform can be documented with some accuracy, it is unlikely that the positions of the eastern shorelines will come to be known in comparable detail. There is little or no suggestion of nearshore deposition in the Ashville Group; it is the calcareous Favel Formation and Boyne Member of the Vermilion River Formation that, of all parts of the sequence, recall most closely the equivalent beds of mid-basinal facies in eastern Colorado, western Kansas, and other parts of the United States; and there are no indications of deposition in proximity to shore in the Pembina Member of the Vermilion River or in the Riding Mountain Formation. It seems reasonable, therefore, to look upon the prism of Cretaceous sediments preserved within Manitoba and Saskatchewan as only part of the western half of the full basinal sequence that developed in Cretaceous time. For the various reasons that follow, that prism of sediments thickens markedly to the west: the source of most of the sediment lay to the west; the floor of the seaway underwent greater subsidence in the west, so that sedimentation was heavier; only the western sequence includes thick tongues of less compactible sands; and the succession in the west appears to be more complete. The preserved sequence in Manitoba is not much more than 2,000 feet (609 m) thick, whereas in western Saskatchewan it approaches 4,000 feet (1,219 m).

Readers wishing a more detailed account of the Cretaceous System in Saskatchewan and Manitoba are referred to Fraser *et al.* (1935), Wickenden (1945), Rudkin (1964), Williams and Burke (1964), and Douglas *et al.* (1970).

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APPENDIX I

LOCATION OF SUBSURFACE SECTIONS FROM WHICH TYPE AND FIGURED SPECIMENS HAVE BEEN RECOVERED

Alwinsal Canada Ltd. mine shaft	Lsd.	4-28-33-23W2
APM Operators Elstow mine shaft	Lsd.	5-22-34-1W3
Central Canada Potash Co. mine shaft	Lsd.	5-33-34-27W2
Cominco Ltd. mine shaft (No. 1)	Lsd.	11-16-35-8W3
Continental Potash cored borehole	Lsd.	12-18-41-23W3
Duval Corporation mine shaft	Lsd.	6-18-36-6W3
Geological Survey of Canada cored borehole 61-1		SW27-21-9W3
Imperial Oil Structure test hole 67		NE10-20-6W3
Imperial Oil Structure test hole 168	Lsd.	4-6-21-6W3
Imperial Oil Structure test hole 176	Lsd.	6-33-22-7W3
Imperial Oil Structure test hole 340		NE36-27-9W3
Imperial Oil Structure test hole 374		NE36-24-7W3
Imperial Oil Structure test hole 376		NE2-25-5W3
Imperial Oil Structure test hole 385		NE36-26-6W3
Imperial Oil Structure test hole 388		NE36-25-6W3
Imperial Oil Structure test hole 392		NE32-25-7W3
Imperial Oil Structure test hole 393		NE¼10-20-8W3
Imperial Oil Structure test hole 451		NE¼36-27-9W3
International Minerals and Chemical Corporation Gerald mine shaft	Lsd.	7-27-19-32W1
Saskatchewan Research Council test hole McEachern	Lsd.	5-30-1-7W3
Saskatchewan Research Council test hole Rosefield	Lsd.	13-7-1-11W3
Southwest Potash Co. cored borehole	Lsd.	11-36-22-1W2
Sun Oil Co. cored borehole CH 10A	Lsd.	3-8-53-1W2
Sun Oil Co. cored borehole CH 16C		NE19-35-25W1
Sun Oil Co. cored borehole CH 17		NW13-31-23W1
Sun Oil Co. cored borehole CH 18		SE4-24-21W1
Sun Oil Co. cored borehole CH 19A		NE12-34-29W1
Sun Oil Co. cored borehole CH 22	Lsd.	2-20-45-4W2
Sylvite of Canada mine shaft (No. 2)	Lsd.	12-22-17-30W1
Western Potash Co. cored borehole Verbata No. 2	Lsd.	7-24-41-24W3

PLATES

All type and figured specimens are lodged in the Geological Museum of the University of Saskatchewan (G.M.U.S.) and are identified by code and number.

As a convenient cross-reference between the plates and the composite distribution chart (Fig. 3), the number of each taxon on the composite distribution chart is given in brackets following the information on each taxon in the plate explanations.

The positions of all illustrated specimens recovered from subsurface sections are given in depth below the surface.

PLATE I

Zones I to IV, Albian and Cenomanian
Lower Colorado and Ashville Groups

Figure 1: *Bathysiphon* cf. *brosgei* Tappan, 1957. Figured specimen G.M.U.S. Pf 185, Southwest Potash Co. cored borehole between 1,139 and 1,149 feet. x35 (19)

Figures 2, 3: *Brachysiphon* sp. (=*Sacculinella* sp. Crespin, 1963, p. 22, Pl. 1, figs. 21, 22). Figured specimens G.M.U.S. Pf 186 (fig. 3), 187 (fig. 2), Southwest Potash Co. cored borehole between 1,149 and 1,159 feet and 1,159 and 1,169 feet, respectively. x65 (17)

Figure 4: *Saccammina alexanderi* (Loeblich and Tappan), 1950. Hypotype G.M.U.S. Pf 188, Central Canada Potash Co. mine shaft between 1,481 and 1,485 feet. x50 (1)

Figure 5. *Saccammina lathrami* Tappan, 1960. Hypotype G.M.U.S. Pf 189, Central Canada Potash Co. mine shaft between 1,386 and 1,391 feet. x100 (23)

Figures 6a, b: *Ammodiscus anthosatus* Guliov, 1967. Hypotype G.M.U.S. Pf 190, Central Canada Potash Co. mine shaft between 1,574 and 1,577 feet. x85 (9)

Figures 7a, b: *Ammodiscus kiowensis* Loeblich and Tappan, 1950. Hypotype G.M.U.S. Pf 191, Central Canada Potash Co. mine shaft between 1,556 and 1,561 feet. x80 (18)

Figures 8a, b: *Glomospira glomerosa* Eicher, 1960. Hypotype G.M.U.S. Pf 192, Cominco Ltd. mine shaft between 1,440 and 1,450 feet. x135 (16)

Figures 9a, b: *Glomospira* sp. Figured specimen G.M.U.S. Pf 193, Central Canada Potash Co. mine shaft between 1,386 and 1,391 feet. x100 (28)

Figures 10a, b, 11: *Psamminopelta bowsheri* Tappan, 1957. Hypotype G.M.U.S. Pf 194 (fig. 10), Alwinsal Canada Ltd. mine shaft between 1,243 and 1,253 feet; G.M.U.S. Pf 195 (fig. 11), Central Canada Potash Co. mine shaft between 1,386 and 1,391 feet. x100 (20)

Figures 12a, b, 13a, b, 14a, b: *Miliammina manitobensis* Wickenden, 1932. Hypotypes G.M.U.S. Pf 196, 197 (figs. 12, 13), Central Canada Potash Co. mine shaft between 1,367 and 1,372 feet; G.M.U.S. Pf 198 (fig. 14), Cominco Ltd. mine shaft between 1,509 and 1,514 feet. x65 (3)

Figures 15a, b: *Miliammina sproulei* Nauss, 1947. Hypotype G.M.U.S. Pf 199, Western Potash Co. cored borehole Verbata no. 2 between 2,050 and 2,060 feet. x65 (2)

Figures 16a, b: *Miliammina ischnia* Tappan, 1957. Hypotype G.M.U.S. Pf 200, Central Canada Potash Co. mine shaft between 1,405 and 1,411 feet. x65 (10)

Figures 17a, b: *Haplophragmoides linki* Nauss, 1947. Hypotype G.M.U.S. Pf 201, Central Canada Potash Co. mine shaft between 1,303 and 1,308 feet. x80 (4)

Figures 18a, b: *Haplophragmoides collyra* Nauss, 1947. Hypotype G.M.U.S. Pf 202, International Minerals and Chemical Corp. Gerald mine shaft between 944 and 952 feet. x100 (36)

Figures 19a, b, 20a, b: *Haplophragmoides gigas* Cushman, 1927. Hypotypes G.M.U.S. Pf 203 (fig. 19), Cominco Ltd. mine shaft between 1,645 and 1,655 feet; G.M.U.S. Pf 204 (fig. 20), Central Canada Potash Co. mine shaft between 1,574 and 1,579 feet. x30 (11)

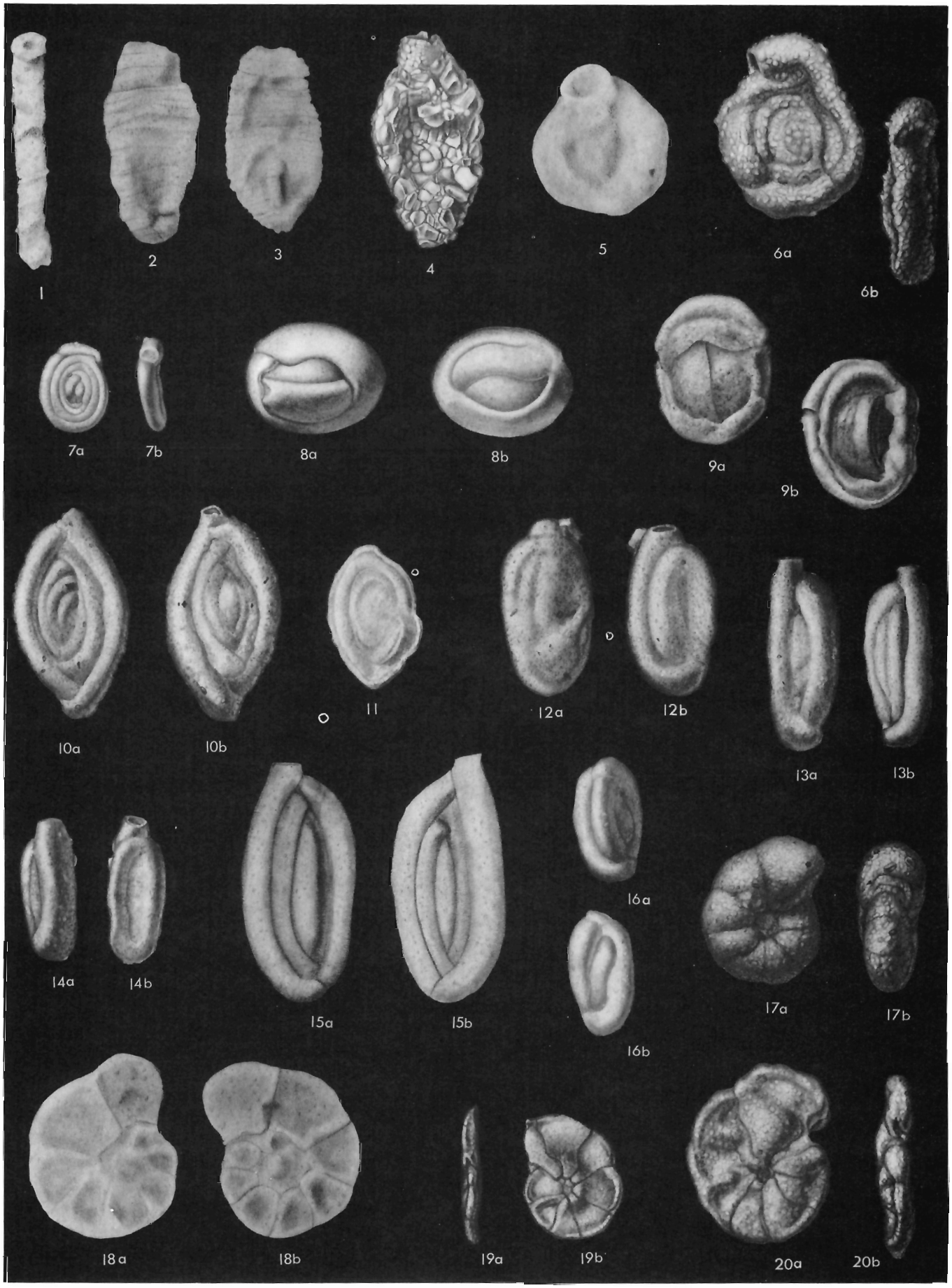
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PLATE II

Zones I to IV, Albian and Cenomanian
Lower Colorado and Ashville Groups

Figures 1a-c: *Haplophragmoides* cf. *kirki* Wickenden, 1932. Figured specimen G.M.U.S. Pf 205, Central Canada Potash Co. mine shaft between 1,332 and 1,337 feet. x90. (32)

Figures 2-5: *Ammobaculites fragmentarius* Cushman, 1927. Hypotypes G.M.U.S. Pf 206 (fig. 2), Central Canada Potash Co. mine shaft between 1,530 and 1,542 feet; G.M.U.S. Pf 207 (fig. 3), 208 (fig. 4), Cominco Ltd. mine shaft between 1,625 and 1,635 and 1,345 and 1,355 feet, respectively; G.M.U.S. Pf 209 (fig. 5), International Minerals and Chemical Corp. Gerald mine shaft between 1,238 and 1,245 feet. x45 (5)

Figures 6, 7: *Ammobaculites petilus* Eicher, 1960. Hypotypes G.M.U.S. Pf 210, 211, Central Canada Potash Co. mine shaft between 1,537 and 1,542 feet. x65 (6)

Figures 8, 9: *Ammobaculites tyrrelli* Nauss, 1947. Hypotypes G.M.U.S. Pf 212 (fig. 8), Cominco Ltd. mine shaft between 1,381 and 1,389 feet; G.M.U.S. Pf 213 (fig. 9), Central Canada Potash Co. mine shaft between 1,322 and 1,328 feet. x65 (29)

Figures 10, 11 *Ammobaculites variabilis* Tappan, 1940. Hypotypes G.M.U.S. Pf 214 (fig. 10), International Minerals and Chemical Corp. Gerald mine shaft between 1,224 and 1,238 feet; G.M.U.S. Pf 215 (fig. 11), Cominco Ltd. mine shaft between 1,335 and 1,345 feet. x45 (12)

Figure 12: *Ammobaculoides whitneyi* (Cushman and Alexander), 1930. Hypotype G.M.U.S. Pf 216, Cominco Ltd. mine shaft between 1,585 and 1,590 feet. x50 (13)

Figure 13: *Ammobaculoides* sp. Figured specimen G.M.U.S. Pf 217, Central Canada Potash Co. mine shaft between 1,584 and 1,589 feet. x50 (14)

Figures 14-16: *Ammotium* sp. Figured specimens G.M.U.S. Pf 218, 219 (figs. 14, 15), Alwinsal Canada Ltd. mine shaft between 1,361 and 1,371 feet; G.M.U.S. Pf 220 (fig. 16), Central Canada Potash Co. mine shaft between 1,319 and 1,324 feet. x30 (21)

Figures 17, 18: *Ammomarginulina asperata* Guliov, 1967. Hypotypes G.M.U.S. Pf 221, 222, Cominco Ltd. mine shaft between 1,675 and 1,685 feet. x50 (15)

Figures 19a, b, 20: *Pseudobolivina variana* (Eicher), 1960. Hypotypes G.M.U.S. Pf 223, 224, Central Canada Potash Co. mine shaft between 1,362 and 1,369 feet. x130 (22)

Figures 21a, b, 22, 23a, b: *Trochammina rainwateri* Cushman and Applin, 1946. Hypotypes G.M.U.S. Pf 224 to 226, Sylvite of Canada mine shaft no. 2 between 908 and 914 feet. x70 (35)

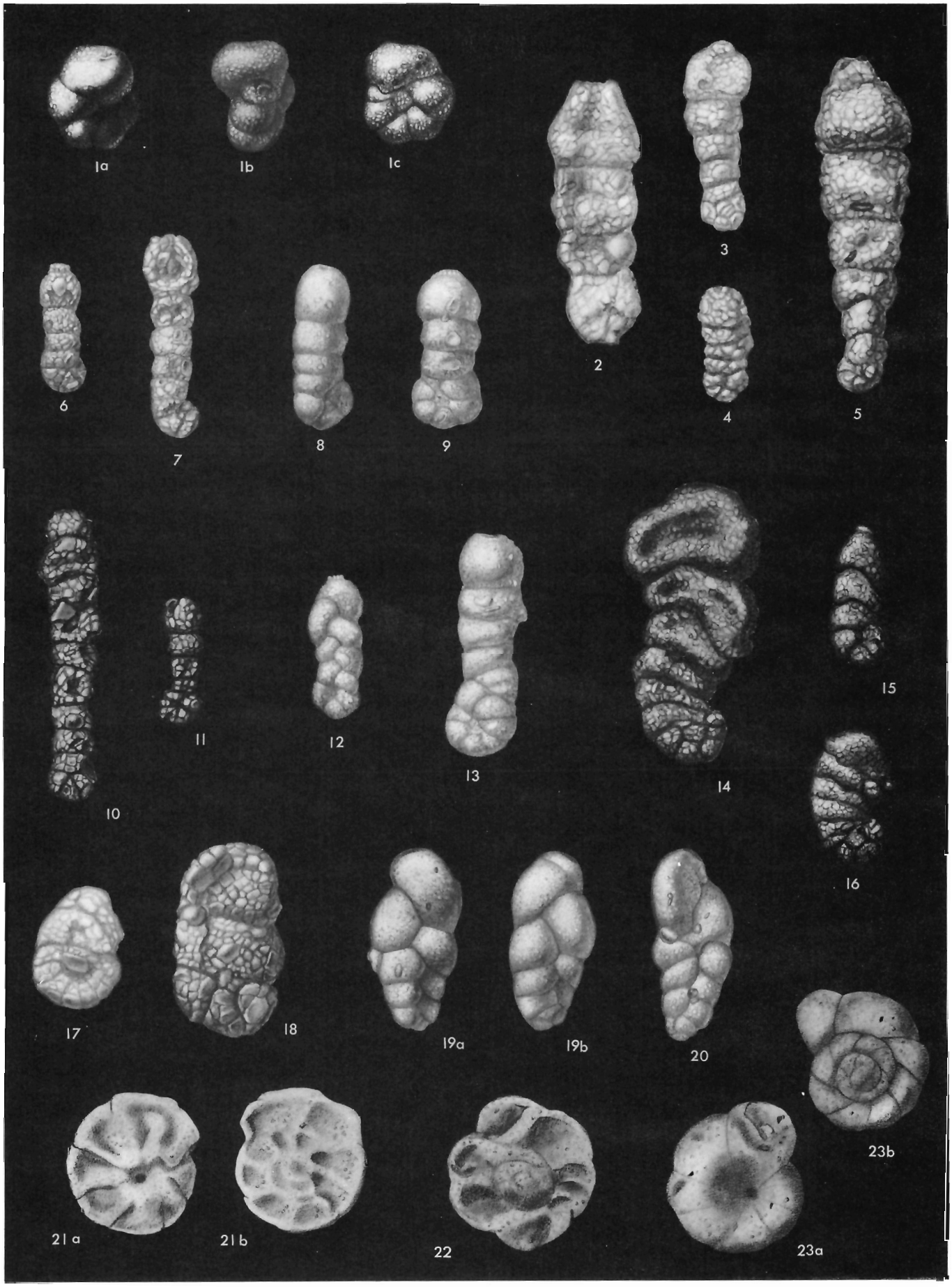
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PLATE III

Zones I to IV, Albian and Cenomanian
Lower Colorado and Ashville Groups

Figures 1a-c: *Trochammina rutherfordi* Stelck and Wall, 1955. Hypotype G.M.U.S. Pf 227, Alwinsal Canada Ltd. mine shaft between 1,263 and 1,273 feet. x100 (26)

Figures 2a-c: *Trochammina* sp. Figured specimens G.M.U.S. Pf 228, Alwinsal Canada Ltd. mine shaft between 1,216 and 1,230 feet. x100 (31)

Figures 3a b: *Verneuilinoides* sp. (=*Verneuilinoides kansasensis* sensu Wall, 1967). Figured specimen G.M.U.S. Pf 229, Central Canada Potash Co. mine shaft between 1,386 and 1,391 feet. x85 (27)

Figures 4, 5a, b: *Verneuilinoides cummingensis* (Nauss), 1947. Hypotypes G.M.U.S. Pf 230 (fig. 4), Continental Potash 12-18 cored borehole between 2,057 and 2,067 feet; G.M.U.S. Pf 231 (fig. 5), Western Potash Co. Verbata no. 2 cored borehole between 2,050 and 2,060 feet. x100 (7)

Figures 6a, b: *Verneuilina canadensis* Cushman, 1927. Hypotype G.M.U.S. Pf 232, Cominco Ltd. mine shaft between 1,510 and 1,530 feet. x50 (24)

Figures 7, 8: *Verneuilinoides perplexus* (Loeblich), 1946. Hypotypes G.M.U.S. Pf 233 (fig. 7), International Minerals and Chemical Corp. Gerald mine shaft between 944 and 952 feet; G.M.U.S. Pf 234 (fig. 8), Southwest Potash Co. cored borehole between 982 and 992 feet. x50 (34)

Figures 9a, b, 10a, b, 11a, b: *Gaudryina canadensis* Cushman, 1943. Hypotypes G.M.U.S. Pf 235 (fig. 9), Cominco Ltd. mine shaft between 1,645 and 1,655 feet; G.M.U.S. Pf 236 (fig. 10), International Minerals and Chemical Corp. Gerald mine shaft between 1,248 and 1,253 feet; G.M.U.S. Pf 237 (fig. 11), Central Canada Potash Co. mine shaft between 1,537 and 1,542 feet. x70 (8)

Figures 12-15: *Gaudryina irenensis* Stelck and Wall, 1955. Hypotypes G.M.U.S. Pf 238 to 241, Alwinsal Canada Ltd. mine shaft between 1,139 and 1,153 feet. x70 (33)

Figures 16a, b, 17a, b: *Arenobulimina paynei* Tappan, 1957. Hypotypes G.M.U.S. Pf 242, 243, Central Canada Potash Co. mine shaft between 1,405 and 1,410 feet. x85 (25)

Figures 18a, b: *Uvigerinammina manitobensis* (Wickenden), 1932. Hypotype G.M.U.S. Pf 244, Alwinsal Canada Ltd. mine shaft between 1,165 and 1,175 feet. x80 (30)

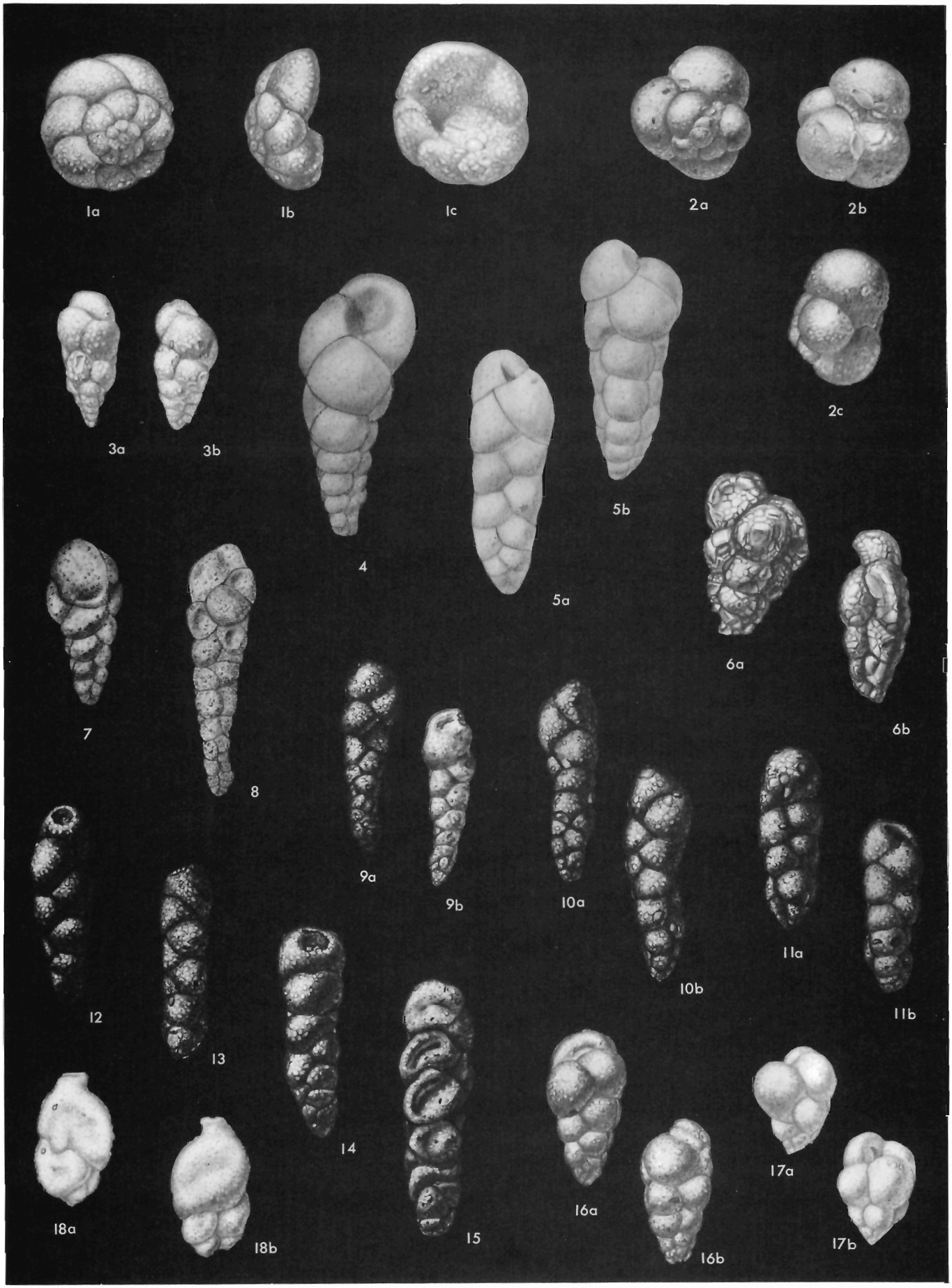
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PLATE IV

Zones V to VII, Cenomanian to Santonian
Upper Colorado Group, Favel Formation, Morden and
Boyne Members of Vermilion River Formation

Figures 1a-c, 2a, b: *Haplophragmoides collyra* Nauss, 1947. Hypotypes G.M.U.S. Pf 245, 246, Sun Oil Co. cored borehole CH 18 between 119 and 126 feet. x85 (36)

Figures 3, 4: *Pseudobolivina rollaensis* (Stelck and Wall), 1954. Hypotypes G.M.U.S. Pf 247, 248, Duval Corp. mine shaft between 1,112 and 1,122 feet. x100 (55)

Figures 5a, b: *Dorothia smokyensis* Wall, 1960. Hypotype G.M.U.S. Pf 249, Sun Oil Co. cored borehole CH 16C between 59 and 64 feet. x85 (48)

Figures 6a-c: *Trochammina ribstonensis* Wickenden, 1932. Hypotype G.M.U.S. Pf 250, Central Canada Potash Co. mine shaft between 1,178 and 1,183 feet. x145 (57)

Figure 7: *Textularia* sp. Figured specimen G.M.U.S. Pf 251, International Minerals and Chemical Corp. Gerald mine shaft between 692 and 700 feet. x55 (56)

Figures 8a, b: *Heterohelix globulosa* (Ehrenberg), 1840. Hypotype G.M.U.S. Pf 252, Sun Oil Co. cored borehole CH 16C between 150 and 157 feet. x85 (37)

Figures 9a-c: *Heterohelix moremani* (Cushman), 1938. Hypotype G.M.U.S. Pf 253, Sun Oil Co. cored borehole CH 19A between 40 and 44 feet. x125 (53)

Figures 10, b: *Heterohelix striata* (Ehrenberg), 1840. Hypotype G.M.U.S. Pf 254, Sun Oil Co. cored borehole CH 22 between 134 and 141 feet. x85 (52)

Figures 11a, b, 14: *Neobulimina albertensis* (Stelck and Wall), 1954. Hypotypes G.M.U.S. Pf 255 (fig. 11), Sun Oil Co. cored borehole CH 19A between 40 and 45 feet; G.M.U.S. Pf 256 (fig. 14), Sun Oil Co. cored borehole CH 22 between 126 and 134 feet. x100 (58)

Figures 12a-c: *Globigerinelloides messinae* (Broenniman), 1952. Hypotype G.M.U.S. Pf 257, Sun Oil Co. cored borehole CH 22 between 134 and 141 feet. x125 (51)

Figures 13a-c: *Globigerinelloides bentonensis* (Morrow), 1934. Hypotype G.M.U.S. Pf 258, Sun Oil Co. cored borehole CH 18 between 25 and 29 feet. x85 (50)

Figures 15a-c: *Hedbergella amabilis* Loeblich and Tappan, 1961. Hypotype G.M.U.S. Pf 259, Sun Oil Co. cored borehole CH 10A between 215 and 220 feet. x85 (45)

Figures 16a-c, 18a-c: *Hedbergella delrioensis* (Carsey), 1926. Hypotypes G.M.U.S. Pf 260 (fig. 16), Sun Oil Co. cored borehole CH 16C between 157 and 165 feet; G.M.U.S. Pf 261 (fig. 18), between 115 and 120 feet. x85 (38)

Figures 17a-c: *Hedbergella loetterlei* (Nauss), 1947. Hypotype G.M.U.S. Pf 262, Sun Oil Co. cored borehole CH 16C between 105 and 110 feet. x85 (39)

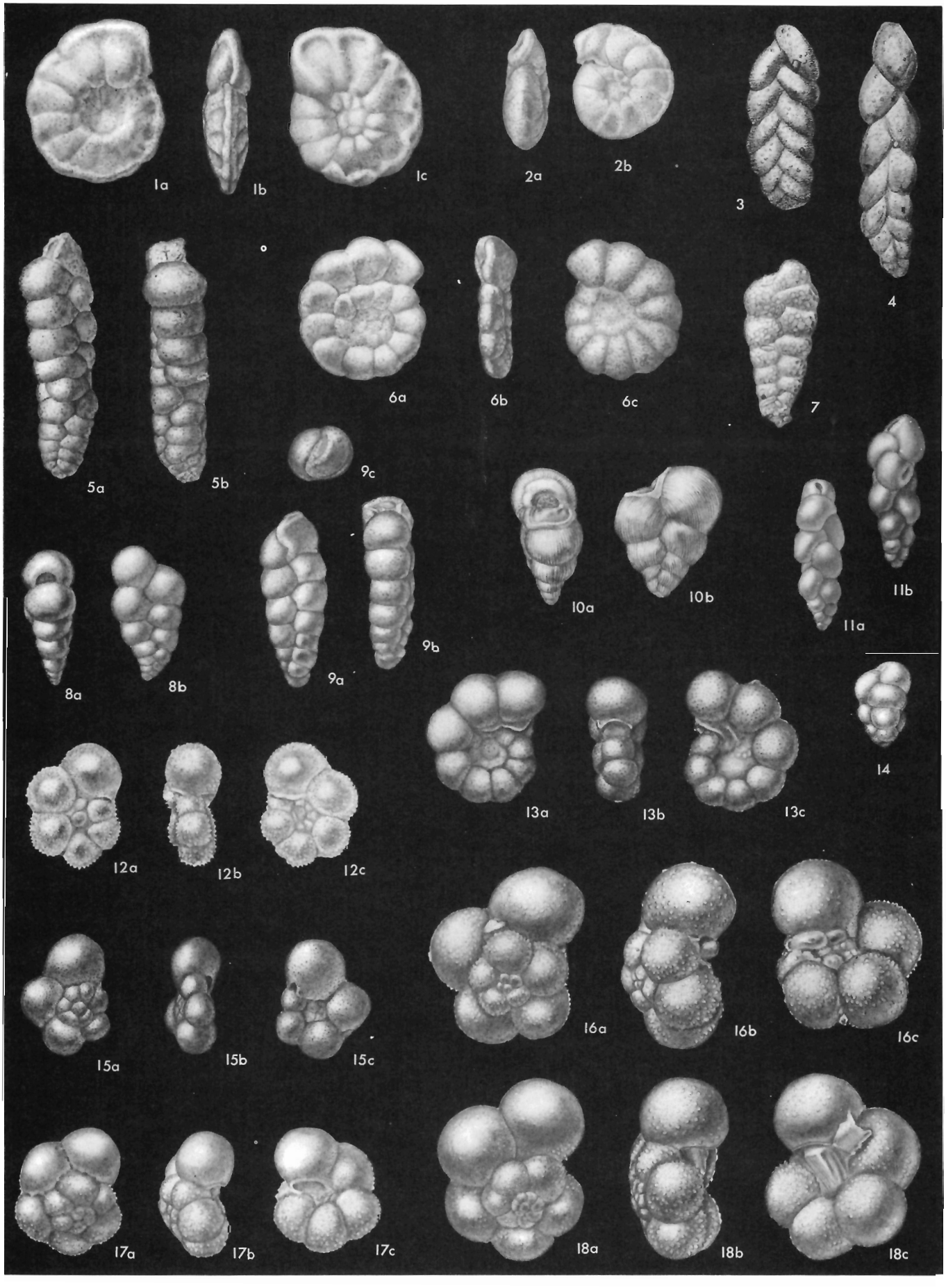
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PLATE V

Zones V to VII, Cenomanian to Santonian
Upper Colorado Group, Favel Formation, Morden and
Boyne Members of Vermilion River Formation

Figures 1a-c: *Hedbergella planispira* (Tappan), 1940. Hypotype G.M.U.S. Pf 263, Sun Oil Co. cored borehole CH 16C between 105 and 110 feet. x85 (40)

Figures 2a-c, 3a, b: *Hedbergella portsdownensis* (Williams-Mitchell), 1948. Hypotypes G.M.U.S. Pf 264 (fig. 2), 265 (fig. 3), Sun Oil Co. cored borehole CH 16C between 150 and 157 feet and 115 and 120 feet, respectively. x85 (41)

Figure 4: *Clavihedbergella simplex* (Morrow), 1934. Hypotype G.M.U.S. Pf 266, Sun Oil Co. cored borehole CH 22 between 224 and 231 feet. x85 (43)

Figures 5a-c: *Clavihedbergella subdigitata* (Carman), 1929. Hypotype G.M.U.S. Pf 267, Sun Oil Co. cored borehole CH 16C between 150 and 157 feet. x85 (44)

Figures 6a-c, 7a-c: *Whiteinella aprica* (Loeblich and Tappan), 1961. Hypotypes G.M.U.S. Pf 268 (fig. 6), Sun Oil Co. cored borehole CH 17 between 111 and 119 feet; G.M.U.S. Pf 269 (fig. 7), Sun Oil Co. cored borehole CH 16C between 150 and 157 feet. x85 (42)

Figures 8a-c: *Gavelinella kansasensis* (Morrow), 1934. Hypotype G.M.U.S. Pf 270, Sun Oil Co. cored borehole CH 18 between 74 and 81 feet. x85 (49)

Figures 9a-c: *Gavelinella* cf. *talaria* (Nauss), 1947. Figured specimen G.M.U.S. Pf 271, Sun Oil Co. cored borehole CH 22 between 126 and 134 feet. x85 (47)

Figures 10a-c: *Gavelinella plummerae* (Tappan), 1940. Hypotype G.M.U.S. Pf 272, Sun Oil Co. cored borehole CH 18 between 59 and 66 feet. x85 (54)

Figures 11a-c: *Lingulogavelinella asteriginoides* (Plummer), 1931. Hypotype G.M.U.S. Pf 273, Sun Oil Co. cored borehole CH 22 between 224 and 231 feet. x85 (46)

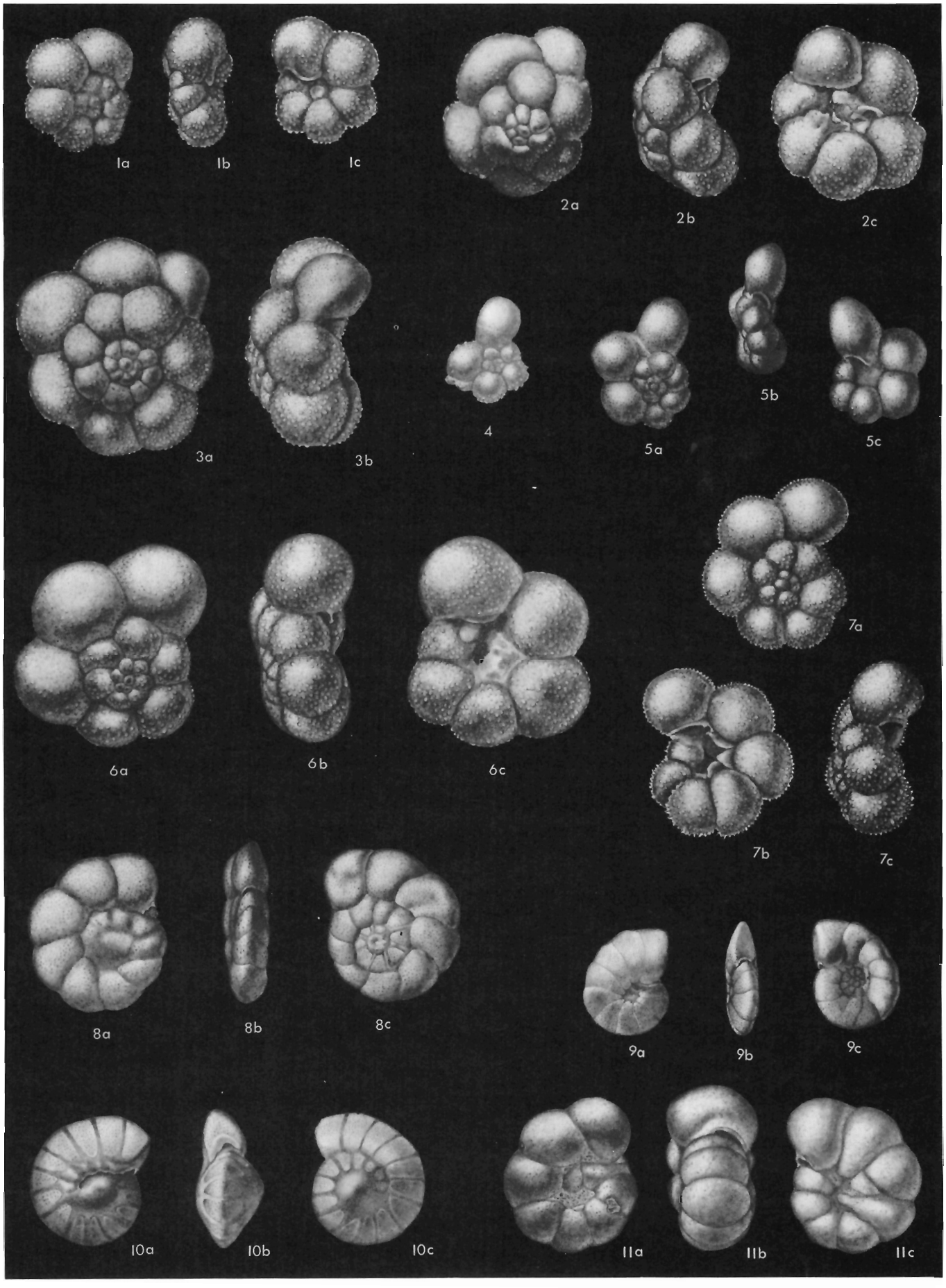
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PLATE VI

Zones VIII to XVI, Campanian and Maestrichtian
Lea Park, Bearpaw and Eastend Formations, Pembina Member
of Vermilion River Formation, Riding Mountain Formation

Figure 1: *Bathysiphon vitta* Nauss, 1947. Hypotype G.M.U.S. Pf 274, Central Canada Potash Co. mine shaft between 1,039 and 1,045 feet. x30 (59)

Figure 2: *Bathysiphon brosgei* Tappan, 1957. Hypotype G.M.U.S. Pf 275, International Minerals and Chemical Corp. mine shaft between 440 and 447 feet. x25 (70)

Figure 3: *Pelosina* sp. Figured specimen G.M.U.S. Pf 276, Duval Corp. mine shaft between 910 and 925 feet. x65 (86)

Figure 4: *Hyperammina erugata* Sliter, 1968. Hypotype G.M.U.S. Pf 277, from isolated knoll in the extreme northwest corner of NW12-3-13W3 between elevations of 2,851 and 2,856 feet. x25 (71)

Figure 5: *Saccammina lathrami* Tappan, 1960. Hypotype G.M.U.S. Pf 278, Central Canada Potash Co. mine shaft between 1,068 and 1,080 feet. x100 (23)

Figure 6: *Saccammina alexanderi* (Loeblich and Tappan), 1950. Hypotype G.M.U.S. Pf 110, Geological Survey of Canada cored borehole 61-1 at 510 feet. x65 (1)

Figures 7a, b: *Glomospira gordialis* (Jones and Parker), 1860. Hypotype G.M.U.S. Pf 112, Imperial Oil Structure test hole 67 at 325 feet. x100 (159)

Figure 8: *Ammodiscus cretaceus* (Reuss), 1845. Hypotype G.M.U.S. Pf 279, a ridge in NE22-1-10W3 between elevations of 2,970 and 2,975 feet. x30 (62)

Figure 9: *Glomospirella inconstans* Mello, 1971. Hypotype G.M.U.S. Pf 280, Central Canada Potash Co. mine shaft between 677 and 682 feet. x100 (126)

Figures 10a, b: *Glomospira corona* Cushman and Jarvis, 1928. Hypotype G.M.U.S. Pf 281, International Minerals and Chemical Corp. mine shaft between 325 and 327 feet. x75 (72)

Figure 11: *Reophax* sp. Figured specimen G.M.U.S. Pf 282, valley in NE22-1-10W3 between elevations of 2,725 and 2,736 feet. x25 (152)

Figure 12: *Reophax texanus* Cushman and Waters, 1927. Hypotype G.M.U.S. Pf 113, Imperial Oil Structure test hole 388 at 390 feet. x65 (135)

Figures 13a, b: *Haplophragmoides calcula* Cushman and Waters, 1927. Hypotype G.M.U.S. Pf 114, Imperial Oil Structure test hole 340 at 436 feet. x35 (149)

Figures 14a, b: *Haplophragmoides collyra* Nauss, 1947. Hypotype G.M.U.S. Pf 283, Central Canada Potash Co. mine shaft between 1,083 and 1,089 feet. x35 (36)

Figures 15a, b: *Haplophragmoides excavata* Cushman and Waters, 1927. Hypotype G.M.U.S. Pf 115, Imperial Oil Structure test hole 67 at 125 feet. x80 (158)

Figures 16, 19a, 19b, 20: *Haplophragmoides fraseri* Wickenden, 1932. Hypotypes G.M.U.S. Pf 284 (fig. 16), 285 (fig. 19), valley west of ridge in NW11-1-10W3 between elevations of 2,790 and 2,795 feet and 2,832 and 2,837 feet, respectively; G.M.U.S. Pf 286 (fig. 20), knoll at southern border of NW14-1-10W3 between elevations of 2,755 and 2,760 feet. x45 (145)

Figures 17a, b: *Haplophragmoides glabra* Cushman and Waters, 1927. Hypotype G.M.U.S. Pf 287, small valley in SE7-1-10W3 between elevations of 2,749 and 2,754 feet. x80 (151)

Figures 18a, b, 22a, b: *Haplophragmoides bonanzaense* Stelck and Wall, 1954. Hypotypes G.M.U.S. Pf 288 (fig. 18), Central Canada Potash Co. mine shaft between 522 and 526 feet; G.M.U.S. Pf 289 (fig. 22), Alwinsal Canada Ltd. mine shaft between 633 and 643 feet. x35 (73)

Figures 21a, b: *Haplophragmoides kirki* Wickenden, 1932. Hypotype G.M.U.S. Pf 120, Imperial Oil Structure test hole 451 at 255 feet. x80 (60)

Figures 23a, b: *Haplophragmoides* cf. *rugosa* Cushman and Waters, 1927. Figured specimen G.M.U.S. Pf 121, Imperial Oil Structure test hole 67 at 75 feet. x80 (156)

Figures 24a, b, 25, 26a, 26b: *Haplophragmoides rota* Nauss, 1947. Hypotypes G.M.U.S. 290 (fig. 25), west side of ridge in NW11-1-10W3 between elevations of 2,645 and 2,650 feet; G.M.U.S. Pf 291 (fig. 24), Cominco Ltd. mine shaft between 331 and 340 feet; G.M.U.S. Pf 292 (fig. 26), APM Operators Elstow mine shaft between 335 and 340 feet. x35 (65)

Figures 27a, b: *Haplophragmoides* sp. Figured specimen G.M.U.S. Pf 293, Central Canada Potash Co. mine shaft between 603 and 610 feet. x31 (108)

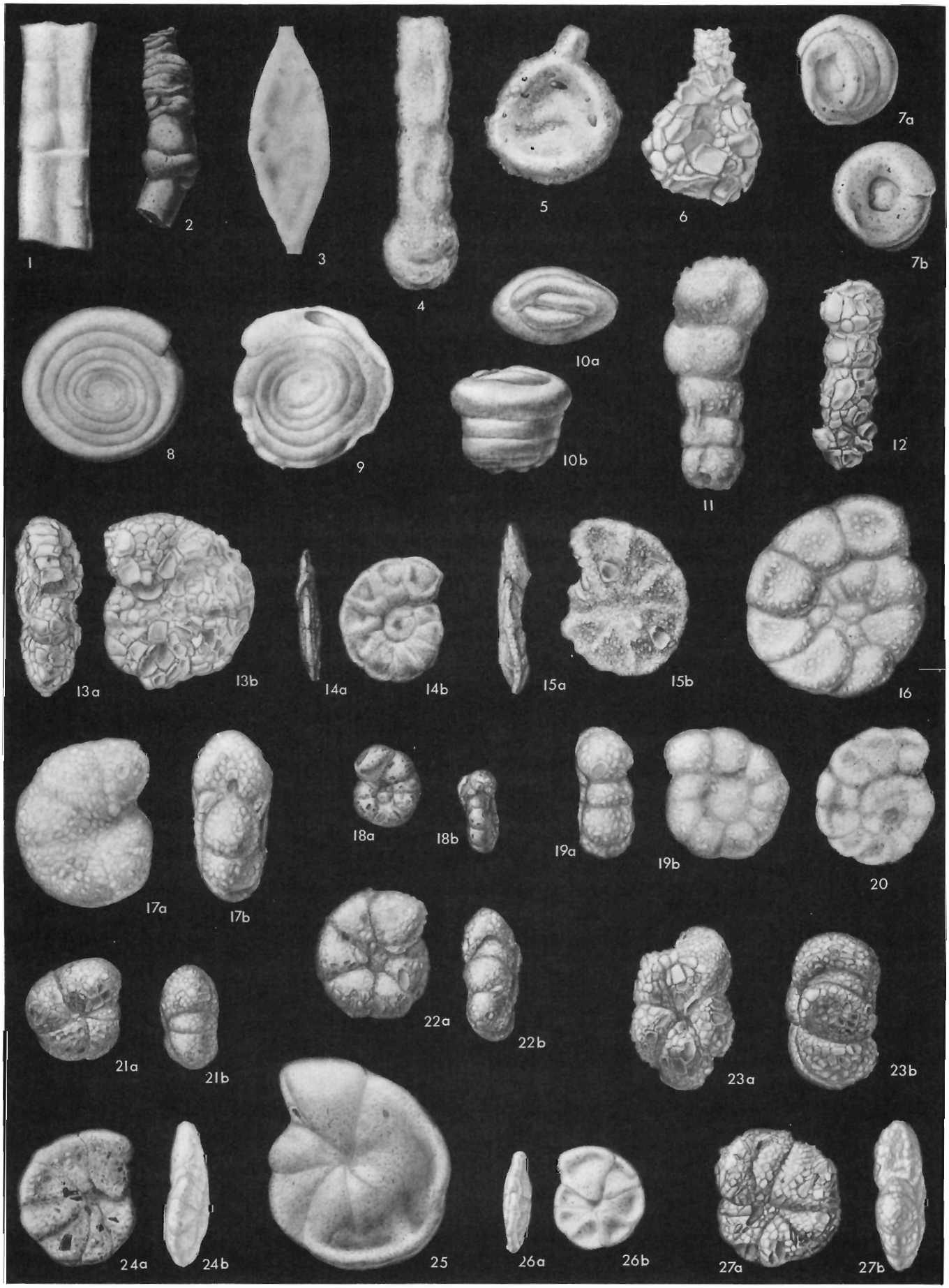
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PLATE VII

Zones VIII to XVI, Campanian and Maestrichtian
Lea Park, Bearpaw and Eastend Formations, Pembina Member
of Vermilion River Formation, Riding Mountain Formation

Figures 1a, b, 2a, b: *Haplophragmoides* cf. *impensus* Martin, 1964. Figured specimens G.M.U.S. Pf 294, Central Canada Potash Co. mine shaft between 603 and 610 feet. x35 (103)

Figure 3: *Ammobaculites* sp. Figured specimen G.M.U.S. Pf 296, knoll on southern border of NW14-1-10W3 between elevations of 2,635 and 2,640 feet. x30 (146)

Figures 4a-c: *Trochamminoides* cf. *velascoensis* Cushman, 1926. Figured specimen G.M.U.S. Pf 297, Duval Corp. mine shaft between 1,002 and 1,012 feet. x50 (63)

Figures 5, 6: *Spiroplectammina* cf. *mordenensis* Wickenden, 1932. Figured specimens G.M.U.S. Pf 123, 124, Imperial Oil Structure test hole 67 at 95 feet. x65 (167)

Figures 7a, b: *Spiroplectammina semicomplanata* (Carsey), 1926. Hypotype G.M.U.S. Pf 125, Imperial Oil Structure test hole 168 at 250 feet. x80 (109)

Figures 8a, b: *Spiroplectammina* sp. Figured specimen G.M.U.S. Pf 298, Central Canada Potash Co. mine shaft between 1,027 and 1,034 feet. x80 (67)

Figures 9a, b: *Spiroplectammina sigmoidina* Lalicker, 1935. Hypotype G.M.U.S. Pf 299, Central Canada Potash Co. mine shaft between 969 and 974 feet. x80 (80)

Figure 10: *Pseudobolivina rollaensis* (Stelck and Wall), 1954. Hypotype G.M.U.S. Pf 247, Duval Corp. mine shaft between 1,112 and 1,122 feet. x100 (55)

Figures 11, 12, 13: *Pseudobolivina* sp. Figured specimens G.M.U.S. Pf 300 (fig. 11), APM Operators Elstow mine shaft between 335 and 348 feet; G.M.U.S. Pf 301 (fig. 12), small valley in SE7-1-10W3 between elevations of 2,523 and 2,526 feet; G.M.U.S. Pf 302 (fig. 13), Central Canada Potash Co. mine shaft between 627 and 635 feet. x75 (68)

Figures 14a-c: *Trochammina albertensis* Wickenden, 1932. Hypotype G.M.U.S. Pf 136, Geological Survey of Canada cored borehole 61-1 at 620 feet. x100 (128)

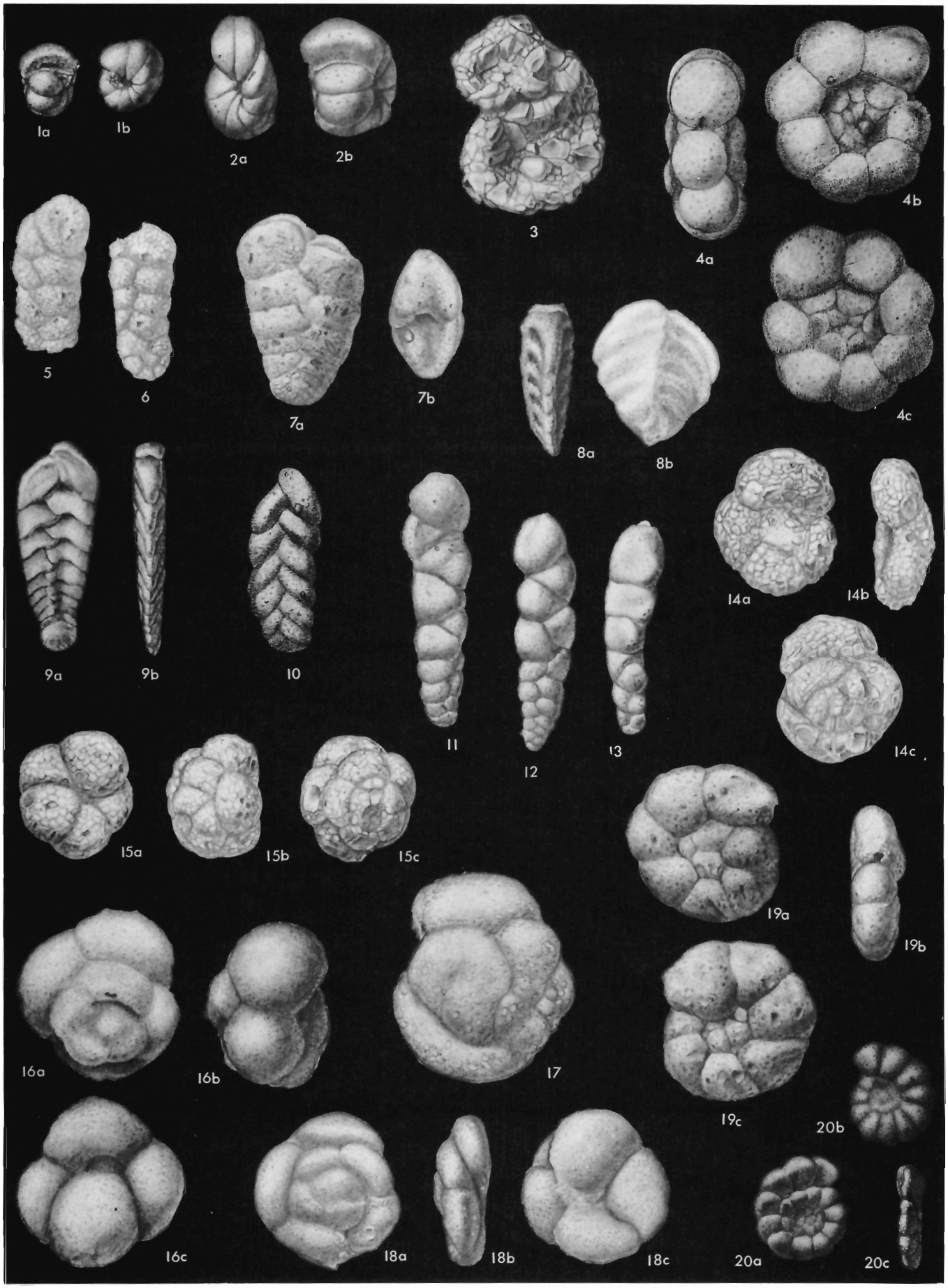
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PLATE VIII

Zones VIII to XVI, Campanian and Maestrichtian Lea Park, Bearpaw and Eastend Formations, Pembina Member of Vermilion River Formation, Riding Mountain Formation

Figures 1a, b: *Verneuilina* cf. *canadensis* Cushman, 1927. Figures specimen G.M.U.S. Pf 307, Central Canada Potash Co. mine shaft between 1,049 and 1,054 feet. x75 (66)

Figures 2a, b: *Verneuilinoides bearpawensis* (Wickenden), 1932. Hypotype G.M.U.S. Pf 308, Cominco Ltd. mine shaft between 660 and 669 feet. x75 (139)

Figures 3a, b: *Verneuilinoides* sp. Figured specimen G.M.U.S. Pf 309, Central Canada Potash Co. mine shaft between 381 and 386 feet. x75 (90)

Figures 4a, b, 5a, b: *Gaudryina bearpawensis* Wickenden, 1932. Hypotypes G.M.U.S. Pf 310 (fig. 4), APM Operators Elstow mine shaft between 630 and 640 feet; G.M.U.S. Pf 311 (fig. 5), Central Canada Potash Co. mine shaft between 557 and 562 feet. x35 (102)

Figures 6a, b: *Gaudryina rudita* Sandidge, 1932. Hypotype G.M.U.S. Pf 134, Imperial Oil Structure test hole 67 at 65 feet. x65 (157)

Figures 7a, b: *Gaudryina bentonensis* (Carman), 1929. Hypotype G.M.U.S. Pf 312, Central Canada Potash Co. mine shaft between 520 and 527 feet. x30 (74)

Figures 8, 9: *Pseudoclavulina* sp. Figured specimens G.M.U.S. Pf 313, 314, Central Canada Potash Co. mine shaft between 945 and 950 feet. x30. (75)

Figures 10, 11: *Pseudoclavulina(?) meidamos* Mello, 1969. Hypotypes G.M.U.S. Pf 315 (fig. 10), Central Canada Potash Co. mine shaft between 726 and 731 feet; G.M.U.S. Pf 172 (fig. 11), Imperial Oil Structure test hole 67 at 255 feet. x80 (100)

Figures 12, 13, 14: *Dorothia* cf. *smokyensis* Wall, 1960. Figured specimens G.M.U.S. Pf 316 (fig. 13), Saskatchewan Research Council test hole Rosefield at 69 feet; G.M.U.S. Pf 317 (fig. 12), 318 (fig. 14), an isolated knoll in extreme northwest corner of NW12-3-13W3 between elevations of 2,880 and 2,885 feet and 2,865 and 2,870 feet, respectively. x80 (141)

Figures 15a, b, 16a, b: *Dorothia* sp. Figured specimens G.M.U.S. Pf 319 (fig. 15), Central Canada Potash Co. mine shaft between 547 and 552 feet; G.M.U.S. Pf 320 (fig. 16), International Minerals and Chemical Corp. Gerald mine shaft between 198 and 207 feet. x50 (69)

Figures 17a-c: *Quinqueloculina sphaera* Nauss, 1947. Hypotype G.M.U.S. Pf 321, Cominco Ltd. mine shaft between 434 and 451 feet. x120 (85)

Figures 18a, b: *Cyclogyra involvens* (Reuss), 1851. Hypotype G.M.U.S. Pf 322, Central Canada Potash Co. mine shaft between 603 and 613 feet. x30 (101)

Figures 19, 20, 21: *Nodosaria proboscidea* Reuss, 1851. Hypotypes G.M.U.S. Pf 323 (fig. 19), Cominco Ltd. mine shaft between 621 and 629 feet; G.M.U.S. Pf 324 (fig. 20), APM Operators Elstow mine shaft between 585 and 590 feet; G.M.U.S. Pf 140 (fig. 21), Imperial Oil Structure test hole 392 at 282 feet. x40 (119)

Figure 22: *Nodosaria* sp. Figured specimen G.M.U.S. Pf 325, Central Canada Potash Co. mine shaft between 705 and 710 feet. x80 (107)

Figure 23: *Citharina strigillata* Reuss, 1845. Hypotype G.M.U.S. Pf 326, International Minerals and Chemical Corp. Gerald mine shaft between 253 and 261 feet. x30 (125)

Figure 24: *Citharina multicostata* (Cushman), 1930. Hypotype G.M.U.S. Pf 327, Saskatchewan Research Council test hole McEachern at 250 feet. x30 (154)

Figure 25: *Dentalina basiplanata* Cushman, 1938. Hypotype G.M.U.S. Pf 141, Imperial Oil Structure test hole 376 at 115 feet. x30 (96)

Figure 26: *Dentalina cylindroides* Reuss, 1860. Hypotype G.M.U.S. Pf. 142, Imperial Oil Structure test hole 388 at 425 feet. x30 (162)

Figure 27: *Nodosaria velascoensis* Cushman, 1926. Hypotype G.M.U.S. Pf 328, Saskatchewan Research Council test hole Rosefield at 78 feet. x50 (144)

Figure 28: *Dentalina lorneiana* d'Orbigny, 1839. Hypotype G.M.U.S. Pf 329, Central Canada Potash Co. mine shaft between 846 and 850 feet. x30 (88)

Figure 29: *Dentalina legumen* Reuss, 1845. Hypotype G.M.U.S. Pf 330, International Minerals and Chemical Corp. Gerald mine shaft between 225 and 228 feet. x30 (104)

Figures 30, 31: *Dentalina* sp. (=*Stilostomella pseudoscripta* North and Caldwell, 1964, p. 22, Pl. 4, figs. 2, 3). Figured specimens G.M.U.S. Pf 331, 332, Central Canada Potash Co. mine shaft between 736 and 741 feet. x55 (79)

Figure 32: *Dentalina* sp. Figured specimen G.M.U.S. Pf 143, Geological Survey of Canada cored borehole 61-1 at 500 feet. x30 (150)

Figure 33: *Oolina globulosa* (Montagu), 1803. Hypotype G.M.U.S. Pf 333, International Minerals and Chemical Corp. Gerald mine shaft between 225 and 228 feet. x35 (118)

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PLATE IX

Zones VIII to XVI, Campanian and Maestrichtian
Lea Park, Bearpaw and Eastend Formations, Pembina Member
of Vermilion River Formation, Riding Mountain Formation

Figures 1a, b, 2a, b: *Lenticulina modesta* (Bandy), 1951. Hypotypes G.M.U.S. Pf 334 (fig. 1), Cominco Ltd. mine shaft between 621 and 629 feet; G.M.U.S. Pf 144 (fig. 2), Imperial Oil Structure test hole 388 at 425 feet. x70 (106)

Figures 3, 4: *Lenticulina* cf. *carlsbadensis* Sliter, 1968. Figured specimens G.M.U.S. Pf 335, 336, Duval Corp. mine shaft between 380 and 385 feet. x70 (129)

Figure 5: *Lenticulina* sp. Figured specimen G.M.U.S. Pf 337, Central Canada Potash Co. mine shaft between 988 and 994 feet. x70 (87)

Figures 6a, b: *Lenticulina muensteri* (Roemer), 1839. Hypotype G.M.U.S. Pf 338, International Minerals and Chemical Corp. Gerald mine shaft between 253 and 261 feet. x70 (95)

Figures 7a, b: *Saracenaria pseudonavicula* Marie, 1941. Hypotype G.M.U.S. Pf 339, Saskatchewan Research Council test hole Rosefield at 90 feet. x50 (143)

Figures 8a, b: *Saracenaria acutauricularis* (Fichtel and Moll), 1798. Hypotype G.M.U.S. Pf 340, International Minerals and Chemical Corp. Gerald mine shaft between 228 and 236 feet. x75 (97)

Figures 9a, b: *Saracenaria triangularis* (d'Orbigny), 1839. Hypotype G.M.U.S. Pf 341, Central Canada Potash Co. mine shaft between 585 and 590 feet. x50 (105)

Figures 10, 11: *Marginulina bullata* Reuss, 1845. Hypotypes G.M.U.S. Pf 342 (fig. 10), Saskatchewan Research Council test hole McEachern at 172 feet; G.M.U.S. Pf 343 (fig. 11), Central Canada Potash Co. mine shaft between 978 and 983 feet. x70 (91)

Figure 12: *Marginulina subtilis* Brotzen, 1936. Hypotype G.M.U.S. Pf 344, International Minerals and Chemical Corp. Gerald mine shaft between 225 and 228 feet. x75 (127)

Figure 13: *Marginulinopsis chandlerensis* Tappan, 1960. Hypotype G.M.U.S. Pf 345, International Minerals and Chemical Corp. Gerald mine shaft between 210 and 216 feet. x75 (130)

Figures 14, 15 16: *Marginulinopsis curvisepta* (Cushman and Goudkoff), 1944. Hypotypes G.M.U.S. Pf 346 to 348, International Minerals and Chemical Corp. Gerald mine shaft between 261 and 269 feet. x30 (110)

Figure 17: *Pseudonodosaria appressa* (Loeblich and Tappan), 1955. Hypotype G.M.U.S. Pf 148, Imperial Oil Structure test hole 67 at 365 feet. x65 (166)

Figure 18: *Pseudonodosaria pygmaea* (Reuss), 1851. Hypotype G.M.U.S. Pf 349, International Minerals and Chemical Corp. Gerald mine shaft between 261 and 269 feet. x75 (121)

Figures 19a-c: *Guttulina adhaerens* (Olszewski), 1875. Hypotype G.M.U.S. Pf. 148, Imperial Oil Structure test hole 392 at 280 feet. x100 (117)

Figure 20: *Vaginulinopsis* sp. Figured specimen G.M.U.S. Pf 350, Sylvite of Canada no. 2 mine shaft between 108 and 117 feet. x35 (131)

Figure 21: *Vaginulinopsis schloenbachi* (Reuss), 1863. Hypotype G.M.U.S. Pf 351, Central Canada Potash Co. mine shaft between 746 and 749 feet. x75 (120)

Figure 22: *Ramulina pseudoaculeata* (Olsson), 1960. Hypotype G.M.U.S. Pf 150, Imperial Oil Structure test hole 67 at 295 feet. x100 (165)

Figures 23a, b: *Globulina* cf. *lacrima* Reuss, 1845. Figured specimen G.M.U.S. Pf 352, Central Canada Potash Co. mine shaft between 968 and 974 feet. x130 (89)

Figures 24a, b: *Pyrulina cylindroides* (Roemer), 1838. Hypotype G.M.U.S. Pf 353, Central Canada Potash Co. mine shaft between 474 and 479 feet. x130 (136)

Figures 25a, b: *Praebulimina prolixa* (Cushman and Parker), 1935. Hypotype G.M.U.S. Pf 152, Imperial Oil Structure test hole 392 at 292 feet. x100 (161)

Figures 26a, b: *Praebulimina venusae* (Nauss), 1947. Hypotype G.M.U.S. Pf 155, Geological Survey of Canada cored borehole 61-1 at 510 feet. x100 (112)

Figures 27, 28: *Praebulimina kickapooensis* (Cole), 1938. Hypotypes G.M.U.S. Pf 354, 355, Saskatchewan Research Council test hole McEachern at 220 feet. x40 (133)

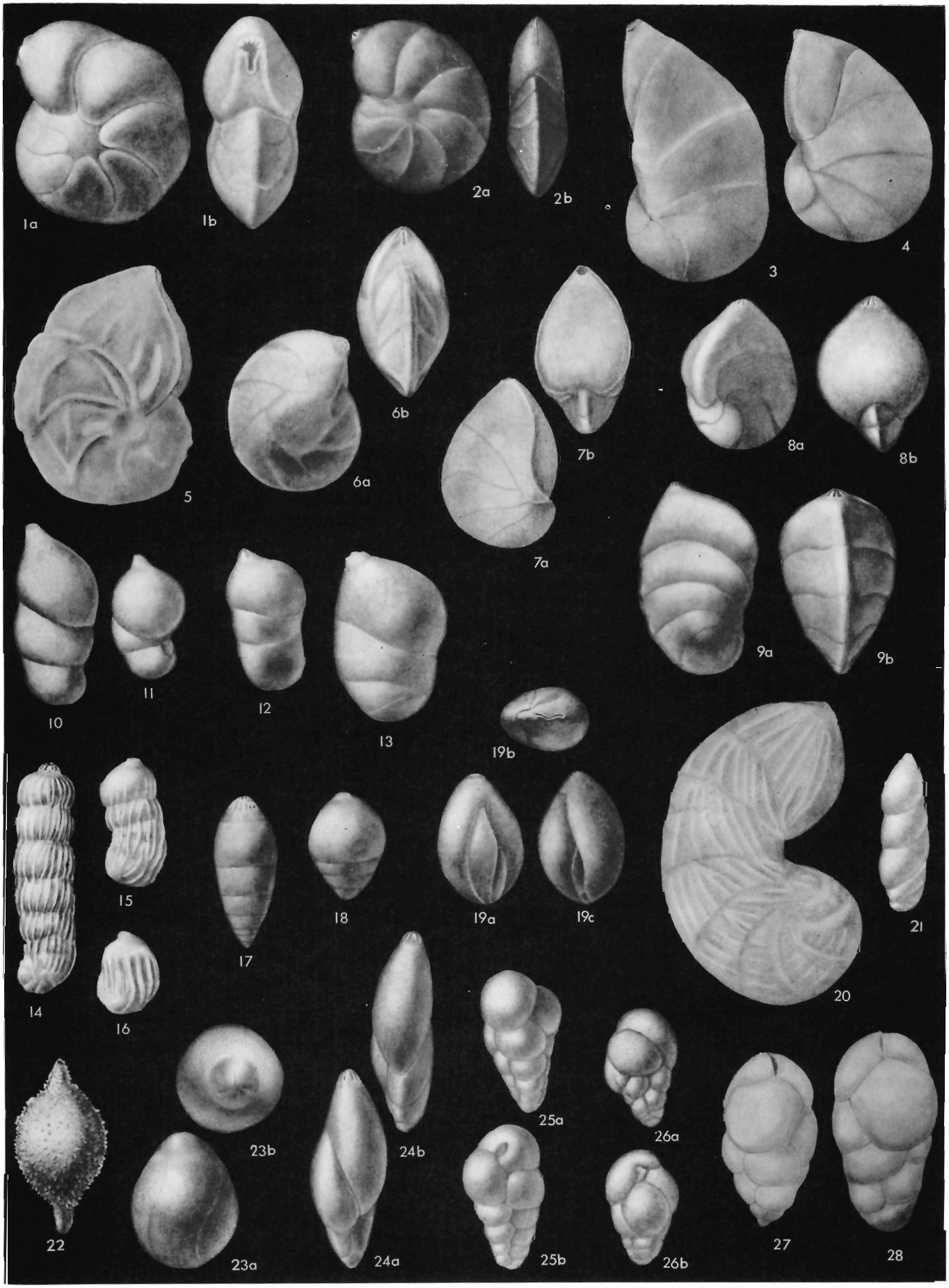
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PLATE X

Zones VIII to XVI, Campanian and Maestrichtian
Lea Park, Bearpaw and Eastend Formations, Pembina Member
of Vermilion River Formation, Riding Mountain Formation

Figures 1a, b, 2a, b: *Praebulimina carseyae* (Plummer), 1931. Hypotype G.M.U.S. Pf 356 (fig. 1), International Minerals and Chemical Corp. Gerald mine shaft between 191 and 198 feet; G.M.U.S. Pf 357 (fig. 2), Saskatchewan Research Council test hole Rosefield at 230 feet. x75 (111)

Figures 3a, b: *Praebulimina reussi* (Morrow), 1934. Hypotype G.M.U.S. Pf 153, Imperial Oil Structure test hole 374 at 305 feet. x100 (81)

Figures 4a, b: *Neobulimina canadensis* Cushman and Wickenden, 1928. Hypotype G.M.U.S. Pf 358, Imperial Oil Structure test hole 392 at 292 feet. x100 (82)

Figures 5a, b: *Bolivina elkensis* Nauss, 1947. Hypotype G.M.U.S. Pf 359, APM Operators Elstow mine shaft between 830 and 840 feet. x120 (115)

Figures 6a-c: *Serovaina* sp. Figured specimen G.M.U.S. Pf 163, Imperial Oil Structure test hole 393 at 235 feet. x100 (168)

Figures 7a-c: *Serovaina orbicella* (Bandy), 1951. Hypotype G.M.U.S. Pf 161, Imperial Oil Structure test hole 376 at 282 feet. x100 (99)

Figures 8a-c, 9a-c, 10: *Eoeponidella strombodes* Tappan, 1951. Hypotypes G.M.U.S. Pf 360 (fig. 8), Central Canada Potash Co. mine shaft between 465 and 469 feet; G.M.U.S. Pf 361 (fig. 9), 362 (fig. 10), Saskatchewan Research Council test hole Rosefield at 170 and 290 feet, respectively. x105 (134)

Figures 11a, b: *Eoeponidella linki* Wickenden, 1947. Hypotype G.M.U.S. Pf 157, Geological Survey of Canada cored borehole 61-1 at 510 feet. x100 (147)

Figures 12a-c: *Valvulineria lenticula* (Reuss), 1845. Hypotype G.M.U.S. Pf 159, Imperial Oil Structure test hole 393 at 275 feet. x110 (83)

Figures 13a, b: *Heterohelix globulosa* (Ehrenberg), 1840. Hypotype G.M.U.S. Pf 164, Imperial Oil Structure test hole 374 at 155 feet. x100 (37)

Figures 14, 15: *Bifarina* cf. *ballerina* Eicher and Worstell, 1970. Figured specimens G.M.U.S. Pf 363 (fig. 14), 364 (fig. 15), Duval Corp. mine shaft between 1,034 and 1,042 feet and 1,010 and 1,015 feet, respectively. x100 (64)

Figures 16a-c: *Globigerinelloides messinae* (Broenniman), 1952. Hypotype G.M.U.S. Pf 165, Imperial Oil Structure test hole 388 at 435 feet. x100 (51)

Figures 17a-c: *Archaeoglobigerina* cf. *blowi* Pessagno, 1967. Figured specimen G.M.U.S. Pf 166, Imperial Oil Structure test hole 392 at 292 feet. x100 (164)

Figures 18a-c: *Hedbergella* sp. Figured specimen G.M.U.S. Pf 365, International Minerals and Chemical Corp. Gerald mine shaft between 191 and 198 feet. x100 (132)

Figures 19a-c: *Cibicides* cf. *excavata* Brotzen, 1936. Figured specimen G.M.U.S. Pf 168, Imperial Oil Structure test hole 392 at 292 feet. x100 (113)

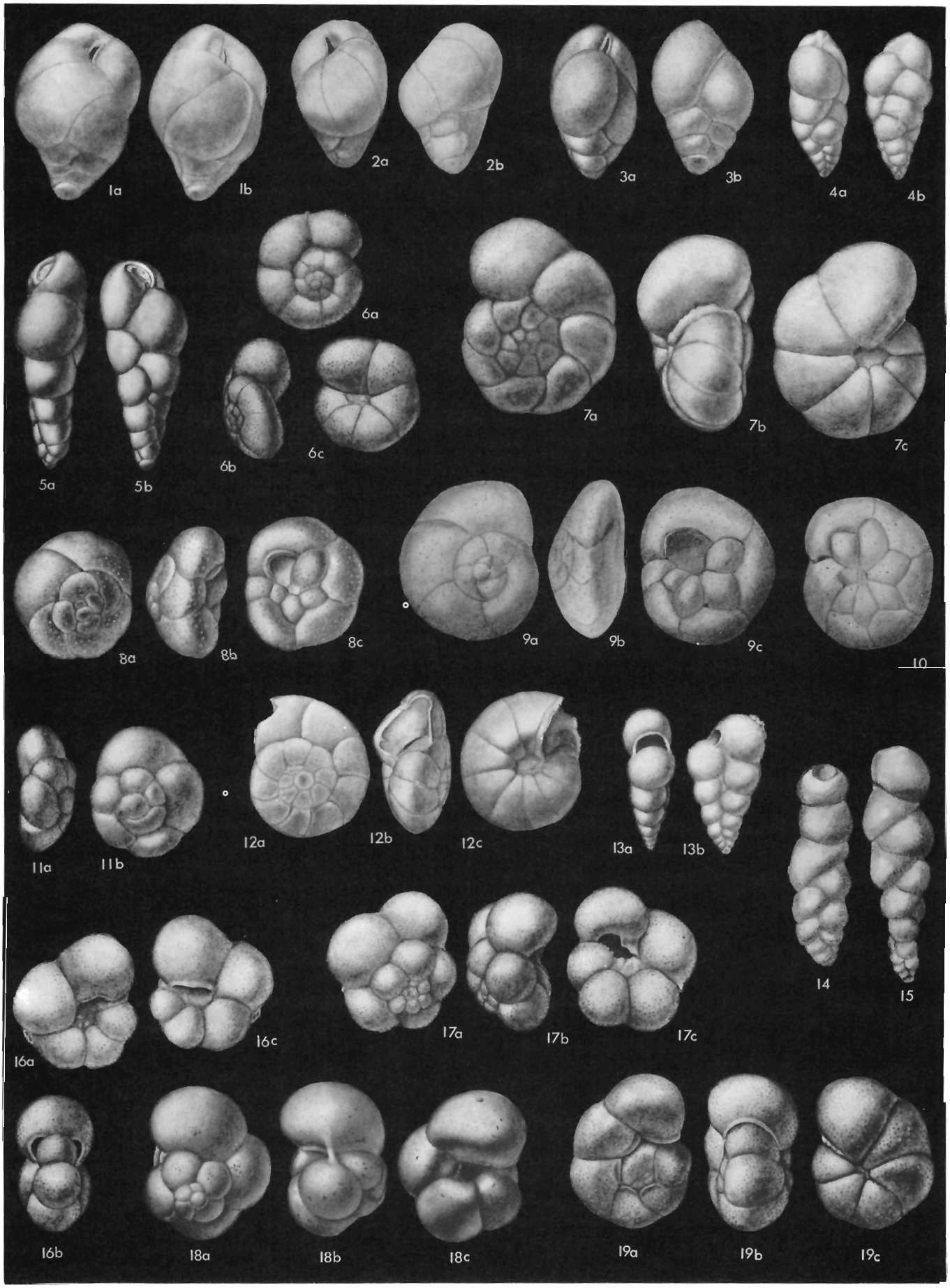
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PLATE XI

Zones VIII to XVI, Campanian and Maestrichtian
Lea Park, Bearpaw and Eastend Formations, Pembina Member
of Vermilion River Formation, Riding Mountain Formation

Figures 1a-c: *Cibicides* cf. *eriksdalensis* Brotzen, 1936. Figured specimen G.M.U.S. Pf 366, International Minerals and Chemical Corp. Gerald mine shaft between 295 and 303 feet. x80 (93)

Figures 2a-c: *Cibicides* cf. *voltziana* (d'Orbigny), 1840. Figured specimen G.M.U.S. Pf 167, Imperial Oil Structure test hole 67 at 355 feet. x100 (163)

Figures 3a-c, 4a-c: *Nonionella* cf. *austinana* Cushman, 1933. Figured specimens G.M.U.S. Pf 367 (fig. 3), small valley in SE7-1-10W3 between elevations of 2,615 and 2,620 feet; G.M.U.S. Pf 368 (fig. 4), Central Canada Potash Co. mine shaft between 465 and 469 feet. x75 (137)

Figures 5a-c: *Nonionella taylorensis* Hofker, 1955. Hypotype G.M.U.S. Pf 369, Cominco Ltd. mine shaft between 374 and 383 feet. x120. (138)

Figures 6a-c, 7a, b: *Quadrimorphina camerata* Brotzen, 1936. Hypotypes G.M.U.S. Pf 370 (fig. 6), APM Operators Elstow mine shaft between 250 and 260 feet; G.M.U.S. Pf 371 (fig. 7), Saskatchewan Research Council test hole McEachern at 290 feet. x120 (116)

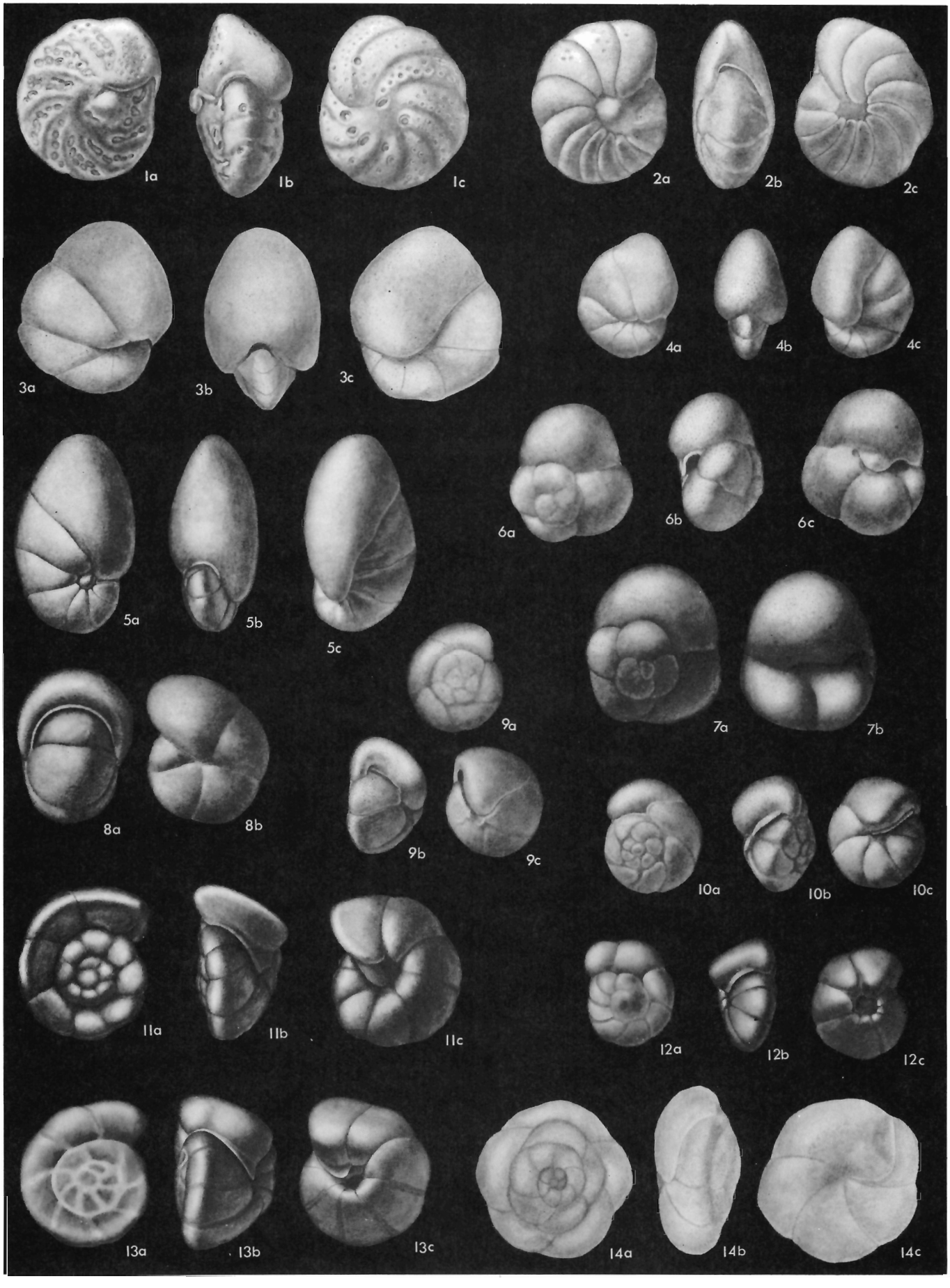
Figures 8a, b: *Pullenia cretacea* Cushman, 1936. Hypotype G.M.U.S. Pf 173, Imperial Oil Structure test hole 176 at 135 feet. x100 (114)

Figures 9a-c: *Alabamina australis australis* Belford, 1960. Hypotype G.M.U.S. Pf 372, International Minerals and Chemical Corp. Gerald mine shaft between 138 and 142 feet. x75 (94)

Figures 10a-c: *Alabamina* sp. Figured specimen G.M.U.S. Pf 373, Central Canada Potash Co. mine shaft between 945 and 950 feet. x75 (84)

Figures 11a-c, 12a-c, 13a-c: *Globorotalites* cf. *subconicus* (Morrow), 1934. Figured specimens G.M.U.S. Pf 374 (fig. 11), valley west of ridge in NW11-1-10W3 between elevations of 2,780 and 2,785 feet; G.M.U.S. Pf 375 (fig. 12), International Minerals and Chemical Corp. Gerald mine shaft between 253 and 261 feet; G.M.U.S. Pf 376 (fig. 13), Cominco Ltd. mine shaft between 621 and 629 feet. x80 (76)

Figures 14a-c: *Charltonina* sp. Figured specimen G.M.U.S. Pf 377, Saskatchewan Research Council test hole McEachern at 210 feet. x100 (155)


1a
1b
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2a
2b
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4a
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5a
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6a
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6c
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11a
11b
11c
12a
12b
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14a
14b
14c

PLATE XII

Zones VIII to XVI, Campanian and Maestrichtian
Lea Park, Bearpaw and Eastend Formations, Pembina Member
of Vermilion River Formation, Riding Mountain Formation

Figures 1a-c: *Gavelinella sandidgei* (Brotzen), 1936. Hypotype G.M.U.S. Pf 180, Imperial Oil Structure test hole 451 at 345 feet. x100 (148)

Figures 2a-c, 3: *Gavelinella talaria* (Nauss), 1947. Hypotypes G.M.U.S. Pf 178, 179, Imperial Oil Structure test hole 67 at 205 feet. x100 (98)

Figures 4a-c: *Gavelinella* cf. *turbinata* Martin, 1964. Figured specimen G.M.U.S. Pf 378, International Minerals and Chemical Corp. Gerald mine shaft between 138 and 142 feet. x80 (77)

Figures 5a-c, 6, 7a, b, 8a-c, 9: *Anomalinoides* sp. Figured specimens G.M.U.S. Pf 379 (fig. 5), Saskatchewan Research Council test hole McEachern at 190 feet; G.M.U.S. Pf 174 (fig. 7), 175 (fig. 9), Imperial Oil Structure test hole 385 at 295 feet; G.M.U.S. Pf 380 (fig. 8), International Minerals and Chemical Corp. Gerald mine shaft between 138 and 142 feet. x80 (78)

Figures 10a-c: *Lingulogavelinella* sp. Figured specimen G.M.U.S. Pf 381, Central Canada Potash Co. mine shaft between 957 and 964 feet. x130 (92)

Figures 11a-c: *Epistomina fax* Nauss, 1947. Hypotype G.M.U.S. Pf 182, Imperial Oil Structure test hole 67 at 295 feet. x100 (122)

Figures 12a, b: *?Islandiella* sp. Figured specimen G.M.U.S. Pf 382, Duval Corp. mine shaft between 435 and 440 feet. x100 (124)

Figures 13a, b: *Causcasina* cf. *vitrea* (Cushman and Parker), 1936. Figured specimen G.M.U.S. Pf 383, Saskatchewan Research Council test hole McEachern at 238 feet. x100 (153)

Figures 14a-c: *Reinholdella* sp. Figured specimen G.M.U.S. Pf 184, Imperial Oil Structure test hole 392 at 385 feet. x140 (160)

Figures 15a-c: *Ceratolamarckina* sp. Figured specimen G.M.U.S. Pf 384, APM Operators Elstow mine shaft between 580 and 590 feet. x100 (123)

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1c
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2c
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8b
8c
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10c
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11b
11c
12a
13a
13b
14a
14b
14c
12b
15a
15b
15c