Shorter Contributions to Paleontology and Stratigraphy

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Shorter Contributions to Paleontology and Stratigraphy

Edited by WILLIAM J. SANDO

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By BRUCE R. WARDLAW and RICHARD E. GRANT

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Conodont Biostratigraphy of the Permian Road Canyon Formation, Glass Mountains, Texas

By Bruce R. Wardlaw[1] *and* Richard E. Grant[2]

Abstract

The Road Canyon Formation is a shallow-water carbonate that was deposited on the seaward side of the narrow southern shelf of the Permian basin of West Texas. The conodont faunal succession of *Neogondolella idahoensis* to *Neogondolella serrata* generally occurs as a sharp transition in the lower part of the Road Canyon Formation. This faunal changeover is rapid and widespread. The Leonardian-Guadalupian Series boundary can be recognized as the level at which *N. idahoensis* is replaced by *N. serrata*.

INTRODUCTION

The unit now known as the Road Canyon Formation has undergone a slow but steady rise in stratigraphic status, beginning as a numbered member of a formation and ending up as the basis for a worldwide stage of the Permian. King (1931) established the unit as the "First Limestone member" of the Word Formation in the Glass Mountains of Texas, thus making it the lowermost stratigraphic unit of the Guadalupian Series. In keeping with a policy of naming the numbered units in the Glass Mountains, Cooper and Grant (1964) designated the "First Limestone member" as the Road Canyon Member of the Word Formation. Continued study of the brachiopods and the discovery of the ammonoid *Perrinites* in the Road Canyon led Cooper and Grant (1966) to the conclusion that the unit belonged more properly to the Leonardian Series and deserved formation status. However, the Road Canyon also contains the fusulinid *Parafusulina rothi*, long considered to be a strong indicator of a Guadalupian age (Wilde, 1975). Because fusulinid workers did not agree that the Road Canyon was Leonardian, the age and correlations of the unit became controversial. As the controversy revolved about its assignment to either the Leonardian or Wordian Stage, one solution was to remove the unit from both and create a new Roadian Stage (Furnish, 1966, 1973). This solution retained the Leonardian as a stage, rather than as a series, and placed the Roadian in the Lower Permian (Furnish, 1973).

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[1] U.S. Geological Survey, Reston, VA 22092.
[2] Smithsonian Institution, Washington, DC 20560.

Wilde (1975) noted that, if only the Road Canyon and the correlative Cutoff Shale of the Apache Mountains were involved, Furnish's suggestion would be a simple and satisfactory solution to the apparent Road Canyon age anomaly. Unfortunately, other units are correlated to all or part of the Road Canyon, and complexities abound. Moreover, recognizing the Roadian as a stage implies potential worldwide usage, and, with the present bipartite subdivision of the Permian, the question remains: "Does the Roadian Stage belong in the Lower or the Upper Permian?" In addition to the problems bearing directly on the Road Canyon Formation, the U.S. Geological Survey currently recognizes the Lower-Upper Permian boundary within the Guadalupian Series at the Word-Capitan boundary, a decision not accepted now by most Permian workers.

The Road Canyon Formation was deposited during a time of maximum worldwide transgression of Permian seas; consequently, many units elsewhere in the world are correlated to it. In Texas, the Road Canyon contains the youngest of the Permian brachiopod bioherms (of Cooper and Grant, 1972; small moundlike organic buildups formed, in part, by brachiopods). A detailed biostratigraphic study was undertaken to resolve some of the apparent age anomalies. Because brachiopods, ammonoids, and fusulinids have produced differing age interpretations, an independent test was conducted by detailed sampling and study of conodonts from carefully measured sections.

THE TYPE SECTION (RC I)

The Road Canyon Formation has been measured by several stratigraphers at several places (King, 1931, p. 71; Cooper and Grant, 1972, p. 67), and the sequence differs from place to place because of irregular carbonate buildups in the lower part of the unit (Cooper and Grant, 1972). The type section is located in the hill north of Leonard Mountain on the east side of Gilliland Canyon, due north of the Iron Mountain Ranch, slightly west of the 103°15′ meridian (Cooper and Grant, 1964; fig. 1). This section, a part of King's (1931) Section 17, was measured in detail by John Cys and published in a guidebook (Cys, 1981). We followed Cys' section, in which the units are identified by painted numbers, taking 7-kg samples about every 10 ft

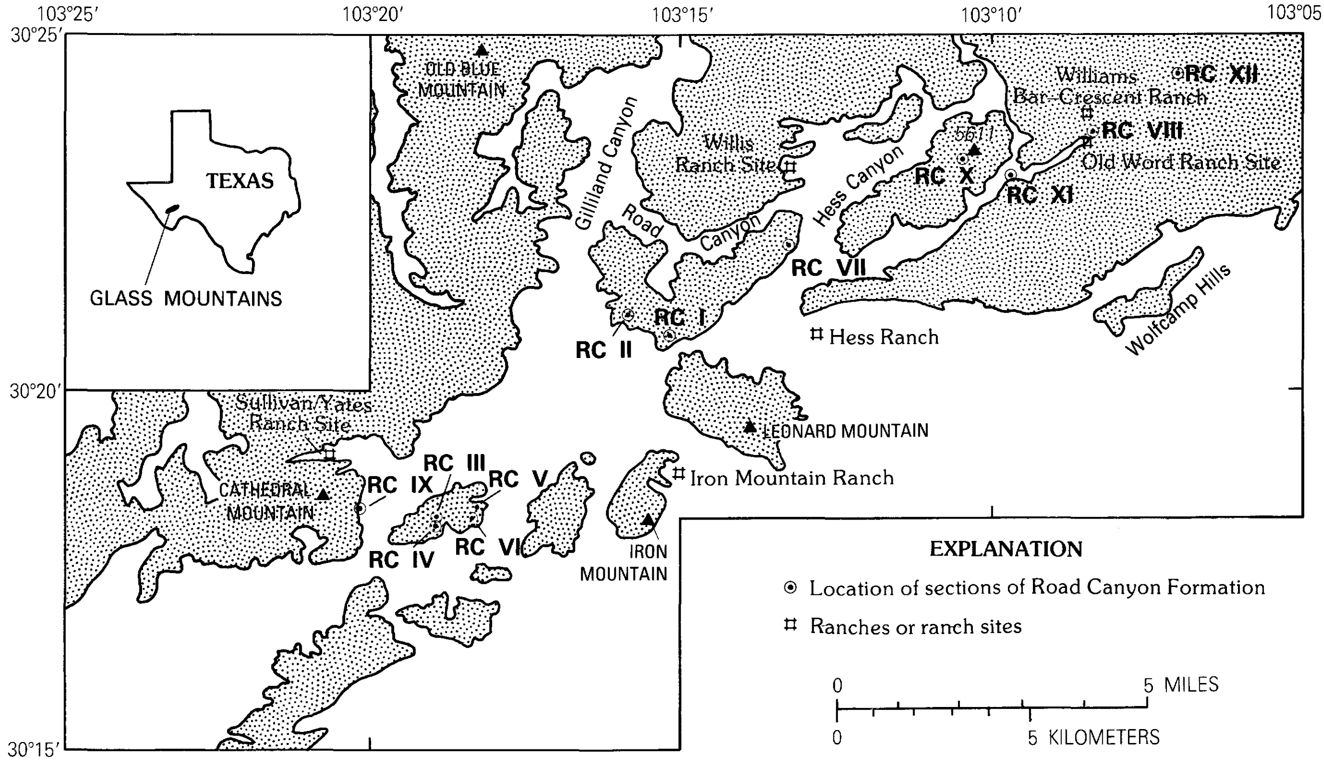

Figure 1. Southwestern portion of the Glass Mountains showing section locations of the Road Canyon Formation.

where beds were exposed and clearly in place. Samples were not collected from silty zones, known from experience to be unlikely sources of conodonts. We then measured 11 more sections, east and west of the type section, to document the sequence of conodonts within the Road Canyon Formation.

Thickness measurements of the Road Canyon vary among workers, even when the identical section is measured. Major variations stem from differing choices of unit boundaries. There is little doubt about the lower boundary at the type section because the limestone of the Road Canyon occurs abruptly above the thick sequence of siltstone and mudstone of the Cathedral Mountain Formation. However, King (1931), Cooper and Grant (1964), Cys (1981), and the present writers all differ as to the upper boundary.

King (1931, p. 139, Section 17) defined the "First Limestone member" strictly on the ledge-forming limestone, 125 ft thick, at or near the type section of the Road Canyon. If significant higher limestone ledges that have intervening siltstone are included, the total thickness is about 208 ft. Cooper and Grant (1964, p. 1588) picked the upper boundary where siltstone becomes predominant, and limestone is present only as thin lenses and stringers and report a total thickness of 228 ft. By using the same criteria at the same section, we measured 232 ft, a small margin of error. Cys (1981, p. 200) picked the upper boundary at the last stringer of limestone and reported a total thickness of 282 ft; there is an error of 10 ft because the painted numbers show 245 followed by 260, rather than 250. Cys' measurement of 272 ft differs from ours only in the choice of the upper boundary; up to 232 ft, we replicated his measurements exactly. Our usage corresponds to the definition of the Road Canyon in its type section (Cooper and Grant, 1964) despite Cooper and Grant's statement that it was a direct equivalent of King's "First Limestone member" of the Word Formation.

Just above a basal crinoidal layer in the type section, a 50-ft-thick fossiliferous conglomeratic unit contains many brachiopods, chert nodules and lenses, algal sheets, and, especially, sponges. Rugose corals and "reef" or bank-forming brachiopods of the families Richthofeniidae and Lyttoniidae are abundant. Some beds in the upper part of the conglomeratic unit have aligned clusters of *Parafusulina*. The conodonts in this part of the unit are *Neogondolella idahoensis*, *Hindeodus excavatus*, and *Xaniognathus abstractus*. The conglomeratic unit is capped by 18 ft of packstone that has chert stringers and abundant crinoid debris; a sample taken at the 52.5-ft level contains the conodont species *Neogondolella idahoensis* and *N. serrata*. Above this level, *N. serrata* totally replaces *N. idahoensis*. Somewhat higher, above a bedded chert interval that Cys (1981, p. 200) reports capped by a local diastem, is a huge massive organic carbonate buildup of the kind that Cooper and Grant (1972) called a bioherm. This buildup is overlain by a 40-ft-thick yellow siliceous siltstone, from which no samples were taken. The top of the formation is placed at the carbonate ledge above which the thin-bedded siltstone typical of the Word Formation begins. Cys' (1981) selection of the uppermost of several carbonate lenses in the siltstone provides an ambiguous boundary for a distinct and mappable unit.

SUPPLEMENTARY SECTIONS

Section RC II is farther west on the same hill that contains the type section (fig. 1), where the slope faces westward into Gilliland Canyon and just above a small clay slide produced by erosion and slumping of the siltstone and mudstone of the Cathedral Mountain Formation. In Section RC II, the Road Canyon Formation is thinner than the type section—only 164 ft thick. As in the nearby type section, the formation begins with conglomeratic limestone that contains clasts of the Cathedral Mountain lithology and sponges, corals, bryozoans, and various brachiopods including such reef or bank-forming types as richthofeniids and the lyttoniid *Coscinophora*. *Coscinophora*, the "beaded" lyttoniid, is distinctive and characteristic of the Road Canyon, although it also occurs lower in the section in the Skinner Ranch and Cathedral Mountain Formations. The occurrence of this brachiopod supported the argument for a Leonardian age of the Road Canyon Formation (Cooper and Grant, 1972, 1973). In Section RC II, the top of the Road Canyon is placed at the base of a 43-ft interval of yellow-orange, thin-bedded siltstone, although thin lenses of pelloidal packstone occur in the siltstone higher in the Word Formation.

One sample in Section RC II contains excellent examples of both *Neogondolella idahoensis* and *N. serrata*, thus revealing the point of transition between the two species. Samples below the 38-ft level contain only *N. idahoensis*, and those above that level contain only *N. serrata*. Beds immediately above and below that level are covered by soil; this cover prevents determination of the full extent of overlap in the ranges of the two species.

One other section (RC VII, 113 ft thick) was measured in the hill that contains the type section, but RC VII is much farther east on the Hess Ranch near the easternmost end of the hill (fig. 1). This section is near USNM (United States National Museum) locality 726c where large specimens of the ammonite *Perrinites*, a genus thought to be Leonardian in age (Miller and Furnish, 1957), were found by Cooper and Grant (1972, pl. 15, fig. 2). This occurrence of *Perrinites* provides one of the strong arguments for a Leonardian age of the Road Canyon Formation. The ostreiform lyttoniid brachiopod *Coscinophora* occurs throughout the formation at this section and forms large banks in the lower part.

A thin bed below the lowest *Coscinophora* bank contains the conodont *Neogondolella idahoensis*, and a *Coscinophora* bed above the massive bank contains *N. serrata*; the change in conodont species is inferred to occur within the lower massive bank, about 35 ft above the base of the formation.

Farther east (fig. 1) on the Appel Ranch (now the Williams Bar-Crescent Ranch), the Road Canyon is only 6 ft thick (Sections RC VIII and RC XII), but the changeover in species of *Neogondolella* is contained within this thin unit. Section RC VIII is a conglomeratic limestone and forms a ledge along the north side of the canyon just north of the old Word Ranch site. Section RC XII is a limestone ledge east of Split Tank above USNM localities 726y, 726w, 702a′, 702a, 702ent, 702un, 702low, 702inst, and 708u (Cooper and Grant, 1972, fig. 22). Transitional in thickness between these thin beds and the *Coscinophora*-rich beds of Section RC VII are Section RC X, located on the western side of hill 5611 near USNM locality 706, and Section RC XI, located on the knob that is USNM locality 702c.

Other sections are farther from the type section. Sections RC III and RC IV are in the hill, where a large carbonate buildup occurs, immediately west of Clay Slide (of King, 1931). Section RC IV is through the core of the carbonate mass, and Section RC III, which ends in a dipslope, is in the bedded flank deposits about 400 ft farther north. Only the conodont *Neogondolella serrata* is present throughout the formation at Sections RC III and RC IV. The change from *N. idahoensis* to *N. serrata* probably took place before carbonate deposition began; that is to say, in the siltstones and mudstones of the underlying Cathedral Mountain Formation.

Two sections were measured on the hill containing Clay Slide. Section RC V is on a subsidiary knob north of the slide itself, just above a smaller, grassier slump in the siltstones and mudstones of the Cathedral Mountain Formation. Both *N. idahoensis* and *N. serrata* were found in a sample taken 36.5 ft above the base of the formation. Section RC VI is immediately above Clay Slide, on the south flank of the hill. There *N. idahoensis* and *N. serrata* occur together at the 30-ft level, but a sample taken 50 ft above the base contained only *N. serrata* (along with species in other genera).

A very thick section (RC IX) was measured on the flank of Sullivan Peak. Here the Road Canyon is thin-bedded and silty and is apparently transitional to the deltaic facies that dominates farther to the northwest on Altuda (or Bird) Mountain (Davis and others, 1983). *N. idahoensis* was found at the base and about 90 ft above the base of the formation, and *N. serrata* and the brachiopod *Coscinophora* were found 246 ft above the base. The zone of transition between the two conodont species was not determined.

THE LEONARDIAN-GUADALUPIAN BOUNDARY

Species ranges of *Neogondolella* are the basis for conodont zonations of the Upper Permian and are important to zonation of the Lower Permian (Kozur, 1978). A relatively rapid changeover in species of *Neogondolella* occurs in the lower part of the Road Canyon Formation (this paper; Wardlaw and Grant, 1987). *N. idahoensis* is commonly found near the base, and *N. serrata* is found above the base. The species are separated by only a few feet or occur within the same sample in several sections, and the occurrences suggest that the changeover is rapid and overlap is small.

A similar relatively rapid changeover from *N. idahoensis* to forms identified as *N. serrata* was documented (Wardlaw and Collinson, 1984, 1986; Behnken and others, 1986) in the lower part of the Meade Peak Phosphatic Shale Member of the Phosphoria Formation in Wyoming and Idaho. Wardlaw and Collinson (1978, 1979) noted this change throughout the Great Basin-Rocky Mountain region. Behnken (1975) showed a similar sharp change in faunas from the Guadalupe Mountains, Texas, where *N. idahoensis* occurs through most of the Victorio Peak and Bone Spring Limestones to the uppermost part of these units, and *N. serrata* occurs at the base of the overlying Cutoff Shale (Behnken, 1975, figs. 5, 6). All of the units that contain the *N. idahoensis* to *N. serrata* succession have been correlated by other fossil groups (for example, brachiopods, Cooper and Grant, 1972, Wardlaw and Collinson, 1978; ammonoids, Furnish, 1973; fusulinids, Wilde and Todd, 1968) and are considered to be time correlatives. The biostratigraphic succession of *N. idahoensis* to *N. serrata* appears to be a widespread (at least over most of a continent) phenomenon that marks a nearly synchronous event.

We propose to define the Leonardian-Guadalupian boundary on the basis of the conodonts; the range of *N. idahoensis* is Leonardian, and the basal Guadalupian begins with the first occurrence of *N. serrata*. The Road Canyon Formation spans the boundary, and the concept of a Roadian Stage ceases to be useful. Consequently, we advocate abandonment of Roadian as a stage. This new boundary definition also conforms more closely to the original definition of the Leonard and Word Formations, upon which the stages are based, by including most of the Road Canyon (First Limestone member of the Word) in the Wordian (basal Guadalupian).

Our conclusions are twofold. (1) The Leonardian-Guadalupian boundary can be defined as the level at which *N. idahoensis* is replaced by *N. serrata*. (2) The concept of a Roadian Stage should be abandoned.

DEPOSITIONAL SETTING

King (1942, fig. 18) (fig. 2) presented the generally accepted Permian regional geography of West Texas. The

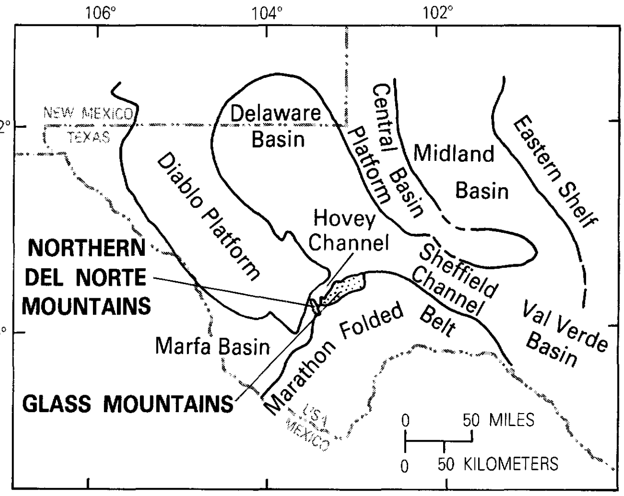

Figure 2. Paleogeographic setting of the Permian of West Texas (from King, 1942) showing location of the Glass and northern Del Norte Mountains.

Permian sediments of the Glass Mountains were deposited on the narrow southern shelf between the Marathon folded belt, which formed a land area to the south, and the Hovey channel and Delaware basin, which formed a relatively deep marine channel and basin to the north. King (1931), in his classic study of the Glass Mountains, noted that the distribution of sediments in Leonard and Word time showed that sandstone, conglomerate, and radiolarite were thickest near the uplifted area to the south and thinned to the north and northeast where they were replaced laterally by limestone (King, 1931, p. 89). This configuration is one of inner shelf clastics and outer shelf carbonates deposited on a very narrow shelf.

Cys (1981) differed with this interpretation radically by postulating a shelf boundary perpendicular to that of King's (Cys, 1981, fig. 11; Cys and Mazzullo, 1978, fig. 5) and by interpreting the Leonard sediments as being largely slope and basin deposits; radiolarites indicating basinal deposition and thin limestones to the northeast indicating shallow shelf deposition.

Cooper and Grant (1972) agreed with King's general shelf deposition for the Leonard and Word sediments. Further, they noted that, to the southwest in the Del Norte Mountains (fig. 2) in late Cathedral Mountain time, local uplift shed coarse conglomerates composed of well-rounded pebbles. Abundant transported ammonoids, fragmentary brachiopods, and numerous plant stem fragments indicated a shore zone (Cooper and Grant, 1972, p. 99). Rohr and others (1982) and Davis and others (1983) interpreted the conglomerates and related siltstones in the Del Norte Mountains to be nonmarine fluvial and marine deltaic deposits. Many delicate, well-preserved leaves are present in the siltstones (Mamay and others, 1984; Rohr and others, 1987), and these sediments are equivalent to the upper part of the Cathedral Mountain and Road Canyon Formations (Mamay and others, 1984; Wardlaw, unpub. conodont data).

The Road Canyon Formation is, perhaps, the most poorly known unit in the Glass Mountains. Although Cys (1981) did not interpret the depositional environment for the Road Canyon Formation in his Leonardian study, he showed it unconformably overlying "basinal" deposits of the Cathedral Mountain Formation.

The Road Canyon Formation represents widespread carbonate deposition during transgression, apparently related to a worldwide sea-level rise (Wardlaw, 1980). The Road Canyon interfingers with the deltaic and fluvial deposits of the Del Norte Mountains and probably represents relatively shallow-water deposition. In many places, the Road Canyon is conglomeratic both at its base and throughout much of its thickness. Clasts include irregular limestone and siltstone cobbles that are either penecontemporaneous or are derived from the underlying Cathedral Mountain Formation and flat siltstone cobbles that are derived from the underlying Cathedral Mountain Formation. In no instance do the limestone clasts and matrix yield different conodont faunas. The clasts indicate active reworking of underlying and penecontemporaneously lithified sediments and very little transport; we interpret this to be indicative of shallow-water deposition.

Carbonate buildups within the Permian of the Glass Mountains have been interpreted as being either in place or redeposited (see Cys and Mazzullo, 1978, and Flores, McMillan, and Watters, 1978). Sedimentologists with one prejudice or another seem to select buildups that tend to support their own interpretations. Each buildup should be analyzed separately; many are in place and many are not. The *Coscinophora* bank at RC IV, the flank deposits at RC III, and the *Coscinophora* banks at RC VII are in-place buildups. The more diversified buildups at the base of RC I and RC IX may be redeposited. In spite of a diversity of opinions, we feel that the depositional features indicate shallow-water deposition.

CONODONT BIOFACIES

Wardlaw and Collinson (1984) showed conodont biofacies distributions for the Permian Phosphoria Formation and related rocks in the Rocky Mountains. The Road Canyon Formation and the lower part of the Phosphoria Formation were deposited during the same time interval (see Behnken and others, 1986), and both formations contain the same conodont species. Generally, Wardlaw and Collinson found that *Hindeodus* and *Sweetina* characterize nearshore environments and *Neogondolella* and *Xaniognathus* characterize offshore environments. Following the distribution model of Wardlaw and Collinson (1984), the Road Canyon Formation would have been deposited in intermediate to offshore environments because there is a mixing of offshore and nearshore elements. *Neogondolella* and the complete seximembrate apparatus of *Xaniognathus* are better represented than the seximembrate apparatuses of *Hindeodus* and *Sweetina*, probably due to transportation of the latter. The distribution of conodonts supports offshore deposition.

Neostreptognathodus, which characterizes intermediate environments in the Phosphoria Formation, is very rare in the Road Canyon Formation. *Sweetognathus*, which is very rare in the Phosphoria, is also rare in the Road Canyon but is more common than *Neostreptognathodus*. Perhaps these differences can be explained by the narrow depositional shelf that must have existed during the deposition of the Road Canyon as compared to the broad depositional shelf that existed during the deposition of the Phosphoria. The narrow shelf would have compressed the biofacies, made differentiation of the biofacies less clear, increased overlap of the biofacies, and perhaps been unfavorable for such intermediate forms as *Neostreptognathodus*. Offshore shelf deposition for the Road Canyon Formation fits well with the original depositional interpretations of King (1931).

The ratios of number of samples containing *Hindeodus* or *Sweetina* or both to number of samples containing *Neogondolella* or *Xaniognathus* or both in each section (table 1) show that *Neogondolella* and *Xaniognathus* are generally more common than *Hindeodus* and *Sweetina*. Section RC IV is the exception, because *Hindeodus* and *Sweetina* are more common than *Neogondolella* and *Xaniognathus*, possibly indicating very shallow-water deposition. Also shown in table 1 is the percentage of samples that yielded conodonts in each section. Samples were generally of equal size and averaged 7 kg. Apparently, two factors severely limit the recoverability of conodonts. Sections RC

Table 1. HOS-NOX ratio and percent of samples that yielded conodonts from sections of the Road Canyon Formation

[HOS, number of samples containing *Hindeodus* or *Sweetina* or both; NOX, number of samples containing *Neogondolella* or *Xaniognathus* or both]

Section	Yield, in percent	HOS:NOX
RC I	88	0.64
RC II	90	.50
RC III	91	.86
RC IV	43	1.50
RC V	50	.50
RC VI	60	.67
RC VII	67	.67
RC VIII	80	1.00
RC IX	50	.33
RC X	100	1.00
RC XI	100	1.00
RC XII	100	1.00

V, RC VI, and RC IX (figs. 1, 3) are dominated by platy and thin-bedded, silty lime-mudstone and siltstones and have poor conodont recovery, reflecting a greater influx of silt during deposition. Sections RC IV and RC VII (figs. 3, 4) are primarily *Coscinophora*-dominated carbonate buildups that have poor conodont recovery, probably reflecting very shallow water deposition.

SYSTEMATICS

Upper Paleozoic conodont species have been shown by Merrill and Powell (1980) to be variably represented by apparatuses. Although most individuals apparently start with a full complement of elements (generally six different kinds), some lose elements during ontogeny. Ontogenetic loss appears to vary among species and between environments but seems most variable between genera. For all practical purposes, genera can be characterized as (1) those that retain a full complement of elements through life, (2) those that lose a few elements (rare), (3) those that commonly lose most of the elements but show rare cases of total retention, and (4) those that occur only as a single element and do not commonly have a full complement of elements. In our material, *Hindeodus*, *Sweetina*, and *Xaniognathus* appear to be represented by seximembrate apparatuses (type 1). *Neostreptognathodus* and *Sweetognathus* appear to be represented by rarely occurring seximembrate apparatuses; both are generally represented by just the Pa element (type 3). *Neogondolella* appears to be represented by a single element platform (Pa) apparatus that probably occurred as a pair (type 4). The occurrence of conodont species in our material is shown in table 2.

Genus *Hindeodus* Rexroad and Furnish, 1964

Type Species.—*Hindeodus cristulus* (Youngquist and Miller, 1949), Rexroad and Furnish, 1964, p. 671–672.

Hindeodus excavatus (Behnken)

Plate 2, figures 1–15; plate 3, figures 3–11

Ellisonia excavata Behnken, 1975, p. 302, pl. 1, figs. 9–14.

Anchignathodus minutus (Ellison) Behnken, 1975, p. 297, pl. 1, figs. 16–18.

Hindeodus excavatus (Behnken), Sweet, 1977a, p. 215, pl. 1, figs. 7–11; Wardlaw and Collinson, 1984, p. 268–269, pl. 5, figs. 1, 2, 4–9; 1986, p. 133, fig. 17:13–20.

Diagnosis.—A species of *Hindeodus* characterized by a Pa element with a large cusp; denticles increase in width anteriorly, except for the anteriormost, and generally decrease in height anteriorly, except for the posteriormost three, which may be of subequal height; cusp is much higher than denticles; and an Sa element with short lateral processes that are slightly upturned laterally and that bear for at least part of their length denticles of alternating (smaller versus larger) sizes (see Behnken, 1975, p. 299, pl. 1, fig. 12). The entire apparatus is illustrated in Sweet (1977a) and Wardlaw and Collinson (1984, 1986).

Discussion.—*H. excavatus* is commonly represented in our collections by the Pa element and a few broken ramiform elements. Of these, Sc elements are most common, followed by M, Sb, and Pb elements. No Sa element was recovered. We interpret the incomplete and broken condition of the elements of *Hindeodus* to indicate that the skeletal remains of this species were probably deposited in high-energy environments and, in part, were probably transported short distances. *H. excavatus* appears to be the only conodont common to the *Coscinophora* banks that we also interpret as being deposited in high-energy and very shallow water environments.

Genus *Neogondolella* Bender and Stoppel, 1965

Type Species.—*Neogondolella mombergensis* (Tatge), 1956, pl. 6, figs. 1, 2.

Neogondolella idahoensis (Youngquist, Hawley, and Miller)

Plate 1, figures 8, 9, 14–16, 19–22; plate 2, figures 20–22, 26–28; plate 4, figures 24, 25

Gondolella idahoensis Youngquist, Hawley, and Miller, 1951, p. 361, pl. 54, figs. 1–3, 14, 15; Clark and Ethington, 1962, p. 108, pl. 2, figs. 15, 16; Clark and Mosher, 1966, p. 388, pl. 47, figs. 9–12; Clark and Behnken, 1971, p. 431, fig. 9; Kozur, 1978, pl. 5, figs. 2, 15, 16.

Neogondolella idahoensis (Youngquist, Hawley, and Miller), Behnken, 1975, p. 306–307, pl. 1, figs. 28–30; Wang, 1978, p. 220–221, pl. 2, figs. 23–26; Igo, 1981, p. 38, pl. 1, figs. 11–13, 15, 16; Wardlaw and Collinson, 1984, p. 269, pl. 1, figs. 10, 11, 1986, p. 133, fig. 17:11, 12; Behnken, Wardlaw, and Stout, 1986, p. 179–181, fig. 4:12–16, 18.

Gondolella phosphoriensis Youngquist, Hawley, and Miller (part), 1951, p. 362, pl. 54, figs. 27, 28; Clark and Ethington, 1962, p. 108, pl. 2, figs. 17–18.

Diagnosis.—A species of *Neogondolella* characterized by a platform of moderate width that gradually narrows in the anterior two-thirds of its length and has a blunt, squared posterior platform margin; denticles that generally increase in size anteriorly, except for the anterior one or two; and well-developed furrows.

Discussion.—Our examples of *N. idahoensis* appear to be very similar to those previously described from the Phosphoria Formation in Idaho (Youngquist, Hawley, and Miller, 1951) and the Bone Spring Limestone in West Texas (Clark and Ethington, 1962; Behnken, 1975). This species seems reasonably consistent in morphology throughout its worldwide distribution.

Neogondolella serrata (Clark and Ethington)

Plate 1, figures 1–7, 10–13, 17, 18; plate 2, figures 16–19, 23–25

Gondolella serrata Clark and Ethington, 1962, p. 108–109, pl. 1, figs. 10, 11, 15, 19, pl. 2, figs. 1, 5, 8, 9, 11–14; Clark and Mosher, 1966, p. 389, pl. 47, figs. 13–15; Clark and Behnken, 1971, p. 431, pl. 1, fig. 10; Kozur, 1978, pl. 5, fig. 22.

Neogondolella serrata (Clark and Ethington), Wang, 1978, p. 222, pl. 2, figs. 6–8, 14, 15, 20–22; Clark and Behnken, 1979, p. 268–271, pl. 1, fig. 12; Wardlaw and Collinson, 1984, p. 270, pl. 2, figs. 13–15, 1986, p. 133–134, fig. 17:7, 8; Behnken, Wardlaw, and Stout, 1986, p. 183, fig. 5:20, 21, 23–31.

Neogondolella serrata serrata (Clark and Ethington), Behnken, 1975, p. 308, pl. 2, figs. 21–24, 37.

Diagnosis.—A species of *Neogondolella* characterized by a platform of moderate width, which is generally short and arched, narrows anterior to the middle, and has a round to blunt posterior platform margin; lateral platform margin variably serrated, commonly with at least three or more paired serrations on the anterior, tapering part of platform, rarely serrated for almost entire margin; a moderate cusp of circular cross section; denticles generally increasing in size anteriorly except commonly one or two smaller denticles along middle of carina and one or two denticles at anterior end; and moderately developed furrows.

Discussion.—*N. serrata* appears to show the earliest regional morphologic variation that begins provincialism in Permian neogondolellids. Specimens from Idaho can be distinguished from those of West Texas, although in both regions *N. serrata* appears to replace *N. idahoensis* with remarkable synchroneity. The younger species of *Neogondolella* in Idaho are completely different from those of West Texas, and so *N. serrata* appears to be the youngest species to show worldwide distribution; however, it presages the later trend of provincialism by developing distinct geographic morphotypes.

Genus *Neostreptognathodus* Clark, 1972

***Type Species.*—*Neostreptognathodus sulcoplicatus* (Youngquist, Hawley, and Miller, 1951), Clark, 1972, p. 155.**

Neostreptognathodus clinei Behnken

Plate 3, figure 2; plate 4, figure 23

Neostreptognathodus clinei Behnken, 1975, p. 309–310, pl. 2, figs. 15, 16; Sweet, 1977b, p. 237, pl. 1, fig. 4; Wardlaw and Collinson, 1984, p. 270, pl. 5, fig. 13; Behnken, Wardlaw, and Stout, 1986, p. 183, fig. 4:6, 7.

Diagnosis.—A species of *Neostreptognathodus* characterized by a platform element (Pa) with two carinae that are smooth or only faintly ornamented posteriorly by poorly developed nodes; carinae separated by a distinct groove; blade joins platform at center.

Discussion.—*N. clinei* is a rare long-ranging form that is found throughout North America in upper Leonardian and lower Guadalupian strata. A Pb element recovered from the lower part of the Word Formation, Section RC I, belongs to the apparatus of *Neostreptognathodus* (see Wardlaw and Collinson, 1986). It is tentatively assigned to *N. clinei* and illustrated (pl. 4, fig. 23) to compare with Pb elements of *Xaniognathus*.

Neostreptognathodus newelli Wardlaw and Collinson

Plate 3, figure 1

Neostreptognathodus newelli Wardlaw and Collinson, 1984, p. 270, pl. 5, figs. 10–12, 14–17; 1986, p. 135, fig. 18:4.

Neostreptognathodus sp. C. Baird, 1975, p. 41–42, pl. 1, figs. 11, 12; Wardlaw and Collinson, 1978, p. 1177; 1979, p. 152.

Diagnosis.—A species of *Neostreptognathodus* characterized by a platform element (Pa) with two carinae ornamented by 12 to 17 pairs of slightly oblique, low transverse ridges that are separated by a narrow but distinct median groove; posteriormost one to three ridges merge, terminating the median groove; blade joins platform slightly off center (in contrast to *N. sulcoplicatus* and *N. clinei*, which are centered) and has a poorly developed groove, which separates the blade from the closest carina.

Discussion.—*N. newelli* is rare in the Road Canyon Formation and occurs only in one sample. It is common throughout most of the Great Basin and northern Rocky Mountains and is diagnostic of the *Peniculauris bassi*-*Neostreptognathodus newelli* Zone (formerly *N.* sp. C) of Wardlaw and Collinson (1978) that they correlated with the upper part of the Road Canyon. This fortuitous recovery strengthens that correlation. The *Peniculauris bassi*-*Neostreptognathodus newelli* Zone is the near-shore time equivalent of the *Neogondolella serrata* Zone, found in the Phosphoria Formation in Idaho and in the Cutoff Shale and Road Canyon Formation in West Texas.

Genus *Sweetina* Wardlaw and Collinson, 1986

***Type Species.*—*Sweetina triticum* Wardlaw and Collinson, 1986, p. 135–138.**

Sweetina festiva (Bender and Stoppel)

Plate 3, figures 18–25

Lonchodina festiva Bender and Stoppel, 1965, p. 345–346, pl. 15, figs. 9, 10.

Stepanovites festiva (Bender and Stoppel), Kozur, 1975, p. 23; Kozur, 1978, pl. 5, fig. 29; Kozur and Movschovitsch, 1979, p. 119, pl. 4, figs. 1, 2; Wardlaw and Collinson, 1984, p. 271, pl. 3, figs. 4–11.

Sweetina festiva (Bender and Stoppel), Wardlaw and Collinson, 1986, p. 138.

Diagnosis.—A species of *Sweetina* characterized by a pastinate Pa element with a poorly developed lateral process and a dygyrate M element with a very large cusp; one to three anterolateral denticles, generally no posterolateral denticles; and a greatly flared triangular basal cavity that is directed posterolaterally.

Discussion.—The entire apparatus of *Sweetina triticum* is illustrated in Wardlaw and Collinson (1986, fig. 20). *S. festiva* appears to have an apparatus that is very similar to that of *S. triticum* except for the Pa element. The Pa element of *S. festiva* has a longer lateral process, a less prominent cusp, and a less well developed basal cavity than the Pa element of *S. triticum*. *S. festiva* is commonly represented in our material by broken ramiform and platform elements. Sc elements are the most common followed by fairly common M elements, and then by Pa, Sb, and Sa elements. No Pb elements were recovered. The occurrence of *S. festiva* is thought to be similar to that of *Hindeodus excavatus*.

Genus *Sweetognathus* Clark, 1972

***Type Species.—Sweetognathus whitei* (Rhoades, 1963), Clark, 1972, p. 155.**

Sweetognathus iranicus Kozur, Mostler, and Rahimi-Yazd

Plate 3, figures 12–17

Sweetognathus iranicus Kozur, Mostler, and Rahimi-Yazd, 1975, p. 9–10, pl. 4, figs. 1–10, pl. 5, figs. 2–4; Kozur, 1978, pl. 6, figs. 4, 7–10, 13, 15, 18.

Diagnosis.—A species of *Sweetognathus* characterized by a Pa element with rounded denticles or nodes that have pustulose microornament forming a row of small nodes connected by a thin pustulose longitudinal ridge that is laterally, not centrally, placed and a variably developed secondary row of nodes that generally through growth become larger than, and merge with, the primary row to form transverse ridges.

Discussion.—*S. iranicus* is rare in the Road Canyon Formation. A partial apparatus has been illustrated for *Sweetognathus* (Ritter, 1986). Our sparse material appears to be represented only by Pa elements. *S. iranicus* was originally described from the Abadeh section of central Iran (Kozur, Mostler, and Rahimi-Yazd, 1975). *S. iranicus* appears to range throughout the Road Canyon Formation and into the lower part of the Word Formation in West Texas.

Genus *Xaniognathus* Sweet, 1970

***Type Species.—Xaniognathus curvatus* Sweet, 1970, p. 262.**

Xaniognathus abstractus (Clark and Ethington)

Plate 4, figures 1–22

Subbryantodus abstractus Clark and Ethington, 1962, p. 112–113, pl. 1, figs. 16, 20, 21, pl. 2, fig. 2.

Lonchodina mulleri Tatge, Clark and Ethington, 1962, p. 110–111, pl. 1, fig. 4.

Apatognathus tribulosus Clark and Ethington, 1962, p. 107, pl. 1, figs. 3, 7, 13, 17.

Xaniognathus abstractus (Clark and Ethington), Behnken, 1975, p. 313, pl. 1, fig. 15; Wardlaw and Collinson, 1984, p. 271, pl. 2, figs. 1–12; Wardlaw and Collinson, 1986, p. 135, fig. 18:17–23; Behnken, Wardlaw, and Stout, 1986, p. 185, figs. 5:4–7, 6:7–20.

Xaniognathus sp. Malkowski and Szaniawski, 1976, p. 83, pl. 1, fig. 2.

Xaniognathus tortilis (Tatge), Behnken, 1975, p. 313, pl. 2, fig. 13.

Sweetocristatus arcticus Szaniawski, 1979, p. 254, pl. 9, figs. 1–7.

Ozarkodina tortilis Tatge, Clark and Behnken, 1971, p. 433, pl. 2, fig. 8.

{A complete element synonymy is given in Behnken, Wardlaw, and Stout, 1986}

Diagnosis.—A species of *Xaniognathus* characterized by the delicate, greatly recurved Sb (*Apatognathus tribulosus*) element with large cusp and low denticles on one process and a large variable Pb element with a twisted posterior process commonly bearing five to eight denticles, rare specimens have more denticles; and an anterior process commonly bearing 7 to 11 or more denticles, with midlateral rib for most of its length; anterior process variable, robust to relatively thin and delicate. The entire apparatus is illustrated in Wardlaw and Collinson (1984, pl. 2; 1986, fig. 18) and Behnken, Wardlaw, and Stout (1986, fig. 6).

Discussion.—*X. abstractus* is abundant and well preserved in many of our samples. Sb, M, and Pa elements are the most commonly recognized, although many undetermined fragments probably represent Sc elements. Sa and Pb elements are slightly less common. The complete representation and excellent preservation of *Xaniognathus* indicate that it is a truly indigenous faunal element.

Table 2. Occurrence of conodont species in samples of the Road Canyon Formation sections that include underlying and overlying units

[1, *Neogondolella idahoensis*; 2, *Neogondolella serrata*; 3, *Hindeodus excavatus*; 4, *Sweetina festiva*; 5, *Sweetognathus iranicus*; 6, *Xaniognathus abstractus*; 7, *Neostreptognathodus clinei*; 8, *Neostreptognathodus newelli*; 9, *Neostreptognathodus sulcoplicatus*]

Sample	Footage	Conodonts								
		1	2	3	4	5	6	7	8	9
RC I										
W81161	0.5	X	—	—	X	—	X	—	—	—
W81162	7.5	X	—	—	X	X	—	—	—	—
W81163	26.0	—	—	—	X	—	X	—	—	—
W81164	40.0	—	—	—	—	—	—	—	—	—
W81165	52.5	X	X	X	X	X	—	—	—	—
W81166	68.0	—	X	—	X	—	—	—	—	—
W81167	77.5	—	—	—	—	—	—	—	—	—
W81168	86.0	—	X	—	—	X	—	—	—	—
W81169	110.0	—	X	—	X	—	X	—	—	—
W81170	155.0	—	X	—	—	—	—	—	—	—
W81171	170.0	—	X	—	—	—	X	—	—	—
W81172	192.0	—	X	—	—	—	X	—	—	—
W81173	212.0	—	—	—	—	—	X	—	—	—
W81174	229.0	—	X	X	—	—	X	—	—	—
W81175	250.0	—	X	X	—	—	X	—	—	—
W81176	272.0	—	X	X	X	X	X	X	—	—
RC II										
W81179	−61.0	X	—	X	X	—	X	—	—	—
W81189	.0	—	—	X	—	—	—	—	—	—
W81188	12.0	—	—	—	—	—	—	—	—	—
W81187	38.0	X	X	—	—	—	X	—	—	—
W81186	61.0	—	X	—	X	—	—	—	—	—
W81185	109.0	—	X	—	—	—	X	—	—	—
W81184	129.0	—	—	—	—	—	X	—	—	—
W81183	144.0	—	X	—	—	—	—	—	—	—
W81182	164.0	—	X	X	—	—	—	—	—	—
W81181	211.0	—	X	X	X	—	—	—	—	—
W81180	234.0	—	X	—	—	—	X	—	—	—
RC III										
W81191	1.0	—	X	X	—	—	X	—	—	—
W8239	2.5	—	—	—	—	X	—	—	—	—
W8240	4.0	—	X	—	—	—	X	—	—	—
W81192	17.0	—	—	X	—	—	—	—	—	—
W81193	28.0	—	—	—	—	—	—	—	—	—
W81194	32.0	—	X	X	—	—	X	—	—	—
W81195	39.0	—	—	X	—	—	—	—	—	—
W81196	45.0	—	X	X	X	—	X	—	—	—
W81197	60.0	—	X	X	—	—	X	—	—	—
W81198	74.0	—	—	—	—	—	X	—	—	—
W81199	86.0	—	—	—	—	—	X	—	—	—
RC IV										
W81200	2.5	—	X	X	—	X	—	—	—	—
W8241	3.0	—	X	X	—	X	—	—	—	—
W81201	17.0	—	—	—	—	—	—	—	—	—
W81202	39.0	—	—	—	—	—	—	—	—	—
W81203	67.0	—	—	X	—	—	—	—	—	—
W81204	80.0	—	—	—	—	—	—	—	—	—
W81205	98.0	—	—	—	—	—	—	—	—	—
RC V										
W81209	4.5	—	—	X	—	—	X	—	—	—
W81208	36.5	X	X	—	—	—	—	—	—	—
W81207	49.0	—	—	—	—	—	—	—	—	—
W81206	77.0	—	—	—	—	—	—	—	—	—
RC VI										
W81214	5.0	—	—	—	—	—	—	—	—	—
W81213	30.0	X	X	X	—	—	—	—	—	—

Table 2. Occurrence of conodont species in samples of the Road Canyon Formation sections that include underlying and overlying units—Continued

[1, *Neogondolella idahoensis*; 2, *Neogondolella serrata*; 3, *Hindeodus excavatus*; 4, *Sweetina festiva*; 5, *Sweetognathus iranicus*; 6, *Xaniognathus abstractus*; 7, *Neostreptognathodus clinei*; 8, *Neostreptognathodus newelli*; 9, *Neostreptognathodus sulcoplicatus*]

Sample	Footage	Conodonts								
		1	2	3	4	5	6	7	8	9
W81212	50.5	—	X	—	—	—	X	—	—	—
W81211	72.0	—	—	—	—	—	—	—	—	—
W81210	87.0	—	—	X	—	—	X	—	—	—
RC VII										
W81217	1.5	X	—	X	X	—	X	—	—	—
W81218	13.5	X	—	—	—	—	X	—	—	—
W81219	18.0	—	—	—	—	—	—	—	—	—
W827	19.0	—	—	—	—	—	—	—	—	—
W828	27.0	—	—	X	—	—	—	—	—	—
W81220	35.0	—	—	—	—	—	—	—	—	—
W829	35.0	—	—	X	—	—	—	—	—	—
W81221	49.0	—	—	—	—	—	—	—	—	—
W81222	70.0	—	X	—	—	—	—	—	—	—
W81223	89.0	—	X	—	—	—	—	—	—	—
W81224	112.0	—	X	—	—	—	—	—	—	—
W81215	130.0	—	X	X	X	—	X	—	—	—
RC VIII										
W81226	1.5	—	—	X	X	—	—	—	—	—
W81227	26.0	X	—	X	X	—	X	—	—	—
W8210	27.5	—	—	X	—	—	X	—	—	—
W8211	28.5	—	—	—	—	—	—	—	—	—
W8212	29.5	X	—	—	X	—	X	—	—	—
W81228	30.5	—	X	X	X	—	X	—	X	—
W81229	39.0	—	—	—	—	—	—	—	—	—
W81230	59.0	—	—	—	—	—	—	—	—	—
RC IX										
W81244	0.0	X	—	—	—	—	X	—	—	—
W81243	5.0	X	—	—	—	—	X	X	—	—
W81241	74.0	X	—	—	—	—	—	—	—	—
W8242	95.0	—	—	—	—	—	—	—	—	—
W8244	114.0	—	—	—	—	—	—	—	—	—
W8243	139.5	—	—	—	—	—	—	—	—	—
W81242	144.0	—	—	—	—	—	—	—	—	—
W8245	160.0	—	—	—	—	—	—	—	—	—
W8246	195.0	—	—	—	—	—	—	—	—	—
W81236	246.0	—	X	X	—	—	X	—	—	—
W81237	251.5	—	X	X	—	—	—	—	—	—
W81238	272.5	—	X	—	—	—	—	—	—	—
W81239	281.5	—	X	X	—	—	X	—	—	—
W81240	291.0	—	X	—	—	—	X	—	—	—
RC X										
W877	1.0	—	X	X	X	—	X	—	—	—
W878	29.0	—	X	X	—	—	—	—	—	—
W879	52.0	—	X	X	—	—	X	—	—	—
RC XI										
W81225	0.5	X	X	X	X	—	X	—	X	X
W876	3.5	—	X	X	X	X	X	—	—	—
702C	5.5	—	X	X	—	—	X	—	—	—
RC XII										
W8471	0.5	X	—	X	X	X	X	—	—	X[1]
W8472	5.5	—	X	X	X	X	—	—	—	—

[1]Poor specimen of *Neostreptognathodus sulcoplicatus*.

MEASURED SECTIONS

Section RC I (fig. 4)

Type section of the Road Canyon Formation. Hill north of Leonard Mountain, east side of Gilliland Canyon, west of 103°15′ meridian. Compare with sections by Cooper and Grant (1964) and Cys (1981) at the same locality.

	Thickness (ft)	Cumulative (ft)
Word Formation		
11. Siltstone, yellow, siliceous with thin- to medium-bedded limestone stringers; conodont sample at 272 ft	20	272
10. Siltstone, yellow, siliceous, capped by 3-ft bed of skeletal packstone with abundant brachiopod spines, brachiopods, echinoids, ammonoids, corals, bryozoans, sponges, aligned fusulinids; conodont sample at 250 ft	20	252
Road Canyon Formation		
9. Limestone, gray, rubbly weathering, medium- to thick-bedded, silty peloid packstone with some chert, most peloids are algal coated; aligned fusulinids, corals, snails, brachiopods (*Collemataria* at 230 ft); conodont samples at 229, 212, 192 ft	42	232
8. Siltstone, yellow, siliceous, thin-bedded, thin lenses of medium-brownish-gray, silty wackestone with *Parafusulina*; conodont sample at 170 ft.........................	23	190
7. Limestone ledge, medium-brownish-gray skeletal packstone with fossil bed at 160 ft containing brachiopods (*Collemataria*, *Derbyia*, *Neophricadothyris*, *Neospirifer*, *Megousia*), sponges, corals, echinoid debris, sponge spicules; conodont sample at 155 ft	13	167
6. Siltstone, yellow, siliceous, shaly-bedded with thin beds of peloid packstone........	27	154
5. Siltstone with thin beds of peloid packstone changing upward to packstone with thin stringers of siltstone; fusulinids, crinoid columnals; conodont sample at 110 ft.....	40	127
4. Limestone, massive organic carbonate buildup, medium-brownish-gray wackestone; sponges, corals, bryozoans, brachiopods (*Composita*, *Coscinophora*, *Derbyia*, *Meekella*, *Peniculauris*); conodont sample at 86 ft; barren sample at 77.5 ft	12	87
3. Chert, bedded, compressed by overlying carbonate, medium-brownish-gray, weathers light brown, spiculitic, top is Cys' "local diastem"...............................	7	75
2. Limestone, brownish-medium-gray packstone with rusty chert stringers of skeletal hash, medium-bedded; conodont samples at 68, 52.5 ft................................	18	68
1. Conglomeratic limestone, medium-brownish-gray, weathers orange to brown, packstone to wackestone, chert as boulders and stringers, clasts from pebble to boulder size, limestone and chert; fossils mostly sponges and corals, also crinoid columnals, brachiopods (*Compressoproductus*, *Coscinophora*, *Derbyia*, *Dyoros*, *Meekella*, *Neophricadothyris*, *Neospirifer*, *Peniculauris*, richthofeniids); base is 0.5 ft of medium-orangish-gray crinoidal packstone; conodont samples at 26, 7.5, 0.5 ft; barren sample at 40 ft	50	50

Section RC II (fig. 3)

Measurements made on the southwest-facing side of Hill 5779 (the same hill that contains the type section on its south side), above an eroded scar of Cathedral Mountain siltstone and mudstone that forms a small clay slide.

	Thickness (ft)	Cumulative (ft)
Word Formation		
9. Siltstone, yellow-orange, thin-bedded, very localized lenses and beds of peloid packstone up to 4 ft thick appear to be channel deposits; corals and other fossils; conodont sample at 234, 211 ft....................	37	244
8. Siltstone, yellow-orange, thin-bedded, minor amounts of limestone, partly covered	43	207
Road Canyon Formation		
7. Limestone, light-brownish-gray, coarse-grained peloid packstone with abundant corals, crinoid debris, few brachiopods (*Meekella*, *Orthotichia*), a massive carbonate buildup that becomes bedded and silty toward top; conodont samples at 164, 144, 129, 109 ft	60	164
6. Covered, probably thin-bedded siltstone.....	40	104
5. Limestone, medium-brownish-gray peloid skeletal packstone with rusty brown silicified "skins" on bedding planes and joints; conodont sample at 61 ft................	17	64
4. Covered, probably shaly siltstone...........	8	47
3. Limestone, medium-olive-gray, fine-grained skeletal packstone with corals, bivalves, crinoid columnals, richthofeniid brachiopods, chert nodules and stringers; conodont sample at 38 ft..........................	2	39
2. Covered, gentle slope probably hides thin-bedded shaly siltstone....................	21	37
1. Conglomeratic limestone, olive-gray skeletal packstone, thick-bedded with yellow siltstone pebbles and platelets of Cathedral Mountain Formation; corals, sponges, fusulinids, bryozoans, brachiopods (*Coscinophora*, richthofeniids); conodont sample at 0 ft; barren sample at 12 ft.................	16	16
Cathedral Mountain Formation		
0. Mudstone and siltstone, easily eroded, partly covered, few beds of silty skeletal wackestone with brachiopods; conodont sample 61 ft below base of Road Canyon Formation.		

Section RC III (fig. 3)

Hill west of hill containing Clay Slide; bedded flank deposits about 400 ft north of core of massive carbonate buildup.

	Thickness (ft)	Cumulative (ft)
Road Canyon Formation		
8. Limestone, medium-gray, sandy, skeletal lime		

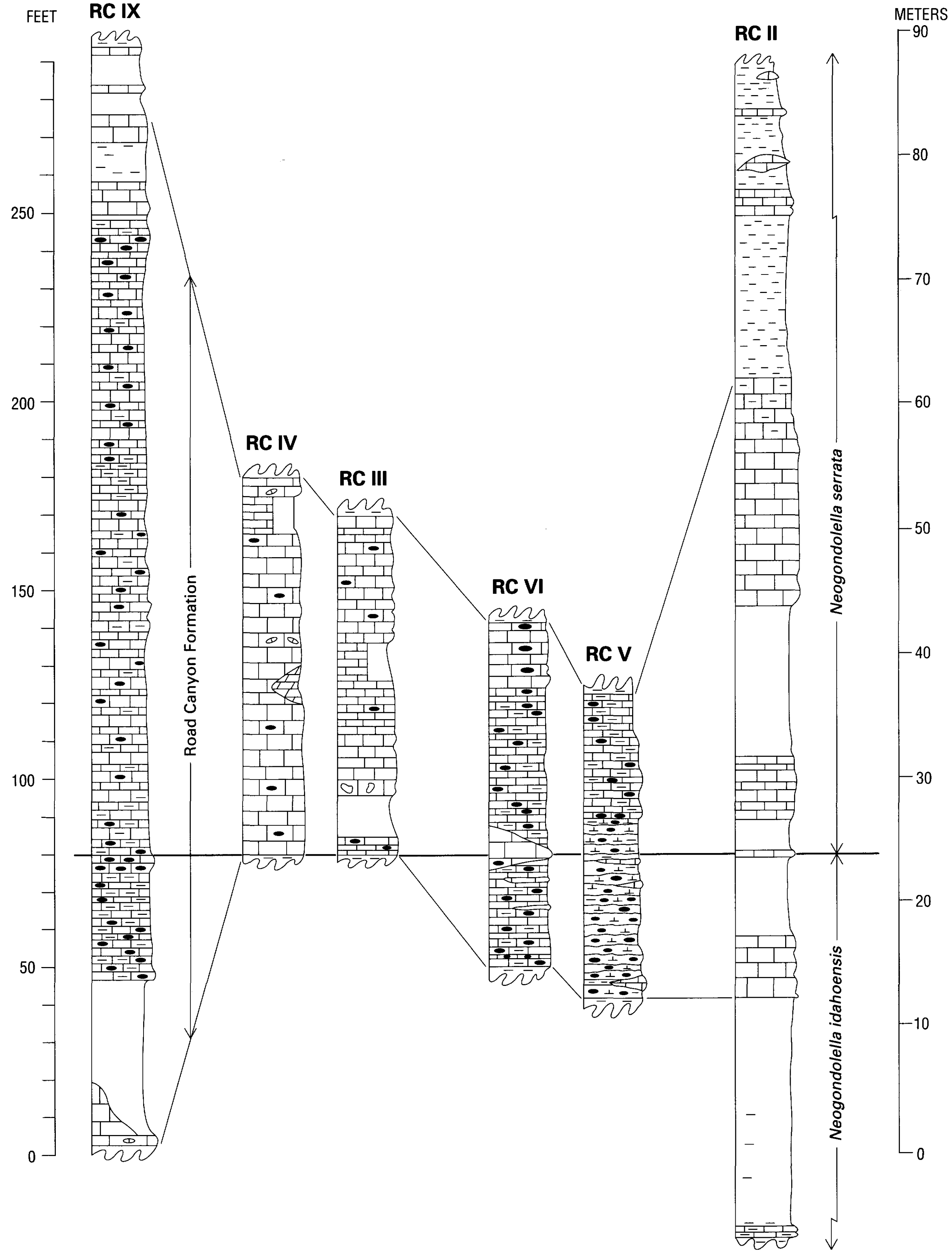

Figure 3. Columnar sections of the Road Canyon Formation, Sections RC IX, RC IV, RC III, RC VI, RC V, and RC II. Lithic symbols as in figure 4.

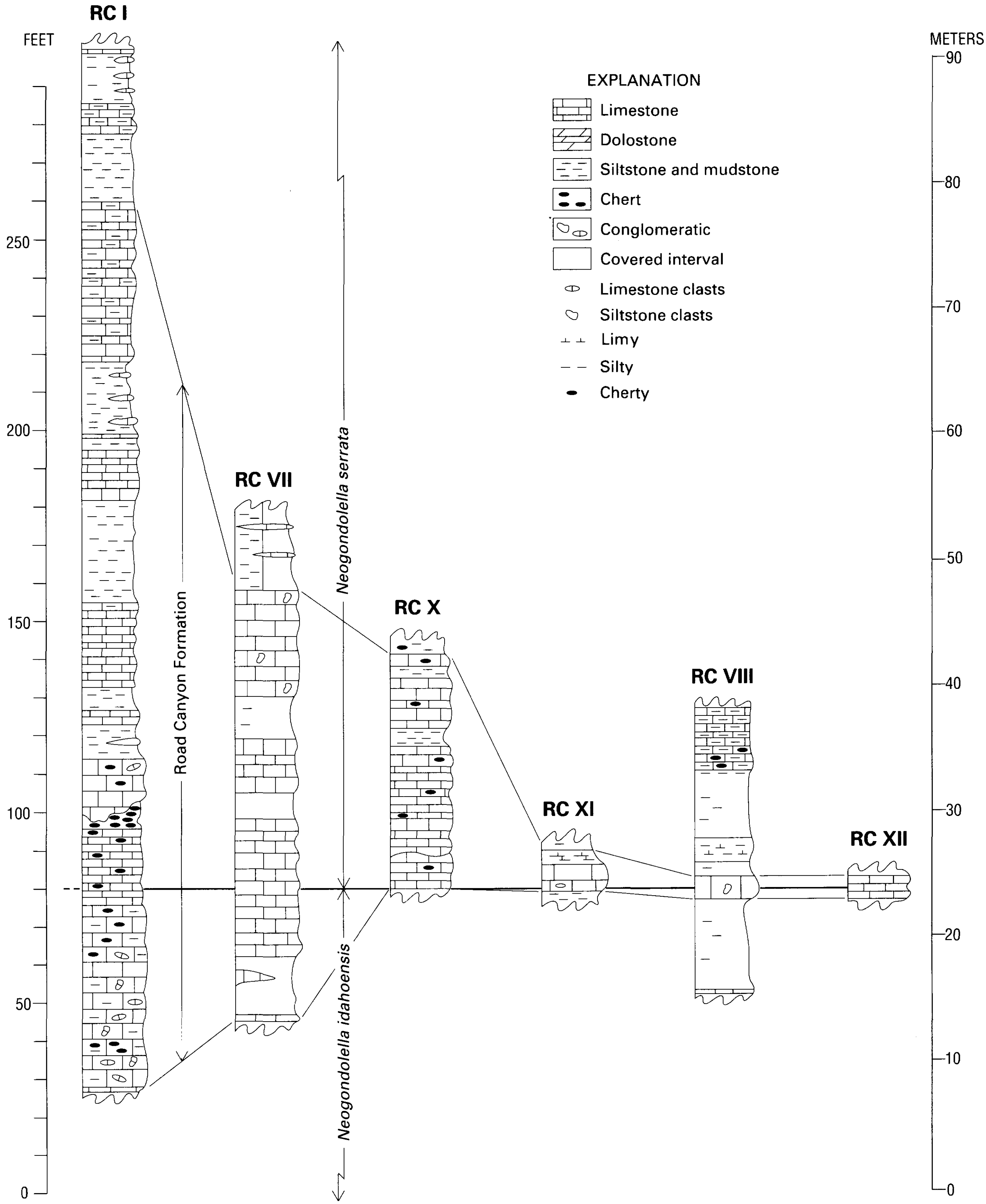

Figure 4. Columnar sections of the Road Canyon Formation, Sections RC I, RC VII, RC X, RC XI, RC VIII, and RC XII. RC I is the type section of the Road Canyon Formation. Datum is the sharp changeover from *Neogondolella idahoensis* to *N. serrata*.

	Thickness (ft)	Cumulative (ft)
mudstone to wackestone with chert nodules and beds; abundant corals, bryozoans, crinoid debris, few sponges, fusulinids in swirls, brachiopods (*Derbyia*, *Meekella*); conodont samples at 86, 74, 60 ft	34	90
7. Limestone, medium-gray lime mudstone with chert lenses, medium-bedded, partly covered	10	56
6. Limestone, medium-gray lime mudstone, medium-bedded with brachiopods (*Neospirifer*, abundant *Megousia*); conodont sample at 45 ft	6.5	46
5. Limestone, orange-brown-gray, silty skeletal wackestone to packstone, bryozoans, crinoid columnals, brachiopods (*Hustedia*), chert nodules (not beds); represents a thin finger of the carbonate buildup into flank deposits; conodont sample at 39 ft	1.5	39.5
4. Limestone, medium-gray sandy lime mudstone, fine-grained; corals, clams, bryozoans, brachiopods (*Neospirifer*, abundant *Megousia* at 37 ft); conodont sample at 32 ft; barren sample at 28 ft................	10	38
3. Limestone, orange-gray skeletal wackestone, thick-bedded with rusty colored sponges, carbonate pebbles and cobbles, corals, sponges, brachiopods (*Coscinophora* clusters); represents a finger of the carbonate buildup into flank deposits; conodont sample at 17 ft.............................	12	28
2. Covered, probably sandy, silty carbonate....	11	16
1. Limestone, medium-gray lime mudstone with chert lenses, fine sand; scattered corals, brachiopods; conodont samples at 4, 2.5, 1 ft	5	5

Section RC IV (fig. 3)

Hill west of Clay Slide, through massive carbonate buildup about 400 ft south of Section RC III.

Road Canyon Formation	Thickness (ft)	Cumulative (ft)
6. Conglomeratic limestone, orange-gray wackestone, massive bed with sponges, *Coscinophora*; barren conodont sample at 98 ft....	5	100
5. Partly covered, silty conglomeratic wackestone	10	95
4. Limestone, orange-gray wackestone, *Coscinophora* bank, and some conglomerate; barren conodont sample at 80 ft................	5	85
3. Limestone, light-gray to orange, silty, crinoidal, dolomitic wackestone with chert nodules; massive, becoming conglomeratic upward; *Coscinophora* bank at 65 ft; conodont sample at 67 ft	30	80
2. Dolostone, light-brownish-gray, silty, crinoidal dolowackestone, massive, localized lens with rusty chert nodules.................	10	50
1. Limestone, light-olive-gray, skeletal wackestone to packstone, crossbedded, locally conglomeratic with clasts within clasts; sponges, corals, bryozoans; *Coscinophora* banks at 35, 25, 15 ft; conodont samples at 3, 2.5 ft; barren samples at 39, 17 ft......	40	40

Section RC V (fig. 3)

Same hill that contains Clay Slide, but on knob north of the slide; slumped Cathedral Mountain siltstone and mudstone capped by Road Canyon limestone.

Road Canyon Formation	Thickness (ft)	Cumulative (ft)
5. Limestone, silty lime mudstone with scattered rusty chert nodules, thin, platy bedded; few fossils, corals, crinoid columnals, brachiopods; forming ledge capping hill; barren conodont samples at 77, 49 ft	33	81
4. Limestone, cherty, silty lime mudstone, platy and wavy bedded, chert in rusty layers with sparse thin interbeds of silty skeletal wackestone with crinoid debris and brachiopods; conodont sample at 36.5 ft...............	18	48
3. Chert and limestone, interbedded, tan, very fine-grained, sandy lime mudstone and chert, chert probably replaced siltier layers, thin wavy bedded chert diminishing upward	24	30
2. Conglomeratic limestone, brownish-gray skeletal pack- to wackestone with limestone and siltstone clasts; irregular lens; sponges, bryozoans, brachiopods (*Meekella*, *Neospirifer*, *Peniculauris*); conodont sample at 4.5 ft	2.5	6
1. Limestone and chert, interbedded, silty lime mudstone and silty spicular chert, platy and wavy bedded...........................	3.5	3.5

Section RC VI (fig. 3)

Just above south flank of Clay Slide.

Road Canyon Formation	Thickness (ft)	Cumulative (ft)
6. Limestone, silty, sandy, skeletal lime mudstone, thin-bedded with sponges and chert replacements of sponges, chert along bedding planes and joints; conodont sample at 87 ft	17	91
5. Limestone, silty, skeletal lime mudstone with crinoid debris, chonetid brachiopods, platy bedded; barren conodont sample at 72 ft ..	20	74
4. Limestone, skeletal lime mudstone with chert on bedding planes, some bedded chert thin-bedded; crinoid debris, corals, gastropods, brachiopods are rare, chonetid bed (*Dyoros*?) at 55 ft; conodont sample at 50.5 ft	23	54
3. Limestone, silty, skeletal wackestone with chert nodules, in massive irregular lens ranging from 2 to 15 ft thickness within 30 ft of section; conodont sample at 30 ft	5	31
2. Limestone, silty, skeletal lime mudstone like unit 1 with sparse thin skeletal wackestone lenses	11	26
1. Limestone, silty, skeletal lime mudstone with thin rusty chert along bedding planes, thin- to medium-bedded with thin siltier horizons forming wavy interbeds; crinoid columnals, corals, brachiopods (*Echinauris*, *Hustedia*, others), forms base of cliff above Clay Slide; barren conodont sample at 5 ft	15	15

Section RC VII (fig. 4)

South face of hill facing Hess Canyon, due north of the west end of the hill that lies just north of the Hess house; the east end of the hogback that contains the type section of the Road Canyon Formation.

	Thickness (ft)	Cumulative (ft)
Word Formation		
11. Limestone, skeletal packstone with corals, sponges, crinoid columnals, brachiopods, and limestone clasts; conodont sample at top, 130 ft	1	130
10. Siltstone, orange, thin-bedded with few thin carbonate beds	16	129
Road Canyon Formation		
9. Limestone, light-brownish-gray, skeletal wackestone with carbonate clasts up to boulder size, thick- to massive-bedded; sponges, corals, brachiopods (*Derbyia*, *Echinauris*, *Hustedia*, *Meekella*, patches of *Coscinophora*); conodont samples at 112, 89 ft	28	113
8. Mostly covered, apparently orange siltstone	11	85
7. Limestone, light-tan-gray peloid packstone with thin rusty chert stringers, blocky, medium-bedded; corals, fusulinids, siltstone breaks; conodont sample at 70 ft	14	74
6. Covered, probably orange siltstone	7	60
5. Limestone, light-tan, sandy, skeletal packstone, massive, large *Coscinophora* banks, large crinoid columnals; barren conodont sample at 49 ft	17	53
4. Limestone, brown-orange skeletal wackestone, massive, large *Coscinophora* banks, either one or several piled up; corals, sponges, fusulinids, mudstone clasts; conodont samples at 35, 27 ft; barren samples at 35, 19, 18 ft	19	36
3. Limestone, lens of light-brownish-gray to orange, silty, skeletal packstone; crinoid columnals, sponges, corals, brachiopods (*Composita*, *Hustedia*, a richthofeniid), most fossils broken; conodont sample at 13.5 ft	0–5	17
2. Covered, possibly yellow siltstone	15	17
1. Limestone, medium-brownish-gray, skeletal wacke- to packstone; a small mound with sponges, corals, bryozoans, brachiopods (*Composita*, *Coscinophora*, *Meekella*, *Neospirifer*, a richthofeniid, *Spiriferellina*); conodont sample at 1.5 ft	2	2

Section RC VIII (fig. 4)

Williams Bar-Crescent Ranch (formerly Appel Ranch) just east of the Old Word Ranch site, near USNM localities 703a, c, of Cooper and Grant (1972).

	Thickness (ft)	Cumulative (ft)
Word Formation		
7. Limestone, silty lime mudstone, very thin-bedded, some cross-laminated, blocky weathering, chert stringers along some bedding planes; few fossils; barren conodont sample at 59 ft	17	76
6. Covered, thin-bedded yellow siltstone	18	59
5. Siltstone, yellow, thin-bedded with stringers of silty lime mudstone; barren conodont sample at 39 ft	6	41
4. Covered, probably yellow siltstone	4	35
Road Canyon Formation		
3. Limestone, skeletal peloid wacke- to packstone weathering as rounded carbonate mounds; abundant fossils with clusters of richthofeniids (*Cyclacantharia*), *Edriosteges*, and many other brachiopods; conodont samples at 30.5, 29.5, 27.5, 26 ft; barren sample at 28.5 ft	6	31
Cathedral Mountain Formation		
2. Mostly covered, yellow siltstone at 20 to 25 ft	23	25
1. Limestone, light-brownish-gray crinoidal packstone with fusulinids and few brachiopods, graded with large crinoid columnals at base, more finely broken crinoid debris upward, a wackestone at top; conodont sample at 1.5 ft	2	2

Section RC IX (fig. 3)

East flank of Sullivan Peak, on lower slopes directly under the peak itself.

	Thickness (ft)	Cumulative (ft)
Word Formation		
18. Limestone, skeletal wackestone, about 40 percent angular carbonate fragments and 60 percent lime mud (all is Word siltstone above this bed); conodont sample at 291 ft	2	292
17. Partly covered, yellow siltstone	8	290
16. Limestone, skeletal wacke- to packstone, thick-bedded; peloids, sponges, mudstone pebbles; conodont sample at 281.5 ft	2	282
15. Partly covered, platy yellow siltstone	6	280
Road Canyon Formation		
14. Limestone, light-brownish-gray packstone with carbonate clasts, massive-bedded; corals, sponges, fusulinids, brachiopods (*Coscinophora* fragments, *Hustedia*); conodont sample at 272.5 ft	7	274
13. Partly covered, platy yellow siltstone	11	267
12. Limestone, medium-brownish-gray, fine-grained pack- to grainstone, medium- to thin-bedded with angular carbonate fragments	3	256
11. Limestone, medium-brownish-gray packstone, massive-bedded, angular carbonate clasts of sand to gravel size, chert; corals, chertified sponges, fusulinids, brachiopods (*Coscinophora*); conodont sample at 251.5 ft	6	253
10. Limestone and siltstone, silty skeletal lime mudstone interbedded with siltstone, black chert nodules; corals, fusulinids, and brachiopods (*Megousia*); conodont sample at 246 ft	12	247
9. Siltstone, yellow with limestone stringers, lowermost bed is limestone with chert on upper bedding surface; barren conodont sample at 195 ft	44	235
8. Limestone and siltstone, interbedded, both		

	Thickness (ft)	Cumulative (ft)
have thin, platy bedding	16	191
7. Limestone, very silty, brown-gray lime mudstone, becoming siltier upward; barren conodont sample at 160 ft	30	175
6. Limestone and siltstone, silty lime mudstone interbedded with siltstone; fossils and chert scarce; barren conodont samples at 144, 139.5, 114 ft	50	145
5. Limestone, cherty, silty, medium-brown-gray lime mudstone, blocky weathering; barren conodont sample at 95 ft	17	95
4. Limestone, medium-brown skeletal packstone with chert stringers, medium-bedded; some corals, fusulinids, crinoids; conodont sample at 74 ft	5	78
3. Limestone and siltstone, silty lime mudstone, thin- to medium-bedded, interbedded with siltstone	28	73
2. Covered	30	45
1. Limestone, medium-brownish-gray skeletal wackestone with lime-mudstone clasts, massive-bedded, lenticular; abundant fossils, fusulinids, sponges, corals, bryozoans, crinoids, brachiopods; conodont sample at 5, 0 ft	0–15	15

Section RC X (fig. 4)

West side of Hill 5611, near USNM locality 706 of Cooper and Grant (1972).

Road Canyon Formation	Thickness (ft)	Cumulative (ft)
9. Siltstone and limestone, moderate-yellowish-brown, sandy calcareous siltstone irregularly alternating with skeletal crinoidal wacke- to packstone (as unit below) and yellowish-brown, silty lime mudstone	6	61
8. Limestone, pale-yellowish-brown skeletal packstone with abundant crinoid columnals; conodont sample at 52 ft	13	55
7. Siltstone, yellowish-orange, thin-bedded	5	42
6. Limestone, pale-yellowish-brown skeletal wacke- to packstone with abundant crinoid columnals, scattered chert nodules	7	37
5. Limestone, pale-yellowish-brown skeletal packstone with abundant fusulinids and crinoid columnals; conodont sample at 29 ft	2	30
4. Limestone, pale-yellowish-brown, slightly recrystallized, skeletal wacke- to packstone with abundant crinoid columnals, scattered chert nodules	13	28
3. Covered	2	15
2. Limestone, recrystallized skeletal wacke- to packstone with abundant crinoid columnals, beds pinching and swelling	6	13
1. Limestone, pinkish-gray, recrystallized, skeletal wackestone (recrystallization due to close proximity to Hess Horst bounding fault); conodont sample at 1 ft	7	7

Section RC XI (fig. 4)

South face of knob that is USNM locality 702c (Cooper and Grant, 1972), includes north-facing dipslope.

Road Canyon Formation	Thickness (ft)	Cumulative (ft)
2. Limestone, poorly exposed on dipslope, light-brownish-gray skeletal wackestone	3.5	10
1. Limestone, light-brownish-gray skeletal wackestone, massive-bedded with very fossiliferous lenses throughout but more common near top, lime-mudstone clasts in lower 2.5 ft; conodont samples at 5.5, 3.5, 0.5 ft	6.5	6.5

Section RC XII (fig. 4)

Limestone ledge east of Split Tank above USNM localities 726y, 726w, 702a', 702a, 702ent, 702un, 702low, 702int, and 708u (refer to fig. 22 in Cooper and Grant, 1972).

Road Canyon Formation	Thickness (ft)	Cumulative (ft)
1. Limestone, pale-yellowish-brown skeletal wackestone, medium- to thick-bedded; conodont samples at 5.5, 0.5 ft	6	6

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PLATES 1–4

Contact photographs of the plates in this report are available, at cost, from the U.S. Geological Survey Photographic Library, Federal Center, Denver, CO 80225.

PLATE 1

NEOGONDOLELLA

[All figures ×60]

Figures 1–7. *Neogondolella serrata* (Clark and Ethington).
1. Oblique upper view, Pa element, USNM 406891, W81169.
2. Upper view, Pa element, USNM 406892, W81169.
3. Upper view, Pa element, USNM 406893, W81169.
4. Oblique upper view, Pa element, USNM 406894, W81176.
5. Upper view, Pa element, USNM 406895, W81176.
6. Oblique upper view, Pa element, USNM 406896, W81176.
7. Upper view, Pa element, USNM 406897, W81174.

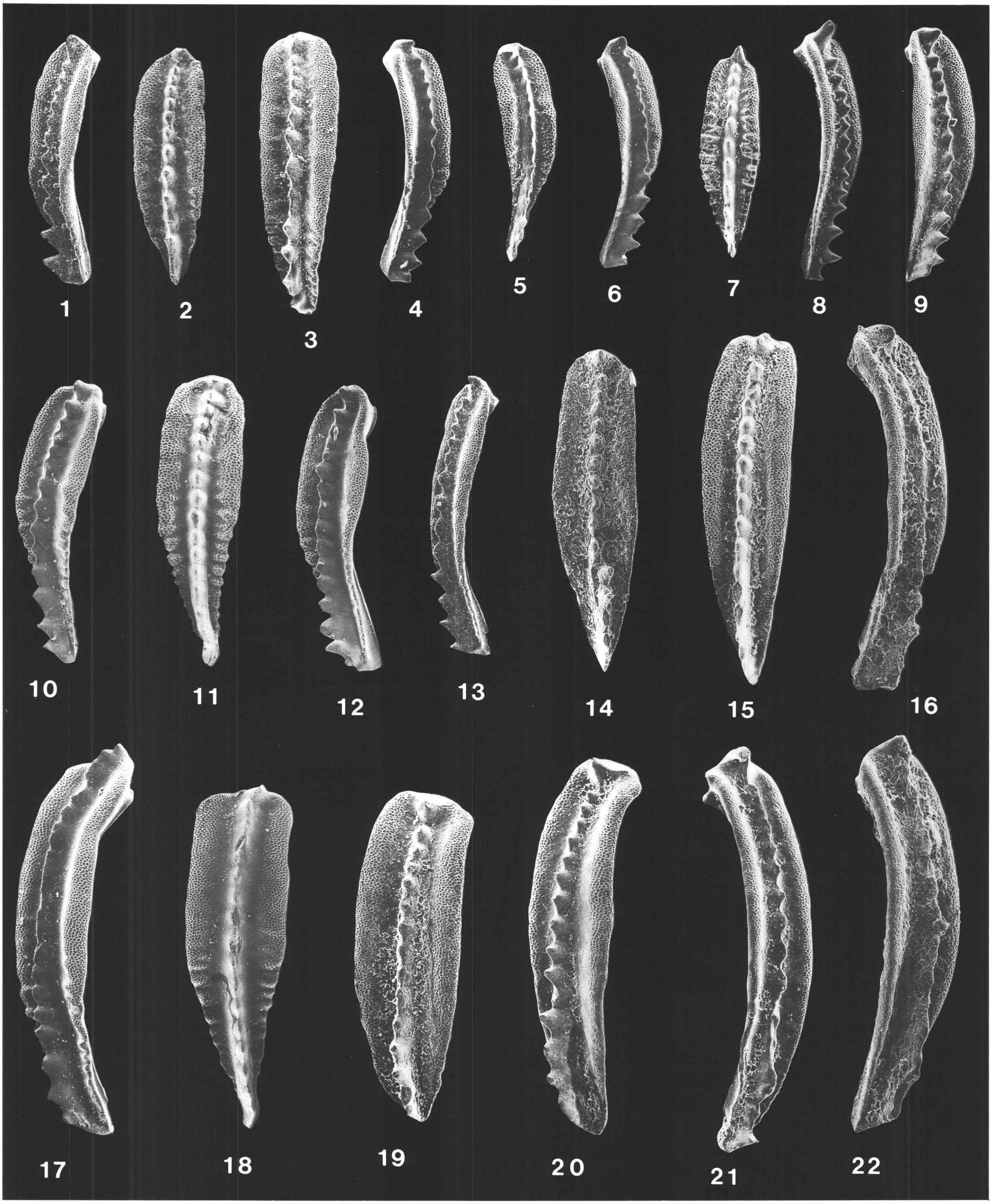
10–13. *Neogondolella serrata* (Clark and Ethington).
10. Oblique upper view, Pa element, USNM 406898, W81176.
11. Upper view, Pa element, USNM 406899, W81176.
12. Oblique upper view, Pa element, USNM 406900, W81176.
13. Oblique upper view, Pa element, USNM 406901, W81169.

17–18. *Neogondolella serrata* (Clark and Ethington).
17. Oblique upper view, Pa element, USNM 406902, W81176.
18. Upper view, Pa element, USNM 406903, W81176.

8–9. *Neogondolella idahoensis* (Youngquist, Hawley, and Miller).
8. Oblique upper view, Pa element, USNM 406904, W81161.
9. Oblique upper view, Pa element, USNM 406905, W81161.

14–16. *Neogondolella idahoensis* (Youngquist, Hawley, and Miller).
14. Upper view, Pa element, USNM 406906, W81179.
15. Upper view, Pa element, USNM 406907, W81161.
16. Oblique upper view, Pa element, USNM 406908, W81179.

19–22. *Neogondolella idahoensis* (Youngquist, Hawley, and Miller).
19. Upper view, Pa element, USNM 406909, W81161.
20. Oblique upper view, Pa element, USNM 406910, W81161.
21. Oblique upper view, Pa element, USNM 406911, W81161.
22. Oblique upper view, Pa element, USNM 406912, W81179.



NEOGONDOLELLA

PLATE 2

HINDEODUS AND *NEOGONDOLELLA*

[All figures ×60]

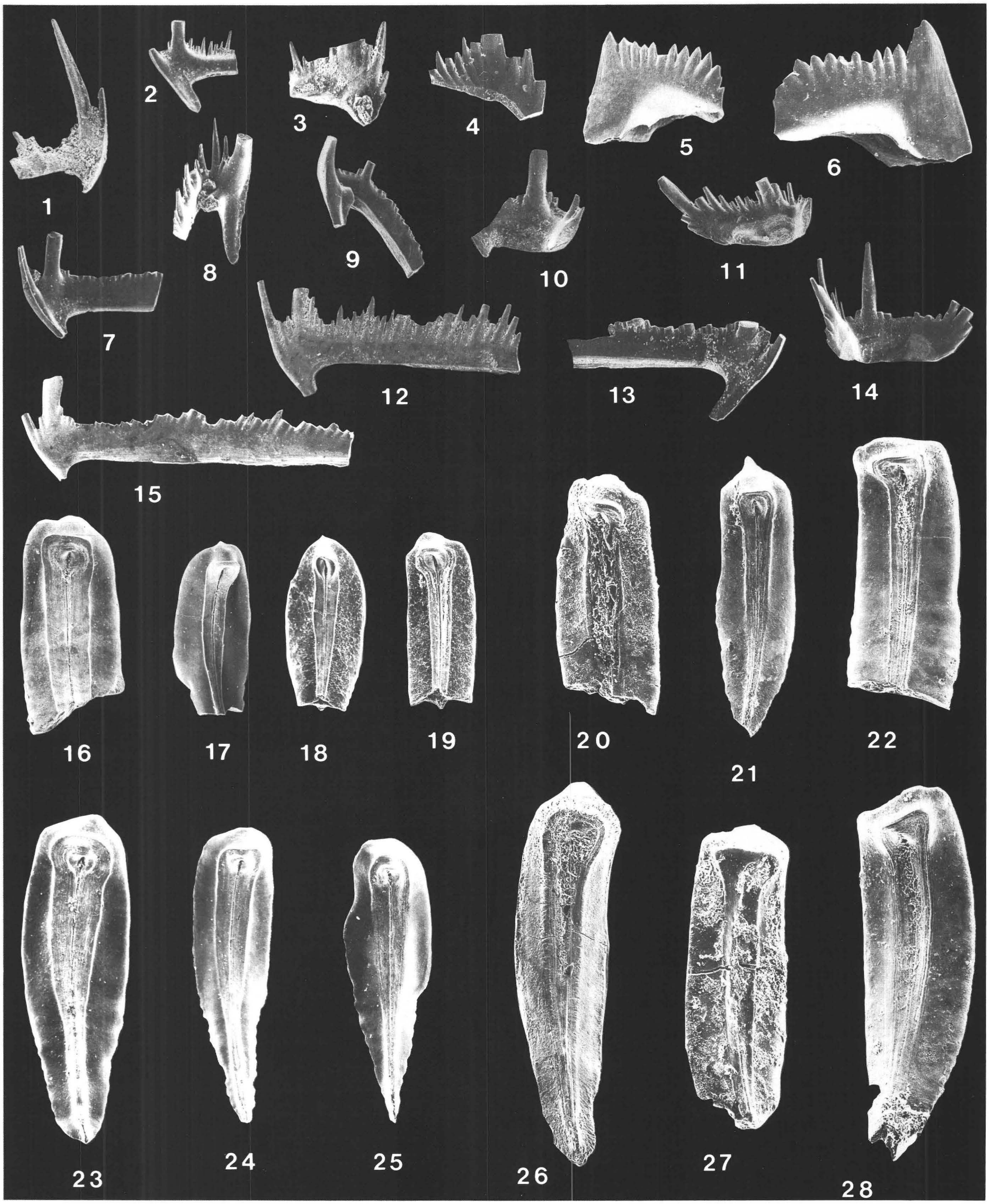
Figures 1–15. *Hindeodus excavatus* (Behnken).
1. Inner view, Sc element, USNM 406913, W81176.
2. Inner view, Sc element, USNM 406914, W81176.
3. Inner view, Pb element, USNM 406915, W81176.
4. Inner view, Pb element, USNM 406916, W81176.
5. Lateral view, Pa element, USNM 406917, W81176.
6. Lateral view, Pa element, USNM 406918, W81176.
7. Inner view, Sc element, USNM 406919, W81176.
8. Posterior view, M element, USNM 406920, W81176.
9. Lateral view, M element, USNM 406921, W81176.
10. Posterior view, Sb element, USNM 406922, W81176.
11. Posterior view, Sb element, USNM 406923, W81176.
12. Outer view, Sc element, USNM 406924, W81176.
13. Inner view, Sc element, USNM 406925, W81176.
14. Posterior view, Sb element, USNM 406926, W81176.
15. Outer view, Sc element, USNM 406927, W81176.

16–19. *Neogondolella serrata* (Clark and Ethington).
16. Lower view, Pa element, USNM 406928, W81174.
17. Lower view, Pa element, USNM 406929, W81176.
18. Lower view, Pa element, USNM 406930, W81169.
19. Lower view, Pa element, USNM 406931, W81169.

23–25. *Neogondolella serrata* (Clark and Ethington).
23. Lower view, Pa element, USNM 406932, W81176.
24. Lower view, Pa element, USNM 406933, W81176.
25. Lower view, Pa element, USNM 406934, W81176.

20–22. *Neogondolella idahoensis* (Youngquist, Hawley, and Miller).
20. Lower view, Pa element, USNM 406935, W81179.
21. Lower view, Pa element, USNM 406936, W81161.
22. Lower view, Pa element, USNM 406937, W81161.

26–28. *Neogondolella idahoensis* (Youngquist, Hawley, and Miller).
26. Lower view, Pa element, USNM 406938, W81161.
27. Lower view, Pa element, USNM 406939, W81179.
28. Lower view, Pa element, USNM 406940, W81161.



HINDEODUS AND *NEOGONDOLELLA*

PLATE 3

NEOSTREPTOGNATHODUS, HINDEODUS, SWEETOGNATHUS, AND *SWEETINA*

[All figures ×60, except where noted otherwise]

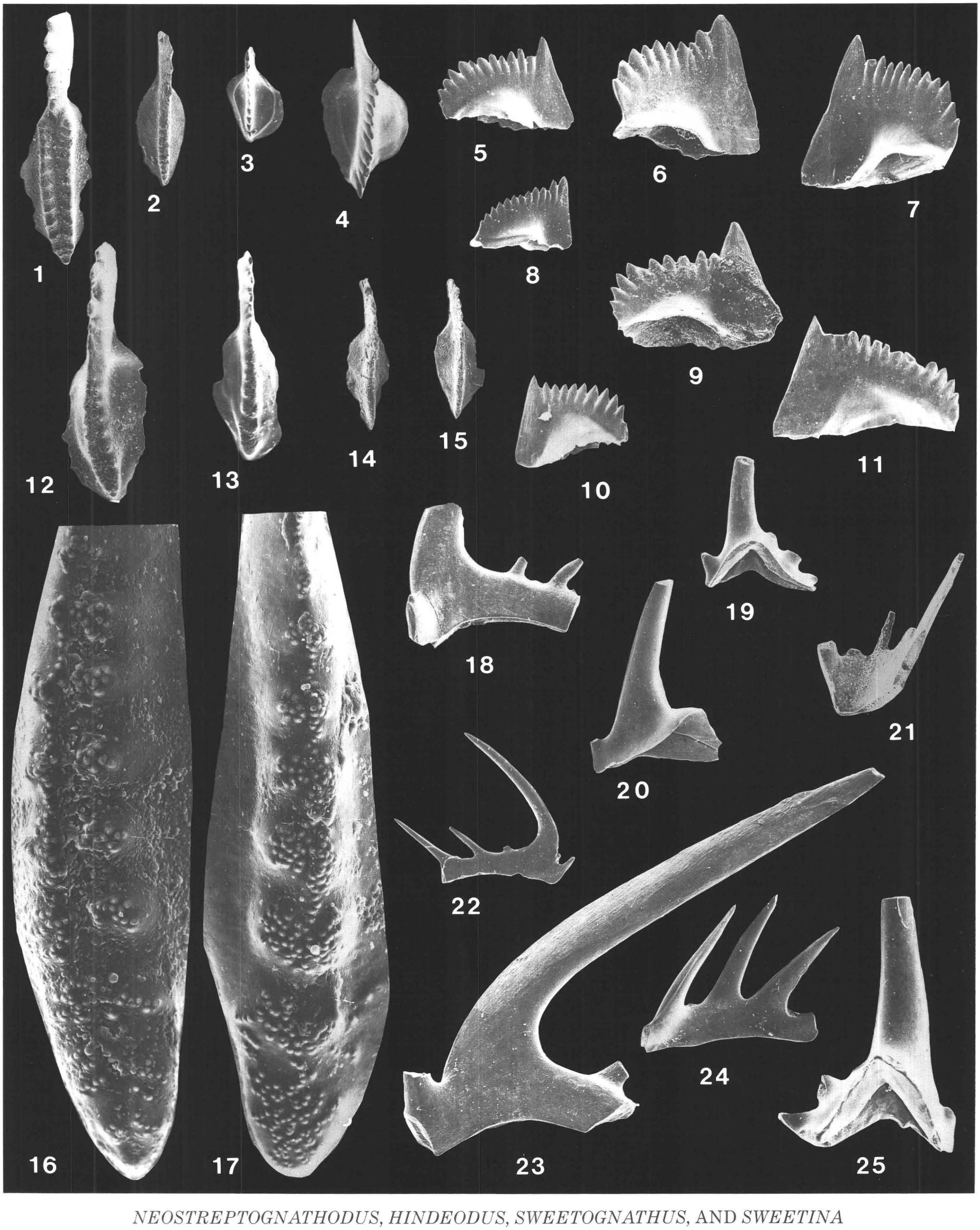
Figure 1. *Neostreptognathodus newelli* Wardlaw and Collinson.
- 1. Upper view, Pa element, USNM 406941, W81228.

2. *Neostreptognathodus clinei* Behnken.
- 2. Upper view, Pa element, USNM 406942, W81243.

3–11. *Hindeodus excavatus* (Behnken).
- 3. Upper view, Pa element, USNM 406943, W81176.
- 4. Oblique upper view, Pa element, USNM 406944, W81176.
- 5. Lateral view, Pa element, USNM 406945, W81176.
- 6. Lateral view, Pa element, USNM 406946, W81176.
- 7. Lateral view, Pa element, USNM 406947, W81176.
- 8. Lateral view, Pa element, USNM 406948, W81176.
- 9. Lateral view, Pa element, USNM 406949, W81176.
- 10. Lateral view, Pa element, USNM 406950, W81176.
- 11. Lateral view, Pa element, USNM 406951, W81176.

12–17. *Sweetognathus iranicus* Kozur, Mostler, and Rahimi-Yazd.
- 12, 16. Upper view, Pa element, USNM 406952, W81176,×60 and enlarged, ×300, showing surface pustules.
- 13, 17. Upper view, Pa element, USNM 406953, W81176, ×60 and enlarged, ×300, showing surface pustules.
- 14. Upper view, Pa element, USNM 406954, W81194.
- 15. Upper view, Pa element, USNM 406955, W81200.

18–25. *Sweetina festiva* (Bender and Stoppel).
- 18. Lateral view, Sa element, USNM 406956, W81165.
- 19. Posterior view, M element, USNM 406957, W81176.
- 20. Posterolateral view, M element, USNM 406958, W81176.
- 21. Posterolateral view, Sb element, USNM 406959, W81162.
- 22. Inner view, Sc element, USNM 406960, W81176.
- 23. Inner view, Sc element, USNM 406961, W81176.
- 24. Lateral view, Sc element, USNM 406962, W81176.
- 25. Posterior view, M element, USNM 406963, W81165.



NEOSTREPTOGNATHODUS, HINDEODUS, SWEETOGNATHUS, AND *SWEETINA*

PLATE 4

XANIOGNATHUS, NEOSTREPTOGNATHODUS, AND *NEOGONDOLELLA*

[All figures ×60]

Figures 1–22. *Xaniognathus abstractus* (Clark and Ethington).

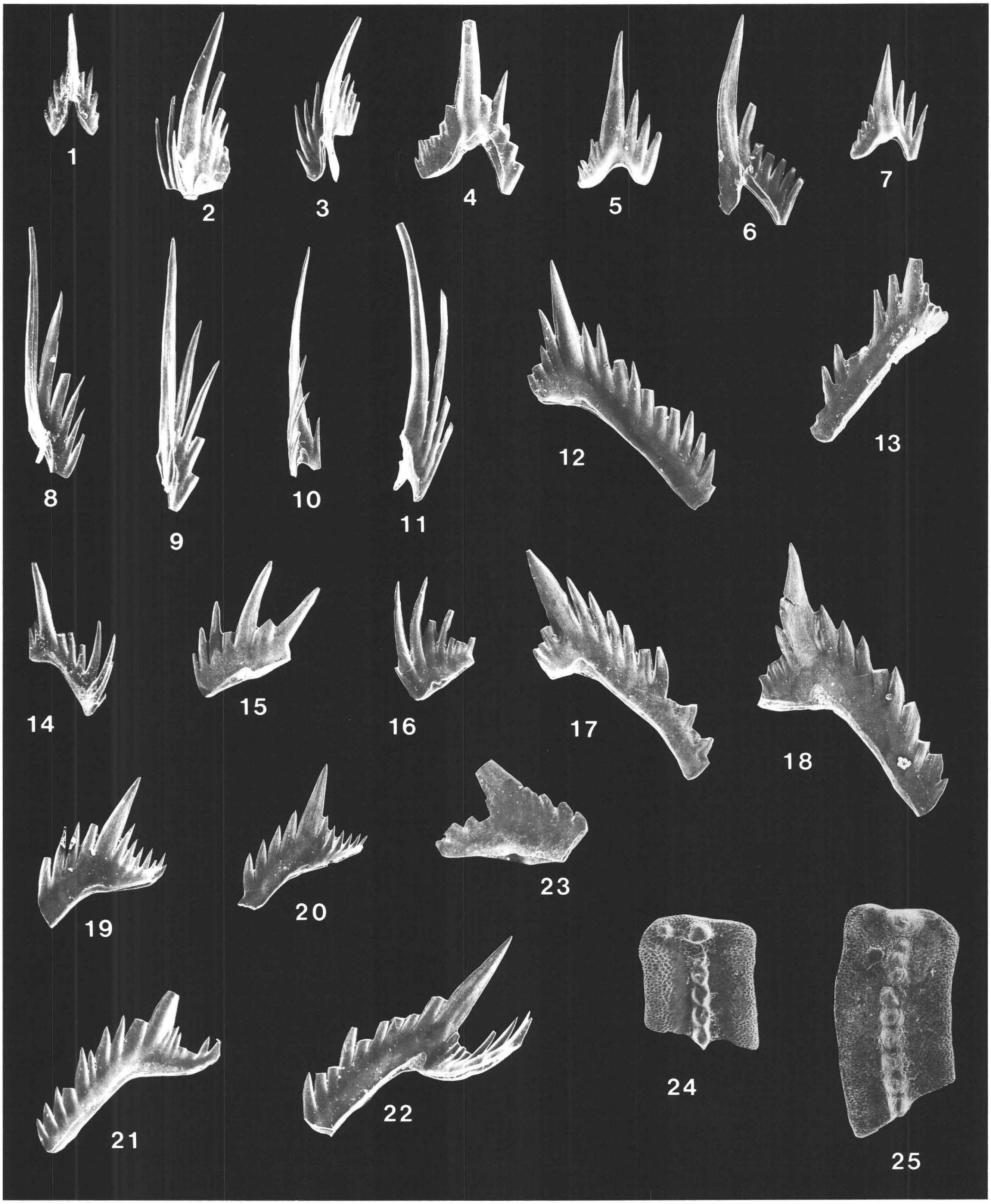
1. Posterior view, Sa element, USNM 406964, W81239.
2. Oblique lateral view, Sa element, USNM 406965, W81176.
3. Oblique lateral view, Sa element, USNM 406966, W81176.
4. Posterior view, M element, USNM 406967, W81176.
5. Anterior view, M element, USNM 406968, W81176.
6. Posterolateral view, M element, USNM 406969, W81176.
7. Posterior view, M element, USNM 406970, W81176.
8. Posterior view, Sb element, USNM 406971, W81176.
9. Posterior view, Sb element, USNM 406972, W81176.
10. Posterolateral view, Sb element, USNM 406973, W81176.
11. Anterolateral view, Sb element, USNM 406974, W81176.
12. Lateral view, Pa element, USNM 406975, W81176.
13. Lateral view, Pa element, USNM 406976, W81176.
14. Lateral view, Sc element, USNM 406977, W81239.
15. Lateral view, Sc element, USNM 406978, W81176.
16. Lateral view, Sc element, USNM 406979, W81176.
17. Lateral view, Pa element, USNM 406980, W81176.
18. Lateral view, Pa element, USNM 406981, W81176.
19. Inner view, Pb element, USNM 406982, W81176.
20. Inner view, Pb element, USNM 406983, W81176.
21. Inner view, Pb element, USNM 406984, W81176.
22. Inner view, Pb element, USNM 406985, W81176.

23. *Neostreptognathodus* sp.

23. Inner view, Pb element, USNM 406986, W81176.

24–25. *Neogondolella idahoensis* (Youngquist, Hawley, and Miller).

24. Upper view, Pa element, USNM 406987, W81161.
25. Upper view, Pa element, USNM 406988, W81161.



XANIOGNATHUS, NEOSTREPTOGNATHODUS, AND *NEOGONDOLELLA*

Chapter B

The Rugose Coral *Ankhelasma*—Index to Viséan (Lower Carboniferous) Shelf Margin in the Western Interior of North America

By WILLIAM J. SANDO, E. WAYNE BAMBER, and BARRY C. RICHARDS

Predictions of Carboniferous shelf-margin locations
using the living zone of a rugose coral

U.S. GEOLOGICAL SURVEY BULLETIN 1895
SHORTER CONTRIBUTIONS TO PALEONTOLOGY AND STRATIGRAPHY

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The Rugose Coral *Ankhelasma*—Index to Viséan (Lower Carboniferous) Shelf Margin in the Western Interior of North America

By William J. Sando,[1] E. Wayne Bamber,[2] *and* Barry C. Richards[2]

Abstract

Ankhelasma, a distinctive, endemic, solitary rugose coral, lived in a belt presently no more than 75 kilometers wide, almost exclusively on the landward side of the Viséan shelf margin in the Western Interior region of western North America. A model of the distribution of this coral, based on known, nonpalinspastic distances to the shelf margin in rocks of early Viséan and early middle Viséan age, suggests that the living zone of this coral was probably no more than approximately 50 kilometers wide. The genus originated either in northeastern Utah or southwestern Canada at the beginning of the early Viséan (Composite Zone 12) and migrated both northward and southward along the shelf margin, dying out by the end of early late Viséan (Composite Zone 14) time, a phylogenetic life span of about 8 million years. Occurrences of this coral in northwestern Montana and east-central British Columbia adjacent to areas where the Viséan depositional record has been removed by subsequent erosion are helpful in determining or confirming inferred locations for the shelf margin in these areas.

INTRODUCTION

During the Early Carboniferous, the Western Interior region of North America was occupied by an epeiric sea that extended from arctic Canada to northern Mexico (fig. 1). *Ankhelasma* Sando, 1961 (fig. 2), is a small, curved-conical solitary rugose coral, endemic to the Western Interior province of Sando and others (1975, 1977), that is distinguished by the extraordinary development of five septal plates in the mature (ephebic) stage. The presence of these plates facilitates recognition in transverse section, even without laboratory preparation. The genus is represented by one nominal species, *A. typicum* Sando, 1961, in the United States and Canada and by at least one unnamed species in Canada. *Ankhelasma* probably evolved from the widespread

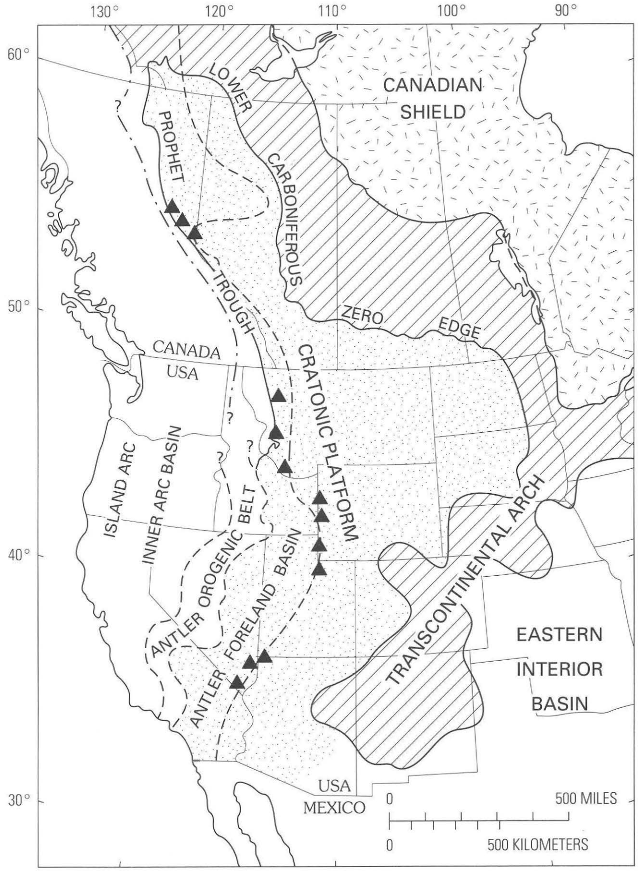

Figure 1. Western North America showing area of Lower Carboniferous sedimentary rocks in Western Interior region (stippled) and Lower Carboniferous paleotectonic elements. Compiled from Sproule (1958, fig. 1), Poole and Sandberg (1977, fig. 1), Sando (1985, fig. 1), and Richards and others (in press). Triangles indicate areas that have one or more occurrences of *Ankhelasma*.

genus *Sychnoelasma* (*Homalophyllites* of earlier reports; see Sando, 1961, p. 67), a coral that occurs commonly in the sequence below the lowest occurrence of *Ankhelasma* and is sparse in the lowermost part of the range of *Ankhelasma* (Sando and Bamber, 1985).

Preliminary studies of the stratigraphic and geographic distribution of *Ankhelasma* suggested that it was

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[1] U.S. Geological Survey, U.S. National Museum of Natural History, Washington, DC 20560.

[2] Geological Survey of Canada, 3303 33d St., NW., Calgary, Alberta, Canada 2TL 2A7.

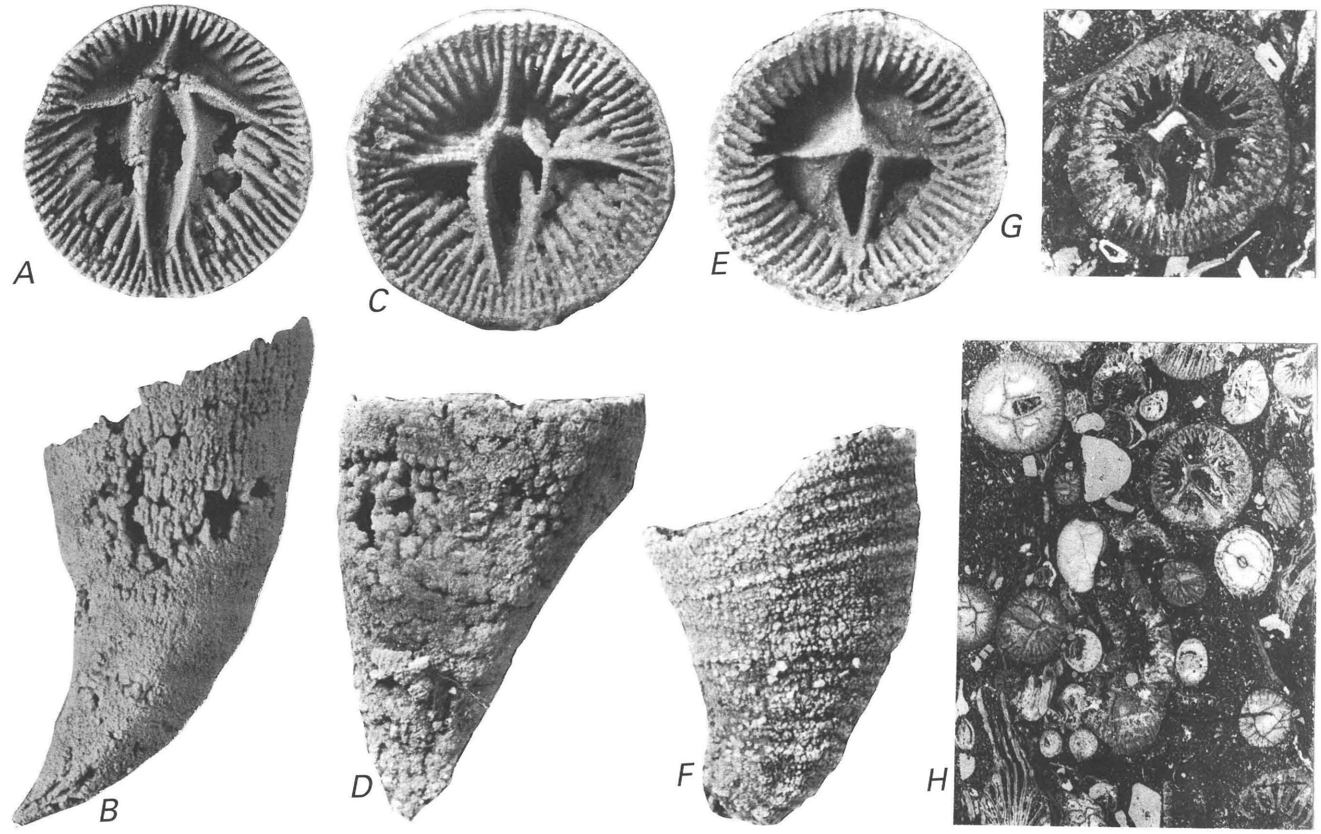

Figure 2. Specimens of *Ankhelasma* Sando, 1961, from the Western Interior region of North America. *A, B.* Calicular and alar views, respectively, ×3, of silicified corallum of *A. typicum*, holotype, USNM 120201, from USGS loc. 17722–PC, Brazer Dolomite (member 3), Composite Zone 12, Rex Peak, Crawford Mountains, Utah. *C, D.* Calicular and alar views, respectively, ×3, of silicified corallum of *A. typicum*, hypotype, USNM 424262, from USGS loc. 27968–PC, Monte Cristo Limestone (Yellowpine Member), Composite Zone 14, Potosi Mine, Goodsprings District, Nevada. *E, F.* Calicular and alar views, respectively, ×3, of silicified corallum of *A.* n. sp., hypotype, GSC 89984, from GSC loc. C–110910, Prophet Formation (member B), Composite Zone 13 or 14, South Mountain Creek, Pine Pass map area, east-central British Columbia. *G.* Transverse thin section, ×3, of *A. typicum*, hypotype, USNM 424263, from USGS loc. 27074–PC, Brazer Dolomite (member 2), Composite Zone 12, Trail Hollow, Uinta Mountains, Utah. *H.* Thin section of *Ankhelasma*-bearing bed showing *A. typicum* and associated fossils in packstone, ×2, same locality as *G.*

restricted to a narrow geographic zone related to the edge of a broad carbonate shelf (shelf margin) during the early to early middle Viséan in the Western Interior region of the United States. A similar distribution pattern was noted in western Canada, where exposures of the shelf margin are extensive but less completely sampled.

Because shelf margins define depositional strike along basin flanks and influence the character and distribution of petroleum-reservoir rocks and seals, they are of prime economic importance (Rose, 1976, p. 449–450). Accurate delineation of Carboniferous shelf margins is important to the preparation of regional paleogeographic maps, which can be used to analyze depositional history. Mapping of shelf margins also can be useful for measuring later structural offsets and translocations. This paper documents a geographic distribution model for *Ankhelasma* and uses this model to predict or confirm shelf-margin locations in areas where the depositional record has been removed or obscured by later events.

Acknowledgments

Early field work by the senior author on the stratigraphy of *Ankhelasma* was done largely with J.T. Dutro, Jr., whose companionship and contributions to the stratigraphy are gratefully acknowledged. Ten years of joint field studies with C.A. Sandberg and R.C. Gutschick laid the foundation for sophisticated analysis of the shelf margin; the creative and inspiring conceptual contributions of these colleagues strongly influenced many of the ideas expressed in this paper. E.E. Bierwagen, J.A. Dockal, M.R. Mudge, C.A. Sandberg, and Betty Skipp contributed samples of *Ankhelasma* to the senior author. Shell Canada Limited supplied specimens and information from several localities

in Canada. Conodont identifications and zonal determinations were made by C.A. Sandberg for samples from the United States, and A.C. Higgins was responsible for the same information on Canadian samples. Identifications of foraminifers and algae and zonal determinations on samples from the United States and Canada were made by B.L. Mamet.

PALEOTECTONIC SETTING

Western United States

Previous studies of Devonian and Carboniferous geology in the Western United States (Poole, 1974; Nilsen, 1977; Poole and Sandberg, 1977) showed that the Western Interior basin was located at the edge of the North American protocontinent and that the basin was affected by Late Devonian and Early Carboniferous plate collision (Antler orogeny). A broad, shallow, epicontinental sea, located on the craton (cratonic platform), was bounded on the east by the Transcontinental arch, a positive area of Precambrian crystalline rocks and lower Paleozoic sedimentary rocks that formed a peninsula during the Early Carboniferous and separated the Western Interior and Eastern Interior basins (fig. 1) (Gutschick and Sandberg, 1983). An island chain composed of uplifted early Paleozoic rocks was formed in the Antler orogenic belt during plate collision and bounded the Western Interior basin on the west. Plate collision also produced a deep trough (Antler foreland basin) between the Antler orogenic belt and the stable cratonic platform during the Viséan.

Deep-water terrigenous and carbonate sediments deposited in the Antler foreland basin were separated from shallow-water carbonate and evaporitic sediments of the cratonic platform by a narrow break in depositional slope, called shelf margin by previous workers (Rose, 1976; Sando, 1976; Gutschick and others, 1980; Sandberg and others, 1982; Gutschick and Sandberg, 1983). The geographic position of the Mississippian shelf margin changed through time, but the shelf margin was always close to the craton margin. *Ankhelasma* has been found only in a narrow belt that follows the frontal zone of Laramide thrusting, approximately coincident with the craton margin and Viséan shelf margin, from southeastern Nevada to northwestern Montana (fig. 1).

Western Canada

Canadian occurrences of *Ankhelasma* are of the same age as those in the United States and occupy similar geographic positions with respect to the craton margin and Viséan shelf margin (figs. 1 and 3). Strata containing *Ankhelasma* were deposited in the southwestern part of the Peace River embayment and in the Prophet trough to the west and south. Although the distribution pattern is similar, there are still some uncertainties concerning exact relations with paleotectonic elements recognized in the United States.

The name Prophet trough was introduced by Richards and others (in press) for an extensive, northwest-trending, downwarped and downfaulted belt that developed on the western margin of the North American protocontinent during the latest Devonian and Carboniferous. The trough was continuous with the Antler foreland basin and extended from southeastern British Columbia into the northern part of the Yukon Territory. A broad hinge zone, marking a point at which water depths and sedimentation rates increased rapidly basinward, formed the boundary between the Prophet trough and the cratonic platform to the east. The western boundary of the trough was an elevated rim, at least locally subaerially exposed during the Early Carboniferous. The Antler orogenic belt of the United States, or a related orogenic belt, may have extended at least as far north as the southern part of the Peace River embayment, thereby forming part of the western rim of the southern Prophet trough (Richards and others, in press). The origin of the trough is not well established. Some workers (Templeman-Kluit, 1979; Gordey and others, 1987; Struik, 1987) believe that the trough is either partly or predominantly an extensional feature resulting from Late Devonian and Early Carboniferous rifting of western North America. Extension, recorded by extensive block faulting, did occur in the central part of the Prophet trough and in the Peace River embayment (Richards and others, in press). However, tectonic and sedimentologic data summarized by Richards and others (in press) suggest that the Antler orogeny or a related compressional event influenced the marked Tournaisian and Viséan subsidence that occurred in the southern part of the trough.

In northwestern Alberta and northeastern British Columbia, the Peace River embayment, a broad reentrant into the cratonic platform, opened westward into the Prophet trough (figs. 1 and 3). The depositional and structural axis of this arcuate embayment had an easterly trend and coincided approximately with the axis of the Late Devonian Peace River arch. Extensive block faulting, accompanied by regional flexural subsidence, produced the embayment, which is characterized by an anomalously thick Lower Carboniferous sequence and by numerous northeasterly and northwesterly striking syndepositional and postdepositional normal faults. Evidence for westward shallowing during the Tournaisian and Viséan indicates that a slightly positive area, possibly a series of islands or a peninsula, was at least periodically present in the southwestern part of the Peace River embayment when strata containing *Ankhelasma* were deposited. Parts of this northwest-trending positive area, which extended well southeastward of the embayment, were intermittently elevated and exposed to subaerial erosion during the earliest middle Tournaisian (earliest Tn2) to Serpukhovin. All

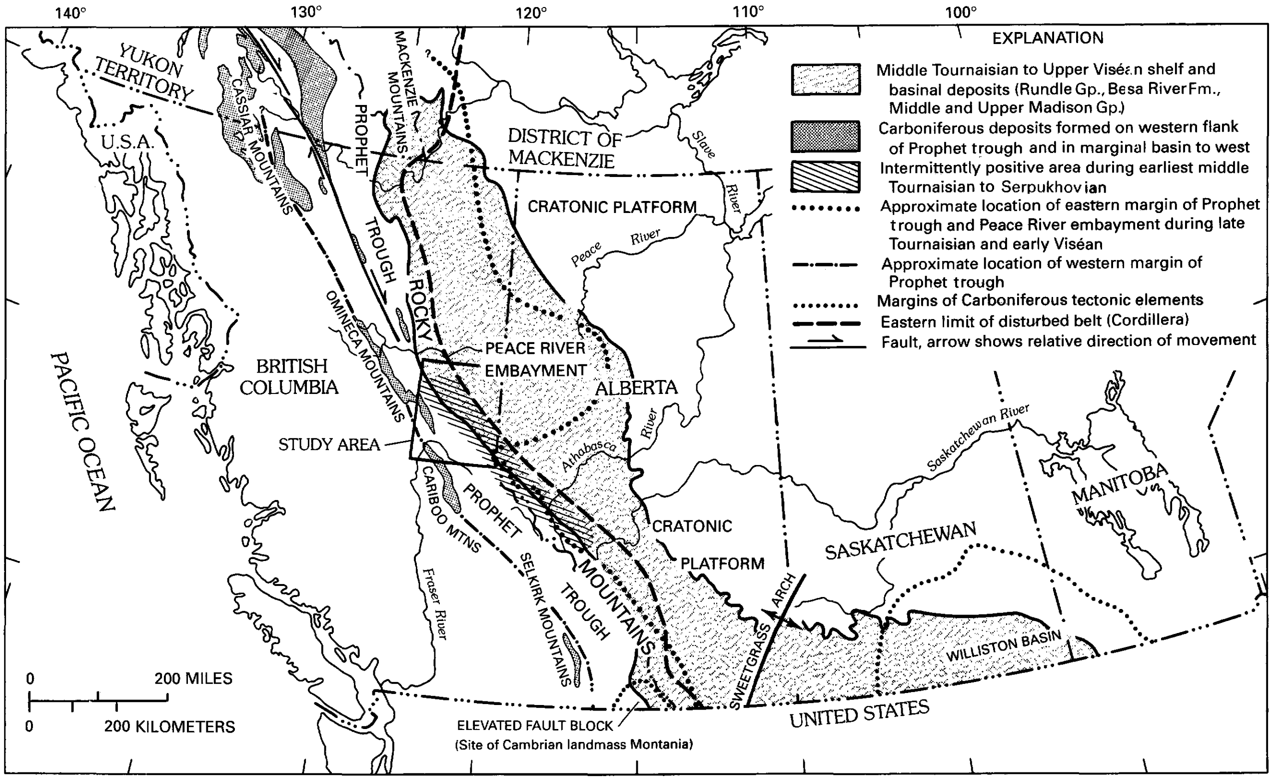

Figure 3. Carboniferous deposits and paleotectonic elements, Western Canada basin (after Richards and others, in press). Study area contains all known Canadian occurrences of *Ankhelasma* (see fig. 9).

known Canadian occurrences of *Ankhelasma* are in carbonate rocks deposited on or near the positive region.

STRATIGRAPHIC, GEOGRAPHIC, AND ECOLOGIC DISTRIBUTION OF *ANKHELASMA*

Western United States

In the United States, *Ankhelasma* occurs at 17 surface localities in a narrow belt (*Ankhelasma* belt) along the western margin of the cratonic platform (fig. 4) (see appendix A for complete descriptions of localities). The spacing of occurrences along the strike of the *Ankhelasma* belt seems to be determined mainly by availability of outcrops of rocks potentially bearing *Ankhelasma*; this relation is most notable in the long stretch of land having no occurrences from the southwestern corner of Utah to northeastern Utah, where rocks potentially bearing *Ankhelasma* do not crop out. Consequently, *Ankhelasma* is not recorded from this area, although no subsurface cores have been examined by the writers.

More than 30 years of intensive collecting of corals by the senior author outside the area herein designated *Ankhelasma* belt, as well as hundreds of collections sent to the senior author for study by other geologists, have failed to reveal even a single specimen of the genus. Moreover, examination of hundreds of collections of Lower Carboniferous rocks made by geologists of the U.S. Geological Survey during the past 80 years revealed only two occurrences of this unique coral, and these were both in the narrow belt revealed by more recent field work.

Ankhelasma occurs in two stratigraphic intervals in the United States (fig. 4). In northeastern Utah, western Wyoming, southeastern Idaho, and western Montana, the occurrences are all dated as early Viséan (Composite Zones 12 and 13 of Sando, 1985) by foraminifers, corals, and conodonts (localities 4–8, 10–13). In south-central Idaho, a poorly dated debris-flow occurrence (locality 9) is also thought to be from the same interval. In southeastern Nevada and northwestern Arizona (localities 1–3), the occurrences are of early middle Viséan age (Composite Zone 14 of Sando, 1985).

A more detailed analysis of stratigraphic distribution (fig. 5) shows that the earliest known occurrences of *Ankhelasma* in the United States are at the base of Composite Zone 12 at localities 4 and 5 in the Uinta Mountains of northeastern Utah. The genus ranges through Composite Zone 12 well into Composite Zone 13 along the *Ankhelasma* belt to the northwest in western Wyoming, southeastern Idaho, and western Montana (localities 6–13).

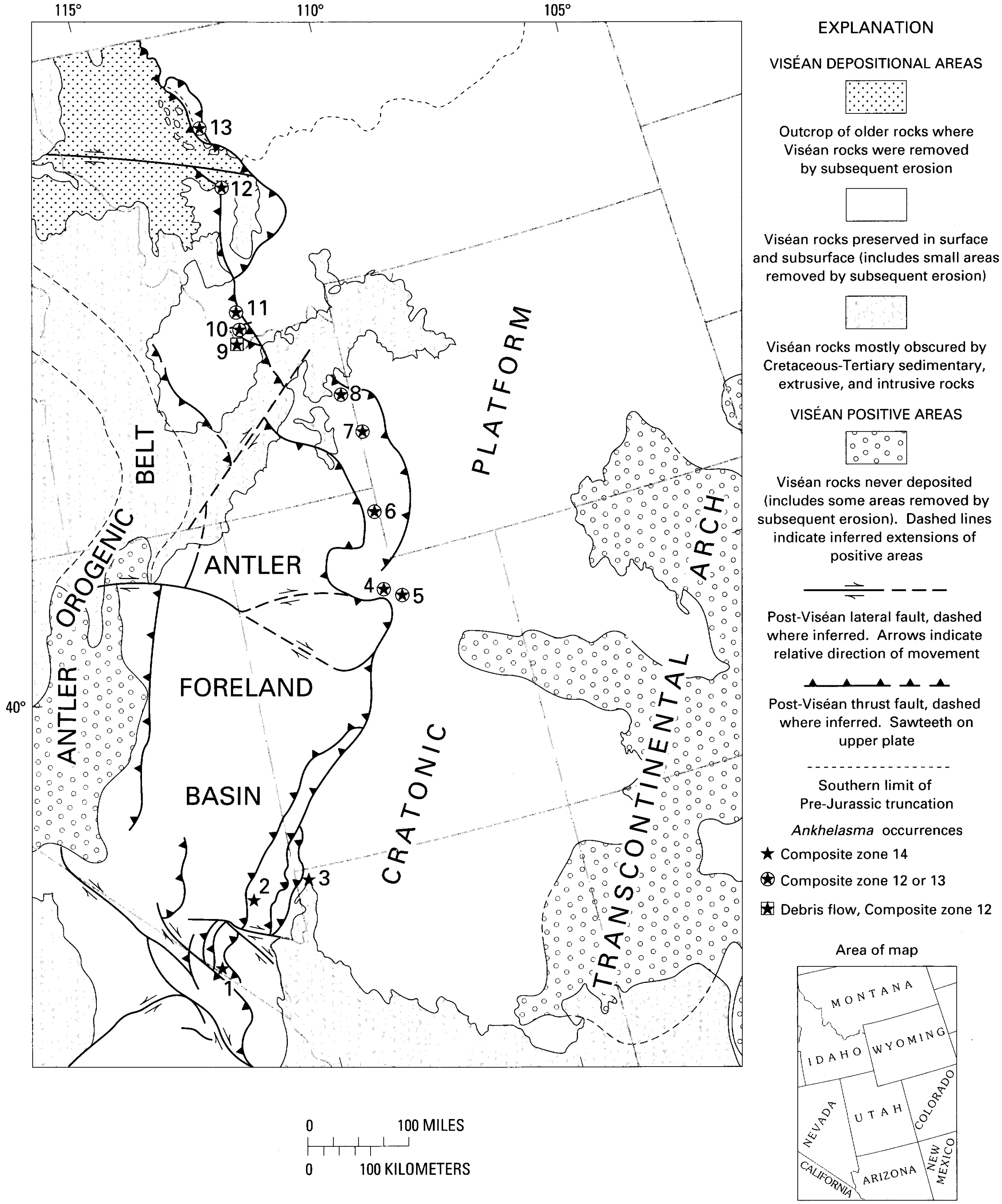

Figure 4. Geologic map of Viséan rocks in Western Interior region of the United States showing locations of *Ankhelasma* occurrences. Modified from Craig and Connor (1979, pl. 2) and Sandberg and others (1982, fig. 2).

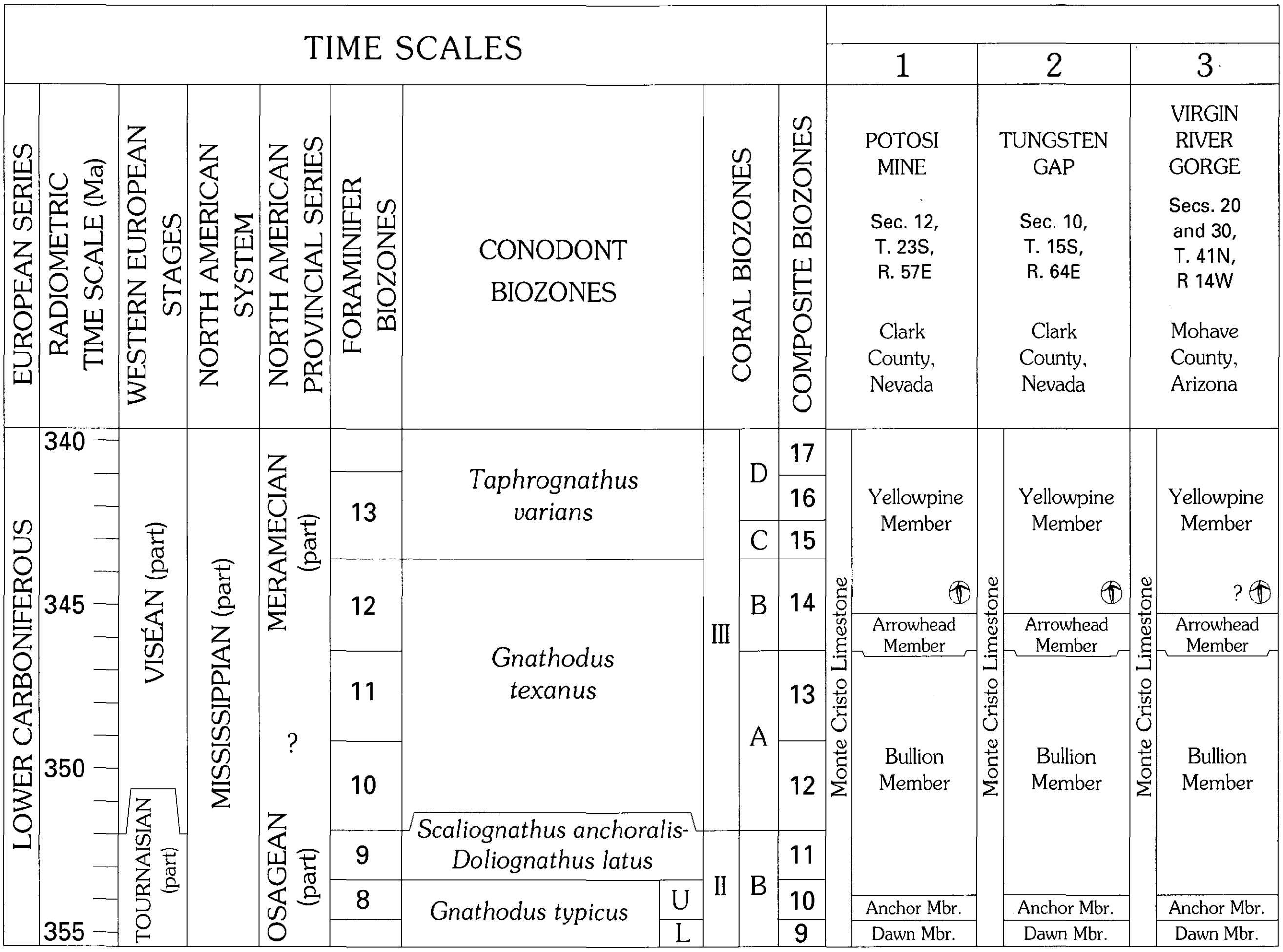

Figure 5. Temporal and stratigraphic distribution of *Ankhelasma* in the Western United States. Time scales from Sando (1985). Coral symbols indicate positions of *Ankhelasma* at each locality. See figure 4 for geographic locations and appendix A for descriptions of localities.

To the southwest, the genus appears again in Composite Zone 14 in northwestern Arizona (locality 3) and in southeastern Nevada (localities 1 and 2).

Nonpalinspastic paleogeographic maps for Composite Zones 12 and 13 (fig. 6) and upper Composite Zone 14 (fig. 7) reveal plausible explanations for the geographic and stratigraphic distribution patterns of *Ankhelasma* noted above. These maps are a revision of maps of slightly different time intervals published previously by Sandberg and others (1982, figs. 16 and 17). Because a lack of outcrop and the influence of major thrust faults prevent actual observation of the exact shelf-margin positions, locations of the Viséan shelf margin are documented by a series of nonpalinspastic chronometric lithofacies profiles across the areas of regional facies change (fig. 8; appendix B). Precise locations of shelf-margin positions must be inferred by projection of on-shelf and off-shelf lithofacies from section control points on either side of the margin. Structural telescoping by thrust faulting undoubtedly distorted pre-Laramide depositional distances, particularly in the northern part of the thrust belt, and major transverse faults offset the shelf margin at several places (figs. 6 and 7). Nevertheless, the regional pattern of demarcation between deep-water basinal sedimentation west of the margin and shallow-water shelf sedimentation east of the margin can be seen clearly on the maps and profiles.

Early Viséan (Composite Zones 12 and 13) time was characterized by a continuous area of shelf carbonate sedimentation extending from Montana to Arizona (fig. 6). This area was divided into a northern Madison shelf and a southern Leadville-Redwall shelf; these shelves are named for formations or groups that include rocks of Viséan age in the respective areas. Both shelves were characterized by mostly open-marine subtidal carbonate and evaporite deposition in predominantly intertidal and supratidal environments in northeastern Utah and southwestern Wyoming. Deposition seaward from the shelf margin was characterized by deep-water carbonate and terrigenous sediments of the Deseret starved basin, Chainman basin, and Middle Canyon-McGowan Creek basin (see Gutschick and others,

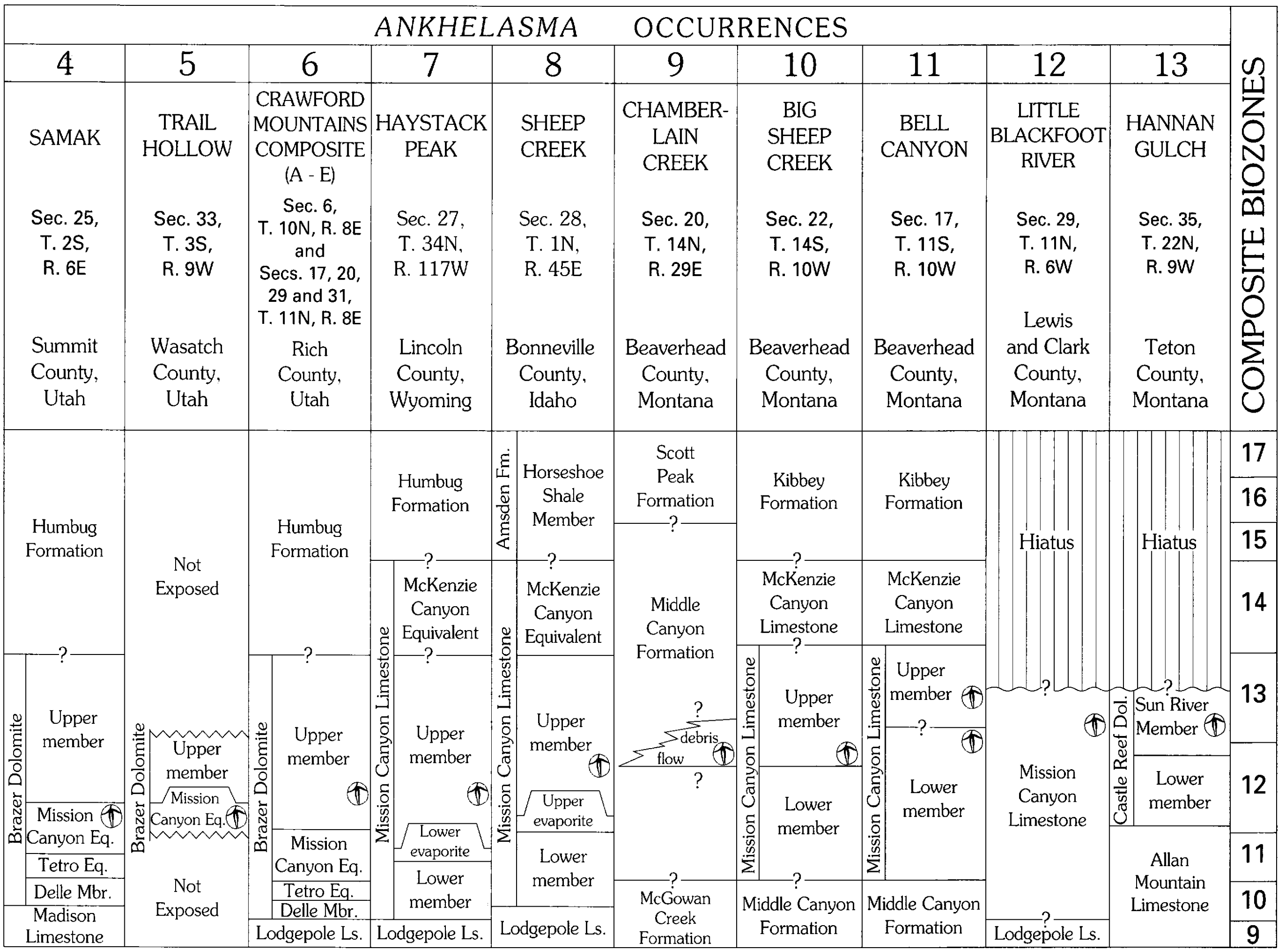

Figure 5. Continued.

1980; Sandberg and others, 1982; and Sandberg and Gutschick, 1984, for descriptions of these sediments).

During the early Viséan (Composite Zones 12 and 13), *Ankhelasma* lived in subtidal environments near the shelf margin (figs. 6 and 8) on the Madison shelf (upper member of Mission Canyon Limestone; fig. 5) and in open-marine incursions into the area of restricted shelf sedimentation (upper member of Brazer Dolomite; fig. 5). The temporal and areal distribution of *Ankhelasma* (figs. 5 and 6) suggests that the genus originated in northeastern Utah at the beginning of Composite Zone 12 time and migrated rapidly both northward and southward along a zone that extended approximately 50 km landward from the shelf margin (table 1). The exception is locality 9 in south-central Idaho, where *Ankhelasma* occurs approximately 10 km seaward from the shelf margin in a debris flow of coarse-grained crinoidal packstone that flowed down the slope into deep-water carbonate sediments of the Middle Canyon Formation. However, the northeastern Utah origin point is not confirmed by the distribution of *Ankhelasma* in Canada, where this coral also occurs at or

Table 1. Nonpalinspastic distances of *Ankhelasma* occurrences landward from known Viséan shelf margin in Western Interior region of the United States

[Asterisk indicates unique debris flow on slope seaward from shelf margin. See figures 4, 6, and 7 for geographic locations]

Occurrence	Distance from shelf margin (km)
Composite Zone 12	
Locality 4	25
Locality 5	50
Locality 6	10
Locality 7	25
Locality 8	30
Locality 9*	10
Locality 10	7.5
Locality 11	25
Composite Zone 13	
Locality 11	25
Composite Zone 14	
Locality 1	60
Locality 2	30
Locality 3	40

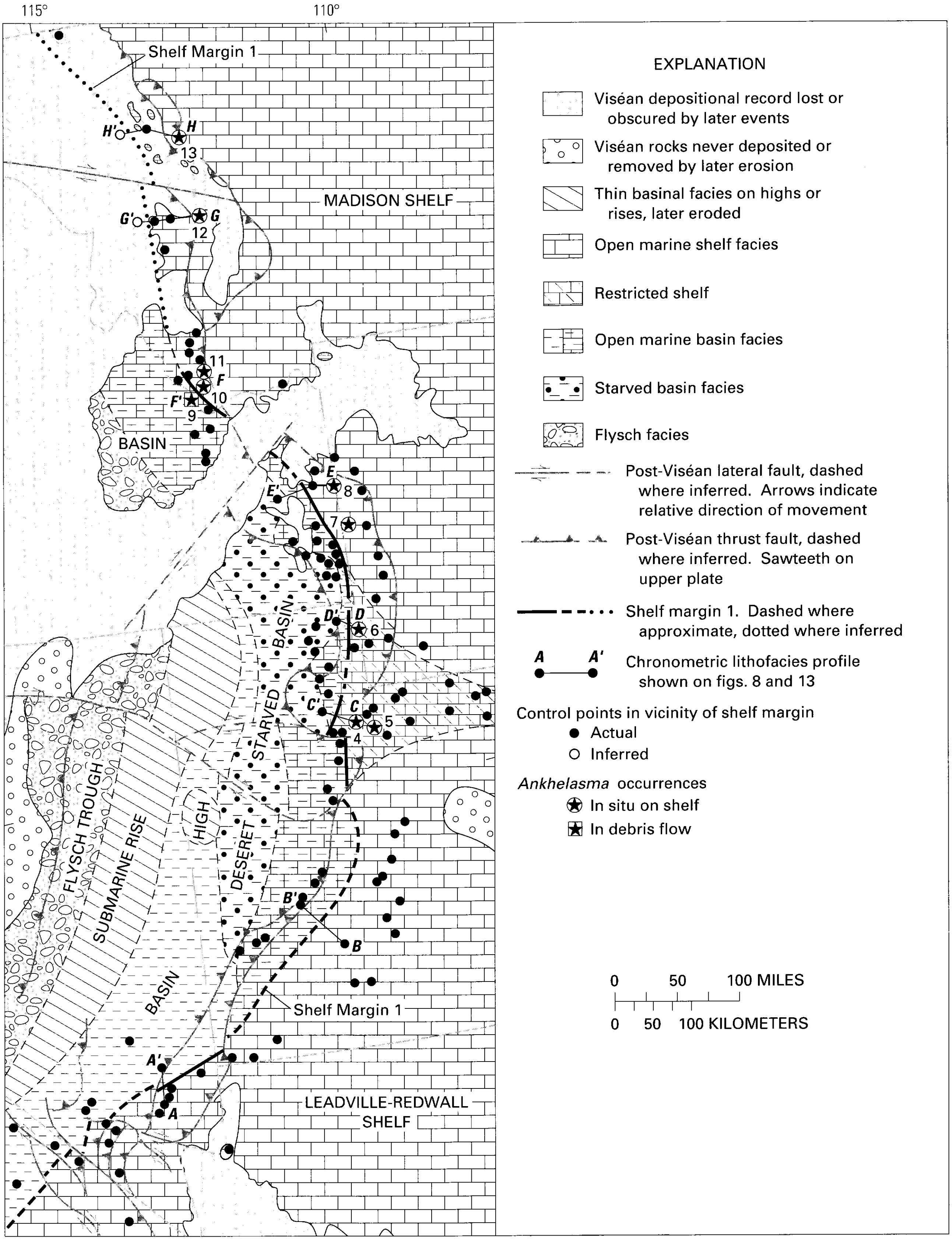

Figure 6. Early Viséan (Composite Zones 12 and 13) paleogeography of a part of the Western Interior basin in the United States and *Ankhelasma* occurrences in relation to shelf margin and lithofacies. Modified from Sandberg and others (1982, fig. 16).

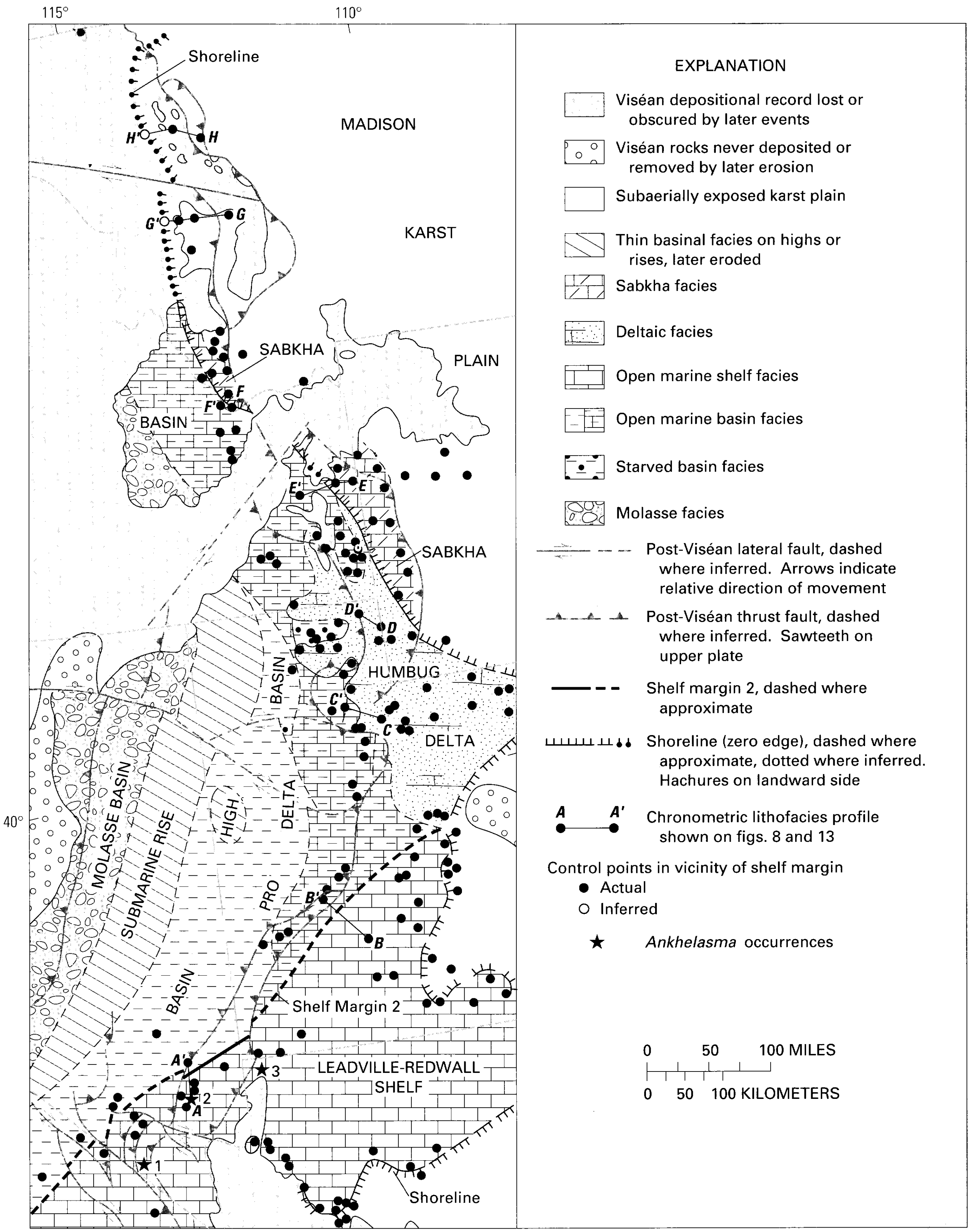

Figure 7. Early middle Viséan (upper Composite Zone 14) paleogeography of a part of the Western Interior basin in the United States and *Ankhelasma* occurrences in relation to shelf margin and lithofacies. Modified from Sandberg and others (1982, fig. 17).

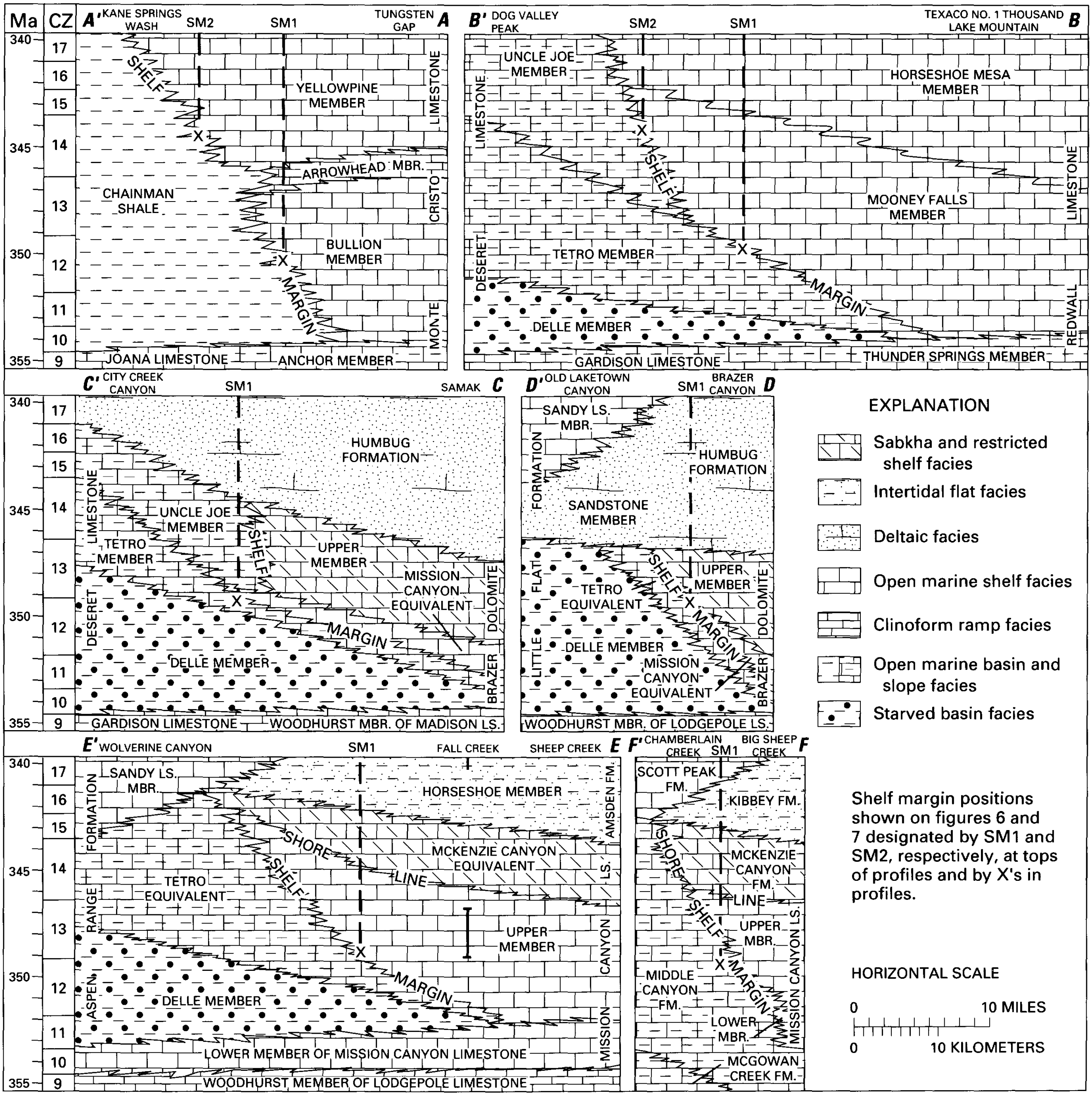

Figure 8. Chronometric lithofacies profiles across Viséan shelf margin in the Western United States. Geographic locations of profiles shown on figures 6 and 7. Control points for these profiles are listed and described in appendix B. Ma = million years before present (radiometric scale). CZ = composite zone.

near the base of Composite Zone 12 at two localities (see subsequent discussion in Western Canada section). Evidently, the genus originated either in northeastern Utah and migrated rapidly northward, or it originated in British Columbia or Alberta and migrated rapidly southward during earliest Viséan time (migration time estimated at <1 m.y.).

The lack of outcrops along the shelf margin between northeastern Utah and the southwestern corner of Utah prevents determination of the southern limit of *Ankhelasma* migration during the late early Viséan (Composite Zone 13). The genus has not been found in the Bullion Dolomite Member of the Monte Cristo Limestone in southeastern Nevada and southwestern Utah or in the Mooney Falls Member of the Redwall Limestone in northwestern Arizona, a distribution that suggests that *Ankhelasma* had not reached the southern part of the shelf at this time. However, the occurrence of *Ankhelasma* in the Yellowpine Member of the Monte Cristo Limestone (upper half of

Composite Zone 14) suggests that the genus was living in the intervening area of no outcrop during the late early Viséan (Composite Zone 13).

The early middle Viséan (Composite Zone 14) was characterized by uplift and subaerial erosion of the northern Madison shelf area to form the Madison karst plain (Sando, 1988) (fig. 7). A sabkha, represented by the McKenzie Canyon Limestone in southwestern Montana and the uppermost part of the Mission Canyon Limestone in southeastern Idaho and western Wyoming, occupied the shore of the karst plain. A tremendous volume of quartz sand derived from the uplifted Transcontinental arch to the east was brought by rivers westward across the karst plain in northwestern Colorado to form the Humbug Formation in northeastern Utah and equivalent rocks in southwestern Wyoming and southeastern Idaho (Sandberg and others, 1982, p. 714). Meanwhile, open marine shelf carbonate deposition continued on the Leadville-Redwall shelf in southern Utah, northern Arizona, and southeastern Nevada. By this time, unfavorable environments excluded *Ankhelasma* from the northern part of the area, but it continued to live within a zone approximately 40 km wide at the shelf margin (figs. 7 and 8) in southeastern Nevada and northeastern Arizona (table 1). The occurrence of the genus approximately 60 km landward from the shelf margin in extreme southeastern Nevada (locality 1) may be the result of incorrect location of the shelf margin due to poor control or to post-Laramide structural extension in this structurally complex area.

In the United States, *Ankhelasma* became extinct by the end of the early middle Viséan (Composite Zone 14), although seemingly favorable shelf carbonate environments continued into Composite Zone 15 on the Leadville-Redwall shelf (columns 1–3 on fig. 5). No phylogenetic successors are known.

Western Canada

In Canada, *Ankhelasma* has been found in a much more restricted area than in the United States. It is known only from east-central British Columbia (figs. 1 and 3), where it occurs in 10 closely spaced outcrop sections within the overthrust belt of the Rocky Mountain front ranges (fig. 9). Most of the occurrences are in a narrow belt of protected-shelf carbonates deposited slightly landward of the shelf margin of a carbonate platform (figs. 9–11) (see appendix C for complete descriptions of localities). The protected-shelf deposits extend northeastward from Jarvis Lakes in southeast Monkman Pass map area (NTS 93I) into the Sukunka River region of the Pine Pass map area (NTS 93O). Numerous specimens have also been collected from middle-slope carbonates (fig. 11) deposited southwest of the shelf-margin grainstone belt in the northwestern part of the study area (figs. 9 and 10, localities 1 and 2). No specimens of *Ankhelasma* have been found elsewhere in the Canadian Cordillera or in the Interior platform to the east, although more than 100 coral collections from correlative strata have been examined. The belt of protected-shelf, shelf-margin, and slope carbonates extends northeastward from the study area into the subsurface (figs. 3 and 9), where very few coral collections are available. South of the study area, the genus has not been observed in the numerous occurrences of protected-shelf and shelf-margin facies examined, but in this area, most of these facies have not been thoroughly sampled. Also, few coral collections have been made from this stratigraphic interval from slope-carbonate rocks in areas other than the study area (fig. 3). Therefore, the apparent geographic restriction of *Ankhelasma* in Canada is probably an artifact of sampling, but the possibility that it is related to undetermined environmental factors cannot be ruled out.

Ankhelasma has the same age range (Composite Zones 12 to 14) in Canada as in the United States (fig. 12). Localities 5 and 9 have yielded specimens from the basal part of Composite Zone 12, but most occurrences are in Composite Zone 13 or in the lower part of Composite Zone 14. The vertical distribution of these occurrences shows no obvious geographic pattern. Their zonal assignments are based on biostratigraphic data from associated foraminiferal faunas. The assignment of specimens from locality 2 was estimated from their stratigraphic position by correlation with nearby, well-dated sections.

Ankhelasma lived on the protected shelf and middle slope of a poorly differentiated middle Viséan carbonate platform that had a broad, sand-dominated shelf margin and low-gradient slope (fig. 11). The main lithofacies belts of the platform are incompletely preserved in the Turner Valley Formation, the lower part of the Mount Head Formation, and the Prophet Formation (fig. 10). The regional and local lithostratigraphy, lithofacies, and depositional environments of these formations have been discussed by Beauchamp and others (1986), Mamet and others (1986), and Richards and others (in press). A complete shelf-to-basin transition is preserved only in a series of sections (localities 1–3, fig. 9) in the northwestern part of the area. This transition reveals a westward progradation of the protected shelf, shelf margin, and slope. Elsewhere in the study area, protected-shelf deposits containing *Ankhelasma typicum* are widely preserved, but shelf-margin deposits are preserved only at locality 10 (fig. 9), and slope lithofacies are absent. In east-central British Columbia, the protected-shelf deposits containing *A. typicum* (figs. 9 and 10) formed near the seaward limit of the protected shelf and grade basinward (southwestward) into coeval shelf-margin and upper-slope facies. The protected-shelf deposits are mainly peloid- and pelletoid-bearing, mixed-skeletal grainstone and packstone deposited in shallow-subtidal (above storm wave base) environments (fig. 11). These deposits generally occur in the Turner Valley Formation and Baril(?) Member of the Mount Head Formation, but some of them

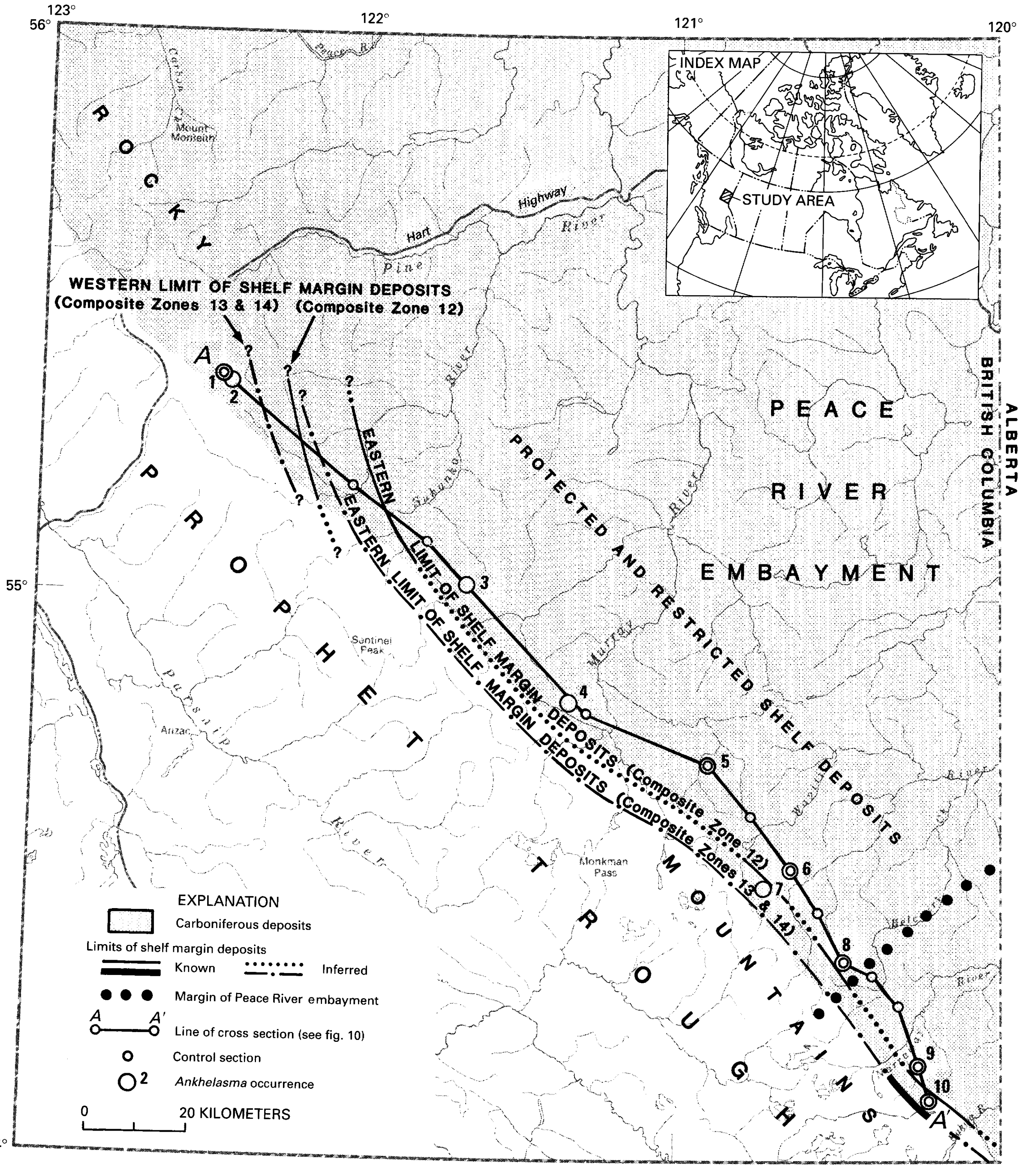

Figure 9. Present nonpalinspastic facies distribution of Viséan (Composite Zones 12 to 14) deposits, east-central British Columbia (see study area, fig. 3) and *Ankhelasma* occurrences in relation to shelf margin.

are in the Wileman(?) Member of the Mount Head Formation (figs. 10 and 12). Toward the east, the broad belt of protected-shelf lithofacies commonly records deepening. Farther eastward, protected-shelf lithofacies indicate shallowing, and eventually grade into intertidal to supratidal carbonates and anhydrite deposited on the inner protected shelf and on a vast restricted shelf (figs. 10 and 11).

The shelf-margin and upper slope facies are mainly bryozoan-pelmatozoan grainstone (fig. 11). In the study area, this belt of high-energy deposits, which has not been

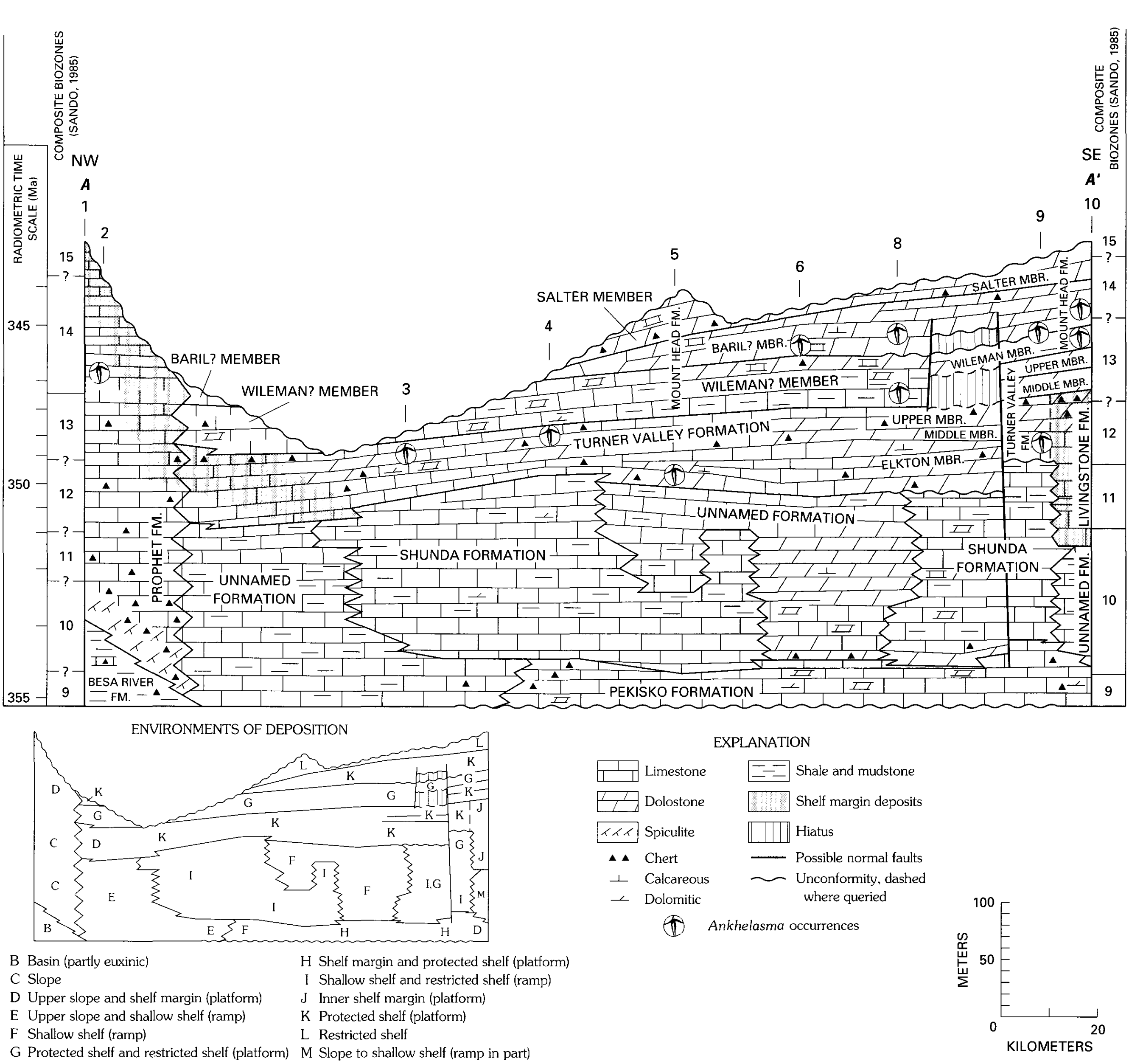

Figure 10. Stratigraphic cross section *A–A'* showing *Ankhelasma* occurrences (appendix C, localities 1–10) and depositional environments (fig. 11) in Rundle Group and Besa River Formation, study area, east-central British Columbia. Line of cross section shown on figure 9. Adapted from Richards and others (in press).

identified near *Ankhelasma* localities in the United States, is thin and relatively narrow compared to that of southwestern Alberta and southeastern British Columbia. In the latter region, the belt of shelf-margin grainstone is more than 30 km wide.

Toward the northwest, the shelf-margin and upper-slope grainstone grades into finer grained middle-slope and upper-slope lithofacies that occur in the Prophet Formation (figs. 9 and 10, localities 1 and 2) and locally contain abundant *Ankhelasma*. The coral-bearing slope deposits are bioturbated, cherty, pelmatozoan-spicule packstone. Corals in these deposits are very well preserved but appear to have been reworked, because they are not in growth position. They are not, however, associated with either shallow-water fossils or abundant bryozoans and pelmatozoan ossicles, the principal allochems of upper-slope and shelf-margin deposits. We conclude that these corals lived on the middle slope and did not originate on the upper slope or shelf margin. These middle-slope dwellers (fig. 11) are represented by a new species of *Ankhelasma* (fig. 2 *E*, *F*) known from no other localities in Canada or the United States. The unique occurrence of this species in Composite

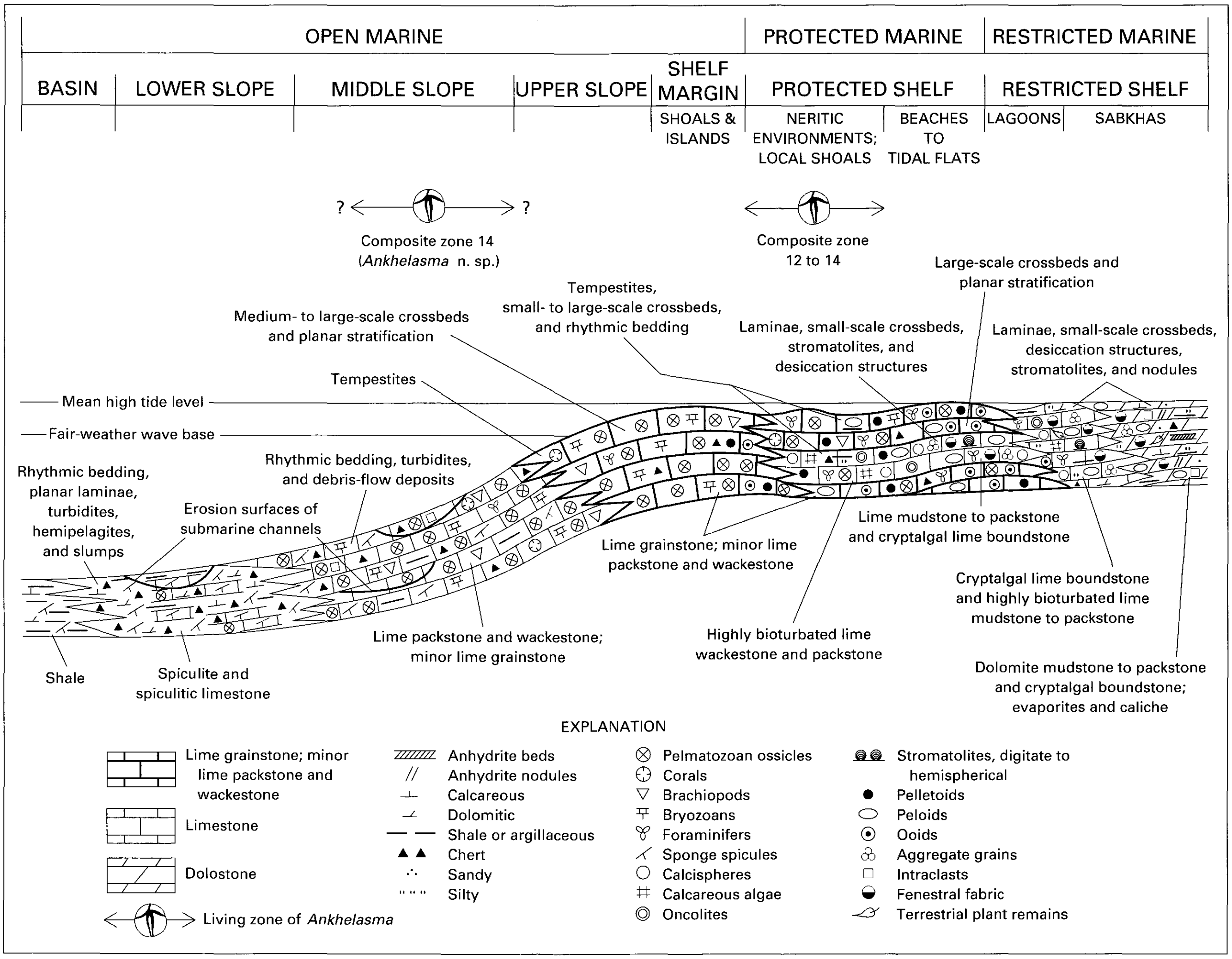

Figure 11. Generalized depositional model of Canadian Early Carboniferous carbonate platform (from Richards and others, in press).

Zone 14 at these localities may represent a migration of the genus down the slope from its earlier habitat behind the shelf margin toward the end of its phylogenetic life span.

The distribution of *Ankhelasma* suggests that the genus has considerable utility as a paleoenvironmental indicator. In east-central British Columbia, this readily identifiable and commonly abundant coral lived principally in neritic settings that were near or above storm wave base and were located on either side of the shelf-margin grainstone belt (fig. 11). All identified specimens of *A. typicum* came from deposits of the outer protected shelf, thereby suggesting that the species lived mainly on the outer protected shelf. *A.* n. sp. from localities 1 and 2 may be a slope indicator because it has been identified only from middle-slope deposits. *Ankhelasma* has not been observed in deep-water, shelf-margin, or intertidal deposits, and where it occurs in protected-shelf facies, these neritic deposits formed near the shelf margin. The fact that *Ankhelasma* has not been found east of the broad shelf-margin grainstone belt in Canada south of the study area may be related to the greater degree of restriction of the protected shelf in that area.

INFERRED SHELF-MARGIN LOCATIONS

Western United States

In northwestern Montana, erosion during and following Mesozoic and Cenozoic uplift removed most of the record of Viséan deposition (Sloss and Laird, 1945; Mudge and others, 1962; Haines, 1977), hence the location of the shelf margin is unknown. The occurrences of *Ankhelasma* at localities 12 and 13 provide a basis for estimating the shelf-margin location (fig. 6), by using the *Ankhelasma*

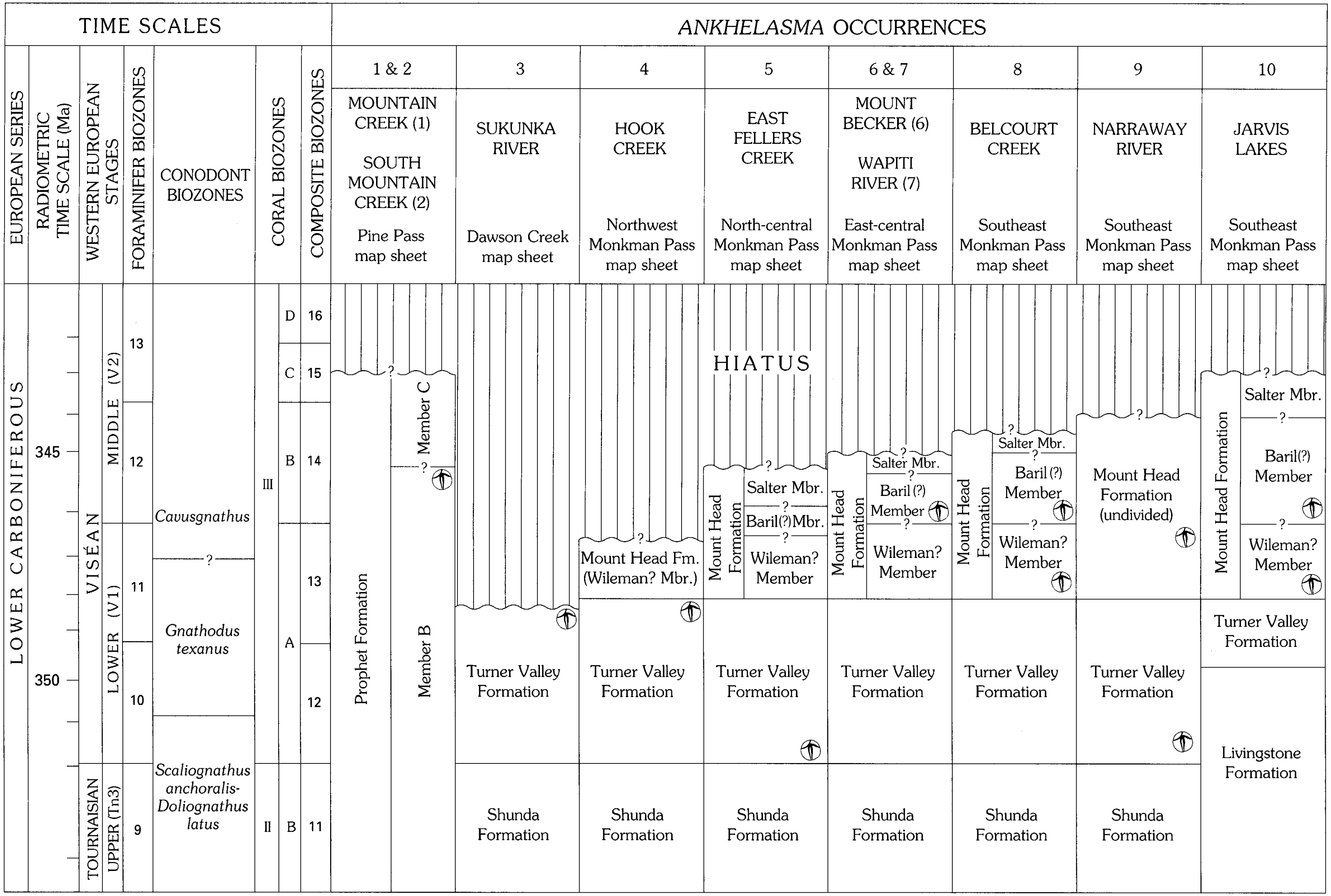

Figure 12. Temporal and stratigraphic distribution of *Ankhelasma* in east-central British Columbia. Coral symbols indicate positions of *Ankhelasma* at each locality. See figures 3 and 9 for geographic locations and appendix C for descriptions of localities. The positions of conodont biozone boundaries with respect to those of foraminifer, coral, and composite biozone boundaries differ slightly from those in the United States (see fig. 5). Foraminifer biozones are from Mamet and Skipp (1970). Conodont biozones are from Richards and others (in press) and Lane and others (1980). Coral biozones are from Sando and Bamber (1985). Composite biozones are from Sando (1985).

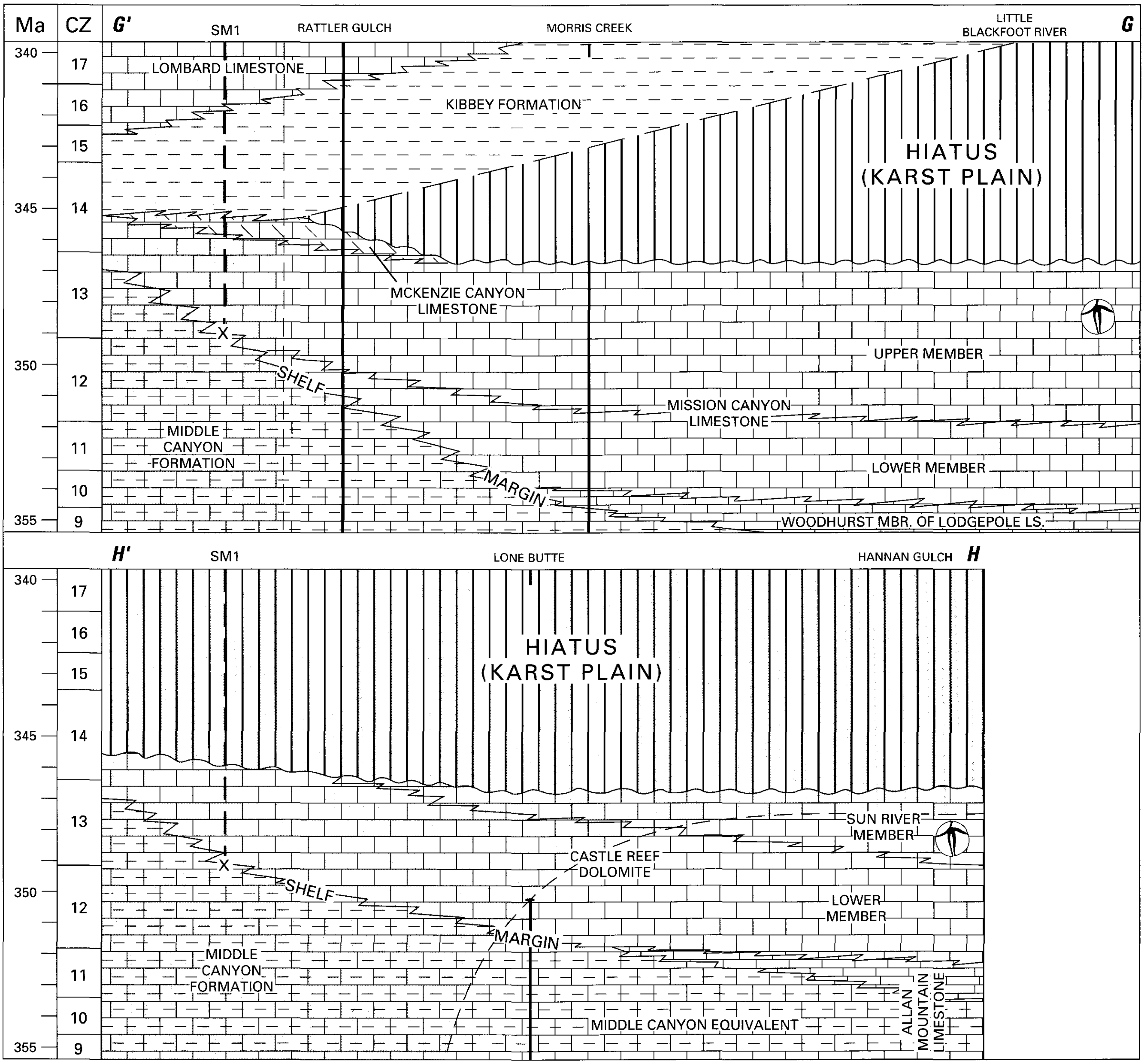

Figure 13. Chronometric lithofacies profiles from *Ankhelasma* localities 12 and 13 in westernmost Carboniferous outcrops in northwestern Montana to inferred shelf margin. Location of control points shown in figs. 6 and 7 and control points described in appendix D. Lost record indicated by shaded pattern. See figure 8 for explanation of other symbols.

distribution model (see p. B4–B11). These occurrences at localities 12 and 13 are in the lower half of Composite Zone 13 (fig. 5).

The *Ankhelasma* occurrence at Little Blackfoot River (locality 12, fig. 6) in profile *G–G'* (fig. 13) suggests a shelf-margin position no more than 50 km to the west of the *Ankhelasma* location, using the distribution model based on known distance from the shelf margin (table 1). However, outcrops of Viséan rocks between locality 12 and Rattler Gulch, 65 km to the west, do not reveal a basinal facies in Composite Zone 13, suggesting a shelf-margin position west of Rattler Gulch. The present position of the inferred shelf margin in this profile (*G–G'*), based on westward projection of lithofacies trends, is approximately 75 km west of locality 12 (fig. 13). This anomaly is thought to be the result of post-Laramide structural extension along this profile, on the basis of recent recognition of structural extension in the thrust belt (W.J. Perry, oral commun., 1987).

The *Ankhelasma* occurrence at Hannan Gulch (locality 13, fig. 6) in profile *H–H'* (fig. 13) is compatible with the distribution model. Westward projection of lithofacies trends in this profile indicates a shelf-margin position 45 km west of the *Ankhelasma* location (fig. 13).

Western Canada

In the overthrust belt of east-central British Columbia, the protected-shelf occurrences of *Ankhelasma* are located in a narrow, northwest-trending outcrop belt subparallel to the depositional and structural strike of Viséan rocks (figs. 3, 9, and 10). Viséan shelf-margin deposits are preserved only in the northwestern and southeastern parts of the Carboniferous outcrop belt. Most *Ankhelasma* occurrences on the protected shelf lie east of an area of lost Viséan record. The relative, present position of the shelf-margin deposits is known for only two of these occurrences (localities 9 and 10, figs. 9 and 10). The eastern limits of the shelf-margin deposits assigned to Composite Zones 12 to 14 were projected into the area of lost record by means of lithofacies analyses based on unpublished field observations. The placement of these projected limits is supported by comparison with the occurrences of *Ankhelasma* shown on figure 9. All protected-shelf occurrences of the genus lie within 11 km of the known and projected eastern shelf-margin limits, well within the present-day width of the *Ankhelasma* belt established for the Western United States.

The maximum present width of the main *Ankhelasma* belt on the protected shelf in Canada is less than the average width (about 22 km) of the *Ankhelasma* belt in the United States (table 1). This may be only an apparent difference resulting from different definitions of the shelf margin in the two areas. In Canada, the shelf margin is defined by a grainstone belt that is more than 10 km wide (fig. 9), whereas in the United States, the margin is defined by an arbitrary line separating shelf and off-shelf lithofacies (figs. 6 and 7). Laramide thrusting and folding also may have reduced the widths of the Carboniferous facies belts more in Canada than in the United States.

CONCLUSIONS

(1) The distinctive, endemic rugose coral genus *Ankhelasma* Sando, 1961, occurs only in a narrow geographic belt in rocks of early and middle Viséan age in the Western Interior region of North America. With very few exceptions, this *Ankhelasma* belt is located on the landward side of the Viséan shelf margins.

(2) Only two species have been recognized thus far in all the known occurrences of the genus. *Ankhelasma typicum* Sando, 1961, the more abundant species, lived exclusively in shallow, subtidal environments of the outer protected shelf within approximately 50 km of the shelf margin during the early and middle Viséan. Toward the end of the phylogenetic life span of *Ankhelasma*, an undescribed new species lived on the middle slope of a middle Viséan carbonate platform on the seaward side of the shelf margin in east-central British Columbia (Peace River embayment).

(3) The model of *Ankhelasma* distribution, based on known occurrences, can be used to predict locations of Viséan shelf margins in areas where the Viséan depositional record was removed by erosion or obscured by later tectonism. This model may also be used to confirm or deny shelf-margin projections by lithofacies analyses into areas where lithofacies data are sparse or unavailable.

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APPENDIX A. *ANKHELASMA* LOCALITIES IN THE UNITED STATES

1. Potosi Mine

Location: CN½ SW¼ NE½ sec. 12, T. 23 S., R. 57 E., Shenandoah Peak quadrangle (15 min), Goodsprings district, Clark County, Nevada.

Stratigraphic position: Yellowpine Member of Monte Cristo Limestone, 0–1.2 m (0–4 ft) above base.

Collections:
- USGS 27968–PC, 0.9–1.2 m (3–4 ft) above base: Approximately 150 silicified specimens of *A. typicum* Sando etched from limestone.
- Sandberg Sample PO–3, lower 0.09 m (0.3 ft): Two silicified specimens of *A.* sp. indet. etched from limestone.

Lithology: Thick-bedded, fine- to medium-grained crinoidal limestone. Collected sample is dark, crinoidal packstone.

Age: Associated fossils (USGS 27968–PC) are *Canadiphyllum*? sp., *Syringopora* sp., and Foraminifer Zone 12 microfossils (table A1). The occurrence is regarded as high in Composite Zone 14 because the underlying Arrowhead Member contains Foraminifer Zone 12 microfossils (table A1) (USGS 27967–PC), and overlying beds in the Yellowpine Member yielded Foraminifer Zone 12/13 microfossils (table A1) (USGS 27969–PC).

2. Tungsten Gap (see Pierce and Langenheim, 1974, for published stratigraphic section.

Location: CN½ sec. 10, T. 15 S., R. 64 E., Arrow Canyon quadrangle (15 min), Arrow Canyon Range, Clark County, Nevada.

Stratigraphic position: Yellowpine Member of Monte Cristo Limestone, 1.5–7.6 m (5–25 ft) above base.

Collections:
- USGS 27974–PC, 7.6 m (25 ft) above base: Approximately 40 calcareous specimens of *A. typicum* Sando in limestone.
- USGS 27841–PC, lower 6.1 m (20 ft): Approximately 20 calcareous specimens of *A. typicum* Sando in limestone.
- USGS 27842–PC, 1.5–2.4 m (5–8 ft) above base: Approximately 100 calcareous specimens of *A. typicum* Sando in limestone.

Lithology: Thick-bedded, dark, fine- to medium-grained crinoidal limestone. Collected samples are dark, medium-grained crinoidal grainstone.

Age: Foraminifer control is lacking in this section. The occurrence of *Siphonodendron* sp., *Vesiculophyllum* sp., *Amplexizaphrentis* sp., and *Syringopora* sp. suggests Coral Zone IIIA or B. Conodont evidence suggests that the *Ankhelasma* occurrence is high in Composite Zone 14, similar to the occurrence at Potosi Mine (C.A. Sandberg, oral commun., 1986).

3. Virgin River Gorge (see Steed, 1980, for general geology of this locality).

Location: Secs. 20 and 30, T. 41 N., R. 14 W., Littlefield quadrangle (15 min), Mohave County, Arizona.

Stratigraphic position: Lowermost part of Yellowpine Member of Monte Cristo Limestone.

Age: Abundant specimens of *Ankhelasma* sp. undet. were identified in the field by C.A. Sandberg (oral commun., 1986). No fossils were collected, but this occurrence is presumably the same stratigraphic level and age (Composite Zone 14) as occurrences at Potosi Mine and Tungsten Gap.

4. Samak (see Dockal, 1980, for additional data).

Location: S½ NE¼ NE¼ sec. 25, T. 2 S., R. 6 E., Woodland quadrangle (7.5 min), Uinta Mountains, Summit County, Utah.

Stratigraphic position: Brazer Dolomite, 1.5 m (5 ft) below top of Mission Canyon equivalent (member 2 of the Brazer).

Collection:
- USGS 27065–PC: One silicified specimen of *A.* cf. *A. typicum* Sando etched from limestone.

Lithology: Medium-bedded, dark, fine- to medium-grained crinoidal limestone. Collected sample is partly dolomitized crinoidal packstone.

Age: *Ankhelasma* occurs here with *Siphonodendron oculinum* Sando, *Sychnoelasma* sp., *Vesiculophyllum* sp., *Lophophyllum*? sp., *Amplexizaphrentis* sp., and

Table A1. Foraminifers and algae in samples from the United States cited in appendix A

[All samples are registered in U.S. Geological Survey Upper Paleozoic Catalog, except for BSH–2A, which is in the catalog of C.A. Sandberg. Identifications of fossils by B.L. Mamet]

Taxa	Potosi Mine			Trail Hollow	Emma Canyon	Unnamed Crawford Mts.	Haystack Peak	Sheep Creek			Big Sheep Creek		Bell Canyon		Little Blackfoot River
	27969	27968	27967	27074	16936	18074	17896	20122	20121	20177	BSH–2A	28605	29305	29309	21483
Atractyliopsis sp.			X												
Brunsia sp.	X														
Calcisphaera laevis Williamson					X		X	X			X			X	
C. pachysphaerica (Pronina)				X	X	X	X	X	X	X	X	X			
C. sp.	X	X	X									X			X
Dainella cf. *D. anivikensis* Mamet			X												
D. sp.			X												
Earlandia clavicula (Howchin)									X						
E. vulgaris (Rauzer-Chernoussova and Reitlinger)		X	X	X	X			X	X			X	X	X	X
E. sp.						X	X	X		X					
Eblanaia sp.		X										X			
Endothyra sp.	X	X	X	X		X						X	X	X	X
cf. *Endothyranopsis*? sp.	X														
Eoendothyranopsis hinduensis (Skipp)		X	X											X	
E. scitula (Toomey)	X														
E. spiroides (Zeller)	X		X		X										
E. spiroides spiroides (Zeller)		X							X						
E. of the group *E. spiroides* (Zeller)								X	X			X		X	X
E. sp.								X					X		
Eoforschia moelleri (Malakhova in Dain)		X													
E. sp.	X	X	X								X			X	X
Eogloboendothyra sp.						X	X	?		X	X				
Eoparastafella ovalis Vdovenko				X	X										
Girvanella sp.	X														
Globoendothyra bridgensis (Skipp)		X													
G. of the group *G. baileyi* (Hall)				X				X	X		X	X			X
G. of the group *G. tomiliensis* (Grazdilova in Lebedeva)	X													X	
G. sp.			X		X		X		X	X				X	
G.? trachida (Zeller)											X				
Issinella devonica Reitlinger												X			
I. sp.											X				
Koninckopora inflata (de Koninck)														X	
K. sp.		X													
Latiendothyra sp.					X	X				X	X				
Mametella sp.		X							X				X		
Orthriosiphon sp.							X			X					
Orthriosiphonoides sp.		X													X
Ortonella sp.										X				X	
Paleoberesella lahuseni (von Möller)												X			
P. sp.							X								X
Parathurammina sp.								X			X	X			
Pohlia henbesti (Skipp, Holcomb, and Gutschick)															X
Priscella sp.	X		X	X	X	X	X	X	X		X	X	X	X	X
Pseudoammodiscus sp.														X	X
Septabrunsiina sp.										X					
S. sp.	X	X	X										X		
cf. *Skippella*? sp.					X			X							
cf. *Spinoendothyra*? sp.											X				
Stacheinae									X						
Stacheoides sp.	?														X
Tetrataxis sp.	X			X					X						X

Syringopora morphogroup C (USGS 27065–PC), which are indicative of Coral Zone IIIA (near base). Conodonts from this stratigraphic level represent either the *Scaliognathus anchoralis-Doliognathus latus* Zone or the *Gnathodus texanus* Zone (C.A. Sandberg, oral commun., 1978). These fossils suggest a zonal position at or near the base of Composite Zone 12.

5. Trail Hollow (see Dockal, 1980, for additional data).
Location: NW1/4 sec. 33, T. 3 S., R. 9 W., Iron Mountain quadrangle (7.5 min), Uinta Mountains, Wasatch County, Utah.

Stratigraphic position: Brazer Dolomite, 1.5–7.6 m (5–25 ft) below top of Mission Canyon equivalent (member 2 of the Brazer).
Collection: • USGS 27074–PC: Approximately 100 calcareous specimens of *A. typicum* Sando in limestone.
Lithology: Thin- to thick-bedded, weakly laminated, coarse-grained bioclastic limestone. Collected sample is dark, partly dolomitized coral packstone.
Age: This sample contains the same assemblage of corals and conodonts as USGS 27065–PC at Samak. It also contains foraminifers that have a possible range of Foraminifer Zone 10 to 12 (table A1). A zonal range at or near the base of Composite Zone 12 is indicated.

6. Crawford Mountains (see Sando and others, 1959, and Sando, 1961, for additional data). All specimens belong to *Ankhelasma typicum* Sando and are from the Randolph quadrangle (15 min), Rich County, Utah.

A. Unnamed locality
Location: NW1/4 NW1/4 sec. 29, T. 11 N., R. 8 E.
Stratigraphic position: Brazer Dolomite, upper member (member 3), exact position unknown.
Collection: • USGS 486–PC: Three specimens preserved as molds and casts in chert.
Lithology: Collected sample is cherty, dark, fine-grained calcitic dolomite.
Age: The sample contains nondiagnostic brachiopods and corals. It is dated as middle Composite Zone 12 on the basis of similarity of its stratigraphic position to collections from nearby localities that have been dated by diagnostic fossils.

B. Brazer Canyon (type section of Brazer Dolomite)
Location: SE1/4 NW1/4 sec. 20, T. 11 N., R. 8 E.
Stratigraphic position: Brazer Dolomite, 44.5–50.6 m (146–166 ft) above base of upper member.
Collections: • USGS 16906–PC, 44.5 m (146 ft) above base: Two poorly preserved calcitic and dolomitic specimens in dolomite.
• USGS 16907–PC, 48.2 m (158 ft) above base: Two poorly preserved calcitic and dolomitic specimens in dolomite.
• USGS 16908–PC, float from 41.2–50.6 m (135–166 ft) above base: Eleven poorly preserved calcitic and dolomitic specimens in dolomite.
Age: These samples contain *Zaphriphyllum* sp., *Canadiphyllum* sp., and *Vesiculophyllum*? sp., which suggest Coral Zone IIIA. A zonal position near the middle of Composite Zone 12 is suggested by proximity to Coral Zone II corals in the underlying Mission Canyon equivalent (member 2 of the Brazer). No conodonts or foraminifers were found.

C. Emma Canyon
Location: C sec. 17, T. 11 N., R. 8 E.
Stratigraphic position: Brazer Dolomite, 44.2–56.4 m (145–185 ft) above base of upper member (member 3).
Collections: • USGS 16936–PC, 48.2 m (156 ft) above base: Approximately 30 specimens preserved as molds and casts in chert.
• USGS 16938–PC, 56.4 m (185 ft) above base: Six poorly preserved calcitic and dolomitic specimens in dolomite.
• USGS 16939–PC, 44.2 m (145 ft) above base: Three poorly preserved calcitic and dolomitic specimens in dolomite.
Lithology: Same as locality 6B; chert preserves pelletal packstone texture.
Age: The interval containing *Ankhelasma* at this locality is approximately the same as that at locality 6B, which has been dated as middle Composite Zone 12. USGS 16936–PC at Emma Canyon contains microfossils of Foraminifer Zone 10 or 11 (table A1), which confirms the Composite Zone 12 determination.

D. Rex Peak
Location: N1/2 sec. 31, T. 11 N., R. 8 E.

Stratigraphic position: Brazer Dolomite, 37.5–40.5 m (123–133 ft) above base of upper member (member 3).

Collections: • USGS 17717–PC, exact position unknown: Several hundred poorly preserved silicified specimens etched from dolomite.

• USGS 17722–PC, 37.5–40.5 m (123–133 ft) above base: 285 well-preserved silicified specimens and several hundred poorly preserved ones etched from dolomite.

Lithology: Same as locality 6B.

Age: Same as locality 6B.

E. Unnamed Crawford Mountains

Location: NW1/4 NW1/4 sec. 6, T. 10 N., R. 8 E.

Stratigraphic position: Brazer Dolomite, upper member (member 3), exact position unknown.

Collection: • USGS 18074–PC, exact position unknown: Approximately five poorly preserved calcitic and dolomitic specimens in dolomite.

Lithology: Same as locality 6B.

Age: Same as locality 6B. USGS 18074–PC contains microfossils of Foraminifer Zone 10 or 11 (table A1), which confirms the Composite Zone 12 determination for *Ankhelasma* at this locality.

7. Haystack Peak (see Sando and Dutro, 1981, for description of stratigraphic section).

Location: NW1/4 NE1/4 sec. 27, T. 34 N., R. 117 W., Bedford quadrangle (7.5 min), Salt River Range, Lincoln County, Wyoming.

Stratigraphic position: Mission Canyon Limestone, 94.5–97.5 m (310–320 ft) below top (unit 49 of Sando and Dutro, 1981, p. 12).

Collection: • USGS 17900–PC: One partly silicified calcitic specimen in limestone and two silicified specimens etched from limestone, all identified as *A.* cf. *A. typicum* Sando.

Lithology: Thin- to medium-bedded, medium- to very coarse grained crinoidal bioclastic limestone. Collected sample is dark crinoidal packstone.

Age: This occurrence is well documented with corals of Zone IIIA (*Siphonodendron oculinum* Sando, *Zaphriphyllum* sp., *Amplexizaphrentis* sp., *Vesiculophyllum* sp., *Sychnoelasma* sp., *Syringopora* morphogroups B and C, *Pleurosiphonella* morphogroup A) that occur in the same bed (USGS 17900–PC) and above (USGS 17901–PC) and below (USGS 17899–PC) it. Foraminifer Zone 9/10 microfossils occur below the collection (table A1) (USGS 17896–PC). A zonal position near the middle of Composite Zone 12 is indicated for *Ankhelasma* here.

8. Sheep Creek (see Sando and Dutro, 1981, for description of stratigraphic section).

Location: E1/2 sec. 28, T. 1 N., R. 45 E., Irwin quadrangle (30 min), Snake River Range, Bonneville County, Idaho.

Stratigraphic position: Mission Canyon Limestone, 93–96 m (305–315 ft) below top (unit 56 of Sando and Dutro, 1981, p. 86).

Collection: • USGS 20122–PC: One calcitic specimen of *A.* cf. *A. typicum* Sando in limestone.

Lithology: Medium- to thin-bedded, dark, predominantly fine-grained limestone. Collected sample is dark, crinoidal, foraminiferal packstone.

Age: This occurrence is well documented with corals of Zone IIIA (*Siphonodendron oculinum* Sando, *Zaphriphyllum* sp., *Amplexizaphrentis* sp., *Vesiculophyllum* sp., *Syringopora* morphogroups B and C). The corals occur with microfossils of Foraminifer Zones 10–11 (table A1) (USGS 20122–PC) and occur below microfossils of Foraminifer Zone 11 (table A1) (USGS 20121–PC) and above microfossils of Foraminifer Zone 10(?) (table A1) (USGS 20117–PC). A zonal position in the upper half of Composite Zone 12 is indicated for *Ankhelasma* here.

9. Chamberlain Creek (see Skipp and others, 1984, pl. 1, for geologic map of the area).

Location: SE1/4 sec. 20, T. 14 N., R. 29 E., Morrison Lake quadrangle (15 min), Beaverhead Mountains, Lemhi County, Idaho.

Stratigraphic position: Debris flow in Middle Canyon Formation, exact position unknown.

Collection: • USGS 29260–PC: One calcitic specimen of *A.* cf. *A. typicum* Sando in limestone.

Lithology: Collected sample is dark, silty and argillaceous, phosphatic, coarse-grained crinoidal grainstone.

Age: Other megafossils collected from the locality (USGS 29584–PC) include indeterminate horn corals, euomphalacean gastropods, a spiriferoid brachiopod, and an orthoceracone cephalopod, none of which is diagnostic for age determination. Matrix from USGS 29584–PC yielded zonally indeterminate conodonts *Bispathodus utahensis* and *Polygnathus communis communis*, which have a range from Osagean to middle Meramecian (late Tournaisian to middle Viséan) (C.A. Sandberg, written commun., 1985). The deposit is interpreted as a debris flow derived from shallow-water-shelf sediments of Composite Zone 12 age (Mission Canyon

Limestone) and redeposited in a deep basin represented by the Middle Canyon Formation. Dating is based on the age of in situ occurrence at Big Sheep Creek (locality 10).

10. Big Sheep Creek

Location: SW1/4 NE1/4 sec. 22, T. 14 S., R. 10 W., Gallagher Gulch quadrangle (7.5 min), Tendoy Mountains, Beaverhead County, Montana.

Stratigraphic position: Mission Canyon Limestone, upper member, approximately 6.7 m (22 ft) above base.

Collection: • USGS 28605–PC: Six calcitic specimens of *A.* cf. *A. typicum* Sando in limestone.

Lithology: Collected sample is dark, partly dolomitized crinoidal packstone.

Age: Corals of Zone IIIA (*Vesiculophyllum* sp., *Siphonodendron oculinum* Sando, and *Syringopora* sp.) occur immediately above the bed containing *Ankhelasma*. Microfossils of Foraminifer Zone 10–11 (table A1) (Sandberg Sample BSH–2A) occur at the same level as the collected sample. A zonal position near the base of Composite Zone 12 is indicated for *Ankhelasma* here.

11. Bell Canyon (see Sando and others, 1985, for section description).

Location: NW1/4 NE1/4 SW1/4 sec. 17, T. 11 S., R. 10 W., Red Rock and Kidd quadrangles (7.5 min), Tendoy Mountains, Beaverhead County, Montana.

Stratigraphic position: Mission Canyon Limestone, near top of lower(?) member to 26 m (85.3 ft) below top of upper member.

Collections: • USGS 29305–PC, 26 m (85.3 ft) below top of upper member: Three calcitic specimens of *A.* cf. *A. typicum* Sando in limestone.
• USGS 28604–PC, structurally complex outcrops seemingly near top of lower member: Five calcitic specimens of *A.* cf. *A. typicum* Sando in limestone.

Lithology: Collected sample USGS 29305–PC is dark, partly dolomitized crinoidal grainstone. Collected sample USGS 28604–PC is light, sheared and veined, crinoidal packstone.

Age: The lowest *Ankhelasma* found in this sequence (USGS 28604–PC) is from structurally complex outcrops that seem to belong to the uppermost part of the lower member of the Mission Canyon Limestone. This sample contains zonally undiagnostic corals (*Vesiculophyllum* sp., *Amplexizaphrentis* sp.) and microfossils of Foraminifer Zone 11 or 12 (table A1).
A higher occurrence near the top of the upper member of the Mission Canyon Limestone (USGS 29305–PC) is well located stratigraphically and is well documented by corals of Zone IIIA (*Siphonodendron oculinum* Sando) both above it (USGS 29306–PC) and below it (USGS 19304–PC). *Ankhelasma* here occurs with microfossils of Foraminifer Zone 11 or 12 (table A1) (USGS 29305–PC), and the occurrence is not far below Foraminifer Zone 12 microfossils (USGS 29309–PC) at the top of the upper member. The total range of *Ankhelasma* at this locality would seem to be from a level low in Composite Zone 13 to about the middle of that composite zone.

12. Little Blackfoot River (Hope Creek) (see Bierwagen, 1964, for description of the locality).

Location: NW1/4 SW1/4 sec. 29, T. 11 N., R. 6 W., Helena quadrangle (15 min), Lewis and Clark County, Montana.

Stratigraphic position: Mission Canyon Limestone, near top.

Collection: • USGS 21483–PC, near top of Mission Canyon Limestone: One calcitic specimen of *A.* cf. *A. typicum* Sando in limestone.

Lithology: Collected sample is dark, medium-grained, crinoidal oolitic grainstone.

Age: Approximate stratigraphic position of this occurrence was established by reconnaissance of the outcrop area by Sando. The collected sample contains microfossils of Foraminifer Zone 11 (table A1), which indicates a position in Composite Zone 13.

13. Hannan Gulch (see Mudge and others, 1962, and Mudge, 1972, for description of stratigraphic section).

Location: Sec. 35, T. 22 N., R. 9 W., Sawtooth Ridge quadrangle (7.5 min), Sawtooth Range, Teton County, Montana.

Stratigraphic position: Sun River Member of Castle Reef Dolomite, 48.8 m (160 ft) above base of member.

Collections: • USGS 18005–PC: One dolomitic specimen (five transverse thin sections) of *A.* cf. *A. typicum* Sando in dolomite.
• USGS 19542–PC: Five dolomitic specimens of *A.* cf. *A. typicum* Sando in dolomite.

Lithology: Collected samples are light, medium- to coarse-grained dolomitized crinoidal grainstone or packstone.

Age: *Ankhelasma* occurs with *Zaphriphyllum* sp., which suggests Coral Zone IIIA for the occurrence. Nichols (1986) reported *Gnathodus texanus* Zone conodonts from the same beds. The zonal level is probably the lower half of Composite Zone 13.

APPENDIX B. CONTROL POINTS FOR CHRONOMETRIC LITHOFACIES PROFILES ACROSS KNOWN VISÉAN SHELF MARGIN IN THE UNITED STATES (FIG. 8)

[Interpretations of the stratigraphy by the writers may differ from published references]

Profile *A–A′*

Kane Springs Wash: T. 11 S., R. 64 E., Lincoln County, Nevada. Graphic section by Langenheim (1962, fig. 2, and 1963, fig. 2). Ages determined by physical correlation to Alamo section in T. 6 S., R. 60 E. (Poole and Sandberg, 1977, fig. 2b, loc. 20).

Tungsten Gap: Secs. 11 and 12, T. 14 S., R. 64 E., Clark County, Nevada. Unpublished section measured by Sandberg and Sando. Ages determined by conodonts and corals.

Profile *B–B′*

Dog Valley Peak: Sec. 17, T. 25 S., R. 6 W., Millard County, Utah. Unpublished section measured by Sandberg, Gutschick, and Sando. Part of section described by Sandberg and Gutschick (1984, fig. 10). Ages determined by foraminifers, conodonts, and corals.

Texaco No. 1 Thousand Lake Mountain well: Sec. 11, T. 28 S., R. 4 E., Wayne County, Utah. Well log by Parker and Roberts (1963, fig. 14). Ages determined by physical correlation to Beaverdam Mountains in sec. 35, T. 42 S., R. 18 W., Washington County (Langenheim, 1963, fig. 1).

Profile *C–C′*

City Creek Canyon: Sec. 5, T. 1 N., R. 2 E., Summit County, Utah. Unpublished section measured by Gutschick. Ages determined by corals.

Samak: Sec. 25, T. 2 S., R. 6 E., Summit County, Utah. Section described by Dockal (1980, p. 263–280). Ages determined by corals, foraminifers, and conodonts.

Profile *D–D′*

Old Laketown Canyon: Sec. 32, T. 32 N., R. 6 E., Rich County, Utah. Section described by Sando and others (1959, p. 2762–2763, fig. 5) and reinterpreted by Sando and others (1981, fig. 6, col. 3). Ages determined by corals, conodonts, and foraminifers.

Brazer Canyon: Sec. 20, T. 11 N., R. 8 E., Rich County, Utah. Section described by Sando and others (1959, p. 2751–2754, fig. 5) and reinterpreted by Sando and others (1981, fig. 6, col. 5). Ages determined by corals, conodonts, and foraminifers.

Profile *E–E′*

Wolverine Canyon: Secs. 1, 2, 10, and 11, T. 2 S., R. 38 E., Bingham County, Idaho. Unpublished section measured by Sandberg and Sando. Ages determined by corals and foraminifers.

Fall Creek: Sec. 8, T. 1 N., R. 43 E., Bonneville County, Idaho. Locality studied by Sando and Sandberg. Ages determined by corals.

Sheep Creek: E½ sec. 28, T. 1 N., R. 45 E., Bonneville County, Idaho. Section described by Sando and Dutro (1981). Ages determined by corals and foraminifers.

Profile *F–F′*

Chamberlain Creek: Sec. 20, T. 14 N., R. 29 E., Lemhi County, Idaho. Locality mapped by Skipp and others (1984). Ages determined by conodonts and by physical correlation to Copper Mountain section in secs. 25 and 26, T. 10 N., R. 30 E., Clark County (Huh, 1967, fig. 3, and 1968, section log).

Big Sheep Creek: Sec. 36, T. 14 S., R. 10 W., Beaverhead County, Montana. Unpublished section measured by Sandberg and Sando. Ages determined by corals and foraminifers.

APPENDIX C. *ANKHELASMA* LOCALITIES IN EAST-CENTRAL BRITISH COLUMBIA, CANADA

1. Mountain Creek

Location: Lat 55°23′30″ N., long 122°26′00″ W.; approximately 2.4 km (1.5 mi) east of Mountain Creek, Pine Pass 1:250,000-scale map sheet (NTS 93O).

Stratigraphic position: Prophet Formation, 129.8 –150 m (426–492 ft) below top, upper part of member B.

Collections:
- GSC loc. C4562, 149.3–150 m (490–492 ft) below top of Prophet Formation: Approximately 250 silicified specimens of *A.* n. sp.
- GSC loc. C4563, 135.3–141.4 m (444–464 ft) below top of Prophet Formation: One immature, silicified specimen of *A. typicum*? Sando.
- GSC loc. C4564, 129.8 m (426 ft) below top of Prophet Formation: Two silicified specimens of *A.* sp. indet.

Lithology: Cherty, peloid-bearing, partly dolomitic, spicular, mixed-skeletal packstone and subordinate wackestone and grainstone. Lower part of unit contains dolomitic spiculite.

Collected samples:
- GSC loc. C4562, slightly cherty and argillaceous, pelmatozoan-spicule packstone having corals, brachiopods, and bryozoans.
- GSC loc. C4563, sparsely fossiliferous, finely crystalline dolostone having brachiopods and corals.

• GSC loc. C4564, cherty, peloid-spicule lime packstone having corals, pelmatozoan ossicles, and brachiopods.

Age: All *Ankhelasma* occurrences at this locality are assigned to Composite Zone 14. Associated corals (GSC loc. C4562) are *Amplexizaphrentis* sp. and *Lophophyllum*? sp., which are zonally nondiagnostic, but microfossils from 19.3 m (63 ft) above *Ankhelasma* belong to Foraminifer Zone 12 (GSC loc. C69462), and those from 11.3 m (37 ft) below *Ankhelasma* are tentatively assigned to Foraminifer Zone 11 or 12 (GSC loc. C69453) (table C1).

2. South Mountain Creek

Location: Lat 55°22′00″ N., long 122°23′15″ W.; approximately 3.2 km (2 mi) east of Mountain Creek, Pine Pass 1:250,000-scale map sheet (NTS 93O).

Stratigraphic position: Prophet Formation, 134.1 m (440 ft) below top, uppermost part of member B.

Collection: • GSC loc. C110910: Twenty-five silicified specimens of *A.* n. sp.

Lithology: Cherty, spicular limestone similar to the rocks described in the Mountain Creek section (locality 1). No matrix was preserved in the collected sample.

Age: No associated fossils were found at South Mountain Creek, but in the nearby Mountain Creek section (fig. 12, locality 1), microfossils from approximately the same stratigraphic level belong to Foraminifer Zone 12. Hence, the South Mountain Creek occurrence of *Ankhelasma* is regarded as Composite Zone 14.

3. Sukunka River

Location: Lat 55°01′20″ N., long 121°38′25″ W.; approximately 6.4 km (4 mi) east of the upper Sukunka River, Dawson Creek 1:250,000-scale map sheet (NTS 93P).

Stratigraphic position: Turner Valley Formation, 7.3 m (24 ft) below top.

Collection: • GSC loc. C4629: Two silicified specimens of *A.* sp. indet.

Lithology: Packstone and wackestone rich in algae and subordinate echinoderm-bryozoan grainstone in upper part of unit. Main bioclasts are calcareous algae, foraminifers, pelmatozoan ossicles, and ostracodes. Collected sample is peloid-pelmatozoan grainstone having calcareous algae, pelletoids, calcispheres, and foraminifers.

Age: Associated corals are *Zaphriphyllum* cf. *Z. disseptum* Sutherland, which suggests the upper part of Coral Zone IIIA. Microfossils of Foraminifer Zone 11 (GSC loc. C69613) (table C1) occur 11.3 m (37 ft) below *Ankhelasma*. The occurrence of *Ankhelasma* here is regarded as Composite Zone 13.

4. Hook Creek

Location: Lat 54°48′40″ N., long 121°19′00″ W.; approximately 1.6 km (1 mi) northeast of Hook Lake, Monkman Pass 1:250,000-scale map sheet (NTS 93I).

Stratigraphic position: Turner Valley Formation, 43 m (141 ft) above base.

Collection: • GSC loc. C7316: Four silicified, immature specimens of *A. typicum*? Sando.

Lithology: Cherty, peloid- and pelletoid-bearing, mixed-skeletal lime grainstone and packstone and subordinate lime wackestone and dolostone. Main bioclasts are calcareous algae, foraminifers, and pelmatozoan ossicles. Collected sample is slightly cherty, pelletoid-foraminifer-pelmatozoan packstone having corals, brachiopods, and peloids.

Age: Associated corals are *Zaphriphyllum* sp., *Amplexizaphrentis* sp., and *Ekvasophyllum* cf. *E. inclinatum* Parks, suggestive of Coral Zone IIIA or B. Microfossils from the same stratigraphic level are tentatively assigned to Foraminifer Zone 11 (GSC loc. C39132) (Mamet and others, 1986, p. 43). Microfossils 11.9 m (39 ft) above *Ankhelasma* (GSC loc. C39134) are definitely assigned to Foraminifer Zone 11, and those 25 m (82 ft) below *Ankhelasma* (GSC loc. C39128) belong to the basal part of Foraminifer Zone 10 (Mamet and others, 1986, p. 43). Hence, we regard the occurrence of *Ankhelasma* at this locality as in the lower part of Composite Zone 13.

5. East Fellers Creek

Location: Lat 54°42′50″ N., long 120°54′30″ W.; approximately 6.4 km (4 mi) northwest of Bone Mountain, Monkman Pass 1:250,000-scale map sheet (NTS 93I).

Stratigraphic position: Turner Valley Formation, 3–14 m (10–46 ft) above base.

Collections:
- GSC loc. C7347, 3 m (10 ft) above base of Turner Valley Formation: Six silicified specimens of *A. typicum* Sando.
- GSC loc. C7350, 14 m (46 ft) above base of Turner Valley Formation: Two silicified, immature specimens of *A.* sp. indet.
- GSC loc. C7351, 13.9 m (45.5 ft) above base of Turner Valley Formation: Two silicified, immature specimens of *A.* sp. indet.

Lithology: Cherty, skeletal dolomite grainstone and fossiliferous, fine- to medium-crystalline dolostone.

Table C1. Foraminifers and algae in samples from Canada cited in appendix C

[All samples registered in Geological Survey of Canada Locality Catalog. Identifications of fossils by B.L. Mamet]

Taxa	Mountain Creek		Sukunka River	Wapiti River	Jarvis Lakes	
	C69462	C69453	C69613	C64248	C39325	C39342
Brunsia sp.	X					
Calcisphaera laevis Williamson				X		
C. pachysphaerica (Pronina)		X		X		
C. sp.	X		X			X
Dainella sp.	X		X	X		
Earlandia vulgaris (Rauzer-Chernoussova and Reitlinger)	X	X		X		
E. sp.			X			
Earlandinella sp.				X		
Endothyra sp.		X		X		X
Eoendothyranopsis hinduensis (Skipp)	X			X		
E. scitula (Toomey)					X	
E. spiroides (Zeller)		X				X
E. of the group *E. spiroides* (Zeller)				X		
E. sp.					X	
Eoforschia sp.	X	X	X	X		
Eoparastafella ovalis Vdovenko			X			
E. sp.				X		
Eotextularia sp.				X		
Eotuberitina sp.				X		
Globoendothyra baileyi (Hall)			X			
G. sp.	X	X		X	X	X
Issinella sp.				X		
Kamaena sp.				X		
Latiendothyra sp.			X			
Orthriosiphon sp.				X		
Paleoberesella sp.				X		
Parachaetetes regularis Konishi				X		
Parathurammina sp.	X			X		
Planoendothyra sp.	X					
Pohlia sp.			X			
Priscella sp.	X			X		
Proninella sp.				X		
Pseudoammodiscus sp.				X		
Quasipolyderma sp.				X		
"*Septatournayella*" *henbesti* Skipp, Holcomb, and Gutschick	X					
Skippella sp.	X			X		X
Spinoendothyra sp.			X			
Stacheoides sp.			X			

Collected samples:
- GSC loc. C7347, slightly cherty, dolomitic, pelletoid-bearing, mixed-skeletal wackestone having corals, brachiopods, spicules, calcareous algae, foraminifers, and pelmatozoan ossicles.
- GSC loc. C7350, slightly cherty and dolomitic, pelletoid-pelmatozoan-algal lime packstone having brachiopods.
- GSC loc. C7351, slightly cherty, dolomitic, pelletoid-bearing, mixed-skeletal wackestone having corals, calcareous algae, foraminifers, pelmatozoan ossicles, and peloids.

Age: Associated corals are *Siphonodendron* cf. *S. oculinum* Sando, *S.* sp., *Vesiculophyllum* sp., *Zaphriphyllum* sp., and *Syringopora* sp., which indicate Coral Zone IIIA. Associated microfossils (GSC locs. C39452 and C39454) are assigned to Foraminifer Zone 10 (Mamet and others, 1986, p. 45). *Ankhelasma* ranges through the lower one-sixth of Foraminifer Zone 10 here. Microfossils of Foraminifer Zone 9 occur in GSC loc. C39450, 5.8 m (19 ft) below the lowest occurrence of *Ankhelasma* here (Mamet and others, 1986, p. 45). This evidence indicates that *Ankhelasma* is restricted to the lower part of Composite Zone 12 at this locality.

6. Mount Becker

Location: Lat 54°31′25″ N., long 120°39′45″ W.; approximately 1.6 km (1 mi) southwest of the peak of Mount Becker, Monkman Pass 1:250,000-scale map sheet (NTS 93I).

Stratigraphic position: Mount Head Formation, 47.2–47.9 m (155–157 ft) above base of formation and 0.6–1.2 m (2–4 ft) above base of Baril Member.

Collection:
- GSC loc. C7377: One silicified, immature specimen of *A.* sp. indet.

Lithology: Cherty, pelletoid-bearing foraminifer-pelmatozoan lime grainstone having brachiopod and mollusk fragments. Collected sample is slightly cherty and dolomitic, foraminifer-pelmatozoan grainstone having brachiopod and mollusk fragments and pelletoids.

Age: Associated corals are *Zaphriphyllum* sp., which is compatible with Coral Zone IIIB. Microfossils of Foraminifer Zone 12 (GSC loc. C39199) occur 7.6 m (25 ft) below *Ankhelasma* here (Mamet and others, 1986, p. 49). Therefore, the *Ankhelasma* occurrence at this locality is regarded as Composite Zone 14.

7. Wapiti River

Location: Lat 54°29′05″ N., long 120°43′08″ W.; approximately 3.2 km (2 mi) east of upper Wapiti River and 8 km (5 mi) northeast of Wapiti Pass, Monkman Pass 1:250,000-scale map sheet (NTS 93I).

Stratigraphic position: Mount Head Formation, lower part of Baril Member.

Collections:
- GSC loc. C64248, lower 1.7 m (5.8 ft) of Baril Member: Ten silicified specimens of *A.* sp. indet.
- GSC loc. C110912, lower part of Baril Member, 85.3 m (280 ft) below top of Mount Head Formation: Four silicified specimens of *A.* sp. indet.

Lithology: Pelletoid-bearing, mixed-skeletal grainstone and subordinate fossiliferous dolostone, wackestone, and packstone. Principal bioclasts are corals, calcareous algae, brachiopods, foraminifers, and pelmatozoan ossicles. Some beds cherty. Collected sample (GSC loc. C64248) is pelletoid-bearing, mixed-skeletal grainstone having corals, brachiopods, bryozoans, foraminifers, intraclasts, and pelmatozoan ossicles, and calcisphere-peloid lime wackestone having foraminifers and spicules.

Age: Associated corals are *Siphonodendron* sp., *Zaphriphyllum* sp., *Vesiculophyllum* sp., and *Ekvasophyllum* sp., indicative of Coral Zone IIIA or B. Microfossils in GSC loc. C64248 (table C1) are assigned to Foraminifer Zone 11 or basal 12. Hence, *Ankhelasma* occurs in Composite Zone 13 or the lower part of Composite Zone 14 at this locality.

8. Belcourt Creek

Location: Lat 54°21′30″ N., long 120°29′40″ W.; approximately 6.4 km (4 mi) northwest of Muinok Mountain at head of tributary to Belcourt Creek, Monkman Pass 1:250,000-scale map sheet (NTS 93I).

Stratigraphic position: Mount Head Formation, 31.1–55.2 m (102–181 ft) above base (Wileman(?) and Baril(?) Members).

Collections:
- GSC loc. C7399, 31.1 m (102 ft) above base of Wileman(?) Member: Two silicified specimens of *A.* sp. indet.
- GSC locs. C7398 and C64249, 15 m (49 ft) above base of Baril(?) Member: Seventeen silicified specimens of *A. typicum* Sando.
- GSC loc. C79699, 38.4 m (126 ft) above base of Wileman(?) Member: Thirty-eight silicified specimens of *A.* sp. indet.

Lithology: The Wileman(?) Member is slightly dolomitic, peloid- and pelletoid-bearing, mixed-skeletal wackestone and subordinate shale and marlstone. Principal bioclasts are ostracodes, calcispheres, calcareous algae, molluscs, and pelmatozoan ossicles.

The Baril(?) Member is mainly cherty, skeletal, dolomite grainstone and fossiliferous, medium- to coarse-crystalline dolostone and subordinate cherty, sparsely fossiliferous, fine crystalline dolostone (dolomitized skeletal wackestone?). The main identifiable allochems are pelmatozoan ossicles and silicified corals.

Collected samples:
- GSC loc. C7399, foraminifer-peloid wackestone having calcispheres and pelmatozoan ossicles.
- GSC loc. C7398, cherty, fossiliferous, fine- to medium-crystalline dolostone having foraminifers, corals, and pelmatozoan ossicles.
- GSC loc. C64249, cherty, fossiliferous, medium-crystalline dolostone having corals and pelmatozoan ossicles.

Age: Associated corals are *Zaphriphyllum* sp., *Vesiculophyllum* sp., *Lophophyllum*? sp., and *Syringopora* sp., which suggest Coral Zone IIIA. Microfossils of

Foraminifer Zone 11 (GSC loc. C39251) occur at the same stratigraphic level as GSC loc. C7399 and are also present (GSC loc. C39249) 45 ft below GSC locs. C7398 and C64249 (Mamet and others, 1986, p. 51). This evidence indicates a Composite Zone 13 occurrence for *Ankhelasma* here.

9. Narraway River

Location: Lat 54°10′35″ N., long 120°15′20″ W.; ridge north of Mount Hanington, approximately 4.8 km (3 mi) southwest of Narraway River, Monkman Pass 1:250,000-scale map sheet (NTS 93I).

Stratigraphic position: 6.1 m (20 ft) above base of Turner Valley Formation to middle(?) part of Mount Head Formation (faulted section).

Collections:
- GSC loc. C79613, 6.1 m (20 ft) above base of Turner Valley Formation: Five silicified, immature specimens of *A. typicum*? Sando.
- GSC loc. C79627, (?)84.5 m (277 ft) above base of Mount Head Formation (faulted section): One silicified specimen of *A.* sp. indet.
- GSC loc. C79632, (?)126.2 m (414 ft) above base of Mount Head Formation (faulted section): One silicified specimen of *A. typicum*? Sando.
- GSC loc. C110911, upper part of Mount Head Formation (faulted section): Four silicified specimens of *A. typicum*? Sando.

Lithology: Alternating succession of dolomitized, skeletal grainstone and sparsely fossiliferous, cherty, fine-crystalline dolomite and subordinate shale and dolomitic marlstone.

Collected samples:
- GSC loc. C79613, slightly cherty, pelletoid-bearing, mixed-skeletal grainstone having foraminifers, bryozoans, and pelmatozoan ossicles.
- GSC loc. C79627, cherty, fossiliferous, medium-crystalline dolostone having pelmatozoan ossicles and corals.
- GSC loc. C79632, dolomitic, coral-pelmatozoan-spicule packstone.

Age: Associated corals are *Vesiculophyllum* sp., ?*Zaphriphyllum* sp., and *Siphonodendron* sp., which suggest Coral Zone IIIA or B. The lowest occurrence of *Ankhelasma* (GSC loc. C79613) is 44 ft below microfossils (GSC loc. C79617) assigned to Foraminifer Zone 10 by Mamet and others (1986, p. 55, 56) and 186 ft above those (GSC loc. C79606) of Foraminifer Zone 9 (Mamet and others, 1986, p. 55, 56). Specimens of *Ankhelasma* in GSC locs. C79627, C79632, and C110911 were not dated by using other fossils but are tentatively assigned to Foraminifer Zone 11 or 12 because of their stratigraphic position several hundred feet above GSC loc. C79613. *Ankhelasma* certainly occurs in Composite Zone 12 and probably ranges into Composite Zone 13 or 14 at this locality.

10. Jarvis Lakes

Location: Lat 54°06′45″ N., long 120°13′15″ W.; approximately 2.4 km (1.5 mi) north of Jarvis Lakes, Monkman Pass 1:250,000-scale map sheet (NTS 93I).

Stratigraphic position: Mount Head Formation, 7–43.6 m (23–143 ft) above base.

Collections:
- GSC C7421, Mount Head Formation, 40.8–43.6 m (134–143 ft) above base: Four silicified specimens of *A. typicum* Sando.
- GSC loc. C7422, Mount Head Formation, 35.4–36.9 m (116–121 ft) above base: Two silicified, immature specimens of *A.* sp. indet.
- GSC loc. C7423, Mount Head Formation, 7 m (23 ft) above base: One silicified, immature specimen of *A.* sp. indet.

Lithology: Alternating succession of dolomitized, commonly cherty, skeletal packstone and subordinate, sparsely fossiliferous, fine-crystalline dolomite.

Collected samples:
- GSC loc. C7421, slightly cherty, pelmatozoan dolomite grainstone.
- GSC loc. C7422, brachiopod-bryozoan-pelmatozoan dolomite grainstone.
- GSC loc. C7423, slightly cherty, very dolomitic, peloid-bearing mixed-skeletal packstone having calcispheres, bryozoans, foraminifers, and pelmatozoan ossicles.

Age: Associated corals are *Vesiculophyllum* sp., *Amplexizaphrentis* sp., *Ekvasophyllum* sp., and *Cyathaxonia* sp., suggesting Coral Zone IIIA or B. Microfossils (GSC loc. C39342, table C1) of Foraminifer Zone 11 are associated with the corals in GSC loc. C7423. Microfossils (GSC loc. C39325, table C1) of Foraminifer Zone 13 occur more than 150 ft above the highest occurrences of *Ankhelasma* (GSC locs. C7422 and C7421). The evidence suggests that *Ankhelasma* is in Composite Zone 13 and may range into Composite Zone 14 at this locality.

APPENDIX D. CONTROL POINTS FOR CHRONOMETRIC LITHOFACIES PROFILES ACROSS INFERRED VISÉAN SHELF MARGIN IN MONTANA (FIG. 13)

[Interpretations of the stratigraphy differ from published references]

Profile *G–G′*

Unnamed inferred control point where no record exists, approximately 10 km west of inferred shelf margin.

Rattler Gulch: Secs. 3, 4, and 9, T. 11 N., R. 13 W., Granite County, Montana. Unpublished preliminary study of section by Sando, Perry, and Schneider. Ages determined by corals, conodonts, and foraminifers.

Morris Creek: Secs. 15 and 22, T. 11 N., R. 12 W., Granite County, Montana. Unpublished preliminary study of section by Sando and Perry. Ages determined by corals.

Little Blackfoot River (Hope Creek): Sec. 29, T. 11 N., R. 6 W., Lewis and Clark County, Montana. Unpublished preliminary study of section by Sando and Perry. Locality described by Bierwagen (1964). Ages determined by corals and foraminifers.

Profile *H–H′*

Unnamed inferred control point where no record exists, approximately 10 km west of inferred shelf margin.

Lone Butte: Sec. 23, T. 23 N., R. 13 W., Flathead County, Montana. Graphic section by Sloss and Laird (1945, col. 3). Ages determined by brachiopods and corals.

Hannan Gulch: Sec. 35, T. 22 N., R. 9 W., Teton County, Montana. Section described by Mudge and others (1962, fig. 3) and Mudge (1972, p. A93–A95). Ages determined by brachiopods and corals.

Chapter C

Lithostratigraphy and Conodont Biostratigraphy Across the Lower-Middle Ordovician Disconformity (Early to Middle Whiterockian) at Pratt Ferry, Central Alabama

By T.H. SHAW, KEITH E. ROBERSON, and ANITA G. HARRIS

Description and conodont correlation of a stratigraphic unit that formed in paleokarst depressions at the onset of Middle Ordovician transgression

U.S. GEOLOGICAL SURVEY BULLETIN 1895
SHORTER CONTRIBUTIONS TO PALEONTOLOGY AND STRATIGRAPHY

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Lithostratigraphy and Conodont Biostratigraphy Across the Lower-Middle Ordovician Disconformity (Early to Middle Whiterockian) at Pratt Ferry, Central Alabama

By T.H. Shaw,[1] Keith E. Roberson,[2] *and* Anita G. Harris[3]

Abstract

Biostratigraphic and lithostratigraphic data from the Newala Limestone (Lower Ordovician) and the disconformably overlying Lenoir Limestone (Middle Ordovician) at Pratt Ferry, Alabama, indicate that (1) the upper Newala Limestone is of late Early Ordovician (late Canadian; lower *Oepikodus communis* Zone) age and the lower Lenoir Limestone is of early Middle Ordovician (late middle to early late Whiterockian; *Phragmodus* "pre-*flexuosus*" Zone to *Cahabagnathus friendsvillensis* Zone) age and (2) a basal, transgressive unit composed primarily of sandy dolostone, the Cottingham Creek Member of the Lenoir Limestone (new name), is the basal unit of the Middle Ordovician sequence locally. Where present, the Cottingham Creek Member aids in the identification of the Lower-Middle Ordovician disconformity in the eastern facies of the Middle Ordovician of Alabama.

The Cottingham Creek Member was deposited in paleokarst depressions developed on the Newala Limestone during the earliest Middle Ordovician. Areal distribution and lithostratigraphic and biostratigraphic data prove conclusively that the Cottingham Creek Member is geographically, lithologically, and chronologically distinct from the Attalla Chert Conglomerate Member of the Chickamauga Limestone of northeastern Alabama, a unit that also lies at the base of the Middle Ordovician transgressive sequence. The Cottingham Creek does appear to be correlative or partly correlative, however, with some of the other units that lie at the base of the Middle Ordovician sequence in the southern Appalachians. It is correlative with the basal part of the Wells Creek Dolomite in south-central Tennessee and the Douglas Lake Member of the Lenoir Limestone in northeastern Tennessee. It may be the same age as the lower part of the Pond Spring Formation in northwestern Georgia but is considerably older than the upper part of the Pond Spring, indicating the possibility of a disconformity within the Pond Spring.

INTRODUCTION

Recognition of the contact between the Newala Limestone (Lower Ordovician) and the disconformably overlying Lenoir Limestone (Middle Ordovician), which occur together only east of the Helena fault, has long been a problem for geologists mapping in Alabama. This contact, the regionally extensive Lower-Middle Ordovician disconformity, is difficult to locate because of the (1) striking similarity between the Newala Limestone and the Mosheim Member of the Lenoir Limestone, the units that, in most places, bound the disconformity, (2) lack of appreciable relief and other reliable exposure indicators on the surface of disconformity (Roberson, 1988), and (3) generally poor exposure of this stratigraphic interval. The disconformity, however, is well exposed near Pratt Ferry, Bibb County, Ala. (fig. 1), where it is clearly delineated by a large paleokarst collapse feature containing conglomeratic dolostone that differs significantly from either the Newala or Mosheim limestones.

On the basis of new data (Shaw, 1987; Roberson, 1988), this report describes the stratigraphy across the Lower-Middle Ordovician disconformity at Pratt Ferry and establishes the age of the basal dolostone of the Middle Ordovician carbonate sequence, which is named herein the Cottingham Creek Member of the Lenoir Limestone. In addition, the age and origin of the Cottingham Creek Member are compared to those of units occupying a similar stratigraphic position elsewhere in Alabama and in Georgia and Tennessee. The Cottingham Creek Member is inferred to have been deposited in paleokarst depressions on the post-Knox erosion surface during the late middle to early late Whiterockian. This report also establishes the age of the upper Newala Limestone at Pratt Ferry as late Early Ordovician (lower *Oepikodus communis* Zone) and discusses the magnitude of the post-Knox hiatus and the nature of the disconformity surface.

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[1] Department of Geology, Queens College, City University of New York, Flushing, NY 11367.

[2]Department of Geological Sciences, University of Tennessee, Knoxville, TN 37996.

[3]U.S. Geological Survey, 970 National Center, Reston, VA 22092.

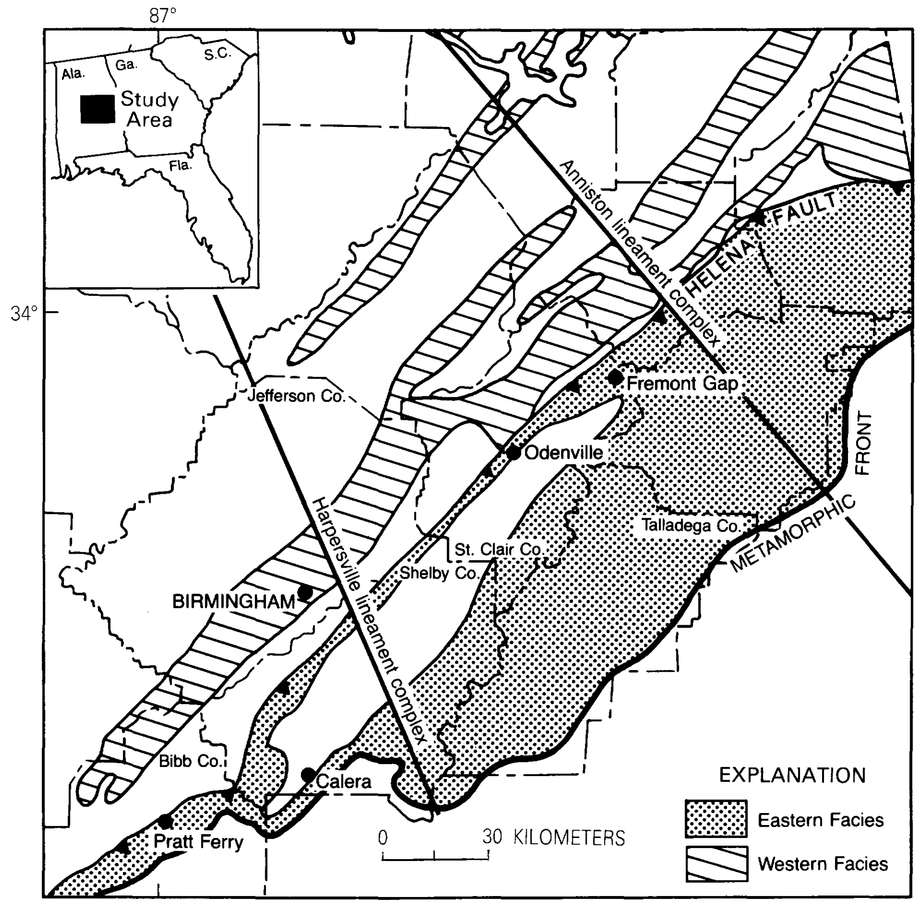

Figure 1. Distribution of the eastern and western carbonate facies of the Middle and Upper Ordovician in central Alabama. The type section of the Cottingham Creek Member of the Lenoir Limestone is at Pratt Ferry (lower left). Modified from Neathery and Drahovzal, 1986.

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LOCATION AND PROCEDURES

The exposure near Pratt Ferry is on the east cutbank of the Cahaba River, north of the Pratt Ferry Bridge, 0.32 km north of the confluence of Cottingham Creek and the Cahaba River, NE 1/4 NE 1/4 sec. 33, T. 24 N., R. 10 E., lat 33°01′25″ N., long 87°01′18″ W., West Blocton East 7.5-minute quadrangle, Bibb County, Ala. (fig. 1). The section is on the north limb of the Bibb County syncline in the Helena thrust sheet.

The section was measured and described, and 34 samples were collected for conodont analysis. Thin sections and acetate peels were made from selected lithologies. The conodont collections are reposited in the U.S. Geological Survey conodont laboratory, Reston, Va.

PREVIOUS WORK

The Lower and Middle Ordovician stratigraphic subdivisions proposed by Butts (1926) have been retained with modification by most workers in Alabama. Butts (1926) recognized that the Upper Cambrian-Lower Ordovician and Middle Ordovician carbonate sequences are separated by an unconformity, and he identified the Mosheim Limestone as the oldest Middle Ordovician unit in the Cahaba Valley east of the Helena fault (fig. 2). The Mosheim is presently considered to be a member of the Lenoir Limestone (Drahovzal and Neathery, 1971; Roberson, 1988) (fig. 2).

Drahovzal and Neathery (1971) observed that, although Butts (1926) recognized the facies relations of units within the post-Knox sequence of central Alabama, his nomenclature reflected a time-stratigraphic succession or "layer-cake" stratigraphy. The general absence of biostratigraphic control and the structural complexity of the Valley and Ridge province resulted in acceptance of Butts' (1926) stratigraphic succession by most subsequent workers. On the basis of lithostratigraphic and paleontologic data, Drahovzal and Neathery (1971) revised the stratigraphic nomenclature to reflect the facies relations of the units recognized by Butts and identified a western, chiefly carbonate facies and an eastern, chiefly clastic facies structurally separated by the Helena fault (figs. 1, 2).

Where the Attalla Chert Conglomerate Member is the lowest unit of the Chickamauga Limestone in the Middle Ordovician western facies, it is the basal transgressive unit of the Middle Ordovician (fig. 2). The Attalla disconformably overlies the Copper Ridge Dolomite, Chepultepec Dolomite, or Longview Limestone and is conformably overlain by the Chickamauga Limestone. The lower Chickamauga in Alabama is late Whiterockian to Blackriveran in age (Hall and others, 1986).

The Attalla Chert Conglomerate Member is absent in the eastern facies of the Middle Ordovician of Alabama, and basal members of the Lenoir Limestone (Middle Ordovician) disconformably overlie the Newala Limestone (upper Lower Ordovician) or Odenville Limestone (uppermost Lower to possibly lowermost Middle Ordovician) (fig. 2). Conodonts indicate that the Lenoir is of middle to late Whiterockian age and is time transgressive westward (Drahovzal and Neathery, 1971; Hall and others, 1986).

LITHOSTRATIGRAPHY

A relatively complete section of lower Paleozoic rocks is exposed in the east cutbank of the Cahaba River north of the Pratt Ferry Bridge and includes the Chepultepec, Longview, and Newala formations and a nearly complete Middle Ordovician sequence from the base of the Lenoir Limestone through the Athens Shale. The focus of this report is on the disconformable contact between the Newala and Lenoir Limestones.

Newala Limestone

At Pratt Ferry, the Newala Limestone is approximately 55 m thick and consists of medium-bedded, light-gray to very light gray, yellowish-gray-weathering, high-calcium limestone interbedded with thin layers of coarsely crystalline, light-brownish-gray-weathering, light-gray dolostone. The limestone is predominantly mudstone and peloidal packstone/wackestone. Thin beds of sucrosic dolostone, arenaceous mudstone, and grainstone are present locally within the lower Newala. With the exception of locally abundant gastropods, megafossils are rare. The Newala conformably overlies the Longview Limestone and is disconformably overlain by the Lenoir Limestone.

Surface of the Lower-Middle Ordovician Disconformity

The disconformable contact between the Newala Limestone and the overlying Cottingham Creek Member of the Lenoir Limestone at Pratt Ferry has a minimum relief of 14 m and forms a paleotopographic low that is at least 48 m across (fig. 3). This depression truncates bedding within the upper Newala. The walls of the depression are very irregular, and the contact between the Newala and rocks filling the depression is sharp (figs. 4*A*, *B*). A slightly tilted, downdropped block of Newala Limestone occupies the center of the depression (fig. 3). Relief on the paleoerosion surface away from the depression is low ($\pm$10 cm), and the disconformity is represented by a sharp and irregular contact.

The absence of slickensides, fault gouge or breccia, and the continuity of bedding within the depression-fill lithologies and within the Newala on either side of the depression suggest that the depression is the result of karst collapse and not faulting.

Lenoir Limestone

Cottingham Creek Member

The paleotopographic depression in the Newala Limestone is filled with a variety of thin- to medium-bedded, laterally discontinuous, argillaceous, brownish-gray- to light-brownish-gray-weathering, moderate- to light-brown dolostone. These rocks are here named the Cottingham Creek Member of the Lenoir Limestone for Cottingham Creek, Bibb County, Ala. The exposure near

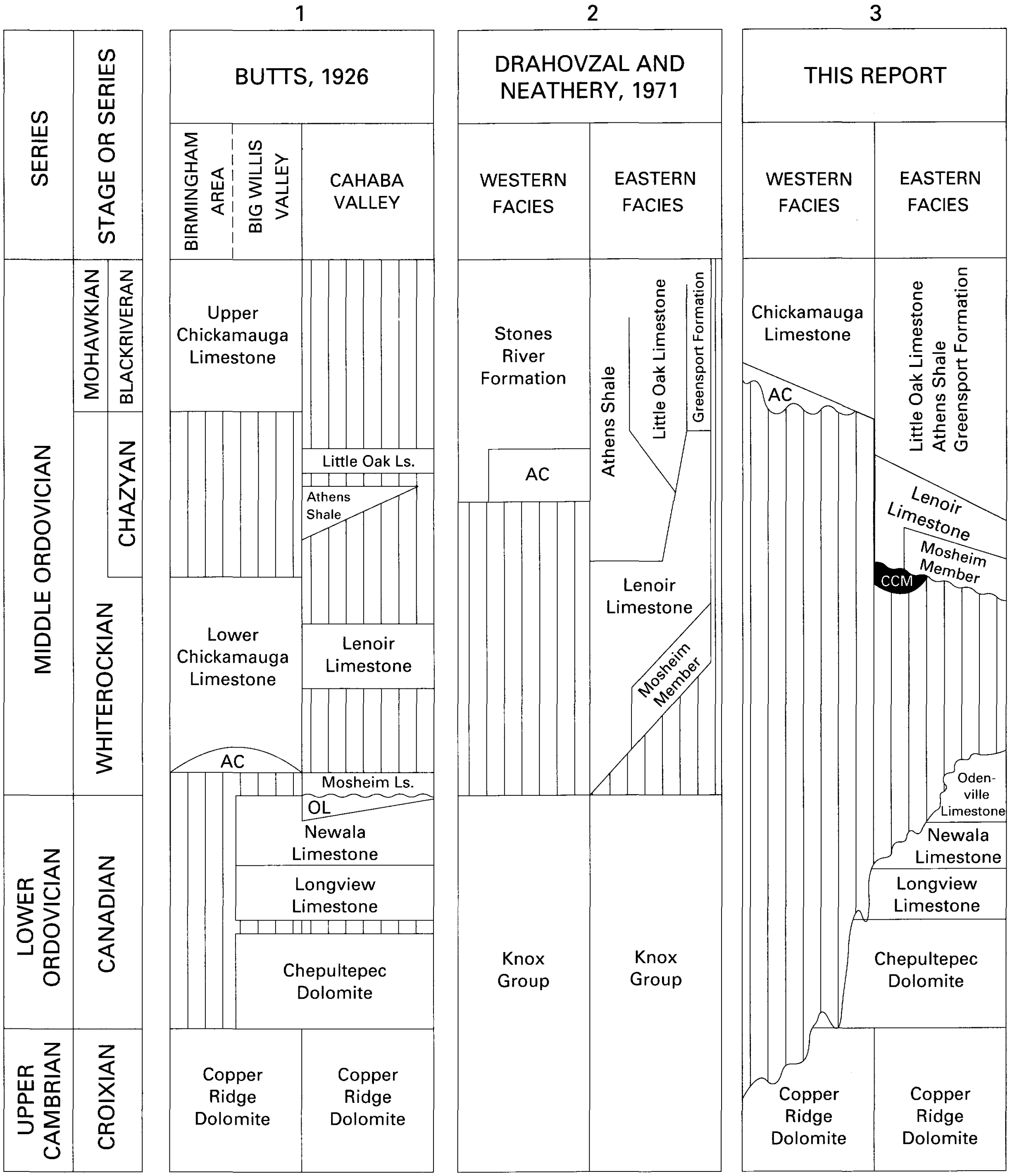

Figure 2. Historical development of stratigraphic nomenclature and correlation of some Upper Cambrian to Middle Ordovician rocks in central Alabama. CCM (shaded unit), Cottingham Creek Member; AC, Attalla Chert Conglomerate Member; OL, Odenville Limestone.

Pratt Ferry, described above, is designated the type section. The base of the member consists of recrystallized conglomeratic dolostone containing pebbles, cobbles, and boulders of lime mudstone, packstone/grainstone, and dolomudstone. The clasts are as much as 30 cm in diameter, and all appear to have been derived from the Newala Limestone (fig. 4C). The basal conglomerate is overlain by dark-brown, bryozoan-rich dolowackestone and dolomudstone; tan, porous dolomudstone; burrowed dolomudstone; and greenish-gray dolosiltite. Crossbedding is well developed

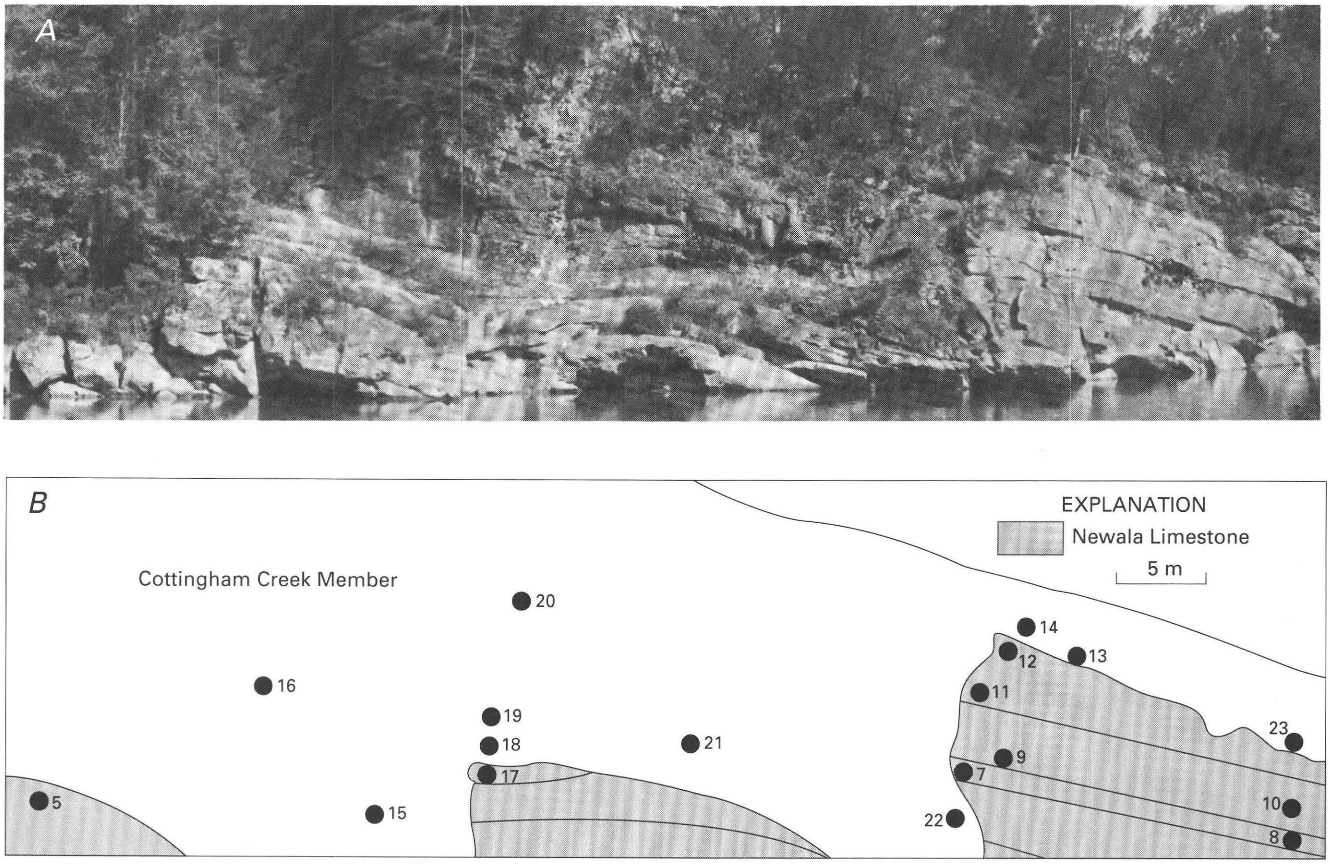

Figure 3. (*A*) Type section of the Cottingham Creek Member of the Lenoir Limestone and (*B*) location of conodont samples 5 and 7 to 23 and truncation of bedding within the Newala Limestone and Cottingham Creek Member. Sample numbers are keyed to table 1.

updip and at the base of the unit (fig. 4*D*). The uppermost part of the member is a thick-bedded, massive, sandy, argillaceous, brownish-gray dolostone that is laterally continuous across the depression.

Megafossils in the Cottingham Creek Member are predominantly bryozoans but also include brachiopods and large specimens of the gastropod *Maclurites magnus* (LeSueur). The occurrence of these fossils indicates that the depression-fill deposits formed under marine conditions, probably during the earliest phase of the post-Knox transgression.

The maximum thickness of the Cottingham Creek Member is uncertain because the paleotopographic depression that forms its base extends beneath the surface of the Cahaba River; it is estimated to be 16 m thick. The Cottingham Creek at Pratt Ferry forms a knoll, possibly because it is composed of dolostone that is relatively more resistant than the adjacent limestones; this topographic characteristic may aid in its recognition elsewhere.

Mosheim Member

The Mosheim Member of the Lenoir Limestone overlies the Cottingham Creek Member. Its lower part is predominantly medium- to thick-bedded, massive, medium-light- to light-gray, fenestral lime mudstone containing a sparse fauna of ostracodes and gastropods. These beds grade upward into thin- to medium-bedded, slightly more argillaceous, fenestral mudstone that locally contains abundant gastropods. The contact between the Mosheim and Cottingham Creek Members is sharp and irregular and may represent an erosional surface; if so, the magnitude of the hiatus is less than a single conodont zone.

CONODONT BIOSTRATIGRAPHY

The rather complete exposure of Ordovician rocks in the vicinity of Pratt Ferry, Ala., has become a key section for biostratigraphic studies in the southernmost Appalachians, particularly for Middle Ordovician index fossil groups (brachiopods: Cooper, 1956; conodonts: Sweet and Bergström, 1962, Bergström, 1971, and Schmidt, 1982; graptolites: Ruedemann, 1947, Decker, 1952, and Finney, 1977, 1984). In this report, we add to the paleontologic documentation of this section the distribution of conodonts in several meters of beds both below and above the

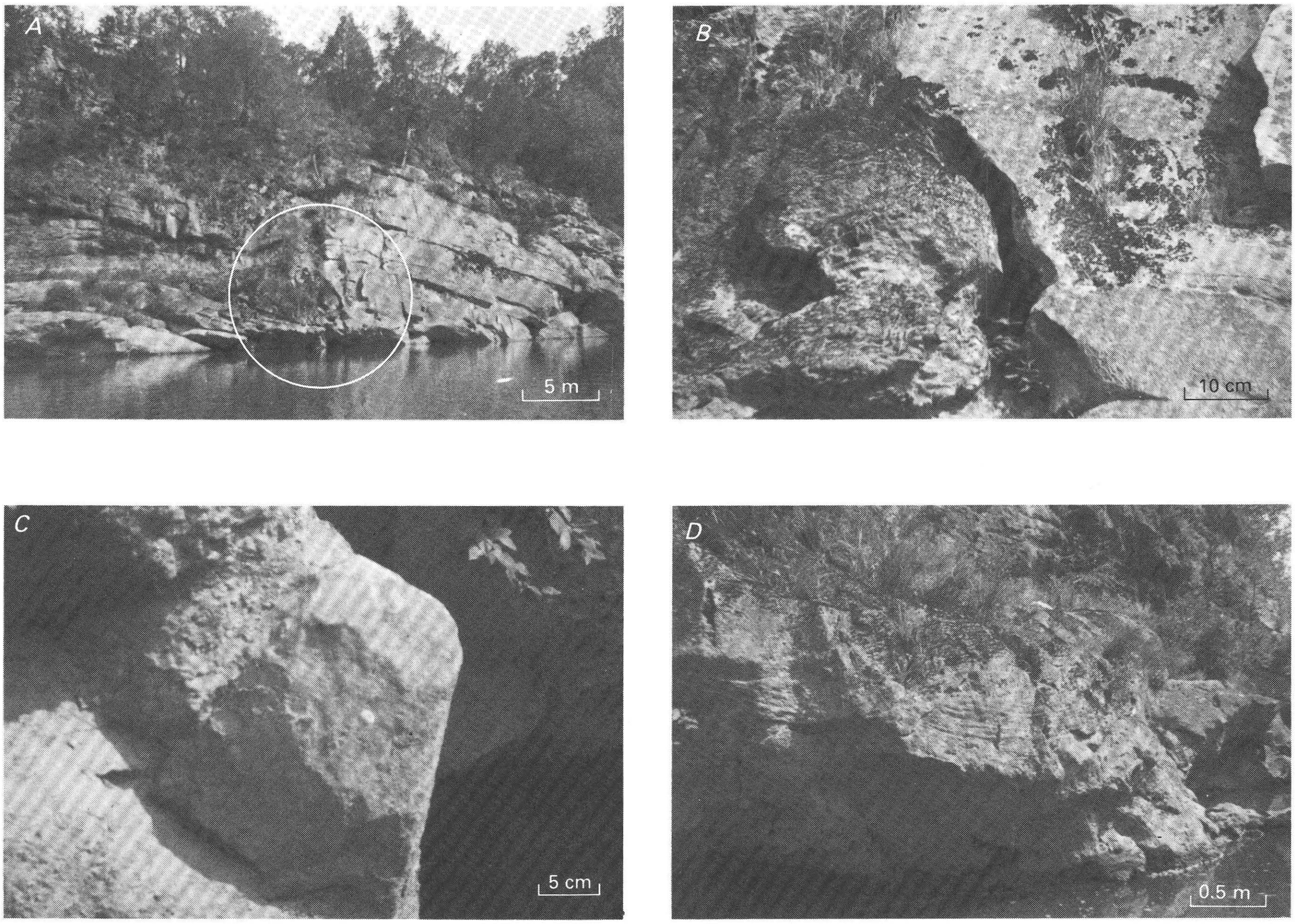

Figure 4. Karstification features and bedforms at the Lower-Middle Ordovician disconformity, Pratt Ferry, Ala. *A*, Sharp, vertical contact (circled area) between the Newala Limestone (lighter gray) and the Cottingham Creek Member of the Lenoir Limestone. *B*, Close-up of contact circled in *A*. *C*, Boulder of Newala Limestone in the lower Cottingham Creek Member. D, Crossbedded dolostone at base of Cottingham Creek Member.

disconformity separating the Newala and Lenoir Limestones, an interval not covered by previous conodont studies.

Of the 34 samples collected for conodont analysis, 31 yielded conodonts. Sample size ranged from 3.9 to 12.1 kg (table 1). Large samples are required to recover even a few conodont elements from either the Newala Limestone or the lower members of the Lenoir Limestone. The ranges of selected conodont species in the section are shown in figure 5; conodont species distribution is summarized in table 1. Conodonts from this section have a color alteration index of 1.5; this index indicates the host rock reached burial temperatures of at least 60 to 90 °C.

The conodont fauna from the Newala is dominated by elements of *Diaphorodus delicatus* (Branson and Mehl) (pl. 1, figs. 18, 19) and *Eucharodus parallelus* (Branson and Mehl) and subordinate numbers of elements of *Cristodus loxoides* Repetski (pl. 1, fig. 21), *Drepanodus concavus* (Branson and Mehl) (pl. 1, fig. 22), *Drepanoistodus suberectus* (Branson and Mehl) subsp. A sensu Repetski, 1982a, *Glyptoconus quadraplicatus* (Branson and Mehl), *Oneotodus costatus* Ethington and Brand (pl. 1, fig. 20), *Scolopodus cornutiformis* Branson and Mehl, "*Scolopodus*" *emarginatus* Barnes and Tuke (pl. 1, fig. 23), *Tropodus comptus* (Branson and Mehl), and *Ulrichodina abnormalis* Branson and Mehl.

Although *Oepikodus communis* has not been found in the Newala Limestone, probably due to unfavorable environmental conditions, *Diaphorodus delicatus*, a species whose first appearance approximates the base of the *O. communis* Zone in rocks that formed in warm, shallow, possibly hypersaline marine environments (Repetski, 1985), occurs throughout the upper 25 m of the formation in the Pratt Ferry section. *D. delicatus* is known to range into the very earliest Whiterockian. Its occurrence in the Newala, together with representatives of *Cristodus loxoides* and *Glyptoconus quadraplicatus* (table 1), species that are not known to range into the Whiterockian, indicates that the

Table 1. Stratigraphic distribution of conodont species across the Lower-Middle Ordovician disconformity, Pratt Ferry, Ala.

[Sample weight, in kilograms, is shown in parentheses after sample number. Stratigraphic position is indicated in meters above (+) and below (−) disconformity]

Conodont element abundance (part 1)

Sample number	USGS colln. number	Stratigraphic position (m)	*Ulrichodina abnormalis*	*Eucharodus* sp.	*Drepanodus concavus*	*Diaphorodus delicatus*	*Eucharodus parallelus*	*Glyptoconus quadraplicatus*	New genus 2 of Ethington and Clark, 1981	*Oelandodus* cf. *O. costatus*	*Oneotodus costatus*	*Oneotodus* n. sp. 1	*Scandodus* cf. *Smysticus*	*Scandodus* sp.	"*Scolopodus*" *emarginatus*	Scolopodiform C of Ethington and Clark, 1981	*Tropodus comptus*	*Glyptoconus* sp.	*Cristodus loxoides*	*Drepanoistodus suberectus* sensu Repetski, 1982a	*Scolopodus gracilis*	*Acontiodus staufferi*
34 (9.2)	10091–CO	+25.7																				
33 (9.6)	10090–CO	+25.5																				
32 (12.1)	10089–CO	+20.8																				
31 (5.1)	Barren	+20.3																				
30 (8.4)	10088–CO	+19.7																				
29 (5.4)	10087–CO	+18.4																				
28 (9.2)	10086–CO	+18.1																				
27 (9.8)	10085–CO	+17.1																				
26 (7.0)	10084–CO	+15.3																				
25 (9.1)	Barren	+13.0																				
24 (9.0)	10083–CO	+ 4.6																				
23 (6.7)	10050–CO	+ 0.5	1																			
22 (5.9)	10044–CO																					
21 (5.1)	10047–CO																					
20 (9.3)	10049–CO				1																	
19 (11.4)	10046–CO	See figure 3																				
18 (11.2)	10045–CO																					
17 (9.0)	10035–CO		1		1		2	9														
16 (7.6)	10048–CO																					
15 (5.4)	10043–CO																					
14 (7.7)	10051–CO	+ 1.3																				
13 (8.0)	10042–CO	+ 0.5					1	4							1							
12 (5.7)	10041–CO	− 0.2				13	14	1									1					
11 (8.5)	10040–CO	− 3.0				6	3	4													1	
10 (3.9)	10037–CO	− 3.9	1			2	9	3			2											
9 (8.4)	10039–CO	− 8.4			5	38	3	9											1	1	1	1
8 (5.4)	10036–CO	−10.5					1	2											1			
7 (7.2)	10038–CO	− 9.0	1		4			11			3											
6 (7.2)	10034–CO	− 0.5	1		2		2	16										2			1	
5 (8.7)	10033–CO	− 1.9	2		1	9	17	16					1								1	
4 (6.4)	10082–CO	− 4.6	2	6			8	2	1		1				2				1	1		
3 (5.1)	Barren	−13.8																				
2 (9.2)	10081–CO	−16.1	3	5		4	9	11			2				1		3	2			1	
1 (11.9)	10080–CO	−18.5	6	12	13	1	32	13	1	3	1	1	3	1	2	4					3	

Conodont element abundance (part 2)

Sample number	*Ansella nevadensis*	*Belodina monitorensis*	*Panderodus* spp.	*Drepanoistodus*? *basiovalis*	*Plectodina joachimensis*	*Scalpellodus*? sp.	"*Scanodus*" *sinuosus*	*Erraticodon* aff. *E. balticus*	*Drepanoistodus suberectus*	*Leptochirognathus quadratus*	*Tripodus* sp.	*Cahabagnathus friendsvillensis*	*Oistodus* cf. *O. lanceolatus*	*Drepanoistodus* cf. *D. forceps*	*Phragmodus flexuosus*	Indeterminate fragments	Total elements and fragments
34 (9.2)		8	29						3			6			4	27	77
33 (9.6)		2	24	3	1				6		1			1		22	60
32 (12.1)		2	10		1				3				1			10	27
31 (5.1)																0	0
30 (8.4)	1	1	15					7	2		1	3				31	61
29 (5.4)	1		6													5	12
28 (9.2)	10	4	37		11					1						8	71
27 (9.8)			3													3	6
26 (7.0)			2													0	2
25 (9.1)																0	0
24 (9.0)			2													0	2
23 (6.7)			2		1											2	6
22 (5.9)	32	13	73	2	3	7	2									30	162
21 (5.1)	2	2	30	1	2	4			2							12	55
20 (9.3)			18		1		4	1								5	30
19 (11.4)			31		10	2				3						15	61
18 (11.2)	1	3	1			2		2	2	1						4	14
17 (9.0)																5	18
16 (7.6)	4	1	29	3	4		2		4	3						17	67
15 (5.4)																4	4
14 (7.7)	1	1	4	1	4	1										7	19
13 (8.0)	3	2	5													0	16
12 (5.7)																13	42
11 (8.5)																4	18
10 (3.9)																4	21
9 (8.4)																15	74
8 (5.4)																0	4
7 (7.2)																4	23
6 (7.2)																11	35
5 (8.7)																25	72
4 (6.4)																5	29
3 (5.1)																0	0
2 (9.2)																23	64
1 (11.9)																38	134

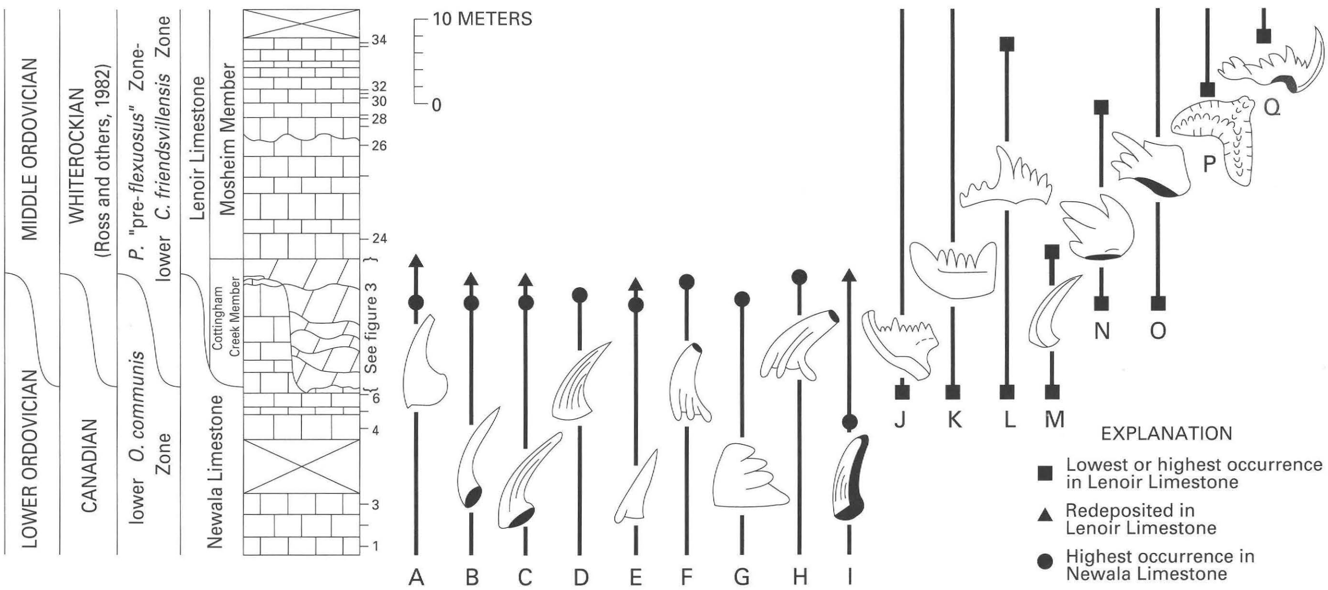

Figure 5. Ranges of selected conodont species in the upper part of the Newala Limestone and lower part of the Lenoir Limestone at the type section of the Cottingham Creek Member of the Lenoir Limestone. Extension of ranges below and above the stratigraphic levels of the Newala and the Lenoir Limestones sampled for this study are, for the Newala, from Shaw (1987) and, for the Lenoir, from Sweet and Bergström (1962), Bergström (1971), and Schmidt (1982). (A) *Drepanodus concavus*, (B) *Eucharodus parallelus*, (C) *Glyptoconus quadraplicatus*, (D) *Oneotodus costatus*, (E) *Ulrichodina abnormalis*, (F) *Tropodus comptus*, (G) *Cristodus loxoides*, (H) *Diaphorodus delicatus*, (I) *"Scolopodus" emarginatus*, (J) *Ansella nevadensis*, (K) *Belodina monitorensis*, (L) *Plectodina joachimensis*, (M) *"Scandodus" sinuosus*, (N) *Leptochirognathus quadratus*, (O) *Erraticodon* aff. *E. balticus*, (P) *Cahabagnathus friendsvillensis*, and (Q) *Phragmodus flexuosus*. Conodont distribution and abundance are given in table 1.

upper Newala was deposited during *O. communis* Zone time (=late Early Ordovician). Moreover, the presence of *C. loxoides* throughout much of this interval further restricts these beds to the lower part of the *O. communis* Zone.

The conodont fauna of the Cottingham Creek Member of the Lenoir Limestone consists chiefly of, in order of decreasing abundance, elements of *Panderodus* spp. (pl. 1, fig. 17), *Ansella nevadensis* (Ethington and Schumacher), *Plectodina joachimensis* (Andrews) (pl. 1, fig. 15), *Belodina monitorensis* Ethington and Schumacher, *Drepanoistodus* spp., *Erraticodon* aff. *E. balticus* Dzik, and "*Scandodus*" *sinuosus* Mound. Reworked elements of *Drepanodus concavus*, *Eucharodus parallelus*, *Glyptoconus quadraplicatus*, *Ulrichodina abnormalis*, and "*Scolopodus*" *emarginatus* are locally present within the Cottingham Creek Member.

With the exception of "*Scandodus*" *sinuosus*, the Middle Ordovician species recovered from the Cottingham Creek Member also occur in the overlying Mosheim Member. In addition, elements of *Tripodus* sp., *Oistodus* cf. *O. lanceolatus* Pander, *Drepanoistodus* cf. *D. forceps* (Lindström), *Cahabagnathus friendsvillensis* (Bergström) (pl. 1, fig. 1), and *Phragmodus flexuosus* Moskalenko (pl. 1, figs. 2–4), first occur in the Mosheim Member.

Specimens of "*Scandodus*" *sinuosus* are the oldest, possibly indigenous conodonts in the basal beds of the Cottingham Creek Member. If they are indigenous and not reworked, then their occurrence in this member, together with elements of *Plectodina joachimensis* and *Erraticodon* aff. *E. balticus*, restricts the age of these beds to the *Phragmodus* "pre-*flexuosus*" Zone of Sweet (1984). The upper limit of the range of "*S.*" *sinuosus* and the lower limit of the ranges of *P. joachimensis* and *E. balticus* appear to be within this chronozone. If, on the other hand, the specimens of "*S.*" *sinuosus* are reworked (these specimens are limited to beds that contain other reworked conodont elements), then the age of the Cottingham Creek Member is less constrained because all other conodonts within this unit are relatively long ranging within the middle to late Whiterockian. Elements of *Cahabagnathus friendsvillensis* first appear several meters above the base of the Mosheim Member in this exposure (fig. 5), indicating a level within the *C. friendsvillensis* Zone of the North American conodont zonation (Sweet, 1984) or the *P. serra* Zone of the Baltoscandia conodont zonation. Bergström (1971 and oral commun., 1988) recovered elements of *Pygodus serra* Hadding and *C. friendsvillensis* from near the top of the Lenoir to at least 65 m below its top in the vicinity of Pratt Ferry. Bergström (1971) has also shown that the boundary between the *P. serra*-*P. anserinus* Zones lies near the top of the Pratt Ferry Formation (Cooper, 1956), about 10 m above the top of the Lenoir Limestone in this vicinity. The known range of *C. friendsvillensis* is from near the base to near the top of the *P. serra* Zone (Bergström, 1983). Its presence throughout the nearly 75 m of Lenoir Limestone that overlies the Cottingham Creek and lower Mosheim beds in the Pratt Ferry section suggests that the Cottingham Creek Member is no younger than the early part of the *C. friendsvillensis* Zone and could well be as old as, but no older than (based on the presence of *Plectodina joachimensis* and *Erraticodon* aff. *E. balticus*), the *Phragmodus* "pre-*flexuosus*" Zone. In terms of the Whiterockian Series, the Cottingham Creek Member is of late middle to early late Whiterockian age.

CORRELATION OF THE COTTINGHAM CREEK MEMBER

The Cottingham Creek Member of the Lenoir Limestone is differentiated from the Attalla Chert Conglomerate Member of the Chickamauga Limestone by the absence of chert, the sparsity of cobble- and boulder-sized clasts, and the absence of sandstone and (or) green shale in the Cottingham Creek Member. Lithologic differences between the Cottingham Creek and Attalla Chert Conglomerate Members are the result of differences in provenance; that is, differences in the rock units that underlie them and the nature of the paleotopographic depressions in which each member was deposited.

On the basis of conodonts in Chickamauga Limestone beds above the Attalla Chert Conglomerate Member at the Red Mountain roadcut in Birmingham, Ala., Hall and others (1986) reported the age of the Attalla as early Blackriveran. Their lowest, biostratigraphically useful, Middle Ordovician conodont collection is from about 12 m above the top of the Attalla, and it and overlying collections only indicate that the Attalla is no younger than latest Whiterockian to early Blackriveran. About 20 km east-northeast of Birmingham, we collected one conodont sample from a Middle Ordovician dolomitic fenestral mudstone, 2 m below the Attalla and another sample from within a noncherty phase of the Attalla (USGS collections 10317–CO and 10316–CO, from outcrops on the northern side of a stream that flows between Butler and Foster Mountains, 400 m east of the Clay-Palmerdale Road and 2 km northwest of Clay, Jefferson County, SE 1/4 NW 1/4 sec. 23, T. 15 S., R. 1 W., lat 33°42.8′ N., long 86°37.1′ W., Argo 7.5-minute quadrangle, Ala.). The presence of representatives of *Phragmodus inflexus* Stauffer and *Plectodina* n. sp. of Votaw (1971) in the lower sample and of these two species and *Appalachignathus delicatus* Bergström and others in the Attalla Chert Conglomerate Member sample indicates that the Attalla is of highest *C. sweeti* Zone to lowest *E. quadridactylus* Zone age. Thus, even though the Cottingham Creek and the Attalla Chert Conglomerate Members formed in similar paleogeographic settings and are the basal units of the Middle Ordovician carbonate sequence that disconformably overlies the Knox Group, they are neither coeval nor contiguous (fig. 2). The Attalla occurs only west of the Helena fault, whereas the Cottingham Creek is found only east of it.

The age relation of the Cottingham Creek Member to the Pond Spring Formation of northwestern Georgia is more complex. The basal few meters of the Pond Spring are lithologically similar to the Cottingham Creek Member and occupy a similar stratigraphic position. In the vicinity of Chickamauga, Ga., its type area, the Pond Spring ranges from about 75 to 95 m in thickness (Milici and Smith, 1969). According to Hall and others (1986), the lowest occurrence of *Plectodina aculeata* (Stauffer) in this area is about 13 m below the top of the formation and about 14 m above the only sample containing *Phragmodus flexuosus* and *P. inflexus*. These data indicate that the lowest sample containing *P. aculeata* is within the *P. aculeata* Zone and that at least the upper Pond Spring is of Blackriveran age and, like the Attalla Chert Conglomerate Member, is younger than any part of the Lenoir Limestone at Pratt Ferry. According to Schmidt (1982), two collections from the lower 20 m of the Pond Spring contain conodonts much older than those from the upper part of the formation. These collections contain abundant representatives of *Phragmodus flexuosus*, lesser numbers of its ancestor *P.* "pre-*flexuosus*," and forms transitional between them. These data seem to indicate that at least the lower 20 m of the Pond Spring are of lowest *C. friendsvillensis* Zone age. This age is somewhat surprising, because the highest occurrence of this species association is only about 30 m below Pond Spring beds that contain *P. aculeata* and that are of definitive Blackriveran age. Moreover, the regional depositional framework and lithology of the Pond Spring suggest rapid deposition. A disconformity may occur within the middle Pond Spring, or alternatively, the specimens assigned by Schmidt (1982) to forms ancestral and transitional to *P. flexuosus* may be ecophenotypes that appear late in the range of *P. flexuosus*. Schmidt (1982) expressed similar concern but offered no suggestions about the apparent long time interval represented by the lower and middle Pond Spring Formation. This problem cannot be resolved without additional data. Nonetheless, at least the lower 20 m of the Pond Spring may be equivalent to the Cottingham Creek Member.

The Cottingham Creek Member is at least partly correlative with the base of the Wells Creek Dolomite (as used by Bentall and Collins, 1945), the unit that disconformably overlies the Knox Group in the subsurface of south-central Tennessee. Conodont collections from the basal few meters of the Wells Creek in four cores from Bedford and Maury Counties (Repetski, 1982b, and unpub. data) contain representatives of *Multioistodus subdentatus* Cullison and *Phragmodus flexuosus*, indicating a level low in the *C. friendsvillensis* Zone. Except for a few redeposited Early Ordovician specimens, the Middle Ordovician conodonts in these collections appear to be indigenous. The base of the Wells Creek Dolomite in at least Bedford and Maury Counties, Tenn., is the same or nearly the same age as the Cottingham Creek Member and appears to be the same age as the lower part of the Pond Spring Formation of northwestern Georgia.

The Cottingham Creek Member is probably correlative with the Douglas Lake Member of the Lenoir Limestone in Tennessee (Laurence, 1944; Bridge, 1955; Harris, 1982). Like the Cottingham Creek, the Douglas Lake Member formed within paleokarst depressions on the post-Knox erosion surface. Rocks of the Cottingham Creek are similar to rocks assigned to unit B by Laurence (1944), which include crossbedded conglomeratic dolostone and fossiliferous argillaceous dolostone. The Douglas Lake Member disconformably overlies the Mascot Dolomite, a cherty dolomite that is coeval in part with the Newala Limestone. The Douglas Lake consists predominantly of noncarbonate rocks that contain chert locally and thus are unlike rocks of the Cottingham Creek Member. Differences in rock type reflect the composition of the underlying Knox Group and the paleotopography and paleoregolith developed on the surface of disconformity.

Laurence (1944) reported the age of the Douglas Lake Member as post-Canadian and pre-Chayzan or Chayzan, or middle to late Whiterockian of current usage (Ross and others, 1982). Harris (1982) and Broadhead and others (in press) reported elements of *Phragmodus flexuosus* from about 3 m above the top of the Douglas Lake Member in the main body of the Lenoir Limestone. In a collection taken 20 m higher in the section from the overlying Whitesburg Formation, they reported the presence of *Eoplacognathus foliaceus* (Fahraeus), *Cahabagnathus friendsvillensis,* and *Pygodus serra*. These data indicate that the Douglas Lake Member is no younger than the lower part of the *C. friendsvillensis* Zone and is of that age or of slightly older late *P.* "pre-*flexuosus*" Zone age and falls within the age range determined for the Cottingham Creek Member.

REGIONAL DISTRIBUTION OF THE COTTINGHAM CREEK MEMBER

Rocks resembling and occurring at the same stratigraphic level as the Cottingham Creek Member have been identified near Fremont Gap, St. Clair County, Ala. (SE 1/4 sec. 9, T. 14 S., R. 5 E.) (Roberson, 1988). At both Pratt Ferry and Fremont Gap, these rocks occur in paleokarst depressions developed on the Newala Limestone. At Fremont Gap, the dolostones are very similar to those at the type section of the Cottingham Creek; however, the basal conglomerates are less conspicuous, and the geometry of the deposit is difficult to determine because of extensive covered intervals.

The Cottingham Creek is apparently restricted to areas where the Newala Limestone is the highest unit preserved beneath the Lower-Middle Ordovician disconformity. This may be related to the character of the Newala, local structure, magnitude of the hiatus, and (or) proximity to the source area for clasts within Cottingham Creek conglomerate.

Paleotopographic depressions resulting from karst collapse or dissolution have not been observed where the Odenville Limestone is the highest unit preserved beneath the post-Knox Group disconformity. Dolomitic, siliceous, and argillaceous impurities within the Odenville, typically 10 to 12 percent, may have inhibited the development of large subsurface solution cavities by retarding migration of ground water. In contrast, the Newala Limestone rarely contains more than two percent noncarbonate impurities and appears to be very susceptible to aqueous dissolution.

Subtidal, chert-free, coarsely crystalline dolostone within the Newala Limestone may increase its dissolution potential relative to that of the Odenville or Longview Limestones. Rocks of this type are highly susceptible to sinkhole formation (Brink, 1984). Holocene caverns within the lower Newala are commonly encountered during drilling in the type area of the formation (B. Kitchens, Vulcan Materials Corporation, and T. Flannery, Blue Circle Industries, oral commun., 1986). A collapsed cave occurs within the lower Newala near the base of the Vulcan Materials Corporation quarry north of Calera, Ala.; the age of this feature is unknown. Holocene sinkholes in the type area of the Newala are most common in the subjacent Longview Limestone because this unit contains tectonically fractured chert that provides pathways for fluid migration (LaMoreaux, 1984).

Local structure may also significantly influence the development of relief on the Knox paleoerosion surface. The Attalla Chert Conglomerate Member is restricted to an area between the Anniston and Harpersville lineament complexes (fig. 1; Drahovzal, 1974). Moreover, the thickest and coarsest development of the Attalla is associated with the lineament complexes (Drahovzal and others, 1974); within the Anniston lineament complex, high-angle faults vertically offset the top of the Knox Group by as much as 45 m. These faults may be the result of differential movement of crustal blocks contemporaneous with, or prior to, deposition of the Attalla Chert Conglomerate Member (Drahovzal and others, 1974). These data imply that development of the Attalla is related to regional structural features.

In contrast, the known Cottingham Creek deposits do not appear to be associated with regional structures. At the type section of the Cottingham Creek, there is no evidence for tectonic deformation of the Newala prior to deposition of the Cottingham Creek, and stratigraphy appears to be the controlling factor for paleokarst development.

Duration of exposure may also significantly influence the configuration of the paleoerosion surface developed on the Knox Group. Repetski and Harris (1986) and Roberson

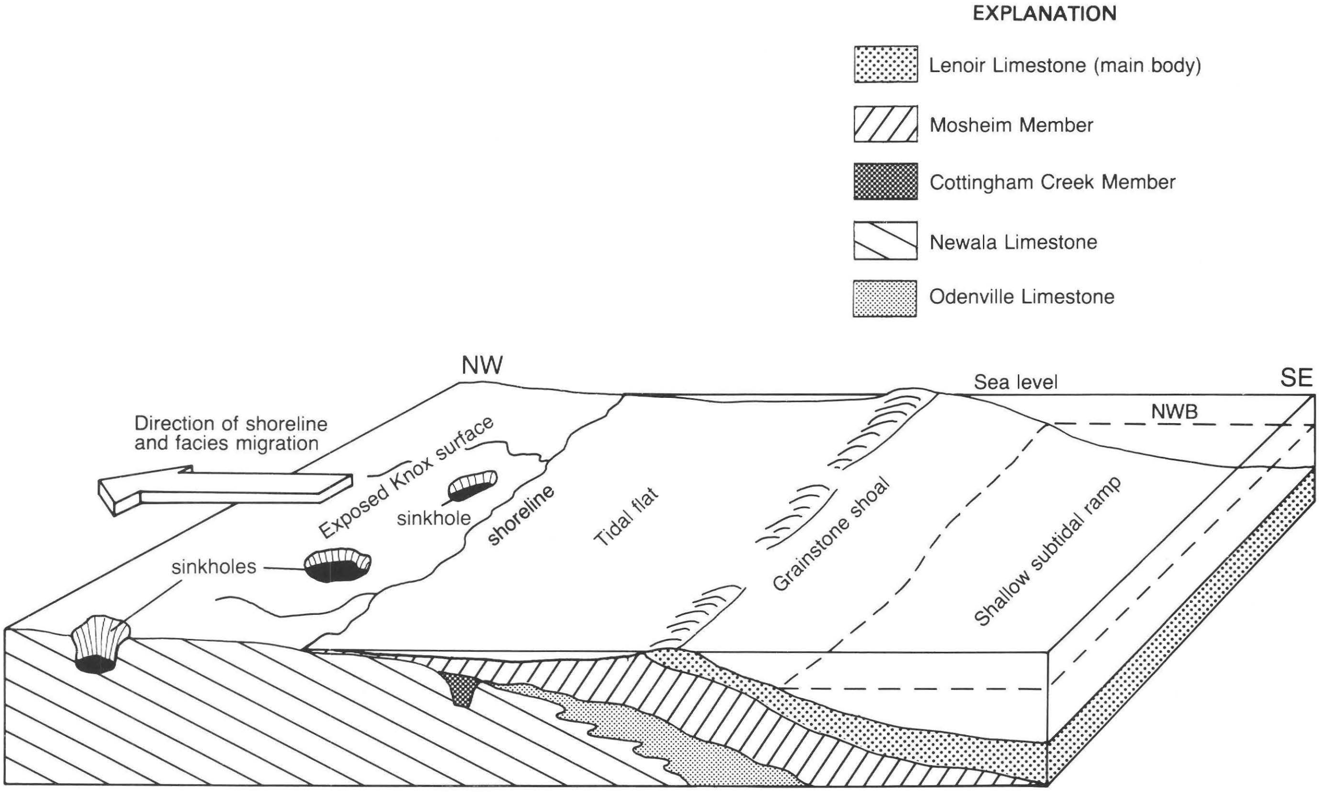

Figure 6. Inferred paleogeographic setting during deposition of the Cottingham Creek Member of the Lenoir Limestone in what is now part of central Alabama. NWB, normal wave base.

(1988) reported that the magnitude of the post-Knox, Middle Ordovician disconformity generally decreases eastward in the Appalachian basin. In addition, Neathery and Drahovzal (1971, 1986) reported a dark-maroon shale and a red to pink, cherty claystone near the base of the Attalla Chert Conglomerate Member and interpreted these rocks to represent a paleosol developed on the Knox surface. The apparent decrease in magnitude of the post-Knox, Middle Ordovician disconformity eastward and the development of a paleosol at the base of the Attalla imply that rocks below the disconformity in the western facies belt may have been exposed long enough to develop a valley and hill topography having a primarily surficial drainage, whereas rocks of the eastern facies belt may have been submerged before a surficial drainage pattern could be established. Furthermore, tectonic deformation of the chert-bearing rocks underlying the Attalla Chert Conglomerate, associated with the Anniston and Harpersville lineaments, may have accelerated degradation of the Knox paleosurface and dissolution in the subsurface. The Attalla Chert Conglomerate Member has a greater areal distribution than the Cottingham Creek Member. This supports the hypothesis that the Attalla Chert Conglomerate Member may represent valley-fill deposits, rather than locally restricted karst-depression fills represented by the Cottingham Creek deposits.

Neathery and Drahovzal (1971, 1986) reported that the Attalla Chert Conglomerate Member near Hensley Mountain, Ala., exhibits an upward size gradation and an increase in clast size approximately 12 m above the base of the unit. They attributed this increase to renewed influx of clastic material into the basin. Furthermore, some clasts are rounded and suggest mechanical transportation. The absence of conglomerate above the basal beds of the Cottingham Creek Member and the general angularity of clasts in these beds indicate their local derivation.

Figure 6 shows our interpretation of the paleogeographic setting when Cottingham Creek deposits accumulated in karst depressions within the Newala Limestone during the late middle to early late Whiterockian in the area that is now central Alabama. About 30 to 40 km northeast of Pratt Ferry and east of the Helena fault, the Odenville Limestone conformably overlies the Newala Limestone. Conodonts from the Odenville (J.E. Repetski, U.S. Geological Survey, unpub. data) indicate a very latest Early Ordovician age (highest *O. communis* Zone) to possibly very earliest Whiterockian age. This suggests that the depression at Pratt Ferry formed during early or middle Whiterockian time.

CONCLUSIONS

At Pratt Ferry, Ala., the base of the Lenoir Limestone consists of argillaceous dolostone and conglomerate.

Because these rocks are unlike other rocks in the Lenoir, they are herein designated the Cottingham Creek Member of the Lenoir Limestone. Conodonts indicate that this new member is of late middle to early late Whiterockian age and disconformably overlies the Newala Limestone. At this locality, the Newala Limestone is of late Early Ordovician age. The contact of the Cottingham Creek Member and the overlying Mosheim Member of the Lenoir Limestone is sharp and irregular and represents a discontinuity surface of relatively short duration. The Cottingham Creek deposits occur in paleokarst depressions developed on the Newala during the early and (or) middle Whiterockian. Areal distribution and lithostratigraphic and biostratigraphic data prove conclusively that the Cottingham Creek Member is geographically, lithologically, and chronologically distinct from the Attalla Chert Conglomerate Member. The Cottingham Creek is correlative with the Douglas Lake Member of the Lenoir Limestone of northeastern Tennessee, at least the lowest beds of the Wells Creek Dolomite of south-central Tennessee, and only the lower part, apparently, of the Pond Spring Formation of northwestern Georgia.

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PLATE 1

[SEM photomicrographs of specimens coated with carbon and gold; all specimens reposited in the U.S. National Museum of Natural History (USNM), Washington, D.C.]

Contact photographs of the plates in this report are available, at cost, from the U.S. Geological Survey Photographic Library, Federal Center, Denver, CO 80225.

PLATE 1

Selected conodonts from below and above the Lower-Middle Ordovician disconformity at Pratt Ferry, central Alabama

Figures 1–13. Conodonts from the Mosheim Member of the Lenoir Limestone.

- 1. *Cahabagnathus friendsvillensis* (Bergström), upper view of pastiniplanate element, ×75, USGS colln. 10088–CO, USNM 430386.
- 2–4. *Phragmodus flexuosus* Moskalenko, lateral views of M, P (outer), and Sc elements, ×75, USGS colln. 10091–CO, USNM 430387–89.
- 5–7. *Ansella nevadensis* (Ethington and Schumacher), lateral views of P, M, and Sa elements, ×50, USGS colln. 10086–CO, USNM 430390–92.
- 8, 9. *Belodina monitorensis* Ethington and Schumacher, inner lateral views of oistodontiform and rastrate elements, ×75, USGS colln. 10091–CO, USNM 430393–94.
- 10–12. *Erraticodon* aff. *E. balticus* Dzik, ×50.
    - 10. Anterior view of Pb element, USGS colln. 10091–CO, USNM 430395.
    - 11, 12. Inner lateral views of M and Sc (anterolateral process broken) elements, USGS colln. 10088–CO, USNM 430396–97.
- 13. *Leptochirognathus quadratus* Branson and Mehl, inner lateral view of primadontiform element, ×75, USGS colln. 10086–CO, USNM 430398.

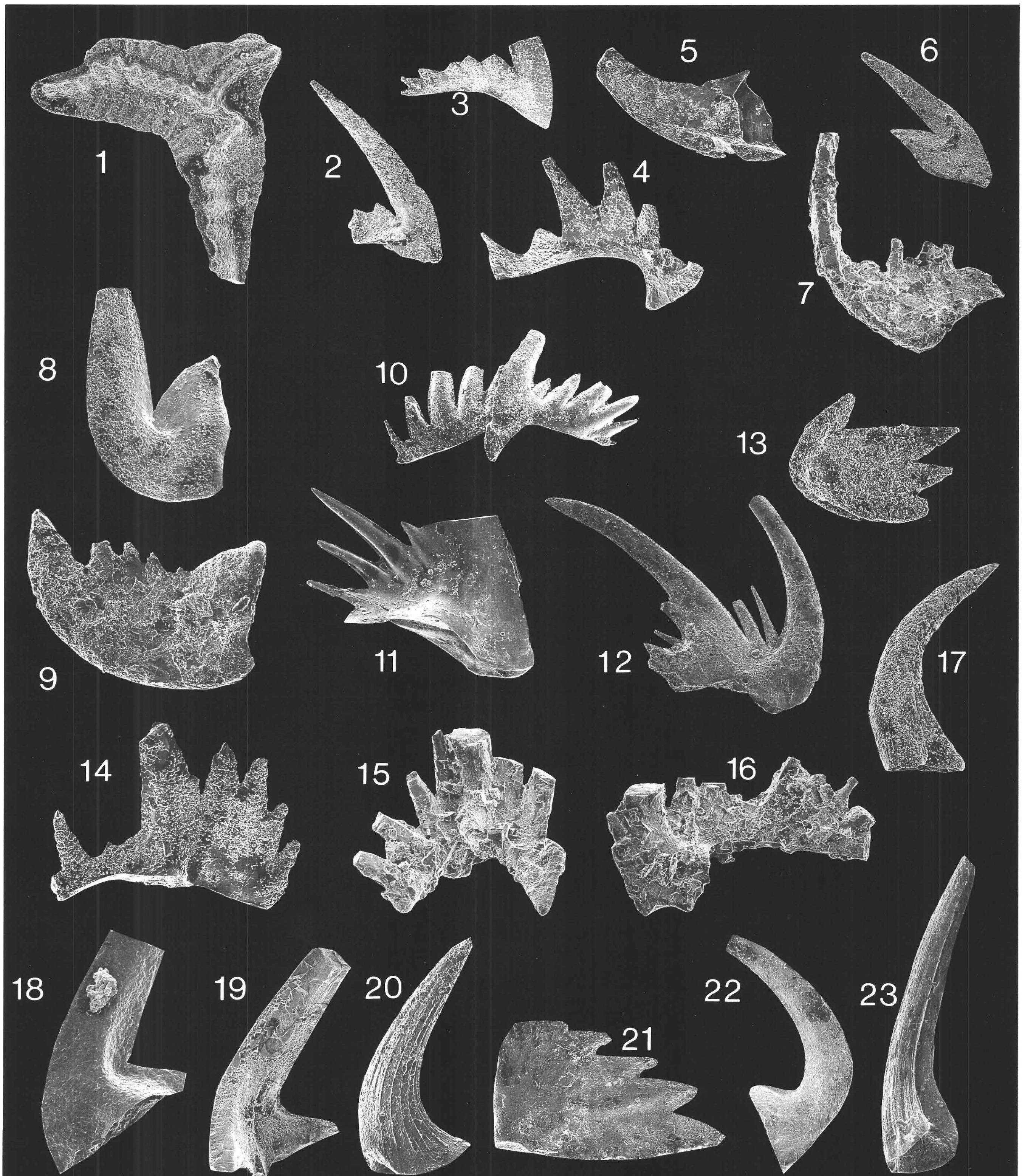
14–16. *Plectodina joachimensis* (Andrews), ×75.

- 14, 16. Inner lateral views of Pa and Sc elements, Mosheim Member of Lenoir Limestone, USGS colln. 10086–CO, USNM 430399, 410816.
- 15. Posterior view of Sb element, Cottingham Creek Member of Lenoir Limestone, USGS colln. 10046–CO, USNM 410817.

17. *Panderodus* sp., outer lateral view, ×75, Cottingham Creek Member of Lenoir Limestone, USGS colln. 10083–CO, USNM 430400.

18–23. Conodonts from the upper part of the Newala Limestone.

- 18, 19. *Diaphorodus delicatus* (Branson and Mehl), inner lateral views of M and Sb elements, ×75, USGS colln. 10039–CO, USNM 430401–02.
- 20. *Oneotodus costatus* Ethington and Brand, inner lateral view (anterobasal margin partly broken), ×75, USGS colln. 10080–CO, USNM 430403.
- 21. *Cristodus loxoides* Repetski, inner lateral view of rastrate element, ×75, USGS colln. 10082–CO, USNM 430404.
- 22. *Drepanodus concavus* (Branson and Mehl), inner lateral view of arcuatiform element, ×75, USGS colln. 10033–CO, USNM 430405.
- 23. "*Scolopodus*" *emarginatus* Barnes and Tuke, inner posterolateral view of Sb? element, ×75, USGS colln. 10080–CO, USNM 430406.



CAHABAGNATHUS, PHRAGMODUS, ANSELLA, BELODINA, ERRATICODON, LEPTOCHIROGNATHUS, PLECTODINA, PANDERODUS, DIAPHORODUS, ONEOTODUS, CRISTODUS, DREPANODUS, AND "*SCOLOPODUS*"

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