Cenomanian-Turonian (Upper Cretaceous) foraminifera from the westernmost Colorado Plateau, southwest Utah, U.S.A

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ABSTRACT: Foraminifera from the Cenomanian-Turonian Dakota Formation, Straight Cliffs Formation, Iron Springs Formation, and Tropic Shale of southwest Utah are described and illustrated in detail. The assemblage comprises 37 taxa including 27 agglutinated species and only nine calcareous taxa. The associations of the foraminifera can be summarized on the basis of their distributions relative to geologic age and formation. The lowermost units of the Dakota Formation in southwest Utah and Coal Mine Mesa Arizona are characterized by a *Trochammina rutherfordi mellariolium-Verneuilinoides perplexus* association. The uppermost strata of the Dakota Formation and lower Tropic Shale (upper Cenomanian) are characterized by a *Trochamminoides apricarius-Haplophragmium arenatum* association. Strata assigned to the lower-to middle Turonian Iron Springs and Straight Cliffs Formation are highly variable with respect to foraminiferal distributions. Lower Turonian deposits from the Tropic Shale, however, contain an association of *Reophax inordinata* and *Ammomargulina lorangerae*. The temporal and spatial variability of the foraminifera are attributed to transgressive-regressive facies shifts during deposition of the Greenhorn Marine Cycle. We recognize four paleoecological associations of agglutinated foraminifera that include: (1) a marsh assemblage dominated by *Trochammina* and *Miliammina*; (2) a central estuary assemblage dominated by *Ammobaculites* and *Trochammina*; (3) a distal estuary assemblage dominated by *Verneuilinoides*, *Textularia*, and *Trochamminoides*; and (4) a shelf assemblage dominated by *Haplophragmium* and *Reophax*.

INTRODUCTION

Upper Cretaceous foraminifera from the westernmost Colorado Plateau (text-fig. 1) bear compositional similarities to those documented elsewhere in the U.S. and Canadian Western Interior Basin (text-figure 2) (e.g., Eicher 1965, 1966; Caldwell et al. 1978; Eicher and Diner 1985). Recent papers by Tibert et al. (2003a, 2003b) and Tibert and Leckie (2004) have applied paleoecological techniques towards understanding sea level and climate changes during the Late Cretaceous without a formal taxonomic treatment. Tibert et al. (2009) have provided a detailed description of the Ostracoda and proposed a formal biostratigraphic zonation for this stratigraphic interval. This paper provides descriptions of both the agglutinated and calcareous taxa reported from the Upper Cretaceous Dakota Formation, lower Tropic Shale, Straight Cliffs Formation, and Iron Springs formation across the Kaiparowits, Paunsaugunt, and Markagunt Plateaus of southwest Utah (text-figs. 1, 2). We discuss the biostratigraphic implications of the foraminiferal ranges followed by a brief paleoecological summary.

BACKGROUND

Cretaceous coal-bearing strata and correlative nearshore mudrocks assigned to the upper Dakota Formation and Tropic Shale, respectively, were deposited during the Greenhorn Marine Cycle (GMC), a 3rd order (10^6 yr) global sequence (Kauffman 1977; Haq et al. 1988; Kauffman and Caldwell 1993; Hardenbol et al. 1998; Lauren and Sageman 2007) (text-fig. 3). Deposition of the GMC includes the Cenomanian/Turonian boundary interval (~94-93 Ma) when 3 to 4, intermediate duration, 4th and 5th order flooding cycles (10^5-10^4 yr) influenced the western Colorado Plateau region (Elder et al. 1994; Leithold 1994; Leithold and Dean 1998; Leckie et al. 1998; Sageman et al. 1998; West et al. 1998; Tibert et al. 2003a).

The Cenomanian/Turonian Boundary Interval (CTBI) is marked by rising eustatic sea level and a global Ocean Anoxic Event (OAE II) (e.g., Arthur et al. 1987; Schlanger et al. 1987; Leckie et al. 2002) that are well-defined in the Western Interior Basin (WIB) (e.g., Kauffman and Caldwell 1993; Leckie et al. 1998; Arthur and Sageman 2004; Sageman et al. 2006) (text-fig. 3). The WIB during this time interval was characterized by significant peat accumulation in coastal environments (Ryer 1984; Tibert et al. 2003a,b; Tibert and Leckie 2004). High molluscan and planktic foraminiferal species turnover (Elder 1985; Leckie 1985; Elder 1991) and stressed foraminiferal assemblages characterize the CTBI (Leckie and others 1998). The strata are thought to record intervals of enhanced stratification when brackish waters, derived from adjacent estuarine systems, capped the basinal waters of the foreland basin (Pratt et al. 1993). Greenhorn deposition in the vicinity of the western Colorado Plateau (text-fig. 1) was primarily non-calcareous and calcareous mud that accumulated at the mouth of a large estuarine system or brackish embayment known as the "Grand Canyon Bight" (Stokes and Heylmun 1963; Elder 1991; Kirkland 1991; Leckie et al. 1991; Elder and Kirkland 1993). The strata in southwest Utah are assigned to the Tropic Shale, which is laterally equivalent to the Tununk Member of the Mancos Shale in eastern Utah and lower Mancos Shale in western Colorado (Lamb 1968; Peterson 1969; Leckie et al. 1997) (text-figs. 2, 3).

TABLE 1
List of Localities

Loc.	Town and Geographic Landmarks	Quad. Info. USGS 7.5	Formations	Stages
1	Big Water, UT	T40S, R1W	Tropic Shale	Cenomanian-Turonian
2a	Henrieville, UT -Entrance to Grand Staircase National Park	T37S, R2W Route 12 (east facing)	Dakota Formation and Tropic Shale	Cenomanian
2b	Henrieville, UT -Entrance to Grand Staircase National Park	T37S, R2W Route 12 (west facing)	Straight Cliffs Formation	Turonian
3	Glory Cove, UT - North of Tropic	T36S, R3W Route 12	Straight Cliffs Formation	Turonian
4	Cedar Canyon, UT (Maple Canyon)	T36S, R10W -Route 14 Mile Marker 6	Dakota Formation and lower Tropic Shale	Cenomanian-Turonian
5	New Harmony UT- Kelsey Deer Camp	T37S, R13W	Iron Springs Formation	Turonian
6	Black Mesa, AZ - Hopi Reservation	Coal Mine Mesa	Dakota Formation	Cenomanian

This is the first detailed report illustrating the marginal marine foraminifera from the Cenomanian-Turonian Dakota Formation, Iron Springs Formation, and Straight Cliffs Formation on Paunsaugunt and Markagunt Plateau. Foraminiferal assemblages from the Tropic Shale and age-equivalent but more distal strata on the Colorado Plateau have been reported by Lamb (1968), Lessard (1973), Leckie et al. 1991; Olesen 1991; Leckie et al. 1998; West et al. (1998), and Tibert and others (2003a). Young (1951) described foraminiferal assemblages from the Cenomanian-Turonian Frontier Formation in southern Montana. A complimentary summary of the offshore foraminiferal assemblages from the Colorado Plateau is forthcoming (Schmidt et al. in prep.).

Mixing of cooler, less saline Boreal water masses and warmer, more saline Tethyan water masses is thought to have contributed to simultaneous increases in productivity and planktic foraminiferal abundances (Eicher and Diner 1989) in areas of inferred seafloor relief (fore-bulge) across the western foreland basin (Leckie et al. 1998). Benthic foraminifera also responded to oceanographic perturbations that were manifested as marked reduced abundances coincident with incursion of an oxygen minimum zone into the central regions of the seaway with rising sea level, or increased sedimentation rates and water column stratification with falling sea level (Leckie et al. 1998; West et al. 1998). Intervals of increased benthic foraminiferal abundance (e.g., *Gavelinella dakotensis, Neobulimina albertensis*, other calcareous taxa) are attributed to improved seafloor oxygenation or enhanced food availability (Eicher and Worstell 1970; Leckie et al. 1998; West et al. 1998). Fisher et al. (2000) demonstrated increased pore size and density in planktic species when Tethyan water masses inundated the seaway. Tibert and others (2003a) and Tibert and Leckie (2004) applied estuarine foraminiferal paleoecology in the coal-bearing strata coeval to the Tropic Shale to identify low magnitude (1-10 m) and high frequency sea level cycles (10^3-10^4 yrs).

SAMPLE LOCALITIES

Samples were collected from six localities (Table 1) (text-fig. 1) that includes: (1) Bigwater Utah, southern Kaiparowits Plateau (Tropic Shale); (2) Henrieville, Utah, Kaiparowits Plateau (Dakota, Tropic Shale, and Straight Cliffs Formations), (3) Glory Cove, Utah, Paunsaugunt Plateau (Straight Cliffs formation); (4) Cedar Canyon (Maple Canyon), Utah, Markagunt Plateau (Dakota Formation and Tropic Shale); (5) Harmony Coal Fields (Kelsey Deer Camp), Utah, Pine valley Mountains (Iron Springs Formation); and (6). Coal Mine Mesa, Arizona, Black Mesa Plateau, (Dakota Formation). Table 1 lists the details regarding the USGS quadrangle position, formation names and locality age.

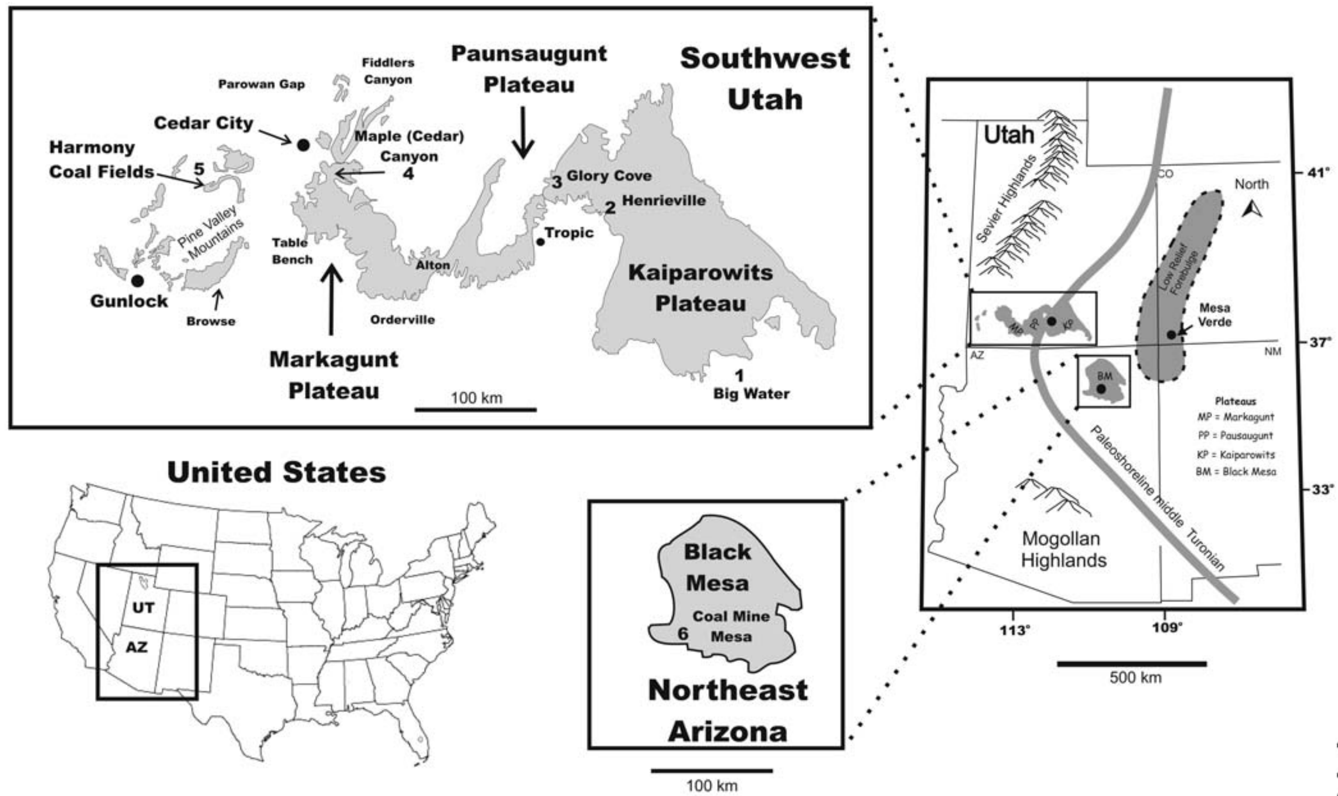
SYSTEMATICS

We follow the classification of Loeblich and Tappan 1987. Stratigraphic ranges are referenced to the Ostracode Zones of Tibert et al. (2009) in the context of the Molluscan Biozones of Kauffman et al. (1993) (text-fig. 2). Stratigraphic range charts are provided for Bigwater (loc. 1, text-fig. 4), Henrieville (loc. 2a-b, text-fig. 5, 6), Glory Cove (loc. 3, text-fig. 6), Maple Canyon (loc. 5, text-fig. 7). The distribution and census counts for Utah localities 1-5 are listed in Tables 2–7. The composite ranges of the taxa relative to their respective biozone are illustrated in text-figure 8.

Order FORAMINIFERA Eichwald 1830
Family SACCAMMINIDAE Brady 1884
Genus *Saccammina* Sars 1869

Saccammina alexanderi (Loeblich and Tappan 1950)
Text-figure 9.1

Proteonina alexanderi LOEBLICH and TAPPAN 1950, pl. 1, figs. 1-2., p. 5.



TEXT-FIGURE 1
The western Colorado Plateau study area and its relative position to the early Turonian (Late Cretaceous) shoreline, southwest Utah from Tibert and others (2009). Formal localities include those from Markagunt, Paunsaugunt and Kaiparowits Plateau in southwest Utah and Black Mesa, northeastern Arizona. Detailed locality information is listed in Table 1 modified from Tibert et al. (2009).

Saccammina alexanderi Loeblich and Tappan. EICHER 1965, pl. 103, fig. 1, p. 891. – EICHER and WORSTELL 1970, pl. 1, fig. 7, p. 280. – MCNEIL and CALDWELL 1981, pl. 9, fig. 8, p. 132.

Description. A coarsely arenaceous test with a "white" or vitreous appearance. A flattened single chamber with a tapered neck and terminal aperture. Maximum dimensions of the test are: Width 374µm; Height 772µm.

Geographic distribution. Species occurs in relative abundance in north and central plains of the USA and Canada. Occurs in the Tropic Shale at Henrieville (locality 2) and Bigwater (locality15).

Stratigraphic range. Albian–Turonian.

Family HORMOSINIDAE Haeckel 1894
Genus *Reophax* Montfort 1808

Reophax inordinatus Young 1951
Text-figure 9.2

Reophax inordinatus YOUNG 1951, pl. 11, figs. 1-2, p. 48. – EICHER 1966, pl. 4, figs. 3-4, p. 21. – MCNEIL and CALDWELL 1981, pl. 10, fig. 6, p. 141.
Reophax deckeri TAPPAN *in* Lessard 1973, pl. 1, fig. 1, p. 18.

Description. A coarsely agglutinated test that comprises a serial array of 4-5 chambers, which gradually increase in size as added, and is commonly flattened. The final chamber has a tapered neck with a terminal aperture. Maximum test dimensions are: W = 544µm; H = 714µm.

Remarks. A prominent taxon in the Turonian; first occurrence is above Bentonite TT3 (Tibert et al. 2003a). Its relative abundance in association with *Saccammina alexanderi* provides a useful Turonian indicator in the southwestern Colorado Plateau area.

Geographic distribution. Common in Turonian strata on the Colorado Plateau and the central and northern plains of the USA and Canada. Proliferates in strata assigned to the Cenomanian-Turonian boundary interval in the Tropic Shale, locality 1, Bigwater, Utah.

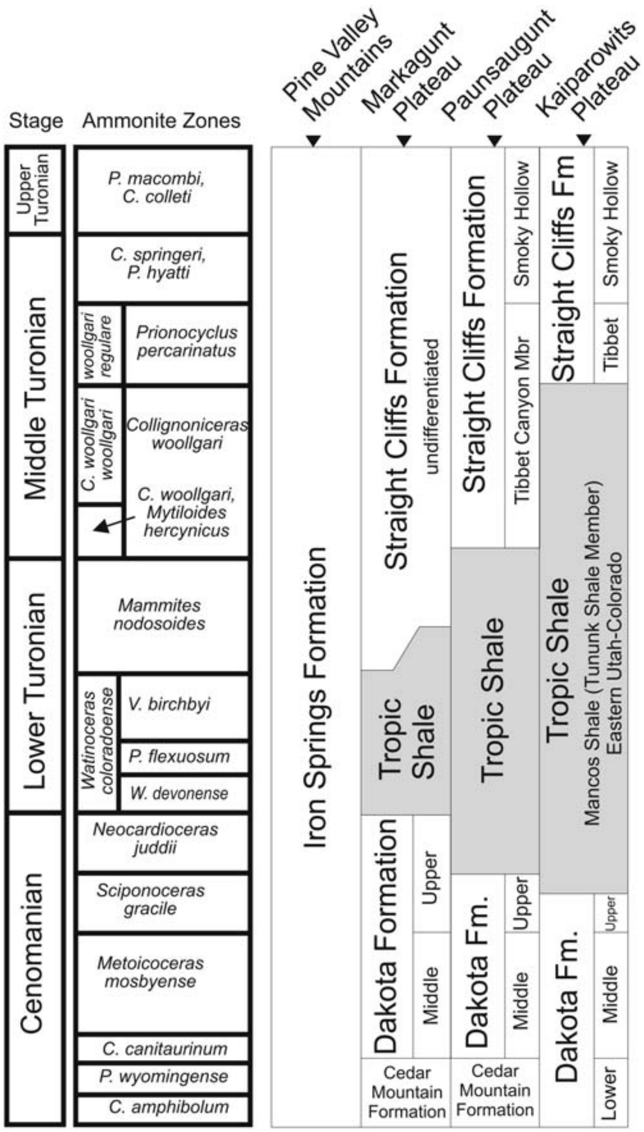
Stratigraphic range. Turonian (Ostracode Biozone III; Tibert et al. 2009).

Reophax* cf. *R. incompta Loeblich and Tappan 1946
Text-figure 9.3

Reophax incompta LOEBLICH and TAPPAN 1946, pl. 35, fig. 1, p. 242. – MCNEIL and CALDWELL 1981, pl. 9, figs. 19, 20, p. 138.

Description. A large, coarsely agglutinated test with a uniserial arrangement of 7-8 chambers that increase in size as added. Maximum test dimensions are: W = 168µm; H = 576µm.

Remarks. This agglutinated taxon has an oblique, 90^o juxtaposition of its growth axis at approximately three quarters of the to-



TEXT-FIGURE 2
Regional stratigraphy for the study interval. Molluscan biozones from Kauffman et al. (1993).

tal height. The figured paratype does not show the juxtaposition of the growth axis. The unique arrangement of the chambers in material from southwest Utah indicates that this is likely a new species; however, we will leave this taxon in open nomenclature until comparisons with the type material can be made. In southwest Utah, this species ranges from the *Sciponoceras gracile* Ammonite Biozone (below bentonite TT2) through to the lower Turonian.

*Geographic distribution***.** Common in the south central plains and the Colorado Plateau, USA. Most common in the Tropic Shale at locality 1, Bigwater, Utah.

Stratigraphic range. Uppermost Cenomanian-lower Turonian (Ostracode Biozones II and III; Tibert et al. 2009).

Reophax **sp**.
Text-figure 9.4

Description. A relatively small agglutinated test comprised of coarse silty particles. The uniserial array has 6-7 obliquely oriented, sigmoidal chambers with faint sutures. The final chamber is acutely pointed with a terminal aperture. Maximum test dimensions are: Width = 136µm; Height = 374µm.

Geographic distribution. Restricted to southwest Utah at locality 4 in Cedar Canyon in the Straight Cliffs Formation.

Stratigraphic range. Middle Turonian (Ostracode Biozone III; Tibert et al. 2009).

Reophax recta Beissel 1886
Text-figure 9.5

Reophax recta BEISSEL 1886, pl. 5, figs. 1-3, p. 22. – EICHER 1966, pl. 17, figs. 3-4, p. 180.

Description. Uniserial test comprising coarse silty grains of quartz and feldspar with minimal amount of fine grained matrix. Five-to six chambers that increase only slightly as added; initial chamber is large and bulbous. Maximum test dimensions are: Width = 116µm; Height = 639µm.

Remarks. This taxon is distinguishable from *Coscinophragma codyensis* because it is truly uniserial and the final chamber is not overly inflated. It resembles *Reophax texanus* figured in McNeil and Caldwell, but has numerous, robust chambers. Co-occurs with *Trochammina ribstonensis* and provides an excellent indicator for the lower Turonian.

Geographic distribution. This taxon is found in post-Greenhorn strata assigned to the Upper Planktonic Zone (Eicher 1966; Eicher and Worstell 1970) that includes the Straight Cliffs Formation and Tropic Shale, localities 1, 2a, 4 (Bigwater, Henrieville, and Cedar Canyon).

Stratigraphic range. Lower-to middle Turonian (Ostracode Biozone III; Tibert et al. 2009).

Family RZEHAKINIDAE Cushman 1933
Genus *Miliammina* Heron-Allen and Earland 1930

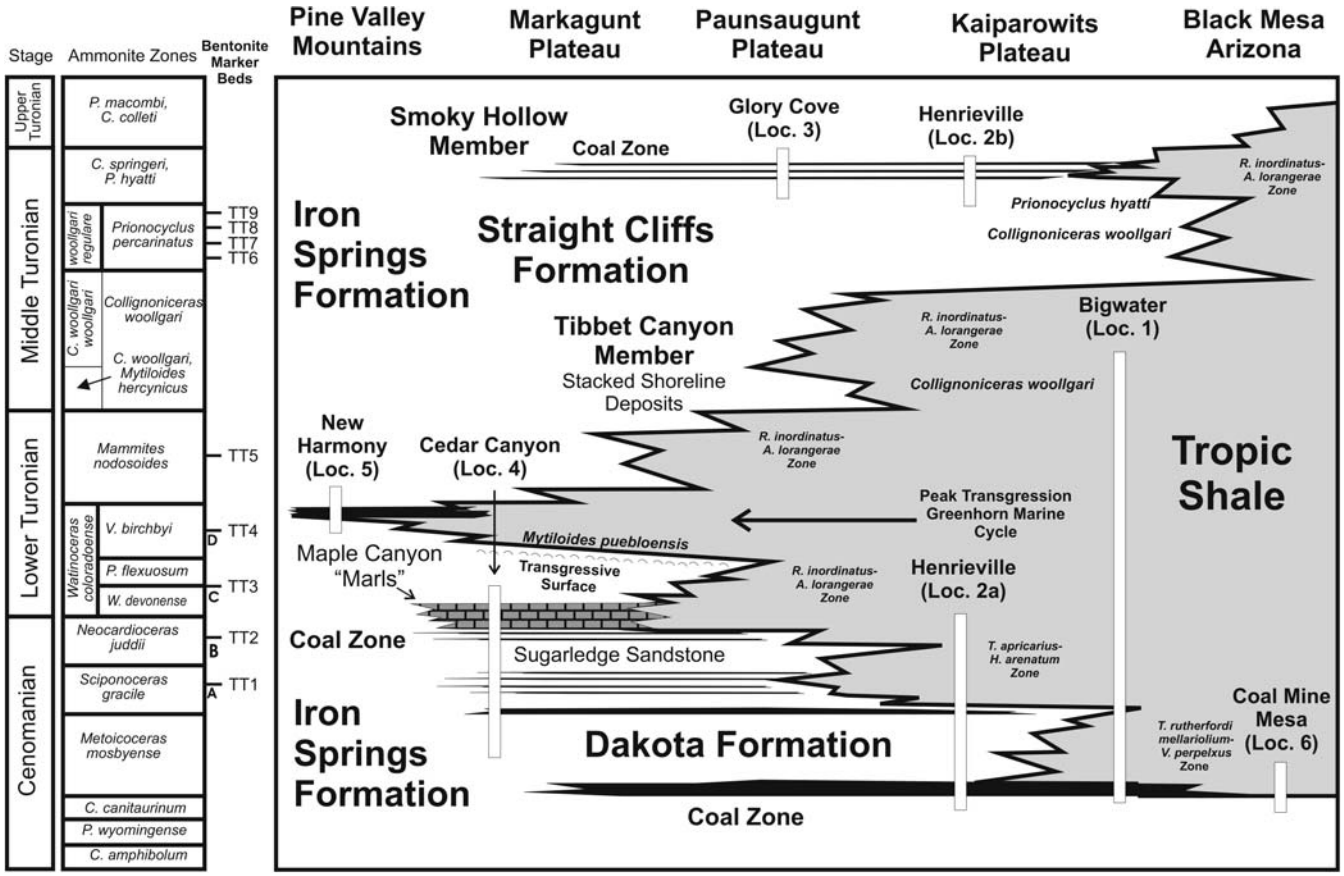
Miliammina ischnia Tappan 1957
Text-figure 9.6

Miliammina ischnia TAPPAN 1957, pl. 67, figs. 25-26, p. 211. – EICHER 1960, pl. 5, figs. 11-12, p. 71. – EICHER 1965, pl. 103, figs. 4-5, p. 893. – STRITCH and SCHROEDER-ADAMS 1999, pl. 2, fig. 5.

Description: A thin, quinqueloculine, agglutinated test comprised of fine silty particles with a large proportion of cement that gives it a whitish appearance. The terminal neck has a wide, circular aperture. Maximum test dimensions are: Width = 102µm; Height = 340µm.

Remarks: Differs from *Miliammina manitobensis* in that it is much thinner. *Psamminopelta bowsheri* differs in its basic coiling design.

Geographic distribution: This taxon has been reported in the strata assigned to the Albian, *Miliammina manitobensis* Foraminifera Biozone, Alberta, Canada (Stritch and Schroeder-Adams, the Albian Thermopolis Shale and Cenomanian Graneros



TEXT-FIGURE 3
Summary figure showing the relative position of the localities and stratigraphic sections in the context of the regional stratigraphy of the Dakota, Tropic Shale, Straight Cliffs, and Iron Springs Formations. Ammonite zones from Kauffman et al. (1993) and bentonite from Elder et al. (1994) and Leithold (1994). TT1-TT5 bentonites ('Tropic-Tununk') from Leithold (1994); A-D bentonites from Elder and Kirkland (1985). Note that Kauffman and other (1993) molluscan zones are calibrated to the radiometric dates reported in Meyers et al. (2012).

Shale, and the Turonian Carlile Formation (Eicher. This taxon is widespread in the Cenomanian Dakota Formation to middle Turonian Straight Cliffs Formation at localites 2, 3, and 4 across the Markagunt, Paunsaugunt and Kaiparowits Plateaus. This species is perhaps the most temporally resilient, in that it occurs in most of the marginal marine coal zones (Tibert et al. 2003a).

Stratigraphic Range: Albian – Turonian (Ostracode Biozone I; Tibert et al. 2009).

Psamminopelta bowsheri Tappan 1957
Text-figure 9.7

Psamminopelta bowsheri TAPPAN 1957, pl. 6, figs. 11-18, 22-24, p. 11. – MCNEIL and CALDWELL 1981, pl. 10, fig. 17, p. 144.
Spirolocammina bowsheri Tappan. EICHER 1965, pl. 103, figs. 6-10, p. 893.
Spirolocammina subcircularis EICHER 1960, pl. 5, figs. 19-20, p. 72.

Description: A spiroloculine agglutinated taxon that has a test comprised of fine silt with a significant proportion of cement. The width of the test is where specimens typically exhibit low width to height ratios and therefore demonstrate a planispiral appearance. There is a large, circular aperture at the end of final chamber. Maximum test dimensions are: Width = 167µm; Height = 237µm.

Remarks: This taxon superficially resembles *Miliammina*, but it can be distinguished by its spiroloculine coiling.

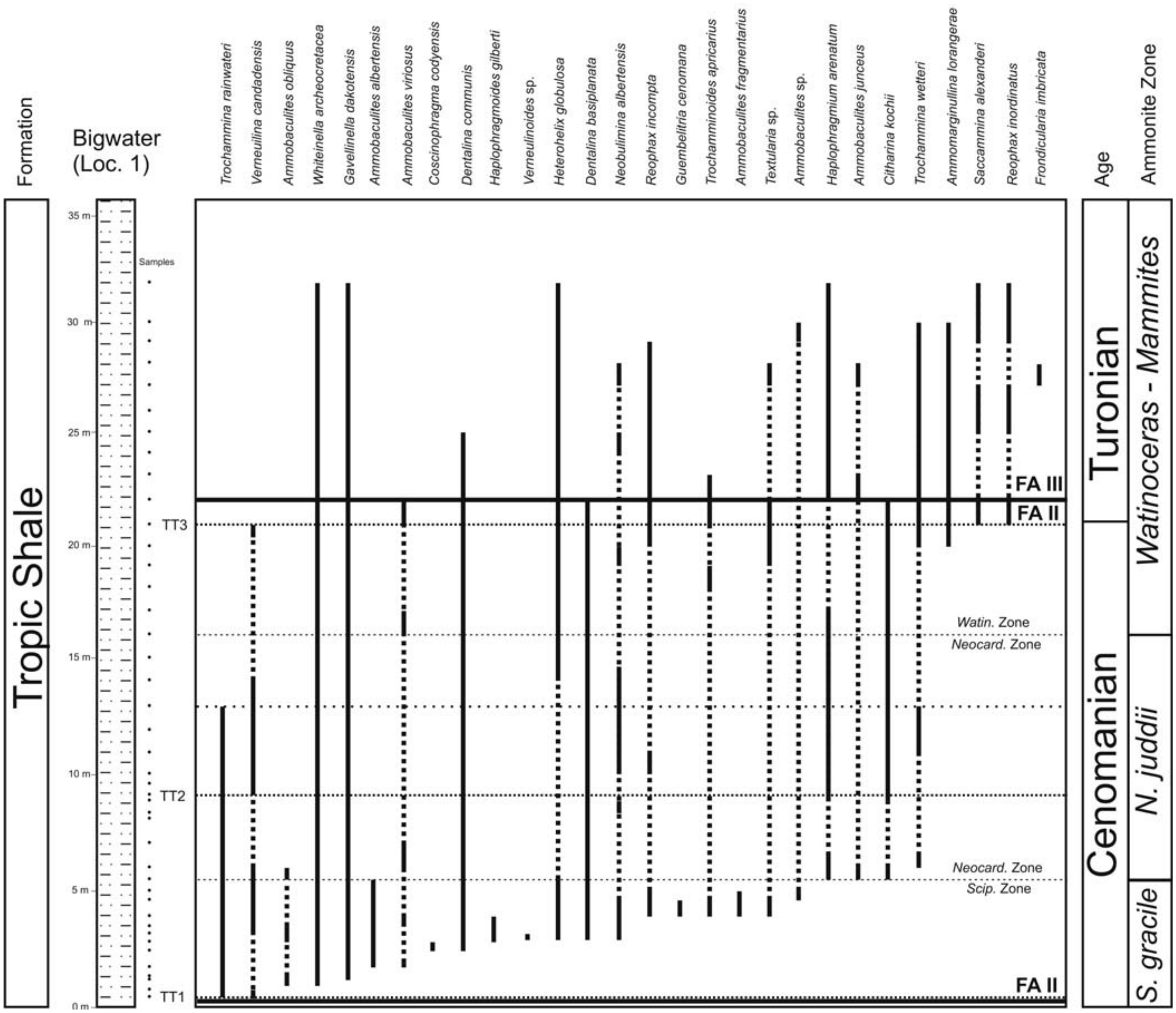
Geographic distribution: This taxon is reported in strata assigned to the *Haplophragmoides gigas* to *Miliammina manitobensis* foraminiferal biozones from Canada, the Cenomanian Graneros Shale (Eicher, and the upper Cenomanian Dakota Formation, localities 1 and 2 (Bigwater and Henrieville). Most common in strata assigned to the upper Cenomanian *Metoicoceras mosbyense* Ammonite Biozone (Tibert et al. 2003a).

Stratigraphic range: Albian-Cenomanian (Ostracode Biozone I; Tibert et al. 2009).

Family LITUOLIDAE Blainville 1827
Subfamily HAPLOPHRAGMOIDINAE Maync 1952
Genus *Haplophragmoides* Cushman 1910

Haplophragmoides gilberti Eicher 1965
Text-figure 9.8

Haplophragmoides gilberti EICHER 1965, pl. 104, figs. 11,13,14, p. 894.



TEXT-FIGURE 4
Biostratigraphic distribution of the foraminiferal and ostracode taxa from the Tropic Shale at Bigwater, Utah (locality 1). Bentonite markers indicated on the column are from Leithod (1994). Molluscan zones are from Kauffman and others (1993). Foraminiferal assemblage zones after Eicher (1965, 1966), Eicher and Worstell (1971), and Eicher and Diner (1985): FA I – *Trochammina rutherfordi mellariolium-Verneulinoides perplexus*; FA II – *Trochamminoides apricarius-Haplophragmium arenatum*; FA III – *Reophax inordinatus-Ammomarginulina lorangerae*.

Description: This is an evolute, planispiral, coarsely arenaceous taxon; test is broad with large, rounded chambers.

Remarks: Haplophragmoides topagorukensis is involute and has more chambers. *H. gigas* and *H. topagorukensis* are both larger in size.

Geographic distribution: This taxon has been reported in the Cenomanian Graneros Shale (Eicher and the upper Cenomanian Tropic Shale, Utah. Most abundant within strata assigned to the *Sciponoceras gracile* Ammonite Biozone occurring between bentonites TT1 and TT2 at localities 1 and 2a (Bigwater and Henrieville) (Tibert et al. 2003a).

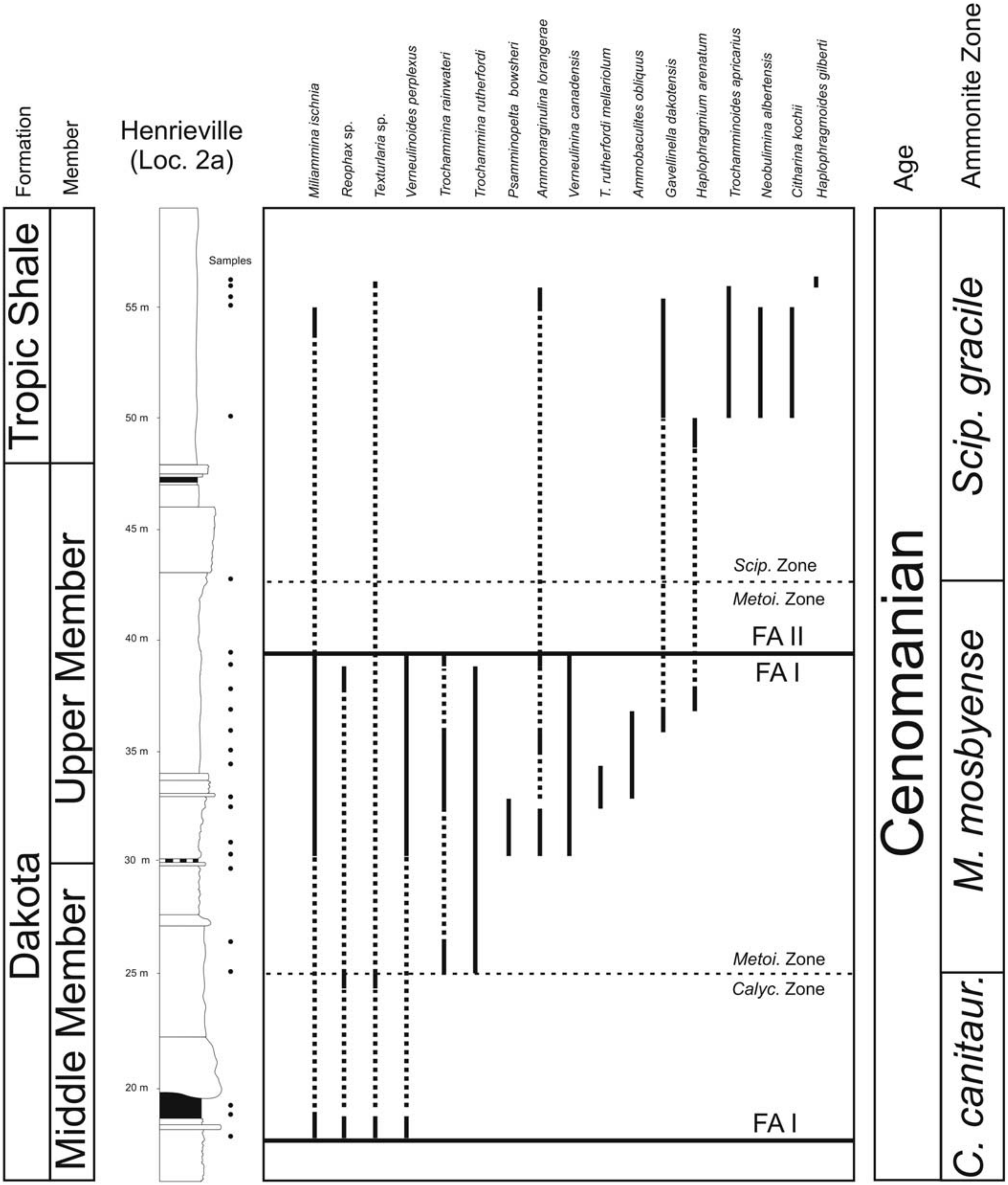
Stratigraphic range: Upper Cenomanian (Ostracode Biozone II; Tibert et al. 2009).

Genus *Haplophragmium* Reuss 1860

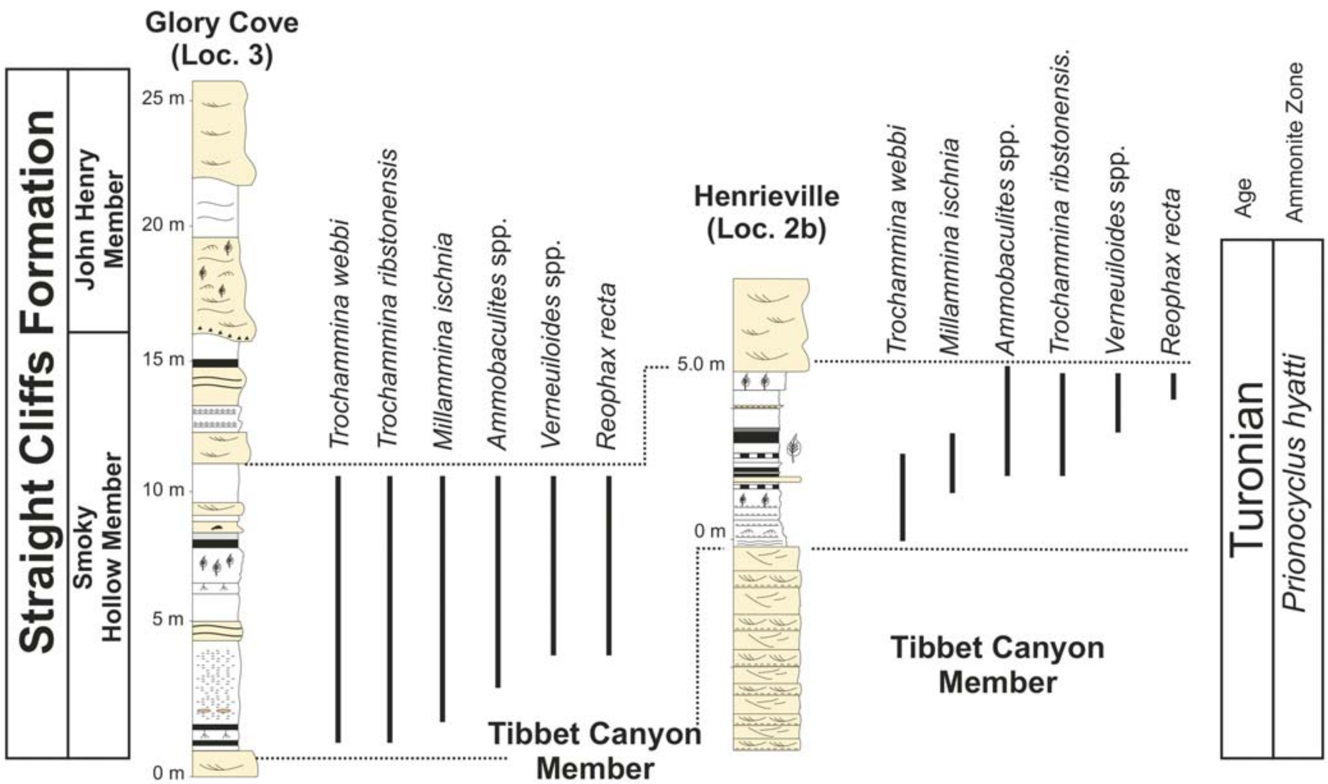
Haplophragmium arenatum Lamb 1969
Text-figure 9.9a-c

Haplophragmoidium arenatum LAMB 1969, text figs. 4-6, p. 143-144.
Ammobaculites obscurus LESSARD 1973, pl. 1, fig. 2, p. 19.

Description: An extremely large, morphologically variable, but distinctive taxon that has loosely coiled chambers. The test comprises fine to medium sized silt particles with significant



TEXT-FIGURE 5
Biostratigraphic ranges of microfossils at Henrieville (Dakota Fm.) (locality 2a). Stratigraphic measurements are meters above the base of the Dakota Formation. See Tibert et al. (2003a,b; 2009) more information on this section. Foraminiferal assemblage zones after Eicher (1965, 1966), Eicher and Worstell (1971), and Eicher and Diner (1985): FA I – Trochammina rutherfordi mellariolium-Verneulinoides perplexus; FA II – Trochamminoides apricarius-Haplophragmium arenatum; FA III – Reophax inordinatus-Ammomarginulina lorangerae.



TEXT-FIGURE 6
Biostratigraphic ranges of microfossils from the Turonian Straight Cliffs Formation at Henrieville (locality 2b) and Glory Cove (locality 3). Stratigraphic measurements are meters above the base of the Tibbet Canyon Member. See Tibert and Leckie (2004) for more information on this section.

amount of calcareous cement easily detectable by applying weak hydrochloric acid to the specimens. The coiling arrangement ranges from planispiral to uncoiled and it is not uncommon to observe broken uniserial specimens. Maximum test dimensions are: Width = 595µm; Height = 935µm.

Geographic distribution: Abundant in the lower Mancos Shale and Tropic Shale near Bigwater and Henrieville, Utah (localities 1, 2a).

Stratigraphic range: Upper Cenomanian-Turonian. An excellent marker for the uppermost Cenomanian *Sciponoceras gracile* and *Neocardioceras juddii* Ammonite Biozones (Kauffman et al. (1993) and Ostracode Biozone II of Tibert et al. (2009).

Genus *Trochamminoides* Cushman 1910

Trochamminoides apricarius Eicher 1965
Text-figure 9.10

Trochamminoides apricarius EICHER 1965, pl. 103, figs. 7, 12, p. 894. – EICHER 1967, pl. 17, fig. 6, p. 181.

Description: A medium size, finely arenaceous planispiral test with 8-9 chambers that increase in size progressively as added. The evolute coiling is subtle and easily mistaken as trochospiral without careful inspection of the sutures that are radial to the umbilicus. Maximum test dimensions are: Width = 408µm; Height = 544µm.

Remarks: The lateral compression of most specimens makes this taxon difficult to differentiate from *Trochammina rainwateri* which has loosely coiled chambers and, thickened curved sutures on the spiral side, and true trochospiral coiling. The nearly planispiral coiling, depressed radial sutures, and robust chambers are key to identifying *T. apricarius*.

Geographic distribution: Common in the Cenomanian Graneros Shale (Eicher 1965, 1967; Eicher and Worstell 1970; Frush and Eicher 1975) and used to define the *Trochamminoides apricarius* Foraminifera Biozone (Eicher and Diner 1985). A prominent taxon in the Dakota Formation and Tropic Shale at localities 1, 2, and 4 (Bigwater, Henrieville, and Cedar Canyon).

Stratigraphic range: Upper Cenomanian. A prominent taxon in the Ostracode Biozone II (Tibert et al. 2009) in the strata assigned to the *Sciponoceras gracile* and *Neocardioceras juddii* Ammonite Biozones of Kauffman et al. (1993).

Genus *Ammobaculites* Cushman 1910

Ammobaculites obliquus Loeblich and Tappan 1949
Text-figure 9.11 a-b

Ammobaculites obliquus LOEBLICH AND TAPPAN 1949, pl. 1, figs. 14-17, p. 90.

Description: An uncoiled agglutinated foraminifera with sigmoidal sutures that slope forward in the direction of the umbilical area. The terminal aperture has a tapered flare. Width = 289µm; Height = 510µm.

Remarks: Ammobaculites fragmentarius differs from others assigned to this genus herein on the basis of its tighter original coil and large aperture without a terminal neck. *Ammobaculites bergquisti* is much more robust and has fewer serial chambers.

Geographic distribution: Reported in the Comanchean Series and widely reported from the northern reaches of the seaway, most common to the *Ammobaculites gravenori* foraminifera biozone of Stelck and Wall and Aptian strata in the United Kingdom (Hart 1990). In Southwest Utah, it occurs at localities 2a, 4, and 5 (Henrieville, Cedar Canyon, New Harmony) and locality 6 in Black Mesa, Arizona.

Stratigraphic range: Aptian – Turonian. A useful indicator for Cenomanian-Turonian in southwest Utah at localities 2a and 4 on Markagunt and Kaiparowits Plateaus. Occurs in all marginal facies from the upper Cenomanian *Metoicoceras mosbyense* through to the middle Turonian *Prionocyclus hyatti* ammonite biozones of Kauffman et al. (1993).

Ammobaculites* cf. *A. fragmentarius (Cushman 1927)
Text-figure 9.12

Ammobaculites fragmentaria CUSHMAN 1927, pl. 1, fig. 8, p. 130. – EICHER 1960, pl. 4, fig. 11, p. 61-62. – MCNEIL and CALDWELL 1981, pl. 12, figs. 6-7, p. 158.

Description: A coarsely arenaceous foraminifera with large flattened chambers that increase rapidly in size as added.

Remarks: Ammobaculites junceus differs by its tight initial coil and chambers that gradually increase in size as added.

Geographic distribution: Widely distributed in late Albian strata on the northern plains in both the USA and Canada. It is sparsely distributed in the southernmost deposits of the seaway that includes the Cenomanian-Turonian, Tropic Shale and Straight Cliffs Formation at localities 1 and 4 on Kaiparowits and Markagunt Plateaus.

Stratigraphic Range: Albian-Cenomanian.

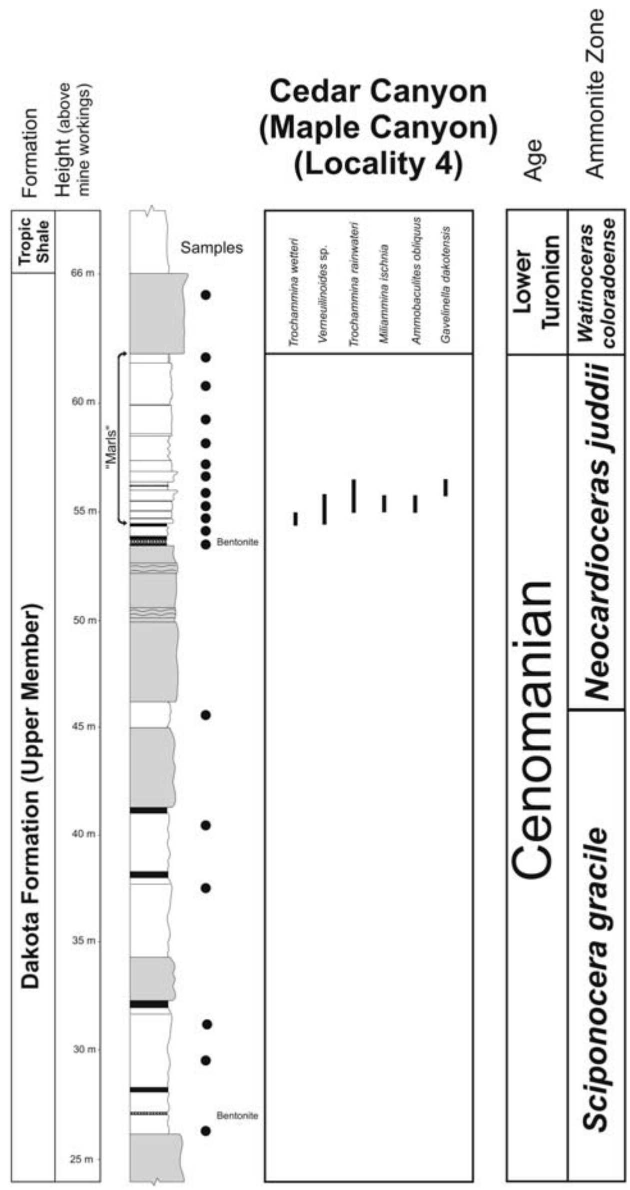
Ammobaculites junceus Cushman and Applin 1946
Text-figure 9.13

Ammobaculites junceus CUSHMAN and APPLIN 1946, pl. 13, fig. 2, p. 72. – EICHER and WORSTELL 1970, pl. 1, fig. 6 a,b, p. 281.

Description: A coarsely arenaceous, tightly coiled test with numerous chambers. Maximum test dimensions are: Width = 425µm; Height = 850µm.

Remarks: Ammobaculites fragmentarius has fewer, loosely coiled chambers and an apertural neck at the terminus of the final chamber.

Geographic distribution: Widespread occurrence in the Woodbine Formation of Texas and the Cenomanian-lower Turonian, Greenhorn Formation, USA, (Eicher and Worstell). Common in the uppermost Cenomanian and lower Turonian, Tropic



TEXT-FIGURE 7
Biostratigraphic ranges of microfossils from the Cenomanian-Turonian Boundary at Cedar Canyon (locality 4). Stratigraphic measurements are meters above the base of the Dakota Formation. See Tibert et al. (2003a; 2009) and Lauren and Sageman (2007) for more information on this section.

Shale and Straight Cliffs Formation at localities 1 and 2a (Bigwater and Henrieville).

Stratigraphic range: Albian to Turonian.

Ammobaculites impexus Eicher 1965
Text-figure 9.14

Ammobaculites impexus EICHER 1965, pl. 104, figs. 3-5, p. 895.

Description: A finely arenaceous test with a tight primary planispiral coil that gives way to 3-5 evenly sized serial chambers. The terminal aperture is notably small. Maximum test dimensions are: Width = 85µm; Height = 374µm.

Remarks: This taxon has a diagnostic "J" shape. *Ammobaculites obliquus* has a sinuous uniserial arrangement and curved sutures. *Ammobaculites junceus* is much larger and has chambers that increase in size as added with a large terminal aperture.

Geographic distribution: Cenomanian, Graneros Shale, USA, (Eicher 1966); Turonian, Straight Cliffs Formation, at localities 2a and 4 on Markagunt and Kaiparowits Plateaus and locality 6 at Black Mesa, Arizona.

Stratigraphic range: Cenomanian-Turonian.

Ammobaculites viriosis Loeblich and Tappan 1949
Text-figure 9.15

Ammobaculites viriosis LOEBLICH and TAPPAN 1949, pl. 47, fig. 1, p. 252.

Description: A large and coarsely arenaceous test with loosely coiled chambers that progressively increase in size as added.

Remarks: A. junceus and *A. fragmentarius* do not exhibit as tight a coil.

Geographic distribution: Reported in the Walnut Formation in Texas and common in strata assigned to the *Sciponoceras gracile* and *Neocardioceras juddii* Ammonite Biozones (uppermost Cenomanian) (Kauffman et al. 1993) in the Tropic Shale at locality 1 (Bigwater).

Stratigraphic range: Albian-Cenomanian.

Ammobaculites cf. ***A. albertensis*** Stelck and Wall 1954
Text-figure 9.16

Ammobaculites albertensis STELCK and WALL 1954, pl. 2, figs. 12-14, p. 18.

Description: A coarsely arenaceous test with an initial tight coil with 2-3 chambers of equal size, separated by oblique suture. The terminal chamber has a simple aperture.

Remarks: Eicher (1965, pl. 2a-b) figured specimens of *A. bergquisti* that resemble those depicted herein, but, his specimens do not possess the projecting neck on the final chamber.

Geographic distribution: Reported from the Kaskapau Formation in western Canada and strata assigned to the *Sciponoceras gracile* Ammonite Biozone (Kauffman et al. 1993) in the Tropic Shale, Utah at locality 1 (Bigwater).

Stratigraphic range: Cenomanian.

Ammomarginulina lorangerae Stelck and Wall 1955
Text-figure 9.17

Ammomarginulina lorangerae STELCK and WALL 1955, pl. 1 figs. 13, 27,p. 34.

Description: The test is flattened and finely arenaceous with a first coil followed by final two serial chambers separated by oblique and sinuous sutures. The final chamber has a tapering neck and small terminal aperture. Maximum test dimensions are: Width = 204µm; Height = 323µm.

Remarks: Ammobaculites obliquus closely resembles *Ammomarginulina lorangerae* but the former's coarsely agglutinated test has more numerous chambers in the uniserial array and they are more equi-dimensional.

Geographic distribution: Reported in strata assigned to the *Ammobaculites gravenori* Foraminifera Zone (below the *A. pacalis* Zone) in western Canada. Widespread in strata assigned to the *Metoicoceras mosbyense* through the *Sciponoceras gracile* Ammonite Biozones (Kauffman et al. 1993) in the upper Cenomanian Dakota Formation at localities 2a and 4 (Henrieville and Cedar Canyon).

Stratigraphic range: Cenomanian.

Family COSINOPHRAGMATINAE Thalmann 1932
Genus *Coscinophragma* Thalmann 1932

Coscinophragma codyensis (Fox 1954)
text-fig. 9.18

Polyphragma codyensis FOX 1954, pl. 25, figs. 1-4, p. 113.
Coscinophragma? *codyensis* Fox. EICHER 1967, pl. 18, figs. 5-6, p. 183. – EICHER and WORSTELL 1970, pl. 1, fig. 14, p. 281.

Description: Test comprises a tight coil that gives way to 7-8 uniserial chambers that increase in size as added. The chambers are spheroidal or flattened whereas the coiled portion is easily broken. Maximum test dimensions are: Width = 306µm; Height = 765µm.

Remarks: Coscinophragma codyensis differs from *Haplophragmium arenatum* by having fewer inflated chambers and a tight initial coil.

Geographic distribution: Reported in the Cody Shale of Wyoming, the Belle Fourche and Greenhorn Formations of the northern Plains USA (Eicher and Worstell. Occurs in the Tropic Shale at localities 1 and 2a (Bigwater and Henrieville).

Stratigraphic range: Cenomanian – Coniacian.

Famliy TEXTULARIIDAE Ehrenberg 1838
Genus *Textularia* Defrance 1824

Textularia sp.
Text-figure 9.19

Description: A biserial agglutinated test with numerous chambers that gradually increase in size as added. The test wall comprises fine silt-sized grains and there is a fair amount of cement. Maximum test dimensions are: Width = 289µm; Height = 374µm.

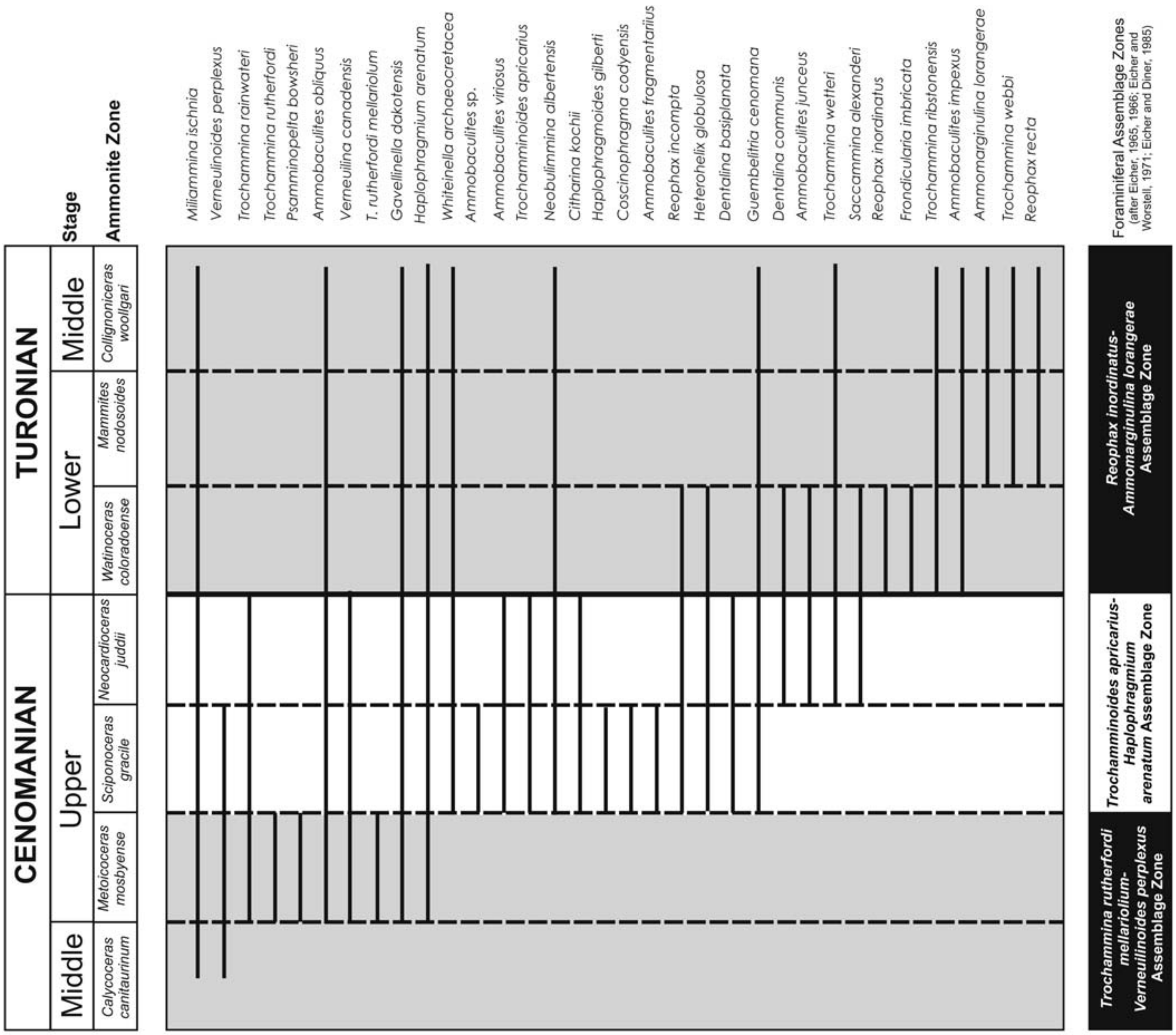
Remarks: This taxon resembles *T. rioensis* (Carsey 1926), but, differs because it is less robust in its degree of taper.

Geographic distribution: Common in strata assigned to the Straight Cliffs Formation at localities 2 a-b, 3, 4, and 5 (Henrieville, Glory Cove, Cedar Canyon, New Harmony).

Stratigraphic range: Cenomanian-Turonian.

Family TROCHAMMINIDAE Schwager 1877
Genus *Trochammina* Parker and Jones 1859

Trochammina rutherfordi Stelck and Wall 1955
Text-figure 9.20



TEXT-FIGURE 8
Composite biostratigraphic range data across the CTBI. Data are plotted relative to the ammonite biozones of Kauffman et al. (1993). Foraminiferal assemblage zones from Eicher (1965, 1966), Eicher and Worstell (1971), and Eicher and Diner (1985).

Trochammina rutherfordi STELCK and WALL 1955, pl. 1, figs. 11-12, 14-16; pl. 3, figs. 20-21, 36-37, p. 56. – EICHER 1965, pl. 105, fig. 1. – MCNEIL and CALDWELL 1981, pl. 14, figs. 2a-c. – BLOCH et al. 1993, figs. 4, 9-10. – STRITCH and SCHROEDER-ADAMS 1999, pl. 4, fig. 13.

Description: A small, tightly coiled trochospiral agglutinated taxon that comprises 7-8 chambers in last whorl that gradually increase in size as added. The test is composed of fine silty particles. The sutures are radial and slightly depressed. Maximum test dimensions are: Width = 170µm; Height = 170µm.

Remarks: Trochammina rainwateri is larger, laterally compressed, and displays lobate chambers. *Trochammina wetteri* has fewer chambers and the sutures are arcuate and not radial, reminiscent of *T. rutherfordi*. Eicher illustrates a specimen of *T. depressa*, which, given the number of chambers and the tight, finely arenaceous test, might be synonymous with *T. rutherfordi*.

Geographic distribution: Common in the Western Interior Basin and most prevalent during deposition of the Mowry Shale and overlying Graneros Shale in the south and the Westgate equivalents in the north. A prominent taxon in strata assigned to the *Metoicoceras mosbyense* Ammonite Biozone (Kauffman et al. 1993) in the Dakota Formation at localities 2a (Henrievillec) and locality 6 at Black Mesa, Arizona.

Stratigraphic range: Albian-Cenomanian (Ostracode Biozone I; Tibert et al. 2009).

TEXT-FIGURE 9
Foraminifera from the Dakota and Straight Cliffs Formations and the Tropic Shale, southwest Utah
Scale Bars = 100µm unless otherwise indicated on the plate.

1 *Saccammina alexanderi*, Tropic Shale, Bigwater UT, Cenomanian;

2 *Reophax inordinatus*, Tropic Shale, Bigwater UT, Cenomanian;

3 *Reophax incompta*, Tropic Shale, Bigwater UT, Cenomanian;

4 *Reophax* sp., Tropic Shale, Bigwater UT, Cenomanian;

5 *Reophax recta*, Tropic Shale, Bigwater UT, Turonian;

6 *Milammina ischnia,* Dakota Formation, Henrieville UT, Cenomanian;

7 *Psamminopelta bowsheri,* Dakota Formation, Henrieville UT, Cenomanian;

8 *Haplophragmoides gilberti,* Dakota Formation, Henrieville UT, Cenomanian;

9a-c *Haplophragmium arenatum,* Tropic Shale, Bigwater UT, Cenomanian;

10 *Trochamminoides apricarius,* Tropic Shale, Bigwater UT, Cenomanian;

11a-b *Ammobaculites obliquus,* Tropic Shale, Bigwater UT, Cenomanian;

12 *Ammobaculites fragmentarius?*, Tropic Shale, Bigwater UT, Cenomanian;

13 *Ammobaculites junceus,* Tropic Shale, Bigwater UT, Cenomanian;

14 *Ammobaculites impexus,* Tropic Shale, Bigwater UT, Cenomanian;

15 *Ammobaculites viriosis,* Tropic Shale, Bigwater UT, Cenomanian;

16 *Ammobaculites albertensis,* Tropic Shale, Bigwater UT, Cenomanian;

17 *Ammomaginulina lorangerae,* Tropic Shale, Bigwater UT, Cenomanian;

18 *Coscinophragma codyensis,* Tropic Shale, Bigwater UT, Cenomanian;

19 *Textularia* sp.*,* Tropic Shale, Bigwater UT, Cenomanian;

20 *Trochammina rutherfordi,* Dakota Formation, Henrieville UT, Cenomanian;

21 *Trochammina rutherfordi mellariolium,* Dakota Formation, Henrieville UT, Cenomanian;

22 *Trochammina rainwateri*, Tropic Shale, Bigwater UT, Cenomanian;

23 *Trochammina ribstonensis,* Tropic Shale, Bigwater UT, Turonian;

24a-b *Trochammina webbi,* Straight Cliffs Formation, Henrieville UT, Turonian;

25 *Trochammina wetteri*, Dakota Formation, Maple Canyon UT, Cenomanian;

26 *Verneuilinoides perplexus,* Dakota Formation, Henrieville UT, Cenomanian;

27 *Verneulina canadensis,* Dakota Formation, Henrieville UT, Cenomanian;

28 *Citharina kochii,* Tropic Shale, Bigwater UT, Cenomanian-Turonian;

29 *Dentalina basiplanata,* Tropic Shale, Bigwater UT, Cenomanian-Turonian;

30 *Dentalina communis,* Tropic Shale, Bigwater UT, Cenomanian-Turonian;

31 *Frondicularia imbricata,* Tropic Shale, Bigwater UT, Cenomanian-Turonian;

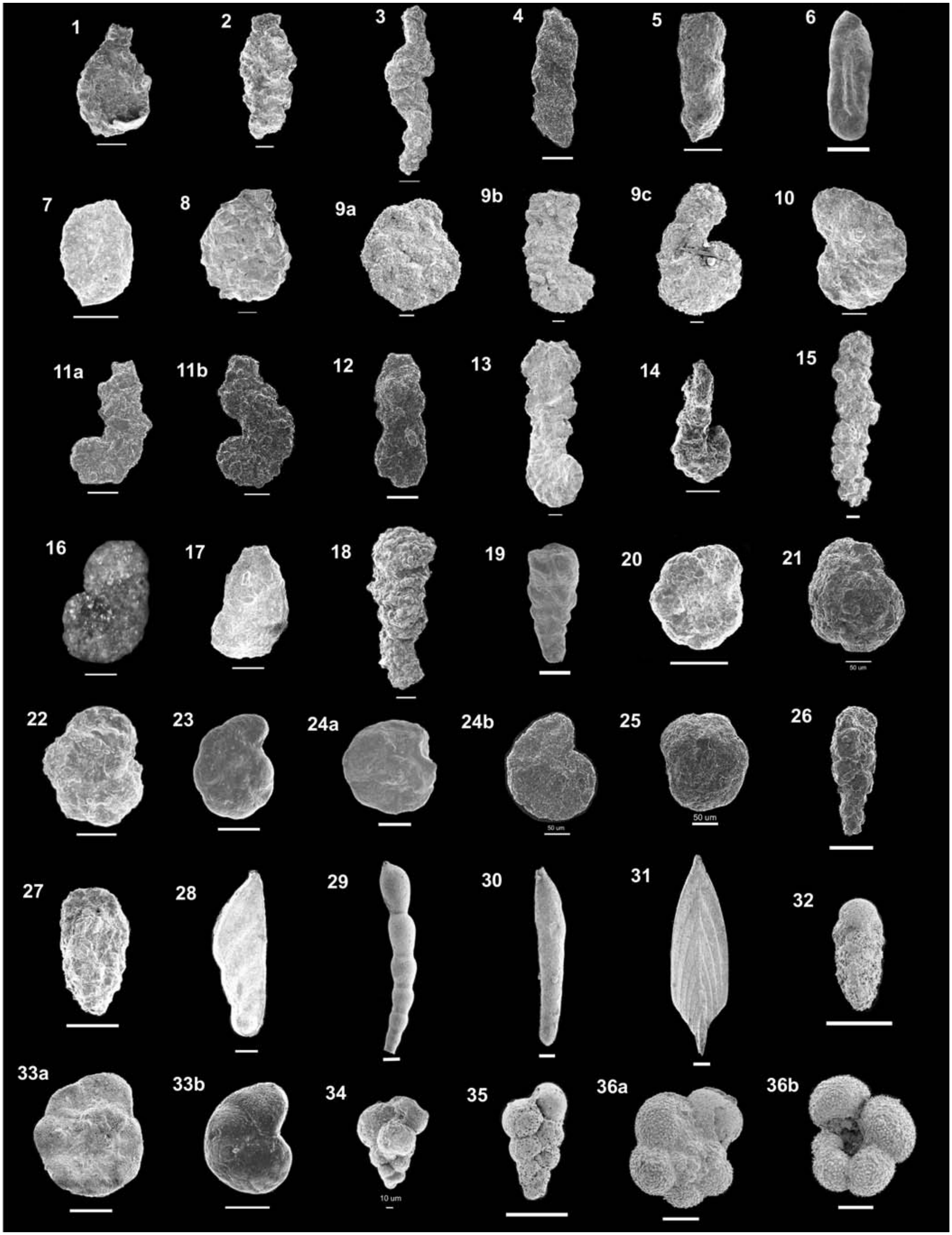
32 *Neobulimina albertensis,* Tropic Shale, Bigwater UT, Cenomanian-Turonian;

33a-b *Gavelinella dakotensis,* Tropic Shale, Bigwater UT, Cenomanian-Turonian;

34 *Guembelitria cenomana,* Tropic Shale, Bigwater UT, Cenomanian-Turonian;

35 *Heterohelix globulosa,* Tropic Shale, Bigwater UT, Cenomanian-Turonian;

36a-b *Whiteinella archaeocretacea,* Tropic Shale, Bigwater UT, Cenomanian-Turonian.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33a
33b
34
10 um
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36a
36b

TABLE 2
Locality 1, Bigwater, Utah (Cenomanian-Turonian).

Sample No.	BW-93-0.45	BW-93-0.9	BW-93-1.2	BW-93-1.4	BW-93-1.5	BW-93-1.9	BW-93-2.7	BW-93-2.92	BW-93-3.2	BW-93-3.5	BW-93-4.0	BW-93-4.7	BW-93-5.1	BW-93-5.5	BW-93-6.0
Strat. Hgt. (meters above base)	0.5	0.9	1.2	1.4	1.5	1.9	2.7	2.9	3.2	3.5	4.0	4.7	5.1	5.5	6.0
Saccammina alexanderi															
Haplophragmium arenatum														C	
Haplophragmoides gilberti									R		A				
Gavelinella plummerae															
Trochamminoides apricarius												R			
Trochammina wickendeni															
Trochammina rutherfordi															
Trochammina rutherfordi mellariolum															
Trochammina wetteri															R
Trochammina sp. indet.									VA		C				
Trochammina rainwateri	C	C	C		R	VA	VA	R		VA		VA	VA	VA	
Trochammina webbi															
Trochammina ribstonensis															
Miliammina ischnia															
Psamminopelta bowsheri															
Ammobaculites obliquus			R						R		C				R
Ammobaculites impexus															
Ammobaculoides sp. indet.															
Ammobaculites albertensis							A		R	C		A	C	C	
Ammobaculites fragmentarius														C	
Ammobaculites junceus												R	R		
Ammobaculites virious							R					R			
Ammomarginulina sp.													R		
Ammomarginulina lorangerae															
Ammomarginulina bergquisti		R			R	R	A			C					
Coscinophragma codyensis							R		R						
Reophax inordinatus															
Reophax incompta											C				
Reophax recta															
Textularia spp.												R	A		
Verneuilinoides perplexus									R						
Verneuilina canadensis	R								C	R	R	R	C	R	R
Gavelinella dakotensis				VA		A		C	C	C	R			C	C
Gavelinella sp. indet.				R			C					A			
Whiteinella spp.			R	C				R				R			
Heterohelix globulosa								R	R				C		
Guembelitria sp.											R				
Neobulimina albertensis								R				C			
Citharina kochii														R	
Frondicularia imbricata															
Dentalina basiplanata									C			R	R	R	
Dentalina communis							R			R		R	R	R	

Sample No.	BW-93-6.5	BW-93-7.0	BW-93-7.7	BW-93-8.2	BW-93-8.7	BW-93-9.0	BW-93-9.5	BW-93-10.1	BW-93-11	BW-93-12	BW-93-13	BW-93-14	BW-93-14.7	BW-93-15	BW-93-16
Strat. Hgt. (meters above base)	6.5	7.0	7.7	8.2	8.7	9.0	9.5	10.1	11.0	12.0	13.0	14.0	14.7	15.0	16.0
Saccammina alexanderi															
Haplophragmium arenatum	VA						C	VA	VA	A	VA	VA	C	C	C
Haplophragmoides gilberti															
Gavelinella plummerae															
Trochamminoides apricarius															
Trochammina wickendeni															
Trochammina rutherfordi															
Trochammina rutherfordi mellariolum															
Trochammina wetteri											C	R			
Trochammina sp. indet.															
Trochammina rainwateri	R	R	R		R	R	R		A		R				
Trochammina webbi															
Trochammina ribstonensis															
Miliammina ischnia															
Psamminopelta bowsheri															
Ammobaculites obliquus	R														
Ammobaculites impexus															
Ammobaculoides sp. indet.															
Ammobaculites albertensis															
Ammobaculites fragmentarius															
Ammobaculites junceus															
Ammobaculites virious	C												R		
Ammomarginulina sp.															
Ammomarginulina lorangerae															
Ammomarginulina bergquisti		R													
Coscinophragma codyensis															
Reophax inordinatus															
Reophax incompta									C						
Reophax recta															
Textularia spp.															
Verneuilinoides perplexus															
Verneuilina canadensis								R	R		R	C			
Gavelinella dakotensis	R	C	C	VA	A	C	C	C	C	R	C			C	C
Gavelinella sp. indet.											R				
Whiteinella spp.			A	R	R			C	A	C	A	C	VA	VA	VA
Heterohelix globulosa												C	C	A	A
Guembelitria sp.															
Neobulimina albertensis				C	R				R		C	A	C		
Citharina kochii							R	R	R			R	R	R	R
Frondicularia imbricata															
Dentalina basiplanata			R		R		R	R	R			R		R	
Dentalina communis			R	R	R		R	R	R			R		R	

Sample No.	BW-93-17	BW-93-18	BW-93-19	BW-93-20	BW-93-21	BW-93-22	BW-93-23	BW-93-24.5	BW-93-25	BW-93-26	BW-93-27	BW-93-28	BW-93-29	BW-93-30	BW-93-32
Strat. Hgt. (meters above base)	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.5	25.0	26.0	27.0	28.0	29.0	30.0	32.0
Saccammina alexanderi					R	C			R			R	C		
Haplophragmium arenatum	C					VA				A	R				R
Haplophragmoides gilberti															
Gavelinella plummerae															
Trochamminoides apricarius		R				C	C								
Trochammina wickendeni															
Trochammina rutherfordi															
Trochammina rutherfordi mellariolum															
Trochammina wetteri				C	C	R		C	C	A		C	R	R	
Trochammina sp. indet.															R
Trochammina rainwateri						C									
Trochammina webbi															
Trochammina ribstonensis															
Miliammina ischnia															
Psamminopelta bowsheri															
Ammobaculites obliquus							R								
Ammobaculites impexus															
Ammobaculoides sp. indet.				C			R		R			R	R		
Ammobaculites albertensis															
Ammobaculites fragmentarius								R					R		
Ammobaculites junceus															
Ammobaculites virious			R			A									
Ammomarginulina sp.														R	
Ammomarginulina lorangerae															
Ammomarginulina bergquisti															
Coscinophragma codyensis															
Reophax inordinatus					R				R			R	C	R	
Reophax incompta					R	R	C		C	C		R	C		
Reophax recta															
Textularia spp.				C		R	R						C		
Verneuilinoides perplexus															
Verneuilina canadensis						R									
Gavelinella dakotensis	C	R	A	C	C	R	R	C		C	C	C	C	C	C
Gavelinella sp. indet.															
Whiteinella spp.	VA	VA	VA	VA	C	R		A	C	C	VA	VA	VA	A	C
Heterohelix globulosa	C	C	VA	C				C	C		A	C	A	C	R
Guembelitria sp.															
Neobulimina albertensis			C					C			A	C			
Citharina kochii		C	C	R	R	R									
Frondicularia imbricata											R				
Dentalina basiplanata		C	C	R		R									
Dentalina communis		C	C	R				C	C	A					

Trochammina rutherfordi mellariolum Eicher 1965
Text-figure 9.21

Trochammina rutherfordi mellariolum EICHER 1965, pl. 105, figs. 4a-c, 9a-b, p. 899.

Description: Similar to *T. rutherfordi* but having a distinct high trochoid spire.

Remarks: High spired trochoid agglutinated taxon that can be distinguished from its counterpart *T. rutherfordi* because it possesses 3-4 coils in a high spire.

Geographic distribution: Prominent in the lower Graneros Shale Eicher on the northern plains. Occurs in strata assigned to the *Metoicoceras mosbyense* Ammonite Biozone of the Dakota Formation at localities 1 and 2a (Bigwater and Henrieville).

Stratigraphic range: Cenomanian (Ostracode Biozone I; Tibert et al. 2009).

Trochammina rainwateri Cushman and Applin 1946
Text-figure 9.22

Trochammina rainwateri CUSHMAN and APPLIN 1946, pl. 13, fig. 9, p. 75. – EICHER 1965, pl. 105, fig. 16. – MCNEIL and CALDWELL 1981, pl. 14, figs. 1 a-c, p. 170. – BLOCH et al. 1993, fig. 4, figs. 7-8.

Description: A coarsely arenaceous test that is loosely coiled and laterally compressed. The 5-6 chambers are lobate and they increase rapidly in size as added. Maximum test dimensions are: Width = 225µm; Height = 306µm.

Remarks: This taxon can be identified by its relatively large size and compressed preservational state.

Geographic distribution: Common in strata assigned to the uppermost Cenomanian *Sciponoceras gracile* and *Neocardioceras juddii* Ammonite Biozones of the Dakota Formation and lower Tropic Shale at localities 1, 2a, and 4 (Bigwater, Henrieville, and Cedar Canyon).

Stratigraphic range: Cenomanian (Ostracode Biozone II; Tibert et al. 2009).

Trochammina ribstonensis Wickenden 1932
Text-figure 9.23

Trochammina ribstonensis WICKENDEN 1932, pl. 1, figs. 12a-c, p. 90. – EICHER 1966, pl. 4, fig. 21, p. 23. – MCNEIL and CALDWELL 1981, pl. 14, figs. 1a-c, p. 170.

Description: A trochospiral agglutinated test that is inflated with globular chambers that gradually increase in size as added. The final whorl has seven chambers arranged with a relatively low profile. The last chamber observed from the ventral side is slightly inflated when observed in end view. Maximum test dimensions are: Width = 170µm; Height = 225µm.

Remarks: Trochammina ribstonensis most closely resembles *T. rutherfordi*, but, they can be distinguished given that the former has fewer chambers and the sutures are more depressed. *Trochamminoides apricarius* also has more chambers in the last whorl and is not truly trochospiral.

Geographic distribution: Reported from the Canadian Prairies and the Fairport and Blue Hill Members of the Carlile Shale of the USA central plain (Eicher 1966). Common in strata assigned to the Straight Cliffs Formation and Tropic Shale at localities 1, 2b, and 5 (Bigwater, Henrieville, and New Harmony).

Stratigraphic range: Turonian – Santonian (Ostracode Biozone III; Tibert et al. 2009).

Trochammina webbi Stelck and Wall 1954
Text-figure 9.24

Trochammina webbi STELCK and WALL 1954, pl. 2, fig. 11, p. 33.

Description: The test is relatively large with trochospiral coiling. There are numerous lobulate chambers (8-9) in the final whorl. The test is composed of fine silt-sized particles and there is a prominent clay matrix. Most specimens are flattened so that the sutures appear thickened and curve backwards.

Remarks: The numerous chambers and the curved sutures make this taxon easily distinguished from *T. ribstonensis* and *T.*

TABLE 3
Locality 2a, Henrieville, Utah (Cenomanian)

Sample No.	HV-DK-26	DK'00-HV-03	DK'00-HV-05	Hv-DK-33	HV-DK-34	HV-DK-11	HV-DK-12	HV-DK-13	HV-DK-14	HV-DK-15	HV-DK-16	HV-DK-20	HV-DK-09	Hv-TR-01	HV-TR-02	HV-TR-03	HV-TR-04
Strat. Hgt. (meters above base)	18.0	25.0	29.5	32.0	32.5	34	35.0	36.0	37.0	38	39.5	43.0	50.0	55.0	55.5	56.0	56.5
Saccammina alexanderi	2																
Haplophragmium arenatum									1				4				
Haplophragmoides sp. indet.		2						7		3						2	
Haplophragmoides gilberti																	3
Trochammina wickendeni						5	15	18	20								
Trochammina rutherfordi		2	20	236	315	2				2							
Trochammina rutherfordi mellariolum				1	1												
Trochammina wetteri		2															
Trochammina sp. indet.											22						
Trochammina rainwateri					6	1			2						140	92	
Trochammina webbi												8					
Miliammina ischnia	3	1	2	7	4	3	3	5	1		2				4		
Psamminopelta bowsheri			1	2	9												
Ammobaculites obliquus						1	2	3									
Ammobaculites impexus																	
Ammobaculites bergquisti					3	2	1	2		3							
Ammobaculites albertensis								2	1								
Ammobaculites viriosus																	
Ammomarginulina lorangerae			1		1	2			2	3					4		
Ammomarginulina sp. indet.							1										
Coscinophragma codyensis																	
Reophax sp. indet.	2									1							2
Textularia spp.	2			3													
Verneuilinoides perplexus	6			7		29	21	9		15	34	11				4	
Verneuilina canadensis			1	2	4		2	8		3	2						
Verneuilinoides sp. indet.						5											
Gavelinella dakotensis								1					1	1			
Gavelinella sp. indet.															1	1	
Heterohelix globulosa													2				
Citharina kochii													1				
Total Foraminifera	15	9	25	258	343	50	45	62	27	33	60	19	8	1	149	101	5

rutherfordi. *T. rainwateri* has fewer, loosely coiled chambers that increase in size as added.

Geographic distribution: Reported in the Kaskapau Formation of western Canada (Stelck and Wall 1954) and in strata assigned to the middle Turonian *Prionocyclus hyatti* Ammonite Biozone (Kauffman et al. 1993) in the Straight Cliffs Formation at localities 1, 2b, and 3 on Kaiparowits and Paunsaugunt Plateaus.

Stratigraphic range: Turonian.

Trochammina wetteri Stelck and Wall 1955
Text-figure 9.25

Trochammina wetteri STELCK and WALL 1955, pl. 2, figs. 1-3, 6, p. 59. – EICHER and WORSTELL 1970, pl. 1, fig. 16 a-c, p. 182. – MCNEIL and CALDWELL 1981, pl. 13, figs 10 a-c, p. 172.

Description: A tiny, five chambered taxon with a finely arenaceous test. The curved sutures are obliquely oriented to the coiling axis, such that the final chamber appears to overlap the second to last and first chamber of the final whorl.

Remarks: Trochammina wetteri has only 5 chambers, and it is therefore readily distinguishable from *T. rutherfordi* and *T. ribstonensis*. *T. webbi* has sutures that are much more distinct, has much more cement, and is generally more lobate and larger than *T. wetteri*.

Geographic distribution: Reported from strata assigned to the *Dunveganoceras* Zone in Alberta and Manitoba (McNeil and Caldwell 1981). Also common in strata assigned to the Benthonic Zone in the Belle Fourche Shale on the northern plains (Eicher 1966; Frush and Eicher. Common in the Dakota and Straight Cliffs Formations at localities 1 and 2 (Bigwater and Henrieville). *Stratigraphic range:* Albian-Turonian.

Family ATAXOPHRAGMIIDAE Schwager 1877
Genus *Verneuilinoides* Loeblich and Tappan 1949

Verneuilinoides perplexus (Loeblich 1946)
Text-figure 9.26

Verneuilina perplexa LOEBLICH 1946, pl. 22, figs. 14-16, p. 138.
Verneuilinoides kansasensis Loeblich. LOEBLICH and TAPPAN, 1950, p. 10.
Verneuilinoides perplexus EICHER 1965, pl. 5, fig. 10, p. 901. - EICHER 1966, pl. 9, fig. 5, p. 185. – MCNEIL and CALDWELL 1981, pl. 14, figs. 19-21, p. 180.

Description: A thin, slender, quasi-triserial agglutinated test with chambers that gradually increase in size as added; aperture occupies the intersection between the last 3 chambers of the final whorl. Maximum test dimensions are: Width = 95µm; Height = 289µm.

Remarks: Easily distinguishable from *V. hectori* which displays a much shorter test where the chambers increase in size rapidly and the aperture is much larger. Given the similarity of the figured specimens, we consider *V. kansasensis* (Loeblich and Tappan, 1950) to be synonymous with *V. perplexus* as proposed by McNeil and Caldwell (1981).

Geographic distribution: Common in the Pepper Shale of Texas, (Loeblich 1946) and strata assigned to the Cenomanian, *Verneuilinoides perplexus* and *Ammobaculites gravenori* Foraminiferal Biozone of the northern plains. Occurs widespread in strata assigned to the *Metoicoceras mosbyense* through *Sciponoceras gracile* Ammonite Biozones (Kauffman et al. 1993) in Utah (all Dakota Fm. localities).

Stratigraphic range: Albian-Turonian.

TABLE 4
Locality 2b, Henrieville, Utah (Turonian)

Sample No.	HV-TB-02	HV-TB-03	HV-TB-05	HV-TB-10	HV-TB-11	HV-SC-1.5	HV-SC-2.2	HV-SC-2.4	HV-SC-3.3
Strat. Hgt. (meters above Tibbet Canyon)	Tropic Shale Below Tibbet Canyon Mbr					Smoky Hollow 1.5	2.2	2.4	3.3
Trochammina webbi								48	56
Trochammina ribstonensis	18		3	13	4	8	4		
Miliammina ischnia								9	43
Ammobaculites bergquisti	1								
Ammobaculites albertensis									1
Reophax recta	5					1			4
Textularia spp. Indet.								1	10
Verneuilinoides sp. indet.				3	2		1		
Heterohelix globulosa	1								
Total Foraminifera	25	0	3	16	6	9	5	58	114

Genus *Verneuilina* d'Orbigny 1848

Verneuilina canadensis Cushman 1927
Text-figure 9.27

Verneuilina canadensis CUSHMAN 1927, pl. 1, fig. 11, p. 131. – EICHER 1960, pl. 5, figs. 1-2, p. 67. – EICHER 1965, pl. 105, fig. 5, p. 901. – EICHER and WORSTELL 1970, pl. 2, fig. 5, p. 282. – STRITCH and SCHROEDER-ADAMS 1999, pl. 4, fig 16 a,b.
Eggerella sp. EICHER 1960, pl. 5, fig. 5, p. 70.
Gaudryina canadensis MCNEIL and CALDWELL 1981, pl. 14, fig. 3, p. 175.

Description: A coarsely arenaceous, stout triserial test with chambers that increase their size proportionately as added. Maximum test dimensions: Width = 170µm; Height = 323µm.

Remarks: Distinguished from *V. perplexus* by being thoroughly triserial and more robust.

Geographic distribution: Common in the Cenomanian Kaskapau Formation in Canada (Stelck and Wall 1955) and strata assigned to the late Cenomanian *Metoicoceras mosbyense* into the *Neocardioceras juddii* Ammonite Zones (Kauffman at al. 1993) in the Dakota Formation near Tropic. Also occurs in the Turonian Straight Cliffs Formation and Tropic Shale at localities 1, 4, and 5 (Bigwater, Cedar Canyon, and New Harmony).

Stratigraphic range: Albian-Turonian.

Family NODOSARIIDAE Ehrenberg
Genus *Citharina* d'Orbigny 1839

Citharina kochii Roemer 1841
Text-figure 9.28

Vaginulina kochii ROEMER 1841, pl. 15, fig. 10, p. 96.
Citharina kochii EICHER and WORSTELL 1971, pl. 2, figs. 2a-b, 3a-b, p. 284.
Citharina arguta (Reuss) *in* LESSARD 1973, pl. 1, fig. 5, p. 20.

Remarks: Citharina kochii is a large calcareous benthic foraminifera. This taxon was originally described from Europe. Eicher and Worstell report this taxon in abundance from the uppermost Cenomanian Benthonic Zone.

Geographic distribution: Common in the uppermost Cenomanian to basal Turonian Tropic Shale near Tropic and Bigwater Utah; it is most abundant in *Neocardioceras juddii* Ammonite Biozone (Kauffman et al. 1993) at localities 1 and 2a (Bigwater and Henrieville).

Stratigraphic range: upper Cenomanian-lower Turonian.

Genus *Dentalina* d'Orbigny 1826

Dentalina basiplanata Cushman 1938
Text-figure 9.29

Dentalina basiplanata CUSHMAN 1938, pl. 6, figs. 6-8, p. 38. – EICHER and WORSTELL 1970, pl. 2, fig. 22, p. 284
Dentalina incrassata LESSARD 1973, pl. 1, fig. 6 a., p. 20.

Remarks: This larger calcareous benthic foraminifera is common to the Western Interior known for its long, gently curved test.

Geographic distribution: Occurs in the Central Plains of the USA in strata assigned to the uppermost Cenomanian Benthonic Zone, USA, (Eicher and Worstell 1970) and in southwest Utah in strata assigned to the Cenomanian, *Sciponoceras gracile* and *Neocardioceras juddii* Ammonite Biozone (Kauffman et al. 1993) in the Tropic Shale at localities 1 and 2a (Bigwater and Henrieville).

Stratigraphic range: Upper Cenomanian-Turonian.

Dentalina communis (d'Orbigny 1826)
text-fig. 9.30

Nodosaria communis D'ORBIGNY 1826, pl. 11, fig. 4, p. 149
Dentalina communis d'Orbigny. EICHER and WORSTELL 1970, pl. 2, fig. 13, p. 285.

Remarks: A nodosarid benthic taxon noted for its moderately inflated chambers in the later chambers.

Geographic distribution: Similar distribution and occurrence as *D. basiplanata* in North America. Occurs in Utah in the Tropic Shale at locality 1 (Bigwater).

Stratigraphic range: Cenomanian-Turonian.

TABLE 5
Locality 3, Glory Cove, Utah (Turonian)

Sample No.	SH-GC-02	SH-GC-03	SH-GC-04	SH-GC-05	SH-GC-10	SH-GC-11	SH-GC-12	SH-GC-13	SH-GC-15	Sh-GC-21
Strat. Hgt. (meters above base)	1.4	1.6	2.3	3.0	5.0	5.1	6.0	6.1	7.0	10
Trochammina sp. indet.		4							2	
Trochammina webbi	2				17	27		2		1
Trochammina ribstonensis	3		40	4			1	14		2
Miliammina ischnia		4			3	1		1		1
Ammobaculites obliquus			4							
Ammobaculites sp. indet.				3	2		1			
Reophax recta						1		1	2	3
Verneuilinoides sp. indet.		1				1				
Total Foraminifera	5	9	44	7	22	30	2	18	4	7

Genus *Frondicularia* Defrance 1826

Frondicularia imbricata Young 1951
Text-figure 9.31

Frondicularia imbricata YOUNG 1951, pl. 13, figs. 4-6, p. 61. – EICHER 1967, pl. 19, fig. 4, p. 185. – EICHER and WORSTELL 1970, pl. 2, figs. 17-18, p. 285.
Frondicularia goldfussi LESSARD 1973, pl. 1, fig. 7, p. 21.

Remarks: Frondiculata imbricata is a large calcareous benthic easily identified given its flat, palmate outline.

Geographic distribution: Reported in the Turonian, Carlile Shale of the northern US plains (Eicher and southwest Utah at locality 1 (Bigwater). Restricted to strata above bentonite TT3 (Leithold, 1994; Tibert et al. 2003a).

Stratigraphic range: Lower Turonian and possibly uppermost Cenomanian.

Family TURRILINIDAE Cushman 1927
Genus *Neobulimina* Cushman and Wickenden 1928

Neobulimina albertensis (Stelck and Wall 1954)
Text-figure 9.32

Guembelitria cretacea Cushman var. *albertensis* STELCK and WALL 1954, pl. 2, fig. 19, p. 23
Neobulimina albertensis Stelck and Wall. EICHER and WORSTELL 1970, pl. 4, figs. 2-4, p. 290. – MCNEIL and CALDWELL 1981, pl. 18, figs. 2, 3
Bulimina prolixa LESSARD 1973, pl. 2, fig. 2, p. 23.

Remarks: This slender triserial calcareous benthic foraminifera with inflated chambers is widely reported in the Western Interior. Given its assumed infaunal mode of life, West et al. and Leckie et al. used this taxon as an indicator for low oxygen conditions.

Geographic distribution: Common on the northern Great Plains in strata assigned to the Cenomanian-Turonian Benthonic and Planktonic zones of Eicher and Worstell (1970). Also occurs in the Tropic Shale at localities 1 and 2 (Bigwater and Henrieville).

Stratigraphic range: Cenomanian-Turonian.

Family ANOMALINIDAE Cushman 1927
Genus *Gavelinella* Brotzen 1942

Gavelinella dakotensis (Fox 1954)
Text-figure 9.33 a,b

Planulina dakotensis FOX 1954, pl. 26, figs. 19-2, p. 119
Gavelinella dakotensis Fox. EICHER and WORSTELL 1970, pl. 5, figs 5 a-c, 6 a-c, p. 293.
Discorbis austinana LESSARD 1973, pl. 2, fig. 4, p. 24.

Remarks: A flat, low-coiled trochoid calcareous benthic foraminifera that is ubiquitous to the WIB. Readily identified by the thickened and radially raised sutures on the dorsal side. Given the assumed epifaunal mode of life for this morphotype, Leckie and others (1998) proposed that it as an indicator for well-ventilated conditions.

Geographic distribution: Widespread in the Cenomanian-Turonian Graneros Shale and Greenhorn Formation on the northern U.S. Great Plains. Occurs in the lower Turonian Tropic Shale within strata assigned to the Benthonic Zone in Utah and Colorado (West et al. In southwest Utah, it occurs in strata assigned to the *Sciponoceras gracile* to *Watinoceras devonense* Ammonite Biozones (Kauffman et al. 1993) in the Tropic Shale at locality 1 where it occurs immediately above the TT2 (Bentonite B). It also occurs in the uppermost Cenomanian, Dakota Formation at localities 1 and 2a (Bigwater and Henrieville).

Stratigraphic range: Cenomanian-Turonian.

Family HETEROHELICIDAE Cushman 1927
Genus *Guembelitria* Cushman 1933

Guembelitria cenomana Keller 1935
Text-figure 9.34

Guembelina cenomana KELLER 1935, pl. 2, figs. 13, 14, p. 547-548.
Guembelitria harrisi EICHER and WORSTELL 1970, pl. 8, figs. 1-2, p. 296.
Guembelitria cretacea LESSARD 1973, pl. 2, fig. 3, p. 23.

Remarks: A tiny, triserial planktonic taxon marked by inflated, spherical chambers that increase in size rapidly as added resulting in a distinctly tapered test. The aperture is at the apex of the last whorl of three bordered by a thin lip. This taxon is rare-to

TABLE 6
Locality 4, Cedar Canyon (Maple), Utah, Utah (Cenomanian-Turonian)

Sample No.	UT98-DK-26	UT98-DK-28	UT98-DK-29
Strat. Hgt (meters above base)	54.7	55.0	56.5
T. rutherfordi mellariolum		2	
Trochammina wetteri	8	17	
Trochammina rainwateri		2	6
Miliammina ischnia		4	
Ammobaculites obliquus		1	
Verneulinoides sp. indet.	1	2	1
Gavellinella dakotensis			1
Total Foraminifera	9	28	8

abundant in uppermost Cenomanian marine shales of the WIS (Eicher and Worstell 1970; Leckie 1985; Leckie et al. 1998).

Geographic distribution: Occurs in the Cenomanian-Turonian Tropic Shale at localities 1 and 2 (Bigwater and Henrieville).

Stratigraphic range: Albian-Turonian.

Genus *Heterohelix* Ehrenberg 1843

Heterohelix globulosa (Ehrenberg 1840)
Text-figure 9.35

Textularia globulosa EHRENBERG 1840, pl. 4, figs. 1b, 2b, 4b, 5b, 7b, 8b, p. 135
Heterohelix globulosa Ehrenberg. EICHER and WORSTELL 1970, pl. 8, figs. 3-6, p. 296. – LESSARD 1973, pl. 2, fig. 5, p. 24.

Remarks: A biserial taxon that is one of the most common planktic foraminiferal taxa in the Tropic Shale and equivalent strata across the Western Interior Basin (Eicher and Worstell 1970; Leckie et al. 1998; West et al. 1998). This taxon dominates the fossil assemblages that mark sea level transgressions and highstands.

Geographic distribution: Occurs in the Cenomanian-Turonian Tropic Shale at localities 1, and 2 (Bigwater and Henrieville).

Stratigraphic range: Upper Cretaceous.

Family HEDBERGELLIDAE Loeblich and Tappan 1961
Genus *Whiteinella* Pessagno 1967

Whiteinella archaeocretacea Pessagno 1967
Text-figure 9.36

Whiteinella archaeocretacea PESSAGNO 1967, pl. 100, fig. 8, p. 298-299. – LECKIE 1985, pl. 1, figs. 5-12, p. 144.

Remarks: Whiteinella archaeocretacea differs from *Hedbergella delrioensis* by is more compressed test and more umbilically oriented aperture. It differs from *Whiteinella aprica* (Loeblich and Tappan 1961) being smaller and in having fewer chambers (generally five) and a smaller umbilicus. Trochospirally coiled planktic foraminferal taxa, including *Whiteinella archaeocretacea*, *Hedbergella delrioensis* and *H. planispira*, occur sporadically in relative abundance. As a group, the planktic foraminifers can be used as proxies for sea level maxima that coincide with total carbonate peaks at Bigwater in the Tropic Shale (Eicher and Worstell 1970; Leckie et al. 1998; West et al. 1998; Tibert et al. 2003a).

TABLE 7
Locality 5, New Harmony, Utah (Turonian)

Sample No.	HC-99-01	HC-99-09	HC-99-00	HC-99-12
Strat. Hgt (meters above base)	0.25	7.5	0	16
Trochammina ribstonensis	3	1	1	4
Miliammina ischnia	1	5		
Ammobaculites obliquus	4			
Verneulina canadensis	4			
Total Foraminifera	12	6	1	4

Geographic distribution: Whiteinella archaeocretaceea occurs in the uppermost Cenomanian-lower Turonian Tropic Shale, *Neocardioceras juddii* and *Watinoceras devonense* Ammonite Biozones (Kauffman et al. 1993) at localities 1 and 2a (Bigwater and Henrieville).

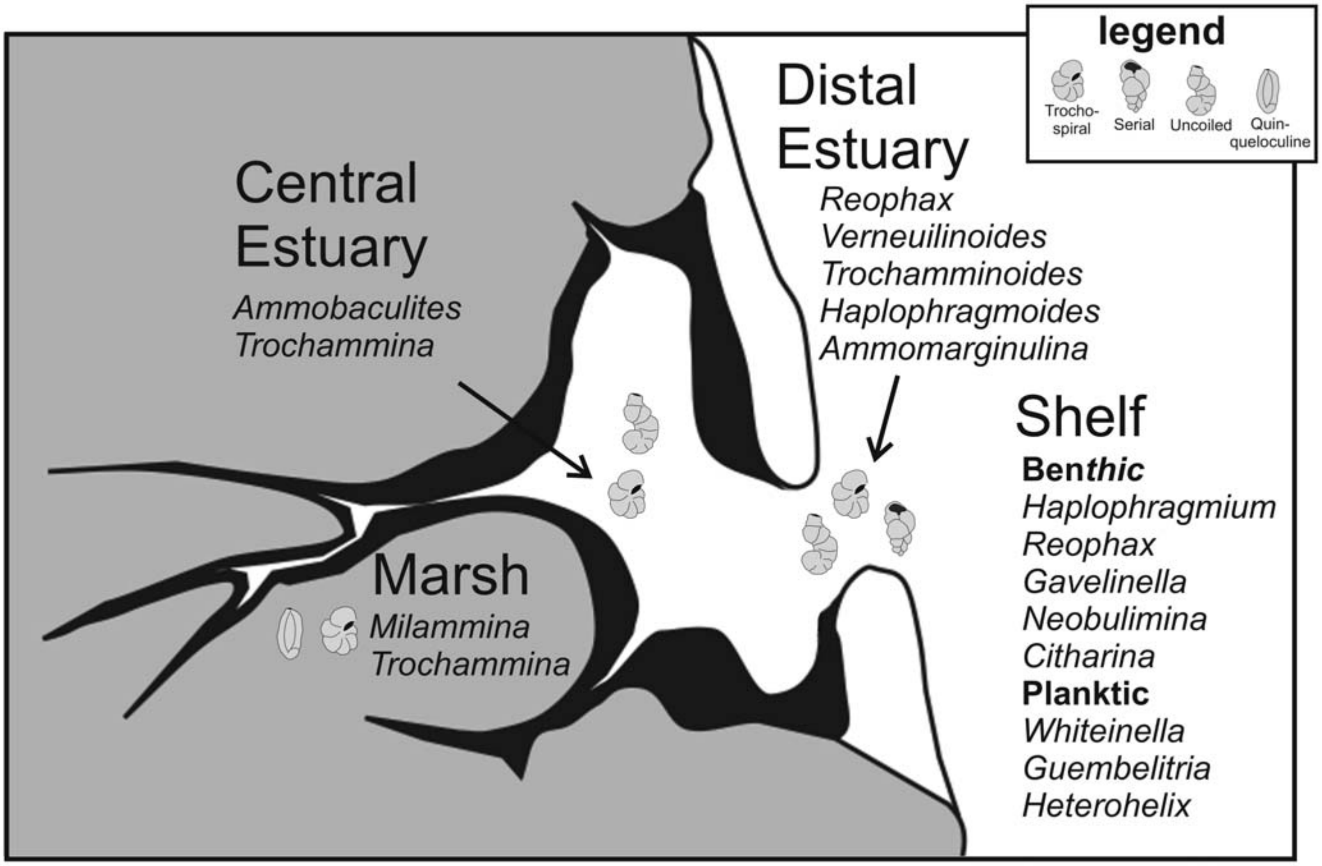
Stratigraphic range: uppermost Cenomanian-Turonian (Ostracode Biozones II-III; Tibert et al. 2009).

BIOSTRATIGRAPHIC IMPLICATIONS

Stratigraphic range charts are provided for the Bigwater (text-fig. 4), Henrieville (text-figs. 5, 6), Glory Cove (text-fig. 6), Maple Canyon (text-fig. 7) sections. The bentonite markers (TT1-4: Leithold 1994; A-D: Elder and Kirkland, 1985) facilitate calibration to the molluscan zones of Kauffman et al (1993). Meyers et al. (2012) recently reported calibrated ages for the bentonites with an assigned age of 93.98 ± 0.14 for the Cenomanian-Turonian Boundary at Pueblo Colorado.

We discuss the temporal distribution of the foraminifera presented herein in the context of the cumulative works of Eicher (1965, 1966), Eicher and Diner (1985), and Eicher and Worstell (1970) (text-fig. 8). Although these zones have the potential to be used as reliable indicators for the middle and upper Cenomanian (Graneros Shale, CO) and uppermost Cenomanian and Middle Turonian (Carlile Shale, CO) (text-fig. 8), this scheme remains a work in progress to be tested in the near future at coeval localities in the Western Interior Basin.

Trochammina rutherfordi mellariolum-Verneuilinoides perplexus Assemblage Zone: This assemblage zone is based on the concept of Eicher's (1965) *Trochammina rutherfordi mellariolum* that was proposed for the lower Graneros Shale that includes an association of estuarine agglutinated foraminifera *Trochamina rutherfordi*, *Trochammina rutherfordi mellariolum*, *Verneuilinoides perplexus*, *Ammobaculites* spp., and *Milammina*. This assemblage is observed in strata assigned to the upper *Calycoceras canitaurinum* and *Metoicoceras mosbyense* Ammonite Biozones of Kauffman and others (1993) within the middle member of the Dakota Formation at Henrieville (text-fig. 5). The zone is broadly defined on the basis of the first occurrence of *Verneuilinoides perplexus* and the last occurrence of *Trochaminna rutherfordi. Verneulinoides perplexus, Miliamina ischnia,* and *Psamminopelta bowsheri* are relatively abundant (text-fig. 8). Observation of *Trochammina rutherfordi mellariolum* in relative proximity to Bentonite TT1



TEXT-FIGURE 10
Paleoenvironmental model for the Greenhorn coastal deposits in southwest Utah. Schematic that depicts a model for distribution of the fossil assemblages (modified from Tibert et al. 2003a).

serves as a marker for the top of this zone (text-figs. 5, 8). This foraminiferal association is similar to the *Trochammina rutherfordi mellariolum* Zone of Eicher (1965) in the Graneros Shale and the lowermost *Verneuilinoides perplexus* Zone of Caldwell and others (1978) in western Canada. Associated ostracodes include *Fossocytheridea mosbyense* and *Ascio-cythere arizonensis* (Ostracode Zone I: Tibert et al. 2009). Representative localities include the western Kaiparowits Plateau at Henrieville (locality 2a) in southwest Utah and Coal Mine Mesa section (Tibert et al. 2003a) on Black Mesa Plateau, Arizona (locality 6).

Trochamminoides apricarius-Haplophragmium arenatum Assemblage Zone: This assemblage zone is based on the concept of Eicher's (1965) *Trochamminoides apricarius* Zone described in the Graneros Shale. It is a relative abundance zone defined by a rich association of foraminifera that includes *Trochamminoides apricarius*, *Trochammina rainwateri*, *Haplophragmium arenatum*, *Ammobaculites albertensis*, *Ammobaculites viriosus*, *Neobulimina albertensis*, and *Gavelinella dakotensis* (text-figs. 4, 8). Although the first occurrence of *Ammobaculites viriosus* can be used to define the approximate base of this zone, the relative abundance of *Trochamminoides apricarius* and *Trochammina rainwateri* in association with *Haplophragmium arenatum* should be regarded as the most reliable indicator for diagnosis (text-fig. 8). The last occurrence of *Trochaminna rainwateri* can be used as a latest Cenomanian marker on the basis of its reported occurrences in the northern Plains (Eicher 1965, 1966; Eicher and Worstell 1970). It's last observed occurrence is in association the Ostracode Interval Zone II (Tibert et al. 2009) with *Cythereis eaglefordensis*, associated with the *Sciponoceras gracile-Neocardioceras juddii* Ammonite Biozones of Kauffman et al. (1993). This zone is associated with Bentonites A and B, and TT1 and TT2 (Elder and Kirkland 1985; Leithold, 1994) which have recently been interpreted as regional equivalent to the "red" bentonites within the Dunvegan and Kaskapau Formations in Alberta which contains a similar agglutinated biota assigned to the *Spiroplectammina ammovitrea* Zone (Tyagi and others 2001). The strata assigned to the zone herein were deposited during rapid transgression of the Greenhorn Cyclothem such that the resultant diachronous architecture will require further testing at coeval deposits in the WIB (Tibert and others 2003a) (see text-fig. 3).

Reophax inordinatus-Ammomarginulina lorangerae Assemblage Zone: This assemblage zone is based on the concept of Eicher's (1966) *Reophax inordinatus* assemblage reported in the Carlile Shale. This interval zone comprises a rich association of foraminifera that characterize lower and middle Turonian nearshore facies of the Tropic Shale and lateral equivalents (text-figs. 2, 3). The first occurrence of the *Ammomarginulina lorangerae* and *Saccammina alexanderi* mark the basal Turonian at or above the Bentonite TT3 (Leithold 1994; Leithold and Dean 1998) (text-figs. 4, 8) and this observation has been noted for the central plains (text-fig. 2) (Eicher 1965, 1966; Eicher and Worstell 1970). *Reophax inordinatus* and *Frondicularia imbricata* are found in relative abundance and can be regarded in environmental association with maximum flooding of the Greenhorn Marine Cycle in southwest Utah (Tibert et al. 2003a). This foraminiferal interval zone is equivalent to the Ostracode Interval Zone III whereas the prominent associated ostracode in the Straight Cliffs Formation include *Cytheropteron clavifragilis* and *Fossocytheridea posterovata* (Tibert et al. 2009). The corresponding Ammonite Biozones include *Watinoceras coloradense* and *Mammites nodosoides* (Kaufman et al. 1993). In the Western Canada Basin, the zone herein corresponds to the Turonian *Hedbergella loetterlei* Zone (Caldwell et al. 1978; Tyagi et al. 2007).

PALEOECOLOGICAL SYNTHESIS

Strata deposited along the westernmost margin of the Cenomanian-Turonian Greenhorn Sea include assemblages of marsh, central estuarine, distal estuarine, and shelf foraminifera (text-fig. 10). We provide a brief summary of previous paleoecological applications (Tibert et al. 2003a,b; Tibert and Leckie 2004).

Marsh Association: A low diversity assemblage of the agglutinated trochospiral and quinqueloculine morphotypes occur exclusively in organic-rich mudstones and shaly-coal associated with major coal seams in both the Dakota Formation and Straight Cliffs Formation (Tibert et al. 2003a; Tibert and Leckie 2004). Cenomanian marsh associations are dominated by *Trochamina rutherfordi* and *Miliammina ischnia* in association with the ostracode *Asciocythere arizonensis*. Turonian marsh associations include *Trochammina webbi* and *Miliammina ischnia* with the ostracode *Fosscytheridea posterovata* (Tibert et al. 2003b). These marsh assemblages were used as stratigraphic reference points for mean sea level in order to identify both intermediate (10-100 kyr) and high frequency (1-10 kyr) sea level cycles (Tibert et al. 2003a; Tibert and Leckie 2004).

Central Estuarine Association: The central estuarine agglutinated assemblage of the Dakota Formation are dominated by a rich assemblage of *Ammobaculites* spp. found in association with *Trochammina rutherfordi*, and *Verneuilinoides perplexus*. Associated invertebrates include the brackish water ostracode *Fossocytheridea mosbyense* (Tibert et al. 2003b, 2009). The Turonian Straight Cliffs Formation includes a similar association that includes *Ammobaculites* spp., *Trochammina webbi*, and *Textularia*. In context of sea level amplitude reconstructions, Tibert and Leckie (2004) assigned a 5-10 m water depth to this association.

Distal Estuarine Association: The agglutinated assemblages in the Tropic Shale deposited during late transgression include *Reophax recta*, *R. inordinatus*, *Textularia* sp., and *Verneuilina canadensis*. In the more distal facies, *Haplophragmium arenatum* and *Trochammina rainwateri* occur in association with the calcareous benthic *Gavelinella dakotensis*. Associated ostracodes in the more distal/lagoonal facies include *Asciocythere posterovata*, *Cytheromorpha perornata*, and *Loonyella leckiei* (Tibert et al. 2003a; 2009). The Distal Estuarine Association of the Tropic Shale occurs at the western edge of the Markagunt Plateau (Tibert et al. 2003a) (text-fig. 1).

Nearshore (inner neritic) Association: The Tropic Shale comprises a thick sequence of neritic shelf deposits that include abundant ammonites, mollusks, and calcareous foraminifera. Relative abundances of calcareous benthic *Gavelinella dakotensis*, *Neobulimina albertensis* occur in association with the ostracode *Cythereis eaglefordensis* and *Cytheropteron eximium* (Tibert et al. 2003a, 2009). Other calcareous benthics include *Citharina kochii* and *Frondicularia imbricata*. Intervals dominated by *Whiteinella archaeocretacea* and *Heterohelix globulosa* in association with the deeper water ostracode *Cytherella ovata* are interpreted as sea level highstand deposits. Relative abundance peaks of planktic foraminifera occur in calcareous shale with high bulk carbonate percentages and serve as maximum flooding events that have been used for regional correlation (West et al. 1998; Tibert et al. 2003a).

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