

FORAMINIFERA OF THE CENOMANIAN-TURONIAN BOUNDARY INTERVAL,
GREENHORN FORMATION, ROCK CANYON ANTICLINE, PUEBLO, COLORADO

R. Mark Leckie
Department of Geology and Geography
University of Massachusetts
Amherst, Massachusetts 01003

ABSTRACT

Seventeen samples bracketing the Cenomanian - Turonian stage boundary in the Bridge Creek Limestone (Greenhorn Formation), Pueblo, Colorado, were analyzed for planktonic and benthic foraminifera. A major turnover in the biostratigraphically important, deep-dwelling planktonic foraminifera occurred across this boundary. The Cenomanian rotaliporids were succeeded by the Turonian globotruncanids, perhaps due in part to dynamic global oceanographic developments including the expansion of an oceanic oxygen-minimum zone. Shallow-dwelling planktonic foraminifera on the other hand, were strongly influenced by regional factors (e.g. salinity) affecting the uppermost water column of the Greenhorn sea.

INTRODUCTION

The Cenomanian-Turonian stage boundary is marked by a faunal turnover in the deep-dwelling, keeled planktonic foraminifera in which the Turonian, and younger, globotruncanids (e.g. *Dicarinella* and *Marginotruncana*) succeed the Cenomanian rotaliporids (*Rotalipora*). This turnover is probably related to global oceanographic events including, a major rise of global sea level, widespread anoxia and an intense episode of organic carbon burial during latest Cenomanian and earliest Turonian time (see reviews by Arthur et al., in press; Schlanger et al., in press).

The Rock Canyon anticline west of Pueblo, Colorado contains a complete, well-preserved record of the advance and retreat of the Greenhorn sea (Greenhorn Cyclothem of Kauffman, 1977a) (Figure 1). During Cenomanian and Turonian time, the Pueblo area was situated near the central axis of this extensive epicontinental seaway. Water depths probably exceeded several hundred meters at peak transgression (i.e. earliest Turonian; Eicher, 1969a). Foraminifera of the Rock Canyon anticline section have been described previously by Eicher and Worstell (1970) and Eicher (1977).

The purpose of this paper is to present the results of a detailed analysis of foraminifera from the uppermost Hartland Shale and lower Bridge Creek Limestone members of the Greenhorn Formation. This study includes 17 samples which embrace the Cenomanian-Turonian stage boundary. In other parts of the world, organic carbon-rich strata such as the Bonerelli bed of Italy and the Black Band of England bracket the Cenomanian - Turonian boundary. Emphasis here is placed on the paleoecologic significance of changes in the composition of planktonic assemblages in an attempt to differentiate global oceanographic events from regional events that affected the Greenhorn sea. Biostratigraphy and the timing evolutionary events in the planktonic foraminiferal

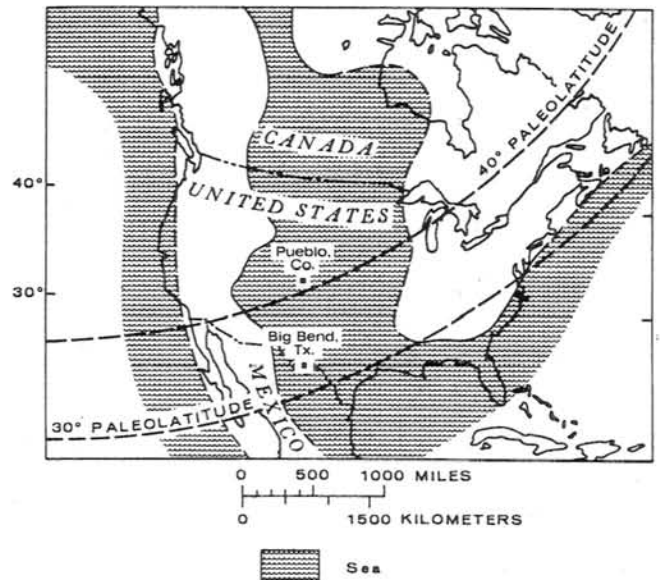


Figure 1. Greenhorn seaway at peak transgression in earliest Turonian. Location of Rock Canyon anticline section west of Pueblo, Colorado and correlative strata of the Big Bend region of Texas (after Pratt, 1984).

record are other important aspects of this study. Benthic foraminifera are discussed briefly.

METHODS

All samples were composed of calcareous shales or marls; limestones were not examined. Samples were crushed and then boiled in a solution of Quaternary-0 for several hours. The samples were then washed over a 75 micron screen (200 mesh) and dried in an oven. The residues were split and foraminifera were picked and counted to establish planktonic to benthic ratios, and statistically valid populations (at least 300 individuals in most samples) of both planktonic and benthic taxa. Residues were then examined for rare species. Distribution tables and computational results are presented in appendices 1-4.

PLANKTONIC FORAMINIFERAL BIOSTRATIGRAPHY

The uppermost meter (3 ft.) of the Hartland Shale and lower 4.6 m (15 ft.) of the Bridge Creek Limestone are latest Cenomanian to earliest Turonian in age. The Cenomanian - Turonian boundary roughly coincides with a barren limestone bed (Bed 84), 3.6 m (12.0 ft.) above the base of the Bridge Creek Limestone, based on ammonite and inoceramid bivalve data (Cobban and Scott, 1972; Kauffman, 1975; W. Elder, pers. comm., 1985). Portions of two foraminiferal zones are recognized, the upper

	Pessagno (1967); Frush and Eicher (1975)		Robaszynski, Caron, et al. (1979); This Study	
EARLY TURONIAN	Marginotruncana helvetica Assemblage Zone	Whiteinella archeocretacea Subzone	Praeglobotruncana helvetica Total Range Zone	F.A. Praeglobotruncana helvetica
		Marginotruncana sigali Subzone		Whiteinella archeocretacea Partial Range Zone
LATE CENOMANIAN	Rotalipora Assemblage Zone	R. cushmani R. greenhornensis Subzone	Rotalipora cushmani Total Range Zone	F.A. Whiteinella archeocretacea

Figure 2. Correlation of zonal scheme utilized in this study with that of Pessagno (1967) and Frush and Eicher (1975) from the Gulf Coastal Plain and the Big Bend region of Texas, respectively. L.A. = last appearance; F.A. = first appearance.

Cenomanian *Rotalipora cushmani* Total Range Zone and the uppermost Cenomanian - lowermost Turonian *Whiteinella archeocretacea* Partial Range Zone (Figure 2). The boundary between these zones is placed between samples BC3 and BC4 based on the highest occurrence of *Rotalipora cushmani*, following the zonal scheme of Robaszynski, Caron, et al. (1979). Strata of the lower Turonian *Praeglobotruncana helvetica* Total Range Zone, as defined by the first appearance of the nominate taxon or approximated by the first appearance of *Marginotruncana sigali*, were not encountered in the study interval.

The stratigraphic ranges of key planktonic foraminiferal taxa are shown in Figure 3. Noteworthy are the sequential first appearances of *Whiteinella archeocretacea*, *W. aprica*, *Praeglobotruncana inornata*, *P. praeHelvetica*, and *Dicarinella hagni* as well as the last appearances of *Rotalipora* spp. and *Globigerinelloides bentonensis* in the uppermost Cenomanian. An identical sequence of originations and extinctions was recorded in uppermost Cenomanian strata in the Big Bend region of Texas (Frush and Eicher, 1975). Two forms of *Anaticinella multiloculata* (Eicher, 1972) also characterize this interval at Rock Canyon anticline.

The Cenomanian - Turonian boundary interval at Rock Canyon anticline is characterized by an abundance of large *Whiteinella* spp. and an absence of keeled planktonic species, an interval commonly referred to as the zone of "grandes globigerines" (e.g. Van Hinte, 1976). Keeled species reappear in the lower Turonian (see also Eicher and Worstell, 1970).

PLANKTONIC FORAMINIFERAL PALEOECOLOGY AND EVOLUTIONARY TRENDS

A marked increase in planktonic foraminiferal diversity in the basal sample (BC1) of the Bridge Creek Limestone records the incursion of warm surface waters from the south (Figure 4). Benthic foraminiferal assemblages also flourished in basal Bridge Creek time under the influence of well-oxygenated bottom waters. The widespread northward advance of a warm water mass was roughly coincident with maximum transgression of the Greenhorn sea. This interval corresponds to the

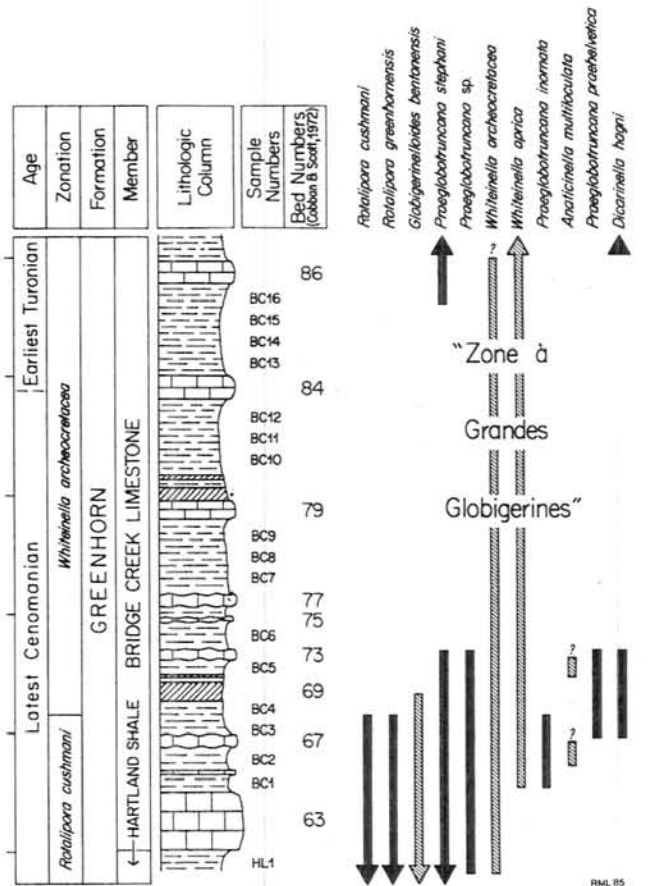


Figure 3. Stratigraphic distribution of key planktonic foraminifera in the Cenomanian-Turonian boundary interval of the Rock Canyon anticline section. Solid bars represent keeled morphotypes, hatch represents non-keeled forms. Ranges above and below study interval are based on data from Eicher and Worstell (1970). Shaded beds in lithologic column represent prominent bentonites. Divisions along left margin represent thickness in meters from base of the Bridge Creek Limestone.

"benthonic zone" of Eicher and Worstell (1970, p. 274) and may represent a nearly synchronous event across the central and southern Greenhorn sea (see Frush and Eicher, 1975). This "event" may be related to change in circulation patterns, climate, or rising sea level and attainment of some critical water depth (sill depth?) at the southern aperture of the seaway, which then permitted well-oxygenated waters to spread northward. Planktonic foraminifera are most diverse in the interval embraced by the benthic zone.

Planktonic foraminiferal diversity declines from samples BC4 through BC7 (Figure 4). This signal is basically global in nature, probably related to dynamic oceanographic developments including expansion of an oceanic oxygen minimum zone (see reviews by Arthur et al., in press; Schlanger et al., in press). In this interval the Cenomanian rotaliporids are succeeded by the Turonian globotruncanids. The last occurrence of *Rotalipora* spp. is in Sample BC3, well within the benthonic zone. In the Big Bend region of Texas, however, *Rotalipora* disappears shortly below the benthonic zone (Frush and Eicher, 1975). If we assume that the benthonic zone represents a roughly synchronous incursion of a water mass from the south, then the extinction level of *Rotalipora* appears to be

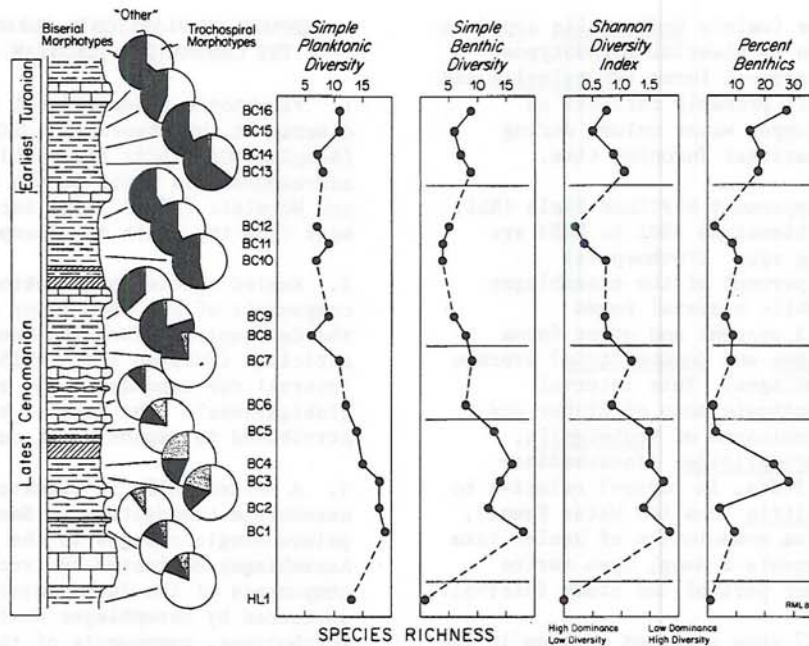


Figure 4. Trends in planktonic and benthic foraminifera from uppermost Hartland Shale and lower Bridge Creek Limestone at Rock Canyon anticline. Divisions in the plots for benthic foraminifera follow brief discussions in text. Samples BC1 to BC5 correspond to the benthonic zone of Eicher and Worstell (1970).

diachronous from south (Big Bend, Texas) to north (Pueblo, Colorado). The extinction level of *Rotalipora* may vary from basin to basin, perhaps due to regional differences in the development of a global mid-water oxygen-minimum zone during latest Cenomanian - earliest Turonian time, a development that would have affected the deepest-dwelling species of planktonic foraminifera.

Modern planktonic foraminifera partition the upper water column such that the inflated, simple morphotypes generally inhabit the shallowest waters (<100 m) while the keeled, specialized morphotypes inhabit the deepest waters (>100 m) (Bè, 1977). Cretaceous planktonic foraminifera are believed to have been distributed in the upper water column in much the same fashion (Sliter, 1972; Douglas and Savin, 1978; Hart and Bailey, 1979; Wonders, 1980; Caron and Homewood, 1982; Leckie, 1984a). The rotaliporids were probably the deepest-dwelling late Cenomanian species by analogy with the living keeled globorotalids. The development and/or expansion of a mid-water oxygen-minimum zone during latest Cenomanian - earliest Turonian time could have created a crisis in the deep niche of *Rotalipora* which may have been ultimately responsible for its extinction.

In response to the expansion of an oceanic oxygen-minimum zone in the latest Cenomanian, the rotaliporids of the southern and central Greenhorn sea gave rise to the endemic(?) genus *Anaticinella* (Eicher, 1972; *Pseudoticinella* of Longoria, 1973). Eicher (1972) clearly documents how *Rotalipora greenhornensis* gave rise to *Anaticinella multiloculata* s.s. by losing its keel. A second form, *Anaticinella multiloculata* s.l., is also recognized in the Pueblo section and is probably the descendant of *R. cushmani* via the same evolutionary mechanism. According to this scenario, the inflated,

non-keeled anaticinellid morphotype may represent an attempt by the rotaliporids to occupy shallower depths and thus avoid an expanding oxygen-minimum zone (Wonders, 1980).

The praeglobotruncanids and early globotruncanids which first appear in the latest Cenomanian and earliest Turonian are characterized by weakly developed keels and somewhat inflated chambers (e.g. *Praeglobotruncana* sp., *P. praehelvetica*, *P. inornata* and *Dicarinella hagni*). These morpho-characters suggest adaptations to shallower habitats than those occupied by the rotaliporids. This too, may have been in response to an expanded oxygen-minimum zone. With suppression of an oceanic oxygen-minimum zone during the early and middle Turonian, the globotruncanids diversified and occupied the deeper habitats vacated by the rotaliporids.

Keeled planktonics are absent from samples BC6 through BC15. This interval, which embraces the Cenomanian - Turonian boundary, is characterized by abundant large *Whiteinella* spp., the so-called zone of "grandes globigerines" (Figure 3). The stratigraphic distribution of keeled vs. non-keeled planktonic foraminifera at Rock Canyon anticline suggests that the central Greenhorn sea was strongly influenced by an intensified global oxygen-minimum zone across the Cenomanian - Turonian boundary (see review by Arthur et al., in press).

The biostratigraphically important keeled morphotypes constitute a minor fraction (generally less than one percent) of the total planktonic foraminiferal assemblages in the Rock Canyon material. Assemblage composition based on the dominant non-keeled morphotypes shows marked changes through the study interval (Figure 4). Most dramatic is the change from assemblages dominated by

trochospiral morphotypes (mainly Hedbergella spp.) to assemblages co-dominated by biserial morphotypes (Heterohelix) and trochospiral forms (Whiteinella and Hedbergella). This shift probably reflects an ecologic change in the upper water column during latest Cenomanian and earliest Turonian time.

Samples from the uppermost Hartland Shale (HL1) and basal Bridge Creek Limestone (BC1 to BC5) are dominated by Hedbergella spp. Trochospiral morphotypes average 75 percent of the assemblages through this interval while biserial forms (Heterohelix) average 13 percent and other forms (mainly Globigerinelloides and Guembelitria) average 12 percent of the assemblages. This interval corresponds with the benthonic zone of Eicher and Worstell (1970). The dominance of Hedbergella, Whiteinella and Globigerinelloides (Intermediate Water Fauna of Leckie, 1984a, in review) relative to Heterohelix and Guembelitria (Shallow Water Fauna), together with the diverse association of keeled taxa (Deep Water Fauna), suggests a deep, open marine environment for the lower part of the study interval.

Samples BC6 and BC7 show a marked decline in the proportion of Globigerinelloides ("other"), and the keeled morphotypes (Deep Water Fauna) disappear from the assemblages. An abrupt change in assemblage composition occurs in Sample BC8 (Figure 4). The proportion of Heterohelix (biserial form) averages 56.2 percent and Whiteinella plus Hedbergella (trochospiral forms) average 42.8 percent of the assemblages from samples BC8 to BC16.

The Cenomanian - Turonian boundary interval roughly corresponds with maximum transgression of the Greenhorn sea, therefore it is unlikely that the observed increase in Heterohelix represents a shallowing trend. A change in surface water characteristics is a more likely explanation for the dramatic shift in assemblage composition, as it also agrees with geochemical and sedimentological information. Pratt (1983, 1984) has suggested that fresh water runoff from the Sevier highlands at the western margin of the Greenhorn sea may have led to periodic development of buoyant plumes of brackish water which extended from the western shoreline nearly across the seaway. The formation of brackish plumes is presumed to have been climatically controlled. Oxygen isotope data through the lower Bridge Creek most likely record salinity effects rather than temperature effects based on the magnitude of the $\delta^{18}O$ excursions (Pratt, this volume). Normal marine conditions are interpreted for the basal Bridge Creek, corresponding $\delta^{18}O$ values above the benthonic zone suggests subsaline surface waters (Pratt, this volume). The observed shift in planktonic foraminiferal assemblages occurs at the same stratigraphic horizon.

Late Cretaceous Heterohelix was an important component of planktonic assemblages of epicontinental seas (Eicher and Worstell, 1970; Sliter, 1972). Leckie (1984a, in review) has proposed that Heterohelix was a eurytopic surface-dweller, tolerant of the variable mixed surface-layer environment. The synchronous occurrence of a negative $\delta^{18}O$ excursion and abrupt foraminiferal assemblage change supports a model of salinity stratification across the Cenomanian - Turonian boundary interval brought about in part by formation of buoyant brackish plumes (Pratt, 1984, this volume; Arthur et al., in press).

SUMMARY OF PLANKTONIC FORAMINIFERAL TRENDS ACROSS THE CENOMANIAN-TURONIAN BOUNDARY IN COLORADO

1. Planktonic foraminiferal assemblages are most diverse in the lowermost Bridge Creek Limestone (Samples BC1 - BC3; Figure 4). This interval corresponds, in part, to the benthonic zone of Eicher and Worstell (1970). The incursion of a warm water mass from the south is interpreted.
2. Keeled species of planktonic foraminifera, components of the Deep Water Fauna, are absent across the Cenomanian - Turonian boundary at Rock Canyon anticline (Samples BC6 - BC15; Figure 3). This interval corresponds to the zone of "grandes globigerines". The loss of keeled morphotypes is attributed to expansion of an oxygen-minimum zone.
3. A marked shift in planktonic foraminiferal assemblage composition in Sample BC8 is attributed to paleoecologic changes in the upper water column. Assemblages dominated by trochospiral morphotypes, components of the Intermediate Water Fauna, were succeeded by assemblages dominated by biserial morphotypes, components of the Shallow Water Fauna (Figure 4). This shift occurs at the same stratigraphic horizon as a negative excursion in $\delta^{18}O$ values, interpreted to record the spread of subsaline surface waters.
4. The Deep Water Fauna (keeled morphotypes) through the study interval was probably most strongly influenced by global oceanographic developments affecting oxygen budgets in the mid-water column during latest Cenomanian - earliest Turonian time, whereas the Intermediate and Shallow Water Faunas (inflated morphotypes) were influenced by regional factors (e.g. salinity) affecting the uppermost water column of the Greenhorn sea.

BENTHIC FORAMINIFERA

Benthic foraminifera are very rare in uppermost Hartland strata, sample HL1 (Figure 4; see also Eicher and Worstell, 1970, text-figure 8). This interval represents the top of Eicher and Worstell's (1970) lower planktonic zone. However, benthic foraminifera increase dramatically both in abundance and diversity in strata of the basal Bridge Creek (samples BC1 to BC5). The sudden increase in benthics is recorded from the Big Bend region of Texas in the south to the Black Hills of South Dakota in the north, some 1000 miles (Eicher and Worstell, 1970; Frush and Eicher, 1975; Diner and Eicher, 1984, this volume). This interval corresponds to the benthonic zone of Eicher and Worstell (1970).

The benthonic zone is characterized by a diverse calcareous benthic fauna. Shannon diversity index is generally greater than 1.50 (Figure 4). Characteristic taxa include Praebulimina fabilis, Neobulimina albertensis, Tappanina laciniosa, Gavelinella plummerae, Lingulogavelinella asterigerinoides, L. newtoni and Valvulineria loetterlei. Arenaceous taxa are very rare, represented by a single species, Textularia ricensis, which has Gulf Coast affinities.

A transitional fauna occurs in samples BC 6 and BC7 characterized by reduced diversities. Shannon diversity index ranges between 0.75 and 1.25. The assemblages are dominated by Praebulimina fabilis, Neobulimina albertensis, and Gavelinella dakotensis.

Arenaceous taxa remain very rare but conspicuous and have cool-water affinities. This interval, and above, corresponds to the upper planktonic zone of Eicher and Worstell (1970).

A depauperate benthic fauna occurs in samples BC8 to BC12. These assemblages are characterized by low diversity and high species dominance; Shannon diversity index is less than 0.75. The assemblages are dominated by *Neobulimina albertensis* and *Gavelinella dakotensis* with a minor component of *Praebulimina fabilis* and a trace of cool-water arenaceous taxa. Lowest diversities occur in samples BC11 and BC12, Shannon diversity index of 0.37 and 0.18, respectively. These samples lie very close to the Cenomanian - Turonian boundary according to macrofossils.

Samples BC13 to BC16 contain a recovery fauna characterized by increased diversities. Shannon diversity index ranges between 0.50 and 1.25. The assemblages are dominated by *Neobulimina albertensis* and *Gavelinella dakotensis*. Also present are *Praebulimina fabilis*, *Lingulogavelinella newtoni*, *Valvulineria loetterlei*, and *Neobulimina canadensis/prolixa* group.

TAXONOMIC NOTES

Species of the genera *Rotalipora*, *Anaticinella*, *Praeglobotruncana*, *Dicarinella*, *Whiteinella*, and *Ventilabrella* are discussed below and illustrated on the plates that follow. These discussions are supplementary to those of Eicher and Worstell (1970). References not cited in the back of this volume may be found in papers by Eicher and Worstell (1970), Robaszynski, Caron et al. (1979), or Leckie (1984b).

Rotalipora greenhornensis (Morrow)

pl. 4, figs. 9-10, 13-14

Globorotalia greenhornensis MORROW, 1934, p. 199, pl. 31, fig. 1.

Rotalipora greenhornensis (Morrow). EICHER and WORSTELL, 1970, p. 312, pl. 12, figs. 2a-2c; pl. 13, figs. 3a-3b.

Rotalipora greenhornensis (Morrow). ROBASZYNSKI, CARON et al., 1979, p. 90, pl. 12, figs. 1,2; pl. 13, figs. 1, 2.

Rotalipora cushmani (Morrow)

pl. 4, figs. 1-2, 11-12, 15-16

Globorotalia cushmani MORROW, 1934, p. 199, pl. 31, figs. 2, 4.

Rotalipora cushmani (Morrow). EICHER and WORSTELL, 1970, p. 310, pl. 12, figs. 3a-c, 4a-b; pl. 13, figs. 1a-b.

Rotalipora cushmani (Morrow). ROBASZYNSKI, CARON et al., 1979, p. 74, pl. 7, fig. 1; pl. 8, figs. 1,2

Discussion: *R. cushmani* is a variable species in the latter part of its range (compare with early forms from the middle Cenomanian; Leckie, 1984b). Specimens in the Rock Canyon material have 4 to 7 1/2 chambers in the final whorl, and there is considerable variability in dorsal convexity and degree of chamber inflation. *Anaticinella multiloculata* s.l. resembles a keel-less *R. cushmani*. The author suggests a phylogenetic relationship between the two taxa similar to that of *Anaticinella multiloculata* s.s. and *R. greenhornensis* (Eicher, 1972).

Anaticinella multiloculata (Morrow)

pl. 4, figs. 3-8

Globorotalia multiloculata MORROW, 1934, p. 200, pl. 31, figs. 3, 5.

Ticinella multiloculata (Morrow). EICHER and WORSTELL 1970, p. 312, pl. 13, figs. 2a-c, 4a-c.

Anaticinella multiloculata (Morrow). EICHER, 1972, p. 185-186, pl. 1, fig. 5; pl. 2, figs. 2-7.

Pseudoticinella multiloculata (Morrow). LONGORIA, 1973, p. 422, pl. 1, figs. 1-10; pl. 2, figs. 1-5, 10, 11.

Discussion: Two forms of *Anaticinella multiloculata* are recognized here. *A. multiloculata* s.s. is characterized by having 6 1/2 to 9 chambers in its final whorl and a tendency to have umbilical supplementary apertures (see Eicher, 1972, pl. 1, fig. 5a; pl. 2, figs. 4a, 6a, 7a). These morphocharacters are shared with its direct ancestor, *Rotalipora greenhornensis*. A second form, *A. multiloculata* s.l. is characterized by fewer chambers, 4 1/2 to 6, and a tendency to have sutural supplementary apertures (see Eicher, 1972, pl. 2, fig. 3a). These characteristics suggest closer affinity to *R. cushmani* via the same evolutionary mechanisms that witnessed the transformation of *Rotalipora greenhornensis* into *Anaticinella multiloculata* s.s. Further study is needed to adequately characterize differences between the two proposed forms of *A. multiloculata*.

Praeglobotruncana inornata (Bolli)

pl. 2, figs. 6-7

Globotruncana inornata BOLLI, 1957, p. 57, pl. 13, figs. 5-6.

Praeglobotruncana inornata (Bolli). EICHER and WORSTELL, 1970, p. 310, pl. 11, figs. 1a-c.

Discussion: *Praeglobotruncana inornata* is distinguished from *Whiteinella baltica* Douglas and Rankin by the presence of a weakly developed keel and is distinguished from *P. aumalensis* (Sigal) by fewer chambers in the final whorl, 4 to 4 1/2 rather than 5 to 7.

Praeglobotruncana prae-helvetica (Trujillo)

pl. 2, figs. 2-3

Rugoglobigerina prae-helvetica TRUJILLO, 1960, p. 340, pl. 49, figs. 6a-c.

Praeglobotruncana prae-helvetica (Trujillo). ROBASZYNSKI, CARON et al., 1979, p. 46, pl. 47, figs. 1, 2.

Praeglobotruncana stephani (Gandolfi)

pl. 2, figs. 9-10, 12-13

Globotruncana stephani GANDOLFI, 1942, p. 130-133, pl. 3, figs. 4, 5; pl. 4, figs. 36, 37, 41-44; pl. 6, fig. 4 (part); pl. 9, figs. 5, 8; pl. 13, fig. 5; pl. 14, fig. 2.

Praeglobotruncana stephani (Gandolfi). EICHER and WORSTELL, 1970, p. 308, pl. 10, fig. 9; pl. 11, figs. 2a-c, 3.

Praeglobotruncana stephani (Gandolfi). ROBASZYNSKI, CARON et al., 1979, p. 50, pl. 48, figs. 1-3.

Discussion: *Praeglobotruncana stephani*, as recognized here, may include forms referable to *P. aumalensis* (Sigal) and *P. gibba* Klaus.

Praeglobotruncana sp.

pl. 3, figs. 9-15

Discussion: *Praeglobotruncana* sp. is distinguished from *P. stephani* (Gandolfi) by its flatter spiral side (low trochospire) and inflated chambers on the umbilical side. *Praeglobotruncana* sp. bears strong resemblance to *Dicarinella hagni* (Scheibnerova) but is distinguished by the presence of a single keel in contrast to the double keel of the latter taxon. A phylogenetic relationship between the two species is suggested.

Dicarinella hagni (Scheibnerova)

pl. 3, figs. 1-8

Praeglobotruncana hagni SCHEIBNEROVA, 1962, p. 219, figs. 6a-c.

Dicarinella hagni (Scheibnerova). ROBASYNSKI, CARON et al., 1979, p. 84, pl. 56, figs. 1, 2; pl. 57, figs. 1, 2.

Discussion: This distinctive latest Cenomanian-early Turonian globotruncanid is characterized by its low trochospire and inflation on the umbilical side. These morphocharacters serve to distinguish D. hagni from chronospecies D. algeriana (Caron) and D. imbricata (Mornod). The latter two taxa have close affinities with Praeglobotruncana stephani (Gandolfi) while D. hagni appears to be closely related to Praeglobotruncana sp. Dicarinella hagni, as recognized here, may include specimens previously referred to as Marginotruncana indica, Praeglobotruncana difformis, and Marginotruncana roddai by Pessagno (1967), Eicher and Worstell (1970), and Frush and Eicher (1975), respectively. As discussed by these authors, the D. hagni species-group is gradational with Marginotruncana renzi (Gandolfi). M. renzi s.s. may have evolved from D. hagni in the late early or early middle Turonian.

Whiteinella aprica (Loeblich and Tappan)
pl. 1, figs. 1-4

Ticinella aprica LOEBLICH and TAPPAN, 1961, p. 292, pl. 4, figs. 14-16.

Whiteinella aprica (Loeblich and Tappan). EICHER and WORSTELL, 1970, p. 314, pl. 11, figs. 7a-c; pl. 12, figs. 1, 2.

Discussion: Whiteinella aprica is characterized by its large test with 5-8 globular chambers in the final whorl, wide umbilicus, umbilical aperture, and low trochospire. Chambers increase gradually in size as added. Portici preserved on few specimens. It is distinguished from W. archeocretacea Pessagno by its numerous, globular chambers and generally larger size.

Whiteinella archeocretacea Pessagno
pl. 1, figs. 5-12

Whiteinella archeocretacea PESSAGNO, 1967, p. 299, pl. 51, figs. 2-4; pl. 54, figs. 19-25; pl. 100, fig. 8.

Whiteinella archeocretacea Pessagno. ROBASYNSKI, CARON et al., 1979, p. 167-168, pl. 33, figs. 1-3 pl. 34, figs. 1, 2.

Discussion: Whiteinella archeocretacea is characterized by its laterally compressed test, low trochospire and 5-6 somewhat elongated chambers in the final whorl. Portici rarely preserved. It is distinguished from W. aprica (Loeblich and Tappan) by its laterally compressed test and fewer, somewhat elongated chambers. W. archeocretacea is distinguished from Hedbergella delrioensis (Carsey) by the umbilical position of its aperture and laterally compressed test.

Whiteinella baltica Douglas and Rankin
pl. 2, figs. 4-5, 8, 11

Whiteinella baltica DOUGLAS and RANKIN, 1969, p. 193, tf. 9A-I.

Whiteinella baltica Douglas and Rankin. ROBASYNSKI, CARON et al., 1979, p. 174, pl. 35, figs. 1-5; pl. 36, figs. 1-2.

Discussion: Whiteinella baltica is characterized by 4 to 4 1/2 chambers in its final whorl and an umbilical aperture. The umbilical position of the aperture serves to distinguish W. baltica from Hedbergella delrioensis (Carsey).

Whiteinella brittonensis/paradubia
pl. 1, figs. 13-16

Globigerina paradubia SIGAL, 1952, p. 28, text-fig. 28.

Whiteinella brittonensis LOEBLICH and TAPPAN, 1961, p. 274, pl. 4, figs. 1-8.

Hedbergella portsdownensis (Williams-Mitchell). EICHER and WORSTELL, 1970, p. 304, pl. 10, figs. 1a-c, 2a-b.

Whiteinella brittonensis (Loeblich and Tappan). ROBASYNSKI, CARON et al., 1979, p. 180, pl. 37, figs. 1, 2; pl. 38, figs. 1, 2.

Whiteinella paradubia (Sigal). ROBASYNSKI, CARON et al., 1979, p. 184, pl. 39, figs. 1, 2.

Discussion: Hedbergella portsdownensis (Williams-Mitchell) has been placed in synonymy with H. delrioensis by the European working group (Robaszynski, Caron et al., 1979) after examination of the type material. The Whiteinella brittonensis/paradubia species group, as recognized here, is characterized by 5 to 6 chambers in its final whorl and a continuous gradation between moderate to high trochospire. Although lacking well-developed and/or preserved portici, this group is placed in the genus Whiteinella based on the umbilical position of the aperture, a characteristic also noted by Eicher and Worstell (1970, p. 304). The specimens present in the Rock Canyon material are part of a plexus that includes moderate-spired forms (= W. brittonensis s.s.; see Eicher and Worstell, pl. 10, figs. 1, 2) and high-spired forms (= W. paradubia s.s.; see pl. 1, figs. 13-16 of this study). The "brittonensis/paradubia" species group is gradational with species of Hedbergella (e.g. H. delrioensis) and true Whiteinella (e.g. W. archeocretacea, W. aprica) in this upper Cenomanian-lower Turonian material, but its true hedbergellid affinities are best displayed in specimens from the upper Albian to middle Cenomanian (e.g. Hedbergella paradubia of Leckie, 1984b, p. 598, pl. 11, figs. 1-4).

Ventilabrella austinana Cushman
pl. 2, fig. 1

Ventilabrella austinana CUSHMAN, 1938, p. 26, pl. 4, fig. 19.

Heterohelix globulosa (Ehrenberg). EICHER and WORSTELL, 1970, pl. 8, fig. 4 (not figs. 3, 5, 6).

ACKNOWLEDGMENTS

The samples were collected and initial data were generated while the author was at the University of Colorado. Discussions with Richard Diner, Don Eicher, Erle Kauffman, Jim Kirkland and Will Elder are especially acknowledged. The manuscript was reviewed by R. Diner, D. Eicher, Wylie Poag, Bill Sliter and Fred Zelt. Scanning electron microscope pictures were taken at Woods Hole Oceanographic Institution with the assistance of Mike Kaminski. Pamela Leckie kindly typed the original manuscript. Post-doctoral research support at W.H.O.I. is gratefully acknowledged.

	<i>Rotalipora cushmani</i>	<i>Rotalipora greenhornensis</i>	<i>Praeglobotruncana stephani</i>	<i>Hedbergella delrioensis</i>	<i>Hedbergella simplicissima</i> [=H. amabilis]	<i>Hedbergella planispira</i>	<i>Whiteinella brittonensis/paradubia group</i>	<i>Globigerinoides bentonensis</i>	<i>Globigerinell. ultramicrus</i> [=G. caseyi]	<i>Heterohelix moremani/globulosa group</i>	<i>Clavohedbergella simplex</i>	<i>Whiteinella archeoretacea</i>	<i>Praeglobotruncana sp.</i>	<i>Whiteinella aprica</i>	<i>Schackoina cenomana</i>	<i>Schackoina multispinata</i>	<i>Guembelitria cenomana</i> [=G. harris]	<i>Clavohedbergella moremani</i>	<i>Praeglobotruncana inornata</i>	<i>Anaticinella multiloculata s.l.</i>	<i>Anaticinella multiloculata s.s.</i>	<i>Praeglobotruncana praevelvetica</i>	<i>Dicarinella hagni</i> [=P. difformis]	<i>Whiteinella battica</i>	<i>Ventilabrella austriana</i>
BC16	V	VC	CV	A	V	C										V								VV	
BC15		CV	RR	A	VV	C										VV								V	V
BC14		C	CR	A	V	C										V								V	V
BC13		C	CR	A	V	C										V								V	V
BC12		C	CV	A	V	C										V								V	V
BC11		C	AR	A	V	R										V								V	V
BC10		C	AR	A	V	R										V								V	V
BC9		C	CV	A	V	R										V								V	V
BC8		V	C	RA	V	R										V								V	V
BC7		AR	CR	RC	VR	V										V								R	V
BC6		AR	CR	RC	VR	V										VV	?							V	V
BC5		VAV	CR	CC	R	V										R	V							VV	V
BC4		VAV	CV	VCC	V	V										C	V							VV	V
BC3	V	VAV	CV	VCC	V	V										C	V	?						VV	V
BC2	V	VAR	RR	CV	V	V										V	V	V	V					V	V
BC1	V	VAR	CR	VRC	VR	V										R	V	V						V	V
HL1	R	VAV	R	RC	V	V																			

Appendix 1. Distribution and relative abundances of planktonic foraminifera from the Cenomanian-Turonian boundary interval of the Rock Canyon anticline section. Based on 300-specimen counts of fraction >75 microns. >25% = abundant (A), 5-25% = common (C), 1-5% = rare (R), and <1% = very rare (V). Species in parentheses refer to names used by Eicher and Worstell (1970). A single specimen of *Rotalipora cushmani* was found in Sample BC16; its occurrence could be ascribed to lab contamination, reworking, or *in situ*(?).

Sample	Simple Diversity	Trochospiral Morphotypes (Percent)	Biserial Morphotypes (Percent)	Other (Percent)	Total Number Specimens
BC16	11	35.3	63.9	0.8	449
BC15	11	56.1	43.1	0.8	381
BC14	7	43.9	55.0	1.1	411
BC13	8	35.0	63.1	1.9	345
BC12	7	41.9	58.1	0.0	502
BC11	9	42.8	56.1	1.1	512
BC10	7	46.9	51.9	1.1	485
BC 9	9	63.1	36.1	0.8	335
BC 8	6	20.0	78.1	1.9	522
BC 7	11	76.1	20.0	3.9	299
BC 6	12	88.0	10.0	1.9	429
BC 5	14	76.9	11.9	11.1	593
BC 4	15	56.1	25.0	18.9	323
BC 3	18	63.0	16.9	20.0	421
BC 2	18	90.0	1.1	8.9	477
BC 1	19	83.0	11.9	5.0	663
HL 1	13	81.1	11.9	6.9	352

Appendix 3. Summary of data for planktonic foraminifera and computations used to construct Figure 4.

	<i>Praeulimina labilis</i>	<i>Neobulimina albertainis</i>	<i>Gavelinella dakotensis</i>	<i>Tappanina laciniosa</i>	<i>Lingulogavelinella asterigerinoides</i>	<i>Lingulogavelinella newtoni</i>	<i>Gavelinella plummerae</i>	<i>Vavulineria (coetleri)</i>	<i>Lingulogavelinella modesta</i>	<i>Citharina Kochii</i>	<i>Pleurostomella nitida</i>	<i>Ramulina aculeata</i>	<i>Conorboides minutissima</i>	<i>Lenticulina gaultina</i>	<i>Cassidella tegulata</i>	<i>Fursenkoina cronseisi</i>	<i>Dentalina communis</i>	<i>Marginulinopsis ampliastriata</i>	? <i>Lagena</i> s.p.	<i>Hoeglundina charlottae</i>	<i>Textularia rioensis</i>	<i>Quinqueloculina moremani</i>	? <i>Nodosaria</i> s.p.	<i>Pyralina cylindroides</i>	<i>Trochamminoides</i> s.p.	? <i>Coscinochama codyensis</i>	<i>Haplophragmoides topogorukensis</i>	<i>Trochammina</i> c.t. <i>wetteri</i>	? <i>Neobulimina canadensis/prolixa</i>	<i>Trochammina rainwateri</i>		
BC16	256	71			11	1	TR																								5	?
BC15	277	42			5																									2	?	
BC14	189	102			9	1																									2	?
BC13	30	230	34		10	8	TR																								3	
BC12	7	363	12		1																											
BC11	2	275	33																													
BC10	28	257	63																													
BC9	17	52	195																													
BC8	3	140	154																													
BC7	151	144	12	17																												
BC6	18	156	38																													
BC5	89	15	7	139	18																											
BC4	109	20	127	7																												
BC3	102	7	5	76	9																											
BC2	49	6	1	18	70																											
BC1	85	118	5	26	6																											
HL1	1																															

Appendix 2. Distribution and abundances of benthic foraminifera from the Cenomanian-Turonian boundary interval of the Rock Canyon anticline section. Based on 300-specimen counts of fraction >75 microns. TR (trace) signifies that a species was not encountered during the count but recorded during further examination for rare species.

Sample	Simple Diversity	Information Function	Total Number Specimens	Percent Benthics
BC16	9	0.73	344	27.7
BC15	6	0.51	327	15.1
BC14	7	0.84	304	18.6
BC13	9	1.06	341	17.7
BC12	5	0.18	383	2.5
BC11	4	0.37	310	8.6
BC10	4	0.73	348	10.5
BC 9	6	0.72	264	6.2
BC 8	8	0.75	298	9.2
BC 7	9	1.21	312	8.3
BC 6	8	0.84	216	1.8
BC 5	13	1.51	301	2.9
BC 4	16	1.51	317	22.7
BC 3	14	1.75	310	28.3
BC 2	12	1.39	342	4.4
BC 1	18	1.84	334	9.8
HL 1	1	0.00	1	0.3

Appendix 4. Summary of data for benthic foraminifera and computations used to construct Figure 4.

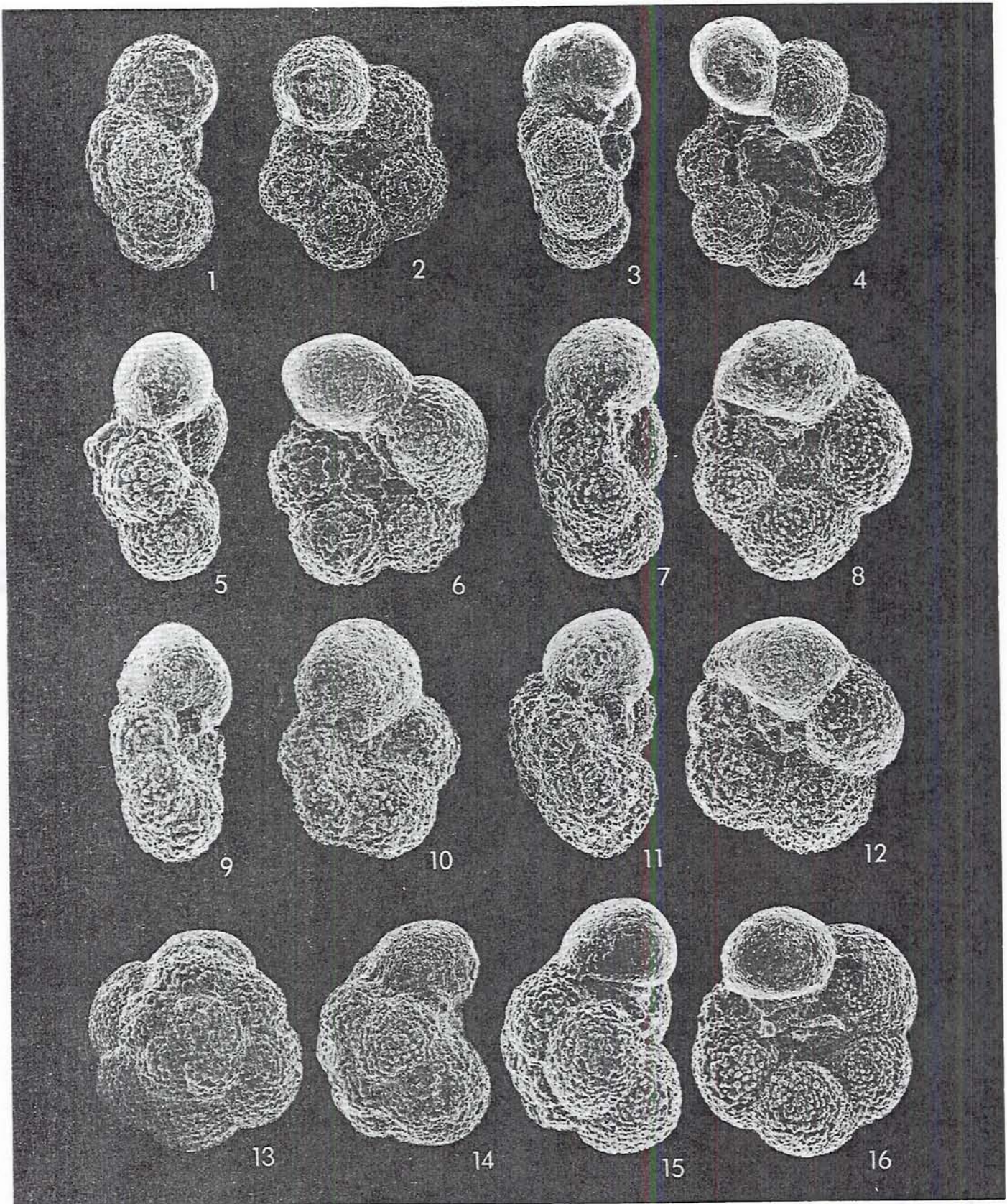


Plate 1 1-4 *Whiteinella aprica*. Figs. 1-2 Sample BC14, X225; Figs. 3-4 Sample BC14, X160; 5-12 *Whiteinella archeocretacea*. Figs. 5-6 Sample BC13, X250; Figs. 7-8 Sample HL1, X250; Figs. 9-10 Sample BC1, X250; Figs. 11-12 Sample HL1, X210; 13-16 *Whiteinella brittonensis/paradubia* gr. Figs. 13-14 Sample BC7, X210; Figs. 15-16 Sample HL1, X250.

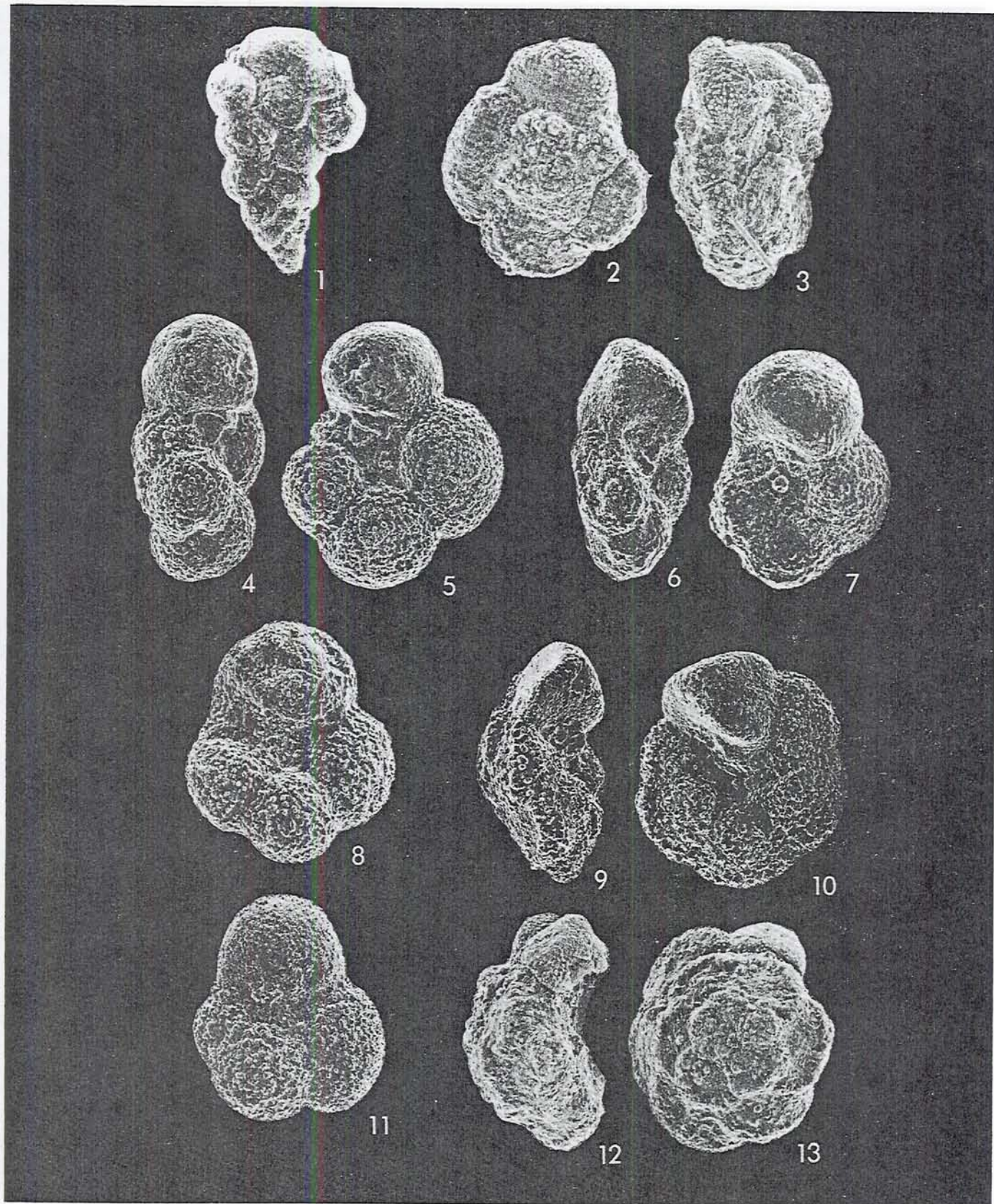


Plate 2 1 *Ventilabrella austinana*. Sample BC16, X200; 2-3 *Praeglobotruncana praehelvetica*. Sample BC4, X180; 4-5, 8, 11 *Whiteinella baltica*. Figs. 4-5 Sample BC14, X200; Fig. 8 Sample BC6, X250; Fig. 11 Sample BC6, X250; 6-7 *Praeglobotruncana inornata*. Sample BC1, X225; 9-10, 12-13 *Praeglobotruncana stephani*. Figs. 9-10 Sample HL1, X200; Figs. 12-13 Sample BC4, X210.

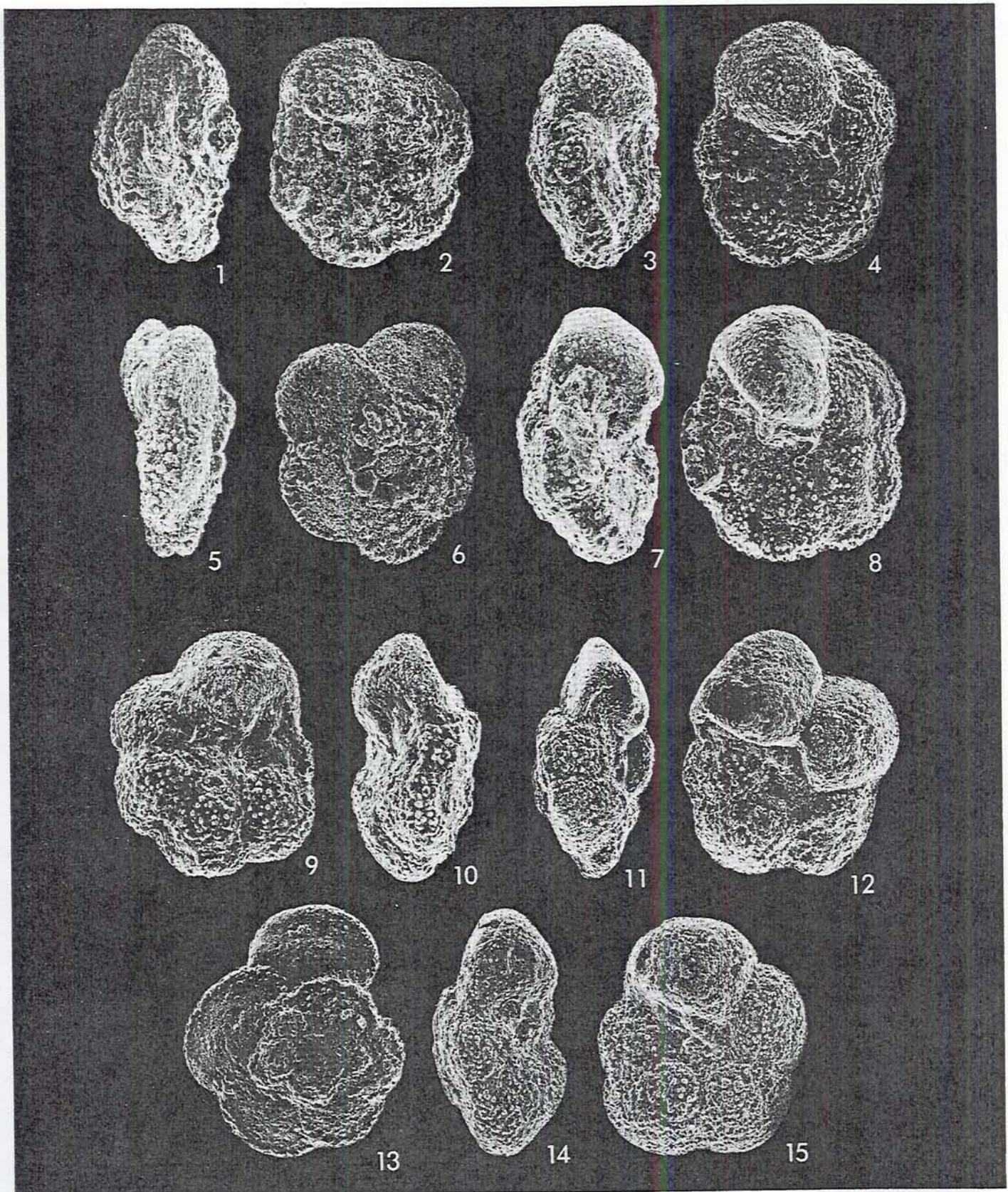


Plate 3 1-8 *Dicarinella hagni*. Figs. 1-2 Sample BC2, X230; Figs. 3-4 Sample BC4, X200; Figs. 5-6 Sample BC3, X265; Figs. 7-8 Sample BC1, X240; 9-15 *Praeglobotruncana* sp. Figs. 9-10 Sample BC4, X210; Figs. 11-12 Sample BC1, X200; Fig. 13 Sample HL1, X220; Figs. 14-15 Sample BC1, X210.

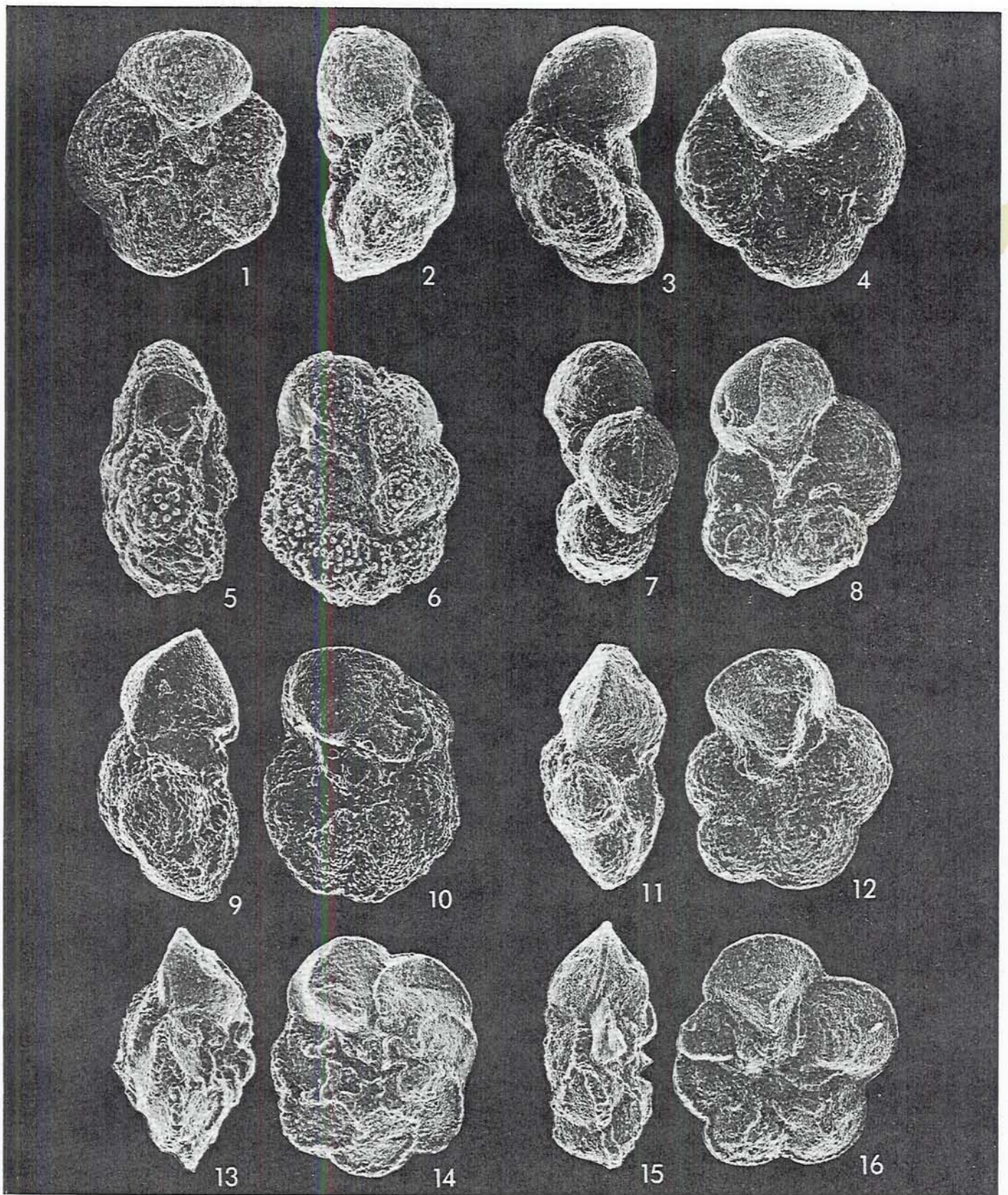
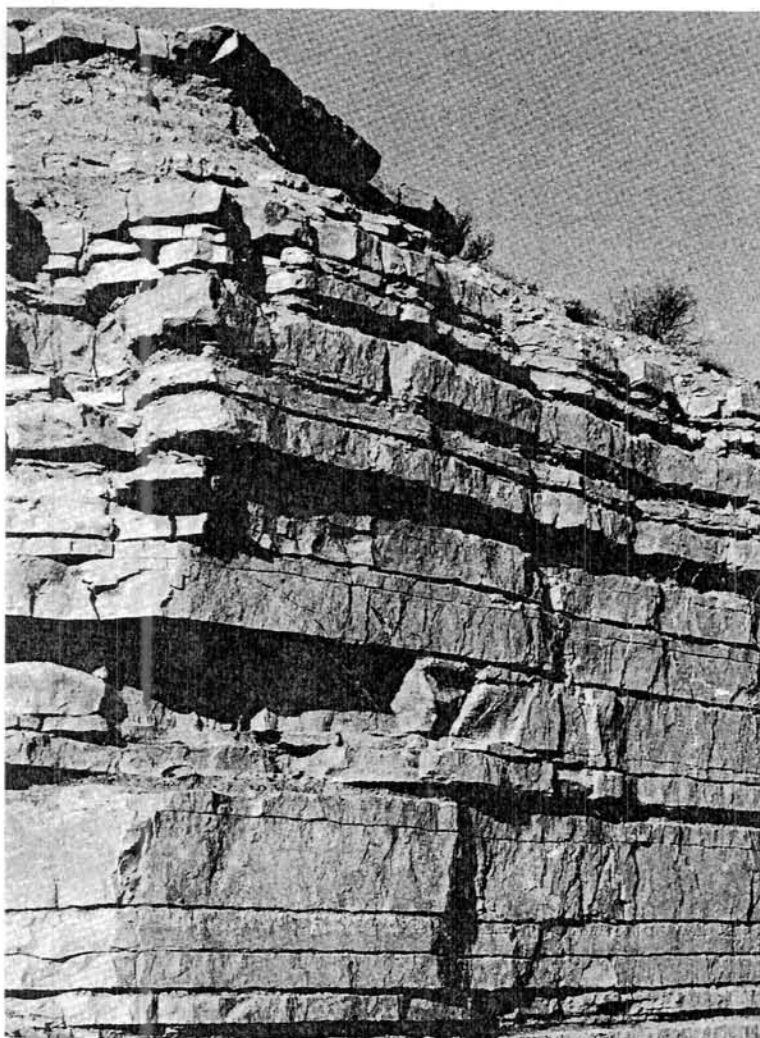


Plate 4 1-2, 11-12, 15-16 *Rotalipora cushmani*. Figs. 1-2 Sample HL1, X260; Figs. 11-12 Sample BC1, X210; Figs. 15-16 Sample BC1, X175; 3-4, 7-8 *Anaticinella multiloculata* s.l. Figs. 3-4 Sample BC1, X230; Figs. 7-8 Sample BC2, X210; 5-6 *Anaticinella multiloculata* s.s. Sample BC2, X210; 9-10, 13-14 *Rotalipora greenhornensis*. Figs. 9-10 Sample BC1, X220; Figs. 13-14 Sample HL1, X175.

Mark Leckie

SEPM FIELD TRIP GUIDEBOOK NO. 4
1985 MIDYEAR MEETING
GOLDEN, COLORADO



Fine-grained Deposits and Biofacies of the
Cretaceous Western Interior Seaway: Evidence of
Cyclic Sedimentary Processes

Society of Economic Paleontologists and Mineralogists



FINE-GRAINED DEPOSITS AND BIOFACIES
OF THE
CRETACEOUS WESTERN INTERIOR SEAWAY:
EVIDENCE OF
CYCLIC SEDIMENTARY PROCESSES

EDITED BY:

LISA M. PRATT
ERLE G. KAUFFMAN
FREDERICK B. ZELT

SEPM Second Annual Midyear Meeting
Golden, Colorado
Field Trip No. 9
August 15, 1985



Society of Economic Paleontologists and Mineralogists