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The Lower Cretaceous Gulf Coast (Tethyan)--Western Interior transition--Microfossil evidence from northeastern New Mexico and adjacent states

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THE LOWER CRETACEOUS GULF COAST (TETHYAN)–WESTERN INTERIOR TRANSITION: MICROFOSSIL EVIDENCE FROM NORTHEASTERN NEW MEXICO AND ADJACENT STATES

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Abstract—The Glenciarn Formation of northeastern New Mexico, southeastern Colorado and the Oklahoma Panhandle contains a Lower Cretaceous (Albian) foraminiferal fauna transitional between the Tethyan faunas of the Gulf Coast region and the Western Interior faunas of Wyoming and southern Canada. The fauna consists of 28 species of Foraminifera and three species of Ostracoda. The foraminiferal fauna is dominated by arenaceous species with distinct affinities with those of the Kiowa Shale of Kansas. Comparison of the Glencairn and Kiowa foraminiferal faunas indicates a greater Western Interior influence on the Glencairn fauna and a greater Tethyan influence on the Kiowa fauna. This suggests greater southern penetration of the Western Interior foraminiferal fauna along the western margin of the Interior basin and a greater northern penetration of the Tethyan fauna along the eastern Interior-basin margin, possibly a result of deflection of currents by the Mesa Rica delta and the associated Bravo dome. This study further suggests the southern Western Interior foraminiferal fauna was populated by opportunistic ("facies") species found in the Tethys region during earlier, Walnut and Kiamichi time.

INTRODUCTION

Ongoing research by workers at the University of New Mexico on the Lower Cretaceous of northeastern New Mexico has produced a microfossil database outlining the nature of the transition from the typical Tethyan faunas of the Tucumcari Shale in east-central New Mexico into the typical Western Interior faunas of the Glencairn Formation in southeastern Colorado (Kietzke, 1985; Kues et al., 1985; Lucas et al., 1986; Kues and Lucas, 1987). This paper examines the Tethyan-Interior transition in New Mexico, Colorado, Texas, Oklahoma and Kansas and briefly outlines the Albian paleobiogeography of foraminiferal faunas of North America. Details concerning the local stratigraphy of the localities from which the samples used in this report were obtained and the regional correlations of the Glencairn Formation can be found in Appendix 1, Lucas et al. (1986) and Kues and Lucas (1987). Samples were basically "grab samples" collected during measurement of stratigraphic sections.

GLENCAIRN MICROFAUNA

The microfauna of the Glencairn Formation of southern Colorado was first examined but not illustrated by Long (1966), who reported 12 species of Foraminifera from the Glencairn Formation of southeastern Colorado (Table 1). I collected 28 species of Foraminifera and three species of Ostracoda from the Glencairn of northeastern New Mexico, southeastern Colorado and adjacent Oklahoma (Fig. 1, Table 1, Appendix 1). Important components of this fauna are illustrated for the first time (Fig. 2). The Glencairn foraminiferal fauna is similar to the fauna of the Kiowa Shale of Kansas (Loeblich and Tappan, 1950), which contains 26 species of Foraminifera (Table 1). Among the arenaceous, agglutinated Foraminifera there are strong similarities, whereas among the calcareous Foraminifera there are pronounced differences.

The arenaceous, agglutinated foraminiferal fauna of the Glencairn Formation of southern Colorado, the Glencairn Formation of northeastern New Mexico and the Kiowa Shale of Kansas consists of 26 species. The species *Saccammina alexanderi* (Loeblich and Tappan, 1950), *Ammodiscus kiowensis* Loeblich and Tappan, 1950, *Ammobaculites euides* Loeblich and Tappan, 1949, *Ammobaculites obliquus* Loeblich and Tappan, 1949, *Trochammina depressa* Lozo, 1944 and *Verneuilinoides perplexus* (Loeblich, 1946) (=*Verneuilinoides kansasensis* Loeblich and Tappan, 1950) are found in all three faunas. The Glencairn Formation of southeastern Colorado contains a single species not represented in the other two faunas. The Kiowa Shale of Kansas contains a single species not found in the other two faunas. The Glencairn Formation of New Mexico and Oklahoma contains nine species

TABLE 1. Foraminifera of the Glencairn Formation and Kiowa Shale. 1 = Colorado, Glencairn Formation, 2 = New Mexico/Oklahoma, Glencairn Formation, 3 = Kansas, Kiowa Formation, 4 = Texas, pre-Washita Group, 5 = Texas, Washita Group, 6 = Texas, post-Washita Group, 7 = Wyoming, Thermopolis Formation, 8 = Manitoba, lower Ashville Formation, 9 = Alberta/Saskatchewan, Joli Fou Formation, 10 = Alaska, Topagoruk/Grandstand formations.

	1	2	3	4	5	6	7	8	9	10
Arenaceous Foraminifera										
Trochammina depressa	X	X	X	X			X	X	X	
Ammobaculites euides	X	X	X	X			X			
Ammobaculites obliquus	X	X	X	X			X			
Ammodiscus kiowensis	X	X	X				X	X	X	
Saccammina alexanderi	X	X	X				X	X	X	
Verneuilinoides perplexus	X	X	X	X			X	X		
Ammobaculites fragmentarius	X	X					X	X	X	X
Reophax sp.	X	X								
Flabellammina dennisonensis	X					X				
Ammobaculoides plummerae	X		X	X	X					
Ammobaculites auricularis	X		X	X						
Ammobaculites subcretaceus		X	X	X			X			
Ammomarginulina cragini		X	X	X			X			
Textularia sp.		X	X							
Bathysiphon sp.		X								
Cribratina texana		X			X					
Ammobaculites petilus		X		X			X	X		
Haplophragmoides linki		X					X	X	X	X
Gaudryina canadensis		X					X	X	X	X
Haplophragmoides gigas		X					X	X	X	X
Verneuilina canadensis		X					X	X	X	
Ammobaculoides whitneyi		X					X	X		
Glomospira tortuosa		X					X	X		
Lituotuba sp.		X					X	X		
Ammobaculites phaulus			X	X			X			
Calcareous Foraminifera										
Hedbergella sp.	X									
Nodosaria obsecura		X			X					
Dentalina sp.		X	X							
Nodosaria sp.		X	X							
Lenticulinia sp. A		X								
Lenticulinia sp. B		X								
Citharina sp.		X								
Lingulina furcillata			X	X	X	X				
Dentalina debilis			X	X	X	X				
Bulimina nannina			X		X	X				
Gumbelitria harrisi			X		X	X				
Eouvigerina laxistoma			X		X					
Pyrulina carebara			X	X						
Neobulimina primitiva			X	X						
Quinloculina nanna			X							
Pseudoglandulina sp.			X							
Hedbergella graysonensis			X							
Lingulina sp.			X							
Lagena exomala			X							
Other Microfauna										
Ostracoda		X	X	X	X	X				

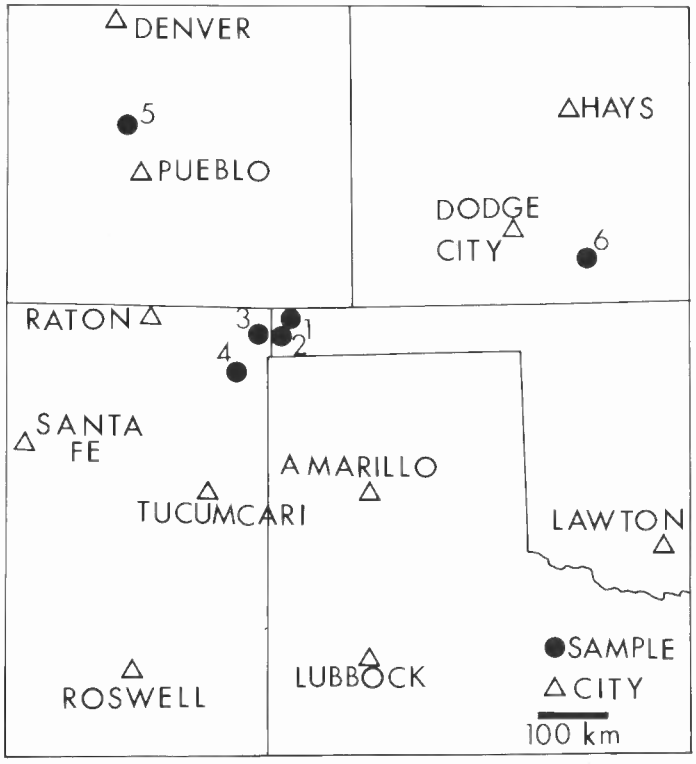


FIGURE 1. Locality map of Glencairn Formation and Kiowa Shale microfossil collections (also see Appendix 1). 1 = UNM locality 1330, 2 = UNM locality 1332, 3 = UNM locality, 4 = Clayton Lake locality, 5 = Bear Creek locality, 6 = Kiowa Shale locality.

not found in the other two faunas. An additional nine species are shared by various combinations of the three faunas, two by the Glencairn of Colorado and the Kiowa of Kansas, two by the Glencairn of Colorado and the Glencairn of New Mexico/Oklahoma and five by the Glencairn of New Mexico and the Kiowa of Kansas. It should be noted (Table 1) that none of these Foraminifera are endemic to these faunas.

The Glencairn of Colorado, the Glencairn of New Mexico and the Kiowa calcareous foraminiferans consist of 19 species. The Glencairn Formation in southeastern Colorado contains only a single species of planktonic foraminiferan (*Hedbergella* sp.). The Glencairn Formation in New Mexico and Oklahoma contains six species, all of which are benthonic. The Kiowa Shale contains 14 calcareous species, one of which is a planktonic species (*Hedbergella graysonensis* Tappan, 1940). Only two of these species can be found in both the Kiowa and Glencairn faunas and, with reservations, because they cannot be identified with certainty below the genus-level. Poor preservation of the rare calcareous microfossils in the Glencairn of New Mexico and Oklahoma makes identification rarely possible below the genus-level. Also, the rarity of calcareous Foraminifera in the Glencairn and Kiowa faunas, with many species represented by a single or very few specimens, makes comparison difficult. The Kiowa calcareous foraminiferal fauna has a relatively large number of endemic species (five) with the remainder being of Tethyan affinity.

The foraminiferal fauna of the Glencairn in northeastern New Mexico and adjacent Oklahoma and the Kiowa fauna of southern Kansas have ties to both the Western Interior foraminiferal faunas and the Tethyan foraminiferal faunas. The following analysis is used to clarify that transition by comparisons between adjacent faunas, and to put the fauna in a regional framework.

TABLE 2. Dispersity/similarity coefficients, New Mexico/Oklahoma. 1 = Kenton locality, 2 = OK-1 locality, 3 = OK-2 locality, 4 = Clayton Lake locality.

Index of Biotal Dispersity - New Mexico/Oklahoma

		1	2	3	4
1	17	X	18	24	22
2	4	16.66	X	14	9
3	13	25.00	22.22	X	19
4	7	9.09	21.43	5.26	X

Similarity Quotient - New Mexico/Oklahoma Faunas

1	17	X	3	6	2
2	4	14.29	X	3	2
3	13	20.00	17.65	X	1
4	7	8.33	18.18	5.00	X

TETHYAN-WESTERN INTERIOR TRANSITION

Since the foraminiferal fauna of the Glencairn Formation in northeastern New Mexico and adjacent Oklahoma has origins in both the Tethyan and Western Interior realms, I have examined the nature of that transition by comparing this fauna not only with the nearby, contemporaneous faunas of the Glencairn Formation of Colorado and the Kiowa Shale of Kansas but also with other well-studied, closely contemporaneous foraminiferal faunas in North America, including the Tethyan faunas of the Duck Creek Formation of Texas (Tappan, 1943), the Tucumcari Shale of New Mexico (Kietzke, 1985) and the pre-Duck Creek (i.e., Fredricksburg Group) faunas of Texas (Lozo, 1943, 1944; Loeblich and Tappan, 1949). Comparisons were also made with the well-studied Western Interior foraminiferal faunas of the Thermopolis Shale in Wyoming (Eicher, 1960), the lower Ashville Formation (Skull Creek Shale Member) of Manitoba, Canada (McNeil and Caldwell, 1981) and the Joli Fou Formation of northern Alberta and Saskatchewan, Canada (Guliov, 1967; Stelck et al., 1956). Some comparisons were also made with the faunas of the Topogoruk and Grandstand formations of Alaska (Tappan, 1962).

Faunas of the Glencairn Formation and Kiowa Shale were compared on the species-level with the above-mentioned faunas (Table 1). Second, the faunas were compared using the Koch (1957) index of biotal dispersity (b.d.) and the Kontkanen (1957) similarity quotient (Tables 3 and 4). Finally, the information was synthesized into the overall pa-

TABLE 3. Index of biotal dispersity. 1 = Alaska-Topogoruk/Grandstand formations, 2 = Manitoba, lower Ashville Formation, 3 = Wyoming, Thermopolis Shale, 4 = Colorado/Oklahoma/New Mexico, Glencairn Formation, 5 = Kansas, Kiowa Shale, 6 = Oklahoma/Texas, Walnut Formation, 7 = Texas, Kiamichi Formation, 8 = New Mexico, Tucumcari Shale, 9 = Texas, Duck Creek Formation.

Total Fauna

		2	3	4	5	6	7	8	9	
1	92	X	108	112	119	118	136	121	158	208
2	28	11.11	X	38	45	52	70	55	96	154
3	24	3.57	36.84	X	37	43	63	47	91	149
4	31	3.36	31.11	48.65	X	44	71	34	98	156
5	27	0.85	5.77	18.60	31.82	X	70	46	93	147
6	45	0.74	4.29	9.52	7.04	2.86	X	60	103	158
7	29	0.00	3.63	12.76	76.47	21.74	23.33	X	72	138
8	68	?	0.00	1.10	1.02	2.15	9.71	34.72	X	141
9	126	4.81	0.00	0.67	0.64	4.08	8.23	12.32	37.59	X

Calcareous Component

		1	2	3	4	5	6	7	8	9
1	60	X	61	60	67	74	86	79	107	145
2	1	0.00	X	1	8	15	27	20	49	92
3	0	0.00	0.00	X	7	14	26	19	48	91
4	7	0.00	0.00	0.00	X	21	31	26	51	97
5	14	0.00	0.00	0.00	0.00	X	40	30	60	103
6	26	0.00	0.00	0.00	0.00	0.00	X	37	68	111
7	19	0.00	0.00	0.00	0.00	10.00	21.62	X	51	105
8	48	9.35	0.00	0.00	0.00	3.33	8.82	31.37	X	95
9	91	4.14	0.00	0.00	1.03	1.94	5.40	4.76	46.31	X

Arenaceous Component

		1	2	3	4	5	6	7	8	9
1	32	X	47	51	53	43	50	42	51	63
2	27	25.53	X	36	38	36	43	35	47	62
3	23	7.84	38.89	X	29	29	36	27	42	57
4	25	7.55	36.84	65.52	X	26	38	29	44	59
5	12	2.32	8.33	20.69	42.31	X	29	15	32	47
6	19	2.00	6.98	16.67	15.79	6.89	X	23	35	43
7	10	0.00	5.71	22.22	20.69	46.66	26.09	X	27	40
8	20	1.96	0.00	2.38	2.27	0.00	11.43	11.11	X	46
9	35	6.35	0.00	1.75	1.69	0.00	25.58	12.50	19.56	X

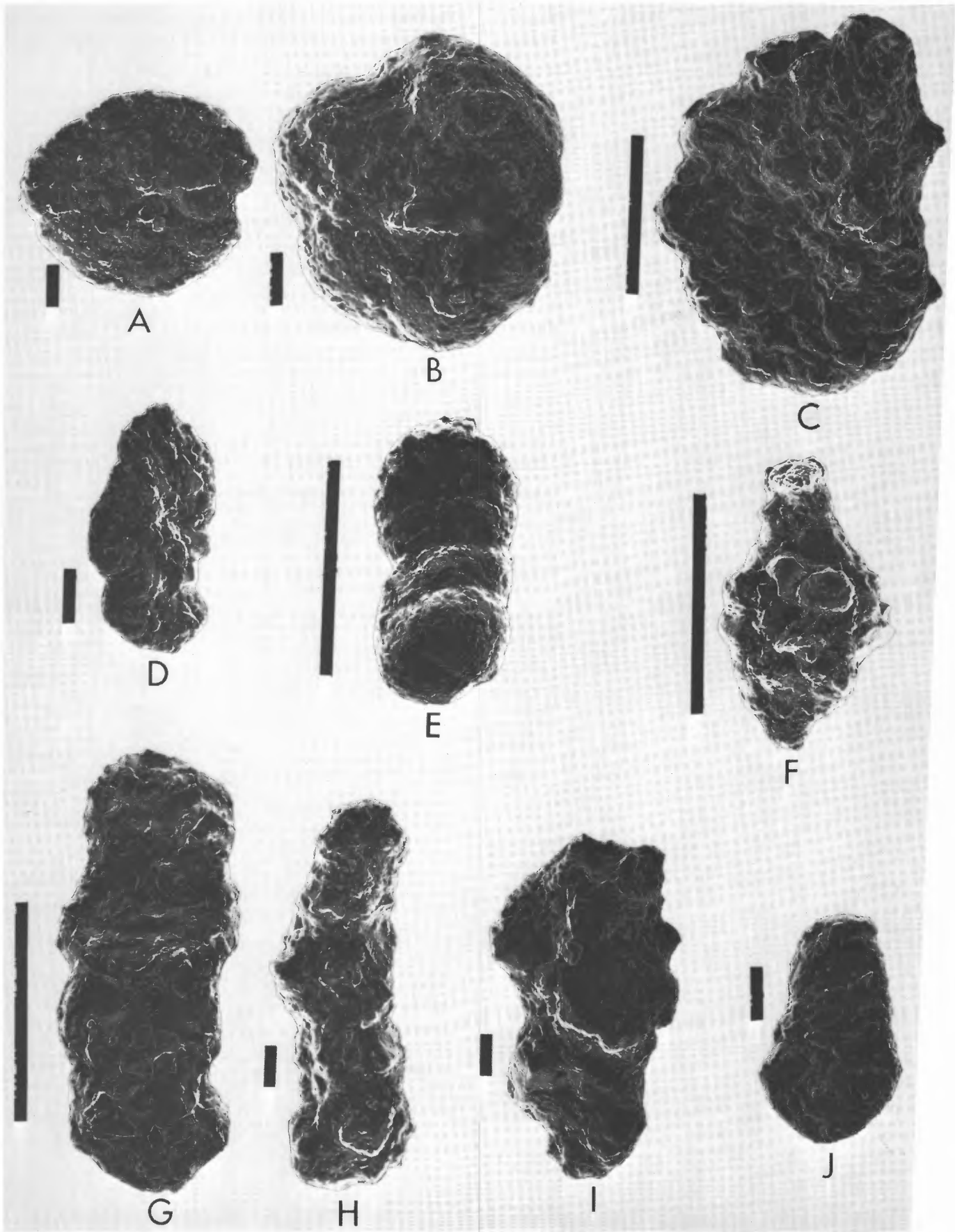


FIGURE 2. Foraminifera of the Glencairn Formation. A, *Trochammina depressa*, UNM 9543, UNM locality 1330. B, *Haplophragmoides linki*, UNM 9544, UNM locality 1330. C, *Ammomarginulis cragini*, UNM 9545, UNM locality 1332. D, *Ammobaculoides whitneyi*, UNM 9546, Clayton Lake locality. E, *Ammobaculites euides*, UNM 9547, Bear Creek locality. F, *Saccammina alexanderi*, UNM 9548, UNM locality 1330. G, *Ammobaculoides plummerae*, UNM 9549, Bear Creek locality. H, *Ammobaculites petilus*, UNM 9550, UNM locality 1330. I, *Ammobaculites fragmentaris*, UNM 9551, UNM locality 1332. J, *Ammobaculites obliquus*, UNM 9552, Clayton Lake locality (large bar = 500 μ, small bar = 50 μ).

TABLE 4. Similarity quotient. 1 = Alaska, Topogoruk/Grandstand formations, 2 = Manitoba, lower Ashville Formation, 3 = Wyoming, Thermopolis Shale, 4 = Colorado/Oklahoma/New Mexico, Glencairn Formation, 5 = Kansas, Kiowa Shale, 6 = Oklahoma/Texas, Walnut Formation, 7 = Texas, Kiamichi Formation, 8 = New Mexico, Tucumcari Shale, 9 = Texas, Duck Creek Formation.

		1	2	3	4	5	6	7	8	9
Total Fauna										
1	92	X	12	4	4	1	1	0	2	10
2	28	20.00	X	14	14	3	3	2	0	0
3	24	6.90	54.90	X	18	8	6	6	1	1
4	31	6.72	47.46	65.45	X	13	5	6	1	1
5	27	1.68	10.91	31.37	44.82	X	2	10	2	6
6	45	1.46	8.22	17.39	13.16	5.48	X	14	10	13
7	29	0.00	7.02	22.64	20.00	35.71	37.83	X	19	11
8	68	2.50	0.00	2.17	2.02	4.21	17.70	39.18	X	53
9	126	8.77	0.00	1.33	1.27	7.84	15.20	14.19	54.64	X
Calcareous Component										
1	60	X	0	0	0	0	0	0	1	6
2	1	0.00	X	0	0	0	0	0	0	0
3	0	0.00	0.00	X	0	0	0	0	0	0
4	7	0.00	0.00	0.00	X	2	0	0	0	1
5	14	0.00	0.00	0.00	19.04	X	0	3	2	5
6	26	0.00	0.00	0.00	0.00	0.00	X	8	6	2
7	19	0.00	0.00	0.00	0.00	6.06	35.56	X	16	6
8	48	1.85	0.00	0.00	0.00	6.45	18.18	17.91	X	44
9	91	7.95	0.00	0.00	2.04	9.52	3.42	8.63	31.65	X
Arenaceous Component										
1	32	X	12	4	4	1	1	0	1	4
2	27	40.67	X	14	14	3	3	2	0	0
3	23	14.54	26.67	X	18	8	6	6	1	1
4	25	14.04	26.09	75.00	X	11	5	6	1	1
5	12	4.54	7.59	45.71	59.46	X	2	7	0	0
6	19	3.92	6.97	14.28	22.73	12.90	X	6	4	11
7	10	0.00	4.12	36.36	34.29	63.64	41.38	X	3	5
8	20	3.85	0.00	4.65	4.44	0.00	20.51	20.00	X	9
9	35	11.94	0.00	1.72	3.33	0.00	40.74	22.22	32.73	X

leogeographic picture of the southern Western Interior basin presented at the end of this paper.

A comparison of the foraminiferal faunas of the Glencairn Formation and the Kiowa Shale indicates they share 20 species with the Tethyan realm and 19 species with the Western Interior realm including eight species shared with both realms. The species shared with the Tethyan realm include six calcareous species. The species from the Tethyan realm (14 species, four calcareous) come primarily from the pre-Duck Creek (i.e., Kiamichi and Walnut formations). Of those species shared with the Western Interior realm, only four are also found in the Alaskan (northern temperate) realm. All of the species shared with the Western Interior realm are shared with the fauna of the Thermopolis Shale of Wyoming.

Since the Western Interior realm has no calcareous, benthonic foraminiferal species, one can safely assume all calcareous benthonic species originated in the Tethyan realm or are endemic to the transition faunas. The arenaceous fauna has 12 species that have a Tethyan origin and 13 species with a Western Interior origin. The remaining two species (*Bathysiphon* sp. and *Reophax* sp.) are of uncertain origin.

Another approach used to study the relationship of the Glencairn and Kiowa foraminiferal faunas to one another and to other contemporaneous faunas is to use the Koch (1957) index. This index is calculated using the formula, b.d. = 100(T–S/n–1)S, where T = the total number of species in both faunas, S = the total number of different species in both faunas and n = the number of samples compared, always two in this case. This index allows comparison of lists of taxa in the absence of quantitative data and thus is ideally suited for my purpose. The more identical taxa in each fauna, the higher the value of the index. Numbers above 10 indicate related faunas, those below 1 are not significantly related. These figures were arrived at by comparison of data from various Glencairn faunas in New Mexico and Oklahoma (Table 2). Table 3 gives the value of S in the upper half and the value of b.d. in the lower half. Three comparisons are made: the total faunas, the calcareous component and the arenaceous component.

The total fauna data indicate the Glencairn fauna is most closely related to the Western Interior faunas of Wyoming and Manitoba and to the fauna of the Kiowa Shale in Kansas. The fauna is not significantly related to the Duck Creek fauna of Texas and only slightly related to the faunas of the Tucumcari Shale of eastern New Mexico and the Alaskan foraminiferal fauna. It is a little more closely related to the faunas of the Kiamichi and Walnut formations. The Kiowa fauna as a whole is most strongly related to the fauna of the Kiamichi Formation of Texas and the Glencairn Formation of New Mexico/Colorado/Oklahoma. It is related, but less so, to the Western Interior fauna of Wyoming. It is not significantly related to the Alaskan fauna and only slightly related to the Walnut fauna of Texas. It is slightly more related to the faunas of the Tucumcari Shale of New Mexico, the Ashville Formation of Manitoba and the Duck Creek Formation of Texas.

The foraminiferal faunas of the Western Interior lack calcareous, benthonic species, and comparison with Tethyan or "boreal" faunas dominated by calcareous, benthonic species using the Koch index (or Kontkanen quotient) would mask the nature of the arenaceous component of the calcareous-dominated fauna. I have attempted to resolve this problem by separating the fauna into calcareous and arenaceous components (Tables 3 and 4). When the fauna is looked at based on these components, several trends become clear.

The Glencairn fauna has slight affinities with the Duck Creek fauna, but, as pointed out previously, some of this is a result of the poor preservation and, hence, generally subgeneric identifications of this component. The arenaceous component has its strongest similarity to the Western Interior Thermopolis Shale fauna and next strongest similarity to the Kiowa and Kiamichi faunas. The Glencairn arenaceous fauna has comparatively weak affinities with the Tucumcari and Duck Creek faunas, suggesting that the fauna is tied to the older, facies-controlled fauna of the Kiamichi and Walnut formations rather than the contemporaneous Tucumcari/Duck Creek faunas. This affinity would probably be even weaker if all "arenaceous" species with calcareous grains as their major components in the Tucumcari and Duck Creek faunas were transferred from the arenaceous component to the calcareous component.

The Kiowa Shale foraminiferal fauna has a better preserved calcareous component than the Glencairn Formation, and this component has its strongest affinities with the Duck Creek fauna. Within the arenaceous component, the strongest ties are with the Glencairn and Thermopolis faunas, with weaker similarities to the Kiamichi and Walnut faunas. Interestingly, the Kiowa has no real similarities to the Tucumcari or Duck Creek faunas once the calcareous component is removed. The Tucumcari Shale has its strongest affinities to the Duck Creek fauna in both its calcareous and arenaceous components. It has its next strongest calcareous-component similarities with the Kiamichi fauna, and its next strongest arenaceous component affinities with the Kiamichi and Walnut faunas.

The Kontkanen (1957) similarity quotient (s.q.) is another way to measure the relatedness of non-quantitative faunal data (i.e., taxonomic lists). It is calculated using the formula, q.s. = [2c/a + b]100, where a = the number of species of fauna A, b = the number of species in fauna B and c = the number of species shared between the two faunas. This quotient measures the similarity of two faunas, and, as with the previous index, a higher number denotes a closer similarity between the faunas. Again, the data were broken down into three parts: the total fauna, the calcareous component and the arenaceous component. Table 4 gives the value of c in the upper half and the value of q.s. in the lower half. The data (Table 4) indicate very similar numbers and results to those obtained with the index of biotal dispersity, and the results further support those obtained by the previous method.

DISCUSSION

Several questions are of special interest in studying the Foraminifera of the Lower Cretaceous of the southern Western Interior. The first question is the origin of the fauna. The second question is the environment responsible for the low diversity and greatly reduced number of calcareous, benthonic elements in the fauna. Another problem that might be related to foraminiferal faunal distribution is that of the timing and extent of transgressive/regressive cycles in the Western Interior basin.

Origin

The origin of the southern Western Interior Albian foraminiferan fauna can be traced to three centers: the Tethyan fauna, the northern Western Interior fauna of Wyoming and endemic elements, primarily in the Kiowa fauna. The transitional foraminiferal faunas of the Kiowa Shale and Glencairn Formation contain 42 species. The Glencairn fauna is composed of 32 species, 27 in the New Mexico and Oklahoma area and 13 in southeastern Colorado. The Kiowa Shale fauna has 25 species. Calcareous species make up 8% (one species) of the Glencairn fauna of Colorado, 22% (six species) of the Glencairn fauna of New Mexico and adjacent Oklahoma and 52% (13 species) of the Kiowa fauna of Kansas. Table 1 lists the species in the Glencairn and Kiowa formations and compares their ranges to units in the Alaskan realm, Western Interior realm and Tethyan realm. To further characterize these faunas, correlation coefficients are provided for all the faunas studied (Tables 3 and 4).

The foraminiferal data indicate no endemic agglutinated foraminiferans in either the Glencairn or Kiowa faunas. The preservation of the calcareous foraminiferans in the Glencairn precludes identification of endemic elements; identification to genus is usually all that is possible. The Kiowa fauna has only five calcareous endemic species, two of which were not assigned to species, indicting it is not a significant endemic center for the Foraminifera. Significantly, the Glencairn Formation and Kiowa Shale share only a single genus of calcareous foraminiferan (*Dentalina*). This indicates that the faunas differ in composition, perhaps reflecting differing environments, with the Kiowa being more openly connected to the Tethyan ocean. Among the agglutinated foraminiferans, species with Tethyan affinities penetrated as far north as Wyoming (six species) and Manitoba (one species). The Western Interior fauna penetrated as far south as New Mexico and Oklahoma (seven species) and Kansas (three species). The Alaskan fauna also penetrated into Colorado/New Mexico and Oklahoma (four species), but not to Kansas.

Environment

The peculiar nature of the Albian Western Interior microfauna, lacking both calcareous, benthonic foraminiferans and ostracodes, and being dominated by agglutinated benthonic foraminiferans with a few scattered planktonic occurrences, suggests environmental controls on the foraminiferans. Tappan (1962) listed seven environmental factors possibly influencing foraminiferal distribution in the Alaskan faunas: depth, salinity, substratum, food supply, temperature, turbulence and currents and turbidity. Eicher (1960) considered depth, reducing bottom conditions, turbidity and salinity to be ecologic factors possibly responsible for the unusual nature of the Western Interior fauna. Later, Eicher and Worstell (1970) suggested various factors influencing foraminiferal distribution during the middle Cretaceous Greenhorn transgression, including: widely fluctuating temperatures and salinities, lack of nutrients, stagnation and anaerobic conditions due to sluggish circulation or the presence of a sill. Frush and Eicher (1975) hypothesized a deep, widespread layer of oxygen-depleted water to explain Cenomanian strata that are barren of Foraminifera. Kauffman (1977, 1984) refined this concept to suggest a water-sediment, aerobic-anaerobic interface restricting microfaunal elements, but allowing inoceramid bivalves and certain epifauna to survive. Schlanger and Jenkins (1976), using information from DSDP cores, found Cretaceous anoxic events in the Aptian-Albian and Cenomanian-Turonian to be of possible worldwide distribution. These authors suggested that the major marine transgressions associated with these time periods increased the area of the seas and hence the amount of organic carbon production. They further suggested that the generally equable Cretaceous climate reduced the amount of cold-oxygenated bottom waters in the oceans. They hypothesized that the combination of these factors led to an expansion of the oxygen-minimum layer and the formation of "oceanic anoxic events." A similar combination of high, organic production and reduced or absent cold, oxygenated, bottom waters in the Western Interior basin might be responsible for the continuation of the anoxic event to the Interior after it had subsided (post-Kiamichi) in the Tethyan seas to the south.

Evidence from the transition zone between the Tethyan and Interior faunas indicates a rather dramatic demarcation line between them, passing through the Glencairn Formation localities of northeastern New Mexico and adjacent Oklahoma and the Kiowa Shale localities in south-central Kansas. While certain oportunistic ("facies") species (e.g., *Trochammina depressa*) are found in both faunas, they tend to be restricted to nearshore and/or marginal-marine units in the Tucumcari Shale, but are widespread in the Glencairn and Kiowa formations. This suggests that a chemical and/or physical barrier was present along the southern end of the Western Interior basin. During the middle-late Albian transgression of Tucumcari-Glencairn-Kiowa time, there was apparently some limited marine exchange with some opportunistic elements in the Tethyan fauna. However, during the latest Albian (Mowry time), the region was apparently either nonmarine and fluvial or nondepositional (Williams and Stelck, 1975). This indicates a possible structural high in the area which might restrict mixing of the Western Interior sea with the more open marine Tethyan sea to the south. Northeastern New Mexico was also the site of a major delta complex (Mesa Rica Sandstone) in Albian time which would be expected to restrict normal marine mixing between the two realms. A further hindrance to mixing and faunal exchange could have resulted from temperature differences between the two regions. Some authors have further postulated a possible constriction at the northern end of the Western Interior basin (Jeletzky, 1971; Stelck, 1975; Williams and Stelck, 1975; Kauffman, 1984), possibly further restricting mixing, circulation and faunal exchange. Stelck (1975) has postulated that fresh to brackish surface waters from adjacent deltas in the northern strait helped to isolate the nektonic/planktonic *Neogastropolites* fauna during the latest Albian. A similar mechanism might have acted in the southern strait and, due to its shallower nature, may have also restricted penetration by certain benthonic elements.

The Frush and Eicher (1975) and Kauffman (1977) models of aerobic-anaerobic bottom conditions suggest poor internal circulation as well as limited mixing with more open marine areas in the Arctic and Gulf regions. To the poor circulation one can add the local effects of extensive freshwater input from marginal deltas reducing salinity, and periodic, extensive volcanic ash falls increasing turbidity, a known control on modern agglutinated foraminiferans (Stainforth, 1952). The Western Interior marine environment was primarily occupied by various opportunistic and/or selectively adapted faunal elements. This assemblage resembles modern, nearshore, brackish faunas.

The presence of rare calcareous benthonic foraminiferans only along the southern and ?eastern margins of the Western Interior basin could be a result of their inability to survive the anaerobic bottom. However, the relative abundance of agglutinated species that presumably also need some oxygen, and the rarity of planktonic species presumably "above it all," are not entirely explained. It seems more likely that the slight acidity of the bottom due to decaying planktonic material in the dark gray muds might be a greater inhibiting factor on the foraminiferal (and ostracode) fauna than the oxygen factor alone. Certainly salinity has a strong effect on modern foraminiferal faunas (Revelle and Fairbridge, 1957).

The near absence of Ostracoda in the Western Interior fauna is of particular interest from a paleoecological viewpoint. Markhoven (1962) has reviewed the ecologic parameters of the Ostracoda in some detail. Several of his observations may be useful in the present case. Among marine Ostracoda, temperature, depth, substrate and pH were found to have little effect on ostracode diversity when they are within the ranges of normal marine habitats. Ostracoda are found from the Arctic Ocean to the Equator, from depths in excess of 3,000 m to the intertidal zone. They inhabit the sediment surface, subsurface and plants above the surface (only a few are planktonic). At pH values of six to eight they are little affected. Salinity is probably the environmental factor with the greatest effect. Marine species show a dramatic diversity drop in salinities below 10%, while freshwater species show a similar effect at salinities above 3%. In the mesio-mesohaline range of 3–10% salinity, a special brackish water fauna has developed which, although of low diversity, is often abundant in numbers of individuals. Typically these species are thick-shelled, with weak ornamentation that is often punc-

tate. The absence of Ostracoda in the true Western Interior fauna (i.e., Wyoming) and their limited occurrence in the transition area indicate a probable salinity range of 3–10%, a lack of adapted species in either the Boreal or Tethyan faunas and perhaps an additional barrier to their dispersal into the seaway. Lack of oxygen or unfavorable pH would be the most likely barriers.

Age/paleogeography

The fauna of the Kiowa, Glencairn and Tucumcari formations is certainly of late Albian age as indicated by the macrofauna (e.g., Cobban and Reeside, 1952; Scott, 1970; Kues et al., 1985) and microfauna (Loeblich and Tappan, 1950; Kietzke, 1985). The period of maximum transgression for this period corresponds to the *Inoceramus comancheanus* Cragin, 1894 zone (Scott, 1970). This is represented by the Skull Creek sea (=Joli Fou sea of Canadian workers) in the Western Interior and is considered late Albian in age. The foraminiferal zone associated with this zone in the Western Interior is the *Haplophragmoides gigas* Cushman, 1924 zone of Stelck et al. (1956). Although originally considered to be middle Albian in age (Williams and Stelck, 1975), Caldwell et al. (1978) reviewed this zone and consider it to be early-late Albian in age.

The paleobiogeography of the transitional area of the Tucumcari, Kiowa and Glencairn formations has been discussed by Scott (1970, 1986) and Scott and Taylor (1977). However, the physical aspects of the paleogeography are still not completely resolved. Unpublished preliminary data by University of New Mexico students indicate a series of basement controlled basins and highs in northeastern New Mexico. These data indicate that probable connection of the Tucumcari and Dalhart basins with the Raton Basin was along or slightly east of the New Mexico state line. The foraminiferal data indicate more Tethyan influence in southern Kansas and a greater Western Interior influence in southeastern Colorado, and, to a slightly lesser extent, in northeastern New Mexico and adjacent Oklahoma. This may reflect the deflection of the clockwise currents of the Tethyan realm by the Bravo dome and associated delta or simply greater Tethyan exchange in southern Kansas.

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APPENDIX 1: LOCALITIES AND FAUNAL LISTS

1. UNM locality 1330: Kenton locality, NE¼ SW¼, sec. 13, T5N, R2E, Cimarron County, Oklahoma. Fauna: *?Bathysiphon* sp., *Saccammina alexanderi, Reophax* sp., *Haplophragmoides linki, Ammobaculites fragmentarius, Ammobaculites petilus, Ammobaculoides whitneyi, Ammomarginulina cragini, Verneuilina canadensis, ?Lituotuba* sp., *Trochammina depressa, Dentalina* sp., *Lenticulina* sp. A, *Lenticulina* sp. B, *Nodosaria obscura, Citherina* sp., *?Hedbergella* sp., *Cytherella* sp., *Cythereis* sp., *Eocytheropteron* sp., Gastropoda, Echinodermata, Vertebrata.
2. UNM locality 1332: OK-2 locality, SE¼ NE¼, sec. 16, T5N, R2E, Cimarron County, Oklahoma. Fauna: *Saccammina alexanderi, Reophax* sp., *Glomospira ?tortuosa, Haplophragmoides gigas, Haplophragmoides linki, Ammobaculites fragmentarius, Ammobaculites petilus, Ammobaculites obliquus, Ammomarginulina cragini, Textularia* sp., *Verneuilinoides perplexa, Trochammina depressa, Bulimina nannina, Cythereis* sp., Gastropoda, ?scolecodont, Vertebrata.
3. UNM locality: OK-1 locality, NE¼ SW¼, sec. 23, T5N, R2E, Cimarron County, Oklahoma. Fauna: *Saccamina alexanderi, Ammodiscus kiowensis, Ammobaculites ?petilus, Trochammina depressa,* Vertebrata.
4. Clayton Lake locality: SW¼ NE¼, sec. 15, T27N, R34 E, Union County, New Mexico. Fauna: *Ammodiscus kiowensis, Ammobaculites petilus, Ammobaculites subcretaceus, Ammobaculites obliquus, Ammobaculites euides, Ammobaculoides whitneyi, Gaudryina canadensis.*
5. Bear Creek locality (Long locality 15): NE¼ NE¼, sec. 11, T14S, R67W, El Paso County, Colorado.
6. Kiowa Shale locality (Loeblich and Tappan locality HTL-245): SE¼, sec. 9, T30S, R16W, Kiowa County, Kansas.

APPENDIX 2: AUTHORS OF FORAMINIFERA

Arenaceous Foraminifera

Trochammina depressa Lozo, 1944
Ammobaculites euides Loeblich and Tappan, 1949
Ammobaculites obliquus Loeblich and Tappan, 1949
Ammodiscus kiowensis Loeblich and Tappan, 1950
Saccammina alexanderi (Loeblich and Tappan, 1950)
Verneuilinoides perplexus (Loeblich, 1946)
Ammobaculites fragmentarius Cushman, 1927
Flabellammina dennisonensis Tappan, 1941
Ammobaculoides plummerae Loeblich, 1946
Ammobaculites auricularis Loeblich and Tappan, 1950
Ammobaculites subcretaceus Cushman and Alexander, 1930
Ammomarginulina cragini Loeblich and Tappan, 1950
Cribrotina texana (Conrad, 1857)
Ammobaculites petilus Eicher, 1960
Haplophragmoides linki Nauss, 1947
Haplophragmoides gigas Cushman, 1927
Gaudryina canadensis Cushman, 1943
Verneuilina canadensis Cushman, 1927
Ammobaculoides whitneyi (Cushman and Alexander, 1932)
Glomospira tortuosa Eicher, 1960
Ammobaculites phaulus Loeblich and Tappan, 1950

Calcareous Foraminifera

Nodosaria obsecura Reuss, 1845
Lingulina furcillata Berthelin, 1880
Dentalina debilis (Berthelin, 1880)
Bulimina nannina Tappan, 1940
Gumbelitria harrisi Tappan, 1940
Eouvigerina laxistoma Loeblich and Tappan, 1946
Pyrulina carebara Loeblich and Tappan, 1950
Neobulimina primativa Cushman, 1936
Quinloculina nanna Loeblich and Tappan, 1950
Hedbergella graysonensis Tappan, 1940
Lagena exomala Loeblich and Tappan, 1950



Landslide from mine dump at Sugarite, Colfax County, New Mexico. Photograph by W. T. Lee circa 1900–1910, courtesy of U.S. Geological Survey and R. Eveleth, NMBMMR.