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EARLY CRETACEOUS TECTONO-SEDIMENTARY EVOLUTION OF THE SOUTHWESTERN MARGIN OF THE BISBEE BASIN

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ABSTRACT

The Bisbee basin is considered to be the primary structural site of sedimentation of the Bisbee Group of Late Jurassic and Early Cretaceous age, in the region of southeastern Arizona and southwestern New Mexico in the U.S.A. and northeastern Sonora in Mexico. Recent studies, however, have confirmed the presence of correlative lithostratigraphic units of the Bisbee Group in several areas of northern and central Sonora, which indicate that the Bisbee basin extended southward of the previously defined boundaries.

Several stratigraphic sections, near the southwestern margin of the basin in Sonora, are discussed in this paper. Paleocurrent directions and sandstone provenance of the Morita and Cintura Formations of the Santa Ana, Cerro Mayo, Cerro de Oro, and Arizpe areas indicate that the meandering-fluvial depositional systems they represent, were linked to sediment-dispersal systems flowing eastward of volcanic sources which lay west of the basin margin.

Carbonate lithostratigraphic units in the studied sections record three transgressive-regressive marine events of probable eustatic origin that occurred in this basin. Geohistory analysis of stratigraphic sections at Cerro de Oro and Lampazos sections yields curves that indicate passive thermotectonic subsidence as the most probable mechanism of subsidence during Early Cretaceous time. This result supports the rift origin previously proposed for the Bisbee basin.

Key words: Tectonics, Early Cretaceous, Bisbee basin, Arizona, Sonora, Mexico.

RESUMEN

La cuenca Bisbee ha sido considerada como la estructura de depósito del Grupo Bisbee durante el Jurásico Tardío y Cretácico Temprano en el sudeste de Arizona, sudoeste de Nuevo México y noreste de Sonora. Sin embargo, estudios recientes han confirmado la presencia de secuencias sedimentarias con unidades litoestratigráficas correlativas del Grupo Bisbee en varias áreas del norte y centro de Sonora, lo que indica que dicha cuenca se extendía hacia el sur más allá de los límites previamente considerados.

Se discute varias secciones estratigráficas cercanas a la margen sudoccidental de la cuenca. Datos de direcciones de paleocorrientes y proveniencia de areniscas de las formaciones Morita y Cintura, en las áreas de Santa Ana, Cerro Mayo, Cerro de Oro y Arizpe, indican que los sistemas de depósito de ríos meándricos, que los sedimentos de esas formaciones representan, tuvieron direcciones de transporte hacia el oriente desde las fuentes volcánicas que se encontraban al poniente de la margen sudoccidental de la cuenca.

Las unidades litoestratigráficas carbonatadas en las secciones estudiadas registran que en esta cuenca tuvieron lugar tres eventos transgresivo-regresivos marinos de probable origen eustático. Las curvas de subsidencia elaboradas para las secciones sedimentarias de las áreas de Cerro de Oro y Lampazos, indican que un proceso de subsidencia termotectónica fue el más probable mecanismo de hundimiento de la cuenca durante el Cretácico Temprano. Estos resultados apoyan las ideas acerca de que la cuenca Bisbee haya sido formada por un proceso de distensión de tipo *rift* y que sus límites sudorientales se extendían hasta el centro de Sonora.

Palabras clave: Tectónica, Cretácico Temprano, cuenca Bisbee, Arizona, Sonora, México.

INTRODUCTION

Late Jurassic to Early Cretaceous sedimentation in southeastern Arizona and northeastern Sonora occurred in the Bisbee basin (Hayes, 1970; Bilodeau and Lindberg, 1983). The main lithostratigraphic unit of the basin fill—the Bisbee Group—was first defined in southeastern Arizona and later recognized in northeastern Sonora (Ransome, 1904; Taliaferro, 1933). The basal unit of the group—Glance Conglomerate of Late Jurassic to earliest Cretaceous age—consists of alluvial-fan and fluvial sedimentary rocks with interbedded volcanics, which in southeastern Arizona have been dated as Late Jurassic (summarized *in* Bilodeau *et al.*, 1987). Ages of younger units of the Bisbee Group are known from biostratigraphic studies (Stoyanow, 1949; Scott, 1987): the fluvial, deltaic to marginal marine Morita Formation is of early Aptian age in its upper part; the shallow marine Mural Limestone contains in its middle part the Aptian-Albian boundary; and the lower-middle Albian boundary is within the lower part of the Cintura Formation.

The southern limits of this basin have been previously placed in northeastern Sonora (Hayes, 1970; Dickinson, 1981; Bilodeau and Lindberg, 1983; Saleeby and Busby-Spera, 1992, pl. 5, F). However, recent reports of strata correlative with the Bisbee Group in northwestern, central and east-central Sonora (Figures 1 and 2) indicate that the boundaries of the basin are located farther south than previously recognized. González-León and Jacques-Ayala (1990) first proposed the name So-

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nora basin to describe this southern extension; however, the name is here abandoned in order not to conflict with the precursor name of "Bisbee basin", and to support the idea that this was a single basin.

Several models have been proposed to explain the origin of the Bisbee basin in the region of southeastern Arizona and northeastern Sonora (Bilodeau, 1982). Of these, the model of northwest-trending extensional faulting related to the opening of the Gulf of Mexico is the most widely accepted (Dickinson *et al.*, 1986; Klute, 1991). This model also incorporates plate-tectonic events occurring along the western margin of the continent where a magmatic arc was contemporaneously active. However, the model does not explicitly consider the southward extension of the basin in Sonora. A synthesis of the characteristics of Lower Cretaceous sections in Sonora is given by González-León and Jacques-Ayala (1990). In the present paper, the evolution of the southwestern margin of the Bisbee basin is analyzed based on stratigraphy, sedimentology, sandstone provenance, paleocurrent directions, and subsidence-history information from some of the best studied sections in Sonora.

STRATIGRAPHY

Lower Cretaceous stratigraphic sections of the Bisbee Group in the Santa Ana, Cerro de Oro, and Arizpe areas of central Sonora are the best-known in this part of the Bisbee basin (Figures 1 and 2). These strata correlate with beds at sierra El Chanate (Jacques-Ayala and Potter, 1987) and Lampazos (González-León, 1988). These localities occur near the western and eastern limits of the approximately NW-SE trending-axis of the basin (González-León and Jacques-Ayala, 1990).

The basal unit of the Bisbee Group, the Glance Conglomerate, is restricted in Sonora to the approximate axis of the basin. It occurs in sections at sierra El Chanate (Jacques-Ayala, 1992a), sierra El Pinito (Gilmont, 1979; Nourse, 1989), Cerro Azul (Rangin, 1986), and Arivechi (Pubellier, 1987). Felsic, arc related Jurassic volcanism in Sierra el Pinito (Figure 1) is overlain by a 1,000 m-thick unit of alluvial fan and fluvial deposits of the Glance Conglomerate (Nourse, 1989). In the Arivechi region (Pubellier, 1987), the 1,500 m thick section of polymictic conglomerate, composed by Paleozoic sedimentary clasts and subordinate volcanics, is overlain by a fossiliferous shallow marine sequence of Early Cretaceous age. McKee (1991) reported from the Cerro Azul area a unit at least 100 m-thick of volcanic conglomerate with interbedded volcanics, which Rangin (1986) correlated with the Glance. A section at Cerro de Oro contains at its base the Cerro de Oro Formation, which unconformably overlies strata of probable Late Proterozoic age, and is disconformably overlain by the Morita Formation. A 25 m-thick conglomerate at the base of the Cerro de Oro Formation may correlate with the Glance Conglomerate (González-León, 1989).

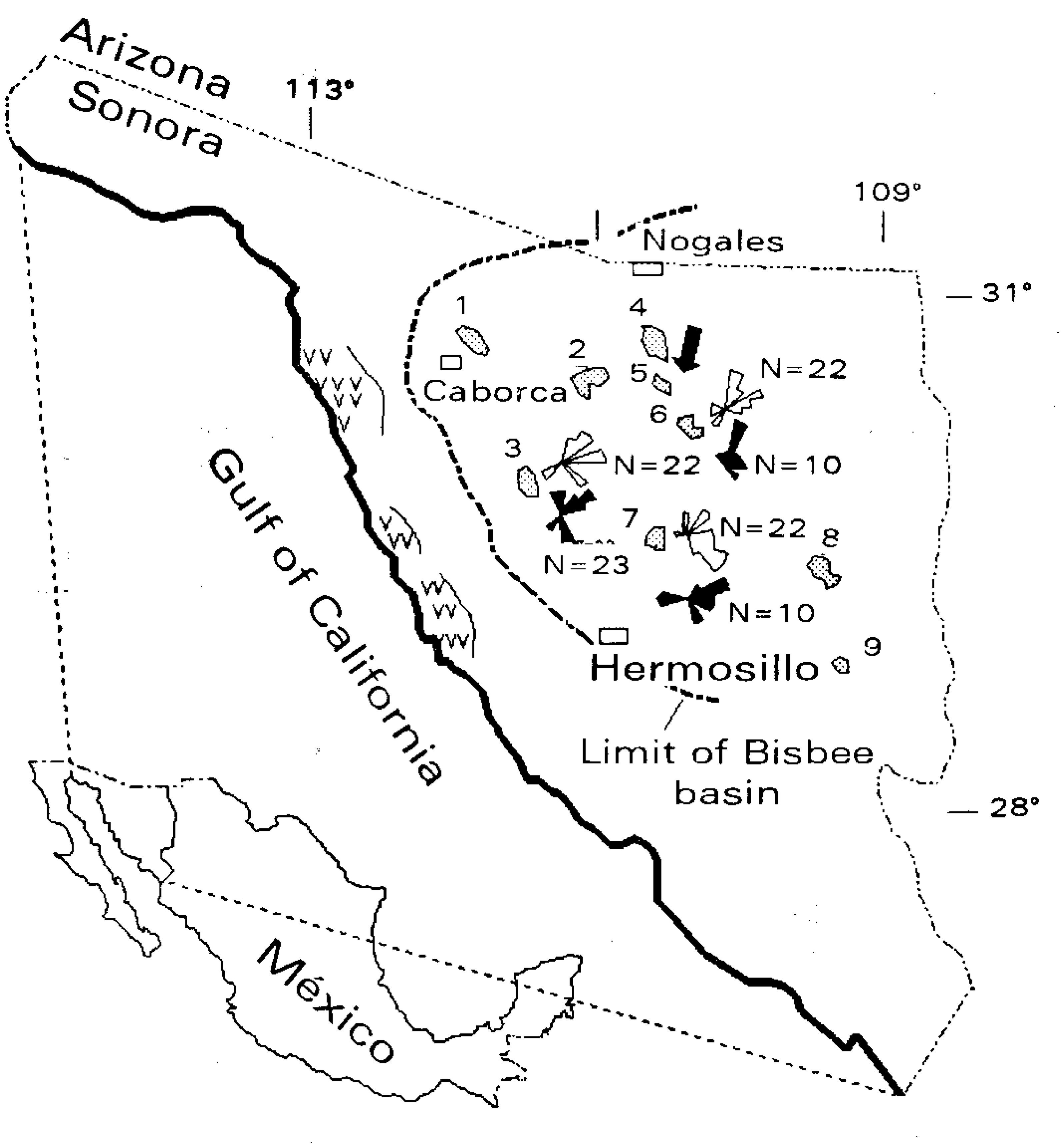

Figure 1.- Locations of Lower Cretaceous outcrops mentioned in the text: *1*, sierra El Chanate; *2*, Santa Ana area; *3*, Cerro Mayo; *4*, sierra El Pinito; *5*, Cerro Azul; *6*, Arizpe; *7*, Cerro de Oro; *8*, Lampazos; *9*, Arivechi. Also shown are paleocurrent directions of the Glance Conglomerate, Morita (filled in black) and Cintura (filled in white) Formations; outcrops of Lower Cretaceous volcanics along the coast of Sonora, and inferred limits of the Bisbee basin. Paleocurrent directions from the Glance Conglomerate in sierra El Pinito taken from Gilmont (1979).

Complete sections of the Morita Formation are known from the Cerro de Oro (González-León and Jacques-Ayala, 1988) and sierra El Chanate (Jacques-Ayala, 1992b) areas, but its base is not exposed in the Arizpe and Santa Ana areas. The Morita Formation grades upward to complete sections of the Mural Limestone in all these areas. The Cintura Formation is present in the sierra El Chanate, Santa Ana, Arizpe, and Cerro de Oro areas. The most complete section of the Cintura Formation is in the locality of Arizpe, where it is capped by a 50 m-thick interval of fossiliferous limestone and shale (Figure 2), but its uppermost part is eroded elsewhere. Recently discovered Lower Cretaceous rocks at Cerro Mayo (Figure 1) include more than 1,000 m of the Morita, Mural and Cintura Formations.

At all localities, including the most marginal sierra El Chanate section (Figure 2), correlative units record similar depositional environments. The Glance Conglomerate formed in continental settings of alluvial fans and fluvial environments. The Cerro de Oro Formation represents shallow-marine transgressive deposits of the first marine incursion in the Bisbee basin. Fluvial environments, predominantly meandering streams, may be recognized in the Morita Formation. Toward its upper part, a transition to marginal marine sedimentation occurs. The shallow-marine Mural Limestone, characterized by well-developed reefal structures, accumulated on an

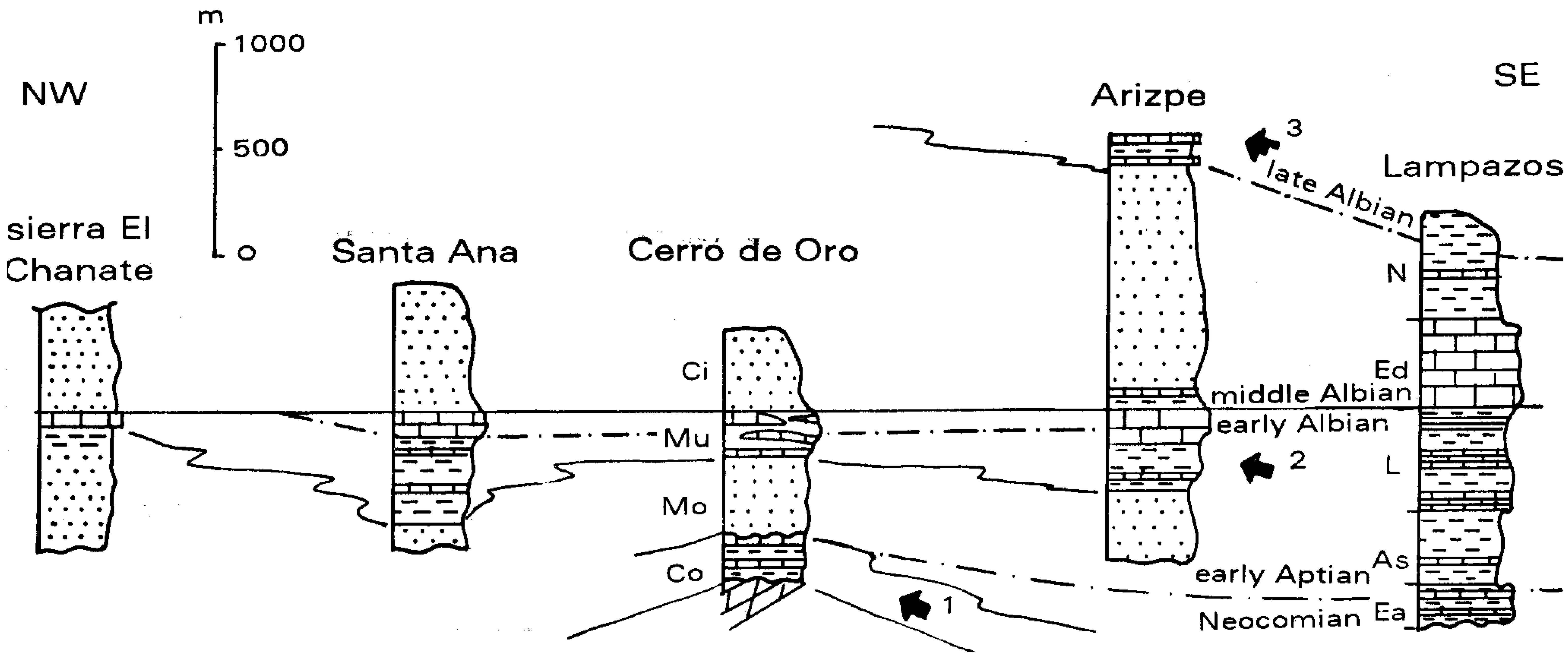

Figure 2.- Correlation of Lower Cretaceous sections in the central and southwestern parts of the Bisbee basin. Locations shown in Figure 1. Time lines indicated by dashed lines; marine transgressions indicated by arrows. Formation names are: Co, Cerro de Oro; Mo, Morita; Mu, Mural Limestone; Ci, Cintura; Ea, El Aliso; As, Agua Salada; L, Lampazos; Ed, Espinazo del Diablo; and N, Nogal.

open platform—with restricted lagoonal environments in sierra El Chanate—(Jacques-Ayala, 1993), indicates the presence of a second, widespread marine transgression. The Cintura Formation records marginal-marine conditions in its lower part and fluvial sedimentation related to meandering streams upwards. The presence of a third marine transgression in the basin, during the late Albian, is indicated by the fossiliferous carbonate interval at the top of the Arizpe section. Toward the east, at Lampazos in east-central Sonora, equivalent rocks to the Bisbee Group are composed of fossiliferous, shallow-marine carbonates with subordinate siliciclastic intervals (Figure 2).

Although no direct age control is available for the Glance Conglomerate in Sonora, a Late Jurassic age, similar to that from southeastern Arizona, is assigned, based upon similar stratigraphic position. Biostratigraphic data indicate the Cerro de Oro and El Aliso Formations, at the base of the sections of Cerro de Oro and Lampazos, respectively, are late Barremian to early Aptian in age (González-León and Lucas, in press). Late Aptian to early and middle Albian ages have been obtained from fossils for the Mural Limestone and equivalent lithostratigraphic units of east-central Sonora. Late Albian is indicated by fossils from the uppermost part of the Arizpe and Lampazos sections (Scott and González-León, 1991; Figure 2).

PALEOCURRENT DIRECTIONS

Primary sedimentary structures suitable for studies of paleocurrent directions are not abundant in the studied sections. Measurements however were obtained of planar cross-stratification and trough cross-stratification axes from the Morita and Cintura Formations of the Cerro Mayo, Arizpe and Cerro de Oro areas. Paleocurrent measurements from these fluvial strata indicate that the source area for sediments lay to the west and southwest. A predominant northeastward paleocurrent direction is indicated for the Morita Formation at Cerro de Oro and Cerro Mayo, whereas a predominant north-northeastward direction has been obtained from Arizpe (Figure 1). The Cintura Formation records predominant paleocurrent directions toward the east-southeast at Cerro de Oro, whereas north-northeast to northeast paleocurrent directions are indicated in the Arizpe and Cerro Mayo areas.

PROVENANCE

Sandstone compositions from the Morita and Cintura Formations are similar at Cerro de Oro, Cerro Mayo, Santa Ana, and Arizpe (Figure 3). Petrographically studied thin sections were stained for potassium feldspar, and point counts of the sandstones were conducted by the Gazzi-Dickinson method (Ingersoll *et al.*, 1984; Tables 1, 2, 3, 4). These rocks range from arkose to feldspathic litharenite, most of them being lithic arkose. Sandstones are composed mainly of plagioclase and lithic fragments. Monocrystalline quartz may show both undulant or straight extinction. Potassium feldspar and polycrystalline quartz are subordinate grain types. Lithic volcanics with microlithic textures dominate the lithic category. Provenance studies using the method described by Dickinson and Suczek (1979) and Dickinson (1985) suggest a predominant volcanoplutonic source. Impoverishment of potassium feldspar and polycrystalline quartz and abundance of detrital plagioclase and microlithic volcanic rock fragments suggest that the provenance area for these sediments was a transitional arc to dissected volcanic arc (Figure 3). According to sandstone petrography and paleocurrent directions, possible

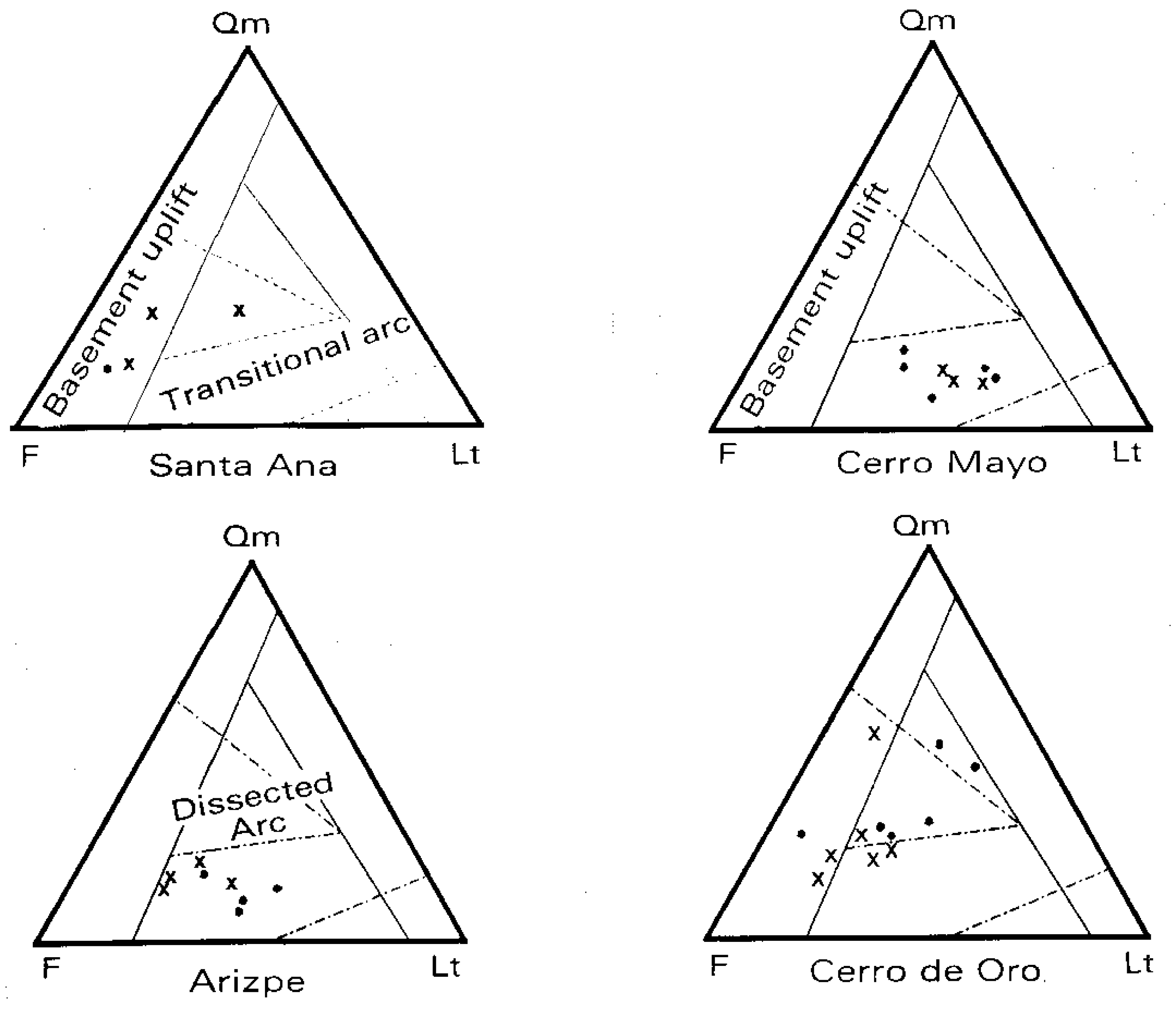

Figure 3.- Qm-F-Lt diagrams showing composition of sandstones from the Morita (•) and Cintura (x) Formations from the Santa Ana, Cerro Mayo, Arizpe, and Cerro de Oro localities.

Table 1.- Petrographic thin-section point counting (400 points) from sandstone samples of the Santa Ana area.

Sample	2-A-1	27-2	9-II	11-II	8-II
Fm.	Km	Km	Kc	Kc	Kc
Qm	15	18	18	33	33
Qp	10	1	1	3	13
P	43	70	69	52	29
K	1	1	0	3	13
Lv	23	7	12	6	20
Ls	8	2	0	3	0
Lm	0	0	0	0	0
Qt	25	19	19	36	46
F	44	71	69	55	34
L	31	9	12	9	20
Lt	41	10	13	12	33

Explanation: Fm., formation; Km, Morita; Kc, Cintura; Qm, monocrystalline quartz; Qp, polycrystalline quartz; P, plagioclase; K, potassium feldspar; Lv, volcanic lithic fragments; Ls, sedimentary lithic fragments; Lm, metamorphic lithic fragments; Qt, total quartz (Qm + Qp); F, feldspar (P + K); L, lithic fragments (Lv + Ls + Lm); Lt, total lithic fragments (L + Qp).

volcanic source areas include contemporaneous volcanism located to the west in the coastal region of Sonora (Anderson *et al.*, 1969; Figure 1). These volcanic source rocks and volcanic rocks associated with Lower Cretaceous sedimentary strata reported from sierra El Chanate (Jacques-Ayala, 1993) are considered to be eastern distal manifestations of the Alisitos magmatic arc of Baja California.

SUBSIDENCE ANALYSIS

Subsidence analysis of the stratigraphic sections in Santa Ana, Cerro de Oro and Arizpe is approached by applying the method of fluvial architecture (Leeder, 1978; Allen, 1978; Blakey and Gubitosa, 1984; Shuster and Steidtmann, 1987) to the Morita and Cintura Formations, and by construction of subsidence curves from the Cerro de Oro and Lampazos sections.

FLUVIAL ARCHITECTURE ANALYSIS

The Morita and Cintura Formations at Santa Ana (Navarro-Fuentes, 1989), Cerro de Oro (González-León, 1989) and Arizpe (González-León, 1978) have different archi-

Table 2.- Petrographic thin-section point counting (300 to 500 points) from sandstone samples of the Cerro de Oro area.

Sample	M1	M2	M5	COM-1	COM-2	COM-6	COM-7	C3	C4	C5	COC-1	COC-2	COC-4
Fm.	Km	Km	Km	Km	Km	Km	Km	Kc	Kc	Kc	Kc	Kc	Kc
Qm	28	33	50	43	31	39	30	21	24	20	47	22	24
Qp	5	6	7	10	5	14	7	10	9	7	3	5	5
P	60	31	22	17	44	23	43	51	54	50	42	46	53
K	1	1	1	1	0	0	0	12	4	2	0	0	0
Lv	3	15	15	16	11	9	14	0	8	19	6	23	17
Ls	2	13	4	13	9	14	7	1	1	2	2	4	1
Lm	1	1	1	0	0	1	0	5	0	0	0	0	0
Qt	33	39	57	53	36	53	37	31	33	27	50	27	29
F	61	32	23	18	44	23	43	63	58	52	42	46	53
L	6	29	20	29	20	24	21	6	9	21	8	27	18
Lt	11	35	27	39	25	38	28	16	18	28	11	32	23

Table 3.- Petrographic thin-section point counting (500 points) from sandstone samples of the Arizpe area.

Sample	AZM-1	AZM-3	AZM-5	AZM-6	AZC-3	AZC-1	ACC-5	AZC-6
Fm.	Km	Km	Km	Km	Kc	Kc	Kc	Kc
Qm	12	9	7	16	12	14	15	19
Qp	10	7	9	7	5	7	5	9
P	34	46	48	51	44	60	58	46
K	2	0	0	1	2	1	1	4
Lv	36	36	36	23	36	18	18	20
Ls	3	2	0	1	1	0	2	2
Lm	3	0	0	1	0	0	1	0
Qt	22	16	16	23	17	21	20	28
F	36	46	48	52	46	61	59	50
L	42	38	36	25	37	18	21	22
Lt	52	45	45	32	42	25	26	31

tectural geometries that are nevertheless consistent within each unit at the different localities. Fluvial cycles in the Morita Formation are dominated by overbank deposits in a ratio of 2/1 to 5/1 with respect to channel deposits. Channel deposits consist of ribbon-type, unconnected sandstone bodies, which may be as thick as 10 m. These sandstone bodies are commonly single story and rarely multistory. Overbank deposits are dominated by siltstone and mudstone, locally with abundant fossil wood and represent floodplain environments. Paleosol horizons in the overbank deposits, indicated by thin intervals of calcareous nodules, are present but not abundant. In the Cintura Formation at Cerro de Oro and Santa Ana, fluvial cycles are characterized by a higher proportion of channel deposits with respect to overbank deposits (2/1 ratio) as compared with the Morita Formation. The channel sandstones have ribbon geometries and may be as thick as 20 m. Toward the upper part of the Cintura Formation, sandstone bodies are generally multistoried and more laterally extensive than those of the Morita Formation. Such a fluvial architecture is consistent with an interpretation of a higher rate of subsidence during accumulation of the Morita Formation, and with decreasing rate of subsidence during accumulation of the upper part of the Bisbee Group—Cintura Formation.

Table 4.- Petrographic thin-section point counting (400 points) from sandstone samples of the Cerro Mayo area.

Sample	CM-10	CM-12	CM-14	CM-15	CM-16	CM-3A	CM-5	CM-8
Fm.	Km	Km	Km	Km	Km	Kc	Kc	Kc
Qm	22	10	14	16	16	12	13	12
Qp	5	6	8	8	8	1	1	3
P	38	45	30	31	48	25	37	38
K	3	0	0	0	0	7	2	0
Lv	28	37	44	36	24	52	45	45
Ls	4	2	3	8	3	3	2	2
Lm	0	0	1	1	1	0	0	0
Qt	27	16	22	24	24	13	14	15
F	41	45	30	31	48	32	39	38
L	32	39	48	45	28	55	47	47
Lt	34	45	56	53	36	56	48	50

GEOHISTORY ANALYSIS

Geohistory analysis of two of the best dated sections in the basin at Cerro de Oro and Lampazos results in tectonic subsidence curves that are typical of rifted basins (Steckler and Watts, 1978; Figure 4). Calculation of the geohistory diagrams—compaction correction, calculation of the total subsidence curve and tectonic subsidence curve of both stratigraphic sections—was done according to procedures of Van Hinte (1978) and Angevine and coworkers (1990). As shown in Table 5, lithology and age control of the formations of the sections are known from previous studies by the author (González-León, 1988; González-León and Jacques-Ayala, 1988; Scott and González-León, 1991; González-León and Lucas, in press). Water depth is estimated from interpretation of depositional environments and fossiliferous content of these formations. Other parameters were taken from Sclater and Christie (in Angevine *et al.*, 1990; Table 5). Magnitudes of sea level changes were not substracted from the total amount of tectonic subsidence as they are not known from this region. For the section of Cerro de Oro, a small hiatus represented by a disconformity between the Cerro de Oro and Morita Formations was also corrected for compaction.

Figure 4 indicates the total subsidence and tectonic subsidence curves from Cerro de Oro and Lampazos. The Lampazos tectonic subsidence curve shows a first pulse of moderate

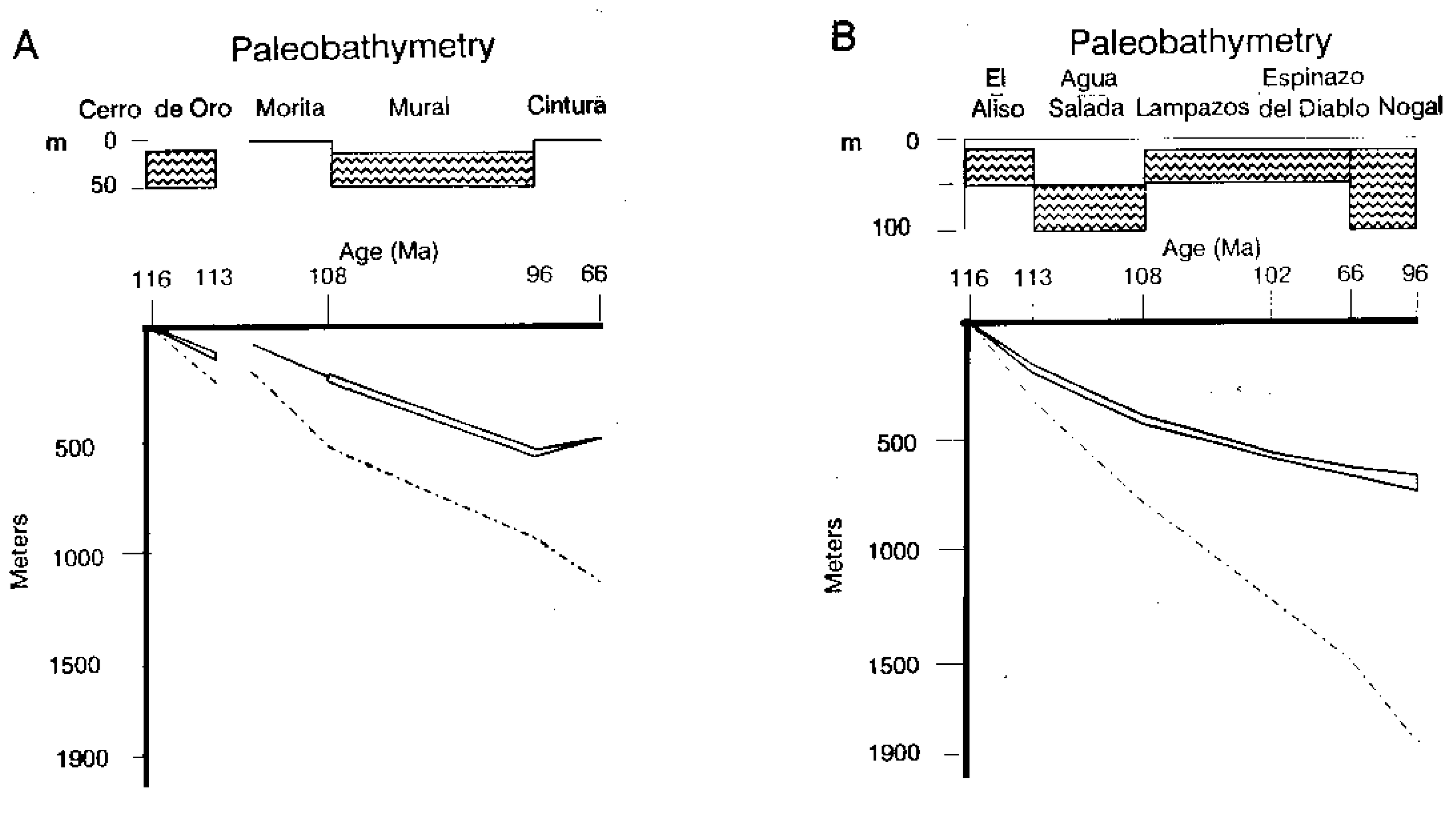

Figure 4.- Curves indicating total subsidence (dashed curve), and minimum and maximum tectonic subsidence curves (solid curves) from the (*A*) Cerro de Oro and (*B*) Lampazos areas. Also shown is estimated paleobathymetry for each formation. Geologic time scale from Haq *et al.*, 1988.

Table 5.- Geologic parameters used to elaborate the geohistory diagrams of the Cerro de Oro and Lampazos sections.

Unit	Thickness [m]	Composition	Original porosity [%]	Age [Ma]	C	Density	Paleobathymetry [m]
Cerro de Oro section							
Ci	290	Ss + Sh	45	99-96	4×10^{-4}	2.685	0
Mu	450	Ls + Ss	45	108-99	5×10^{-4}	2.680	10-50
Mo	260	Ss + Sh	45	111-108	4×10^{-4}	2.685	0
Disconformity				113-111			
Co	147	Sh + Ls	50	116-113	6×10^{-4}	2.715	10-50
Lampazos section							
No	460	Ls + Sh	50	99-96	6×10^{-4}	2.715	10-100
Ed	300	Ls	50	102-99	7×10^{-4}	2.710	10-50
L	500	Ls + Sh	50	108-102	6×10^{-4}	2.715	10-50
As	300	Ss + Ls	50	113-108	6×10^{-4}	2.715	50-100
Ea	200	Sh + Ls	50	116-113	6×10^{-4}	2.715	10-50

Lithologic and water-depth data from these sections taken from González-León and Jacques-Ayala (1988), and González-León (1988). Other parameters taken from Sclater and Christie (*in* Angevine *et al.*, 1990). Formation names are Ci, Cintura; Mu, Mural Limestone; Mo, Morita; Co, Cerro de Oro; No, Nogal; Ed, Espinazo del Diablo; L, Lampazos; As, Agua Salada; Ea, El Aliso.

subsidence rate ending at about 108 Ma. This was followed by an episode of slower subsidence rate which prevailed during the time when the broad, shallow and prograding carbonate platform of the Mural Limestone (González-León and Jacques-Ayala, 1990) occupied most of the basin between 108 and 99 Ma. Slow subsidence continued until 96 Ma, at the end of deposition of the Nogal Formation, which is equivalent to the upper Cintura (Figures 2 and 4). The tectonic subsidence curve from Cerro de Oro shows an approximately similar total amount of tectonic subsidence, but also one short event of slight uplift during the late Albian, which is not indicated in the Lampazos curve.

DISCUSSION

The tectonic setting of the region of Sonora and southeastern Arizona during Late Jurassic and earliest Cretaceous time was dominated by extensional tectonism behind a magmatic arc developing along the western coast of North America (Dickinson, 1981). The most likely origin for continental extension in this region was rift tectonism, propagating through the Chihuahua trough from the Gulf of Mexico during separation of South America from North America (summarized in Dickinson *et al.*, 1986). According to this model, Klute and Dickinson (1987) and Klute (1991) propose that the evolution of the Bisbee basin occurred in three phases: (1) initial Jurassic rifting with contemporaneous silicic volcanism; (2) continued rifting with contemporaneous deposition of fluvial sediments—Glance Conglomerate—and interbedded volcanics in graben and half-graben structures from latest Jurassic to earliest Cretaceous time; and (3) passive thermotectonic subsidence with contemporaneous sedimentation of the remainder of the Bisbee Group in fluvial and shallow-marine environments from earliest to late Early Cretaceous time. Tectonic subsidence curves very similar to the two here reported and that indicate thermotectonic subsidence of the basin during Early Cretaceous time, have been reported from southeastern Arizona (Klute, 1991) and from southwestern New Mexico (Mack, 1987).

The southern boundary of the proposed Bisbee basin, of southern Arizona and northeastern Sonora (Dickinson, 1981), was actually located farther to the south, as indicated by the presence of the Bisbee Group and correlative sections in central Sonora. A rift origin for the southern Bisbee basin is supported by available information from the here reported sections. The thick continental Glance Conglomerate deposits of possible Late Jurassic age present in areas near the NW-SE axis of the basin, are interpreted as having formed during continental extension. The continental extension should have occurred along NW-SE trending extensional faulting similar to that proposed for SE Arizona (Bilodeau *et al.*, 1987) and northern Sonora (Nourse, 1989).

The tectonic subsidence curves from Cerro de Oro and Lampazos are consistent with passive thermotectonic subsidence. An initial steep segment related to fault-controlled subsidence (McKenzie, 1978) is not seen, probably because the Glance Conglomerate is absent in both sections. The slightly smaller subsidence in the Cerro de Oro section, as well as the short event of apparent tectonic uplift, may indicate it was deposited away from the area of maximum subsidence along the basin axis. By the same token, although eustatic changes are not subtracted from the tectonic subsidence curves, the slow and almost constant rate of tectonic subsidence indicates that changes in sea level were small, but still could cause the three marine transgressions recorded in the basin. The inferred high to low rate of subsidence indicated by analysis of fluvial architecture from the base to the top of the Bisbee Group approximately is consistent with the trend followed by the tectonic subsidence curves. The shorelines of the western and southwestern margins of the basin are interpreted to have been located in nearby regions of western Sonora, where a contemporary magmatic arc influenced sediment provenance and sediment dispersal toward the east-northeast. Paleocurrent directions in the Glance Conglomerate of north-central Sonora (Figure 1) agree with postulated northwest-trending normal faulting during Jurassic time.

Nourse (1989) and McKee (1991) interpreted the rocks of the Bisbee Group of central Sonora as deposits of a different embayment formed south of, and parallel to, the Bisbee basin. Such embayment was proposed to be separated from the Bisbee basin by a northwest-trending uplift in northern Sonora. This uplifted region is characterized by the absence of Bisbee Group outcrops, predominance of Upper Cretaceous and Tertiary granitic intrusives and volcanics, and Tertiary detachment faulting. However, that region may actually indicate uplift and erosion related to a belt of Late Cretaceous and Tertiary magmatism and localized detachment faulting during the Tertiary, as indicated by recent geologic compilation (Ortega-Gutiérrez *et al.,* 1992). Lithostratigraphic succession and depositional environments of each one of the Bisbee Group formations are remarkably similar between southeastern Arizona and central Sonora. The Mural Limestone becomes younger and thicker toward east-central Sonora—Lampazos region—which is interpreted as progradation of the Mural shelf toward the deeper part of the basin (González-León and Jacques-Ayala, 1990). Thus, the present author envisions the Bisbee embayment as a continuous feature which extended southward into central Sonora, and with its structural and depositional axes located approximately between the sierra El Chanate to the northwest and the Lampazos area to the southeast (Figure 1).

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