OSTRACODE BIOSTRATIGRAPHY AND PALEOECOLOGY OF THE PLIOCENE OF THE ISTHMIAN SALT BASIN, VERACRUZ, MÉXICO

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CONTENTS

I. ABSTRACT

A detailed systematic and cluster analysis study of samples from the Pliocene of the Isthmian Salt Basin, Veracruz, México, shows characteristic ostracode assemblages for the Encanto, Lower and Upper Concepción, and Agueguexquite strata, and a shallowing-upward trend during the Pliocene.

The Encanto strata, the oldest unit (N19 or upper N18), are characterized by *Ambocythere* spp., *Argilloecia posterotruncata*, *Bradleya normani*, *Krithe trinidadensis* and *Parakrithe* spp., indicating a middle to upper bathyal environment. The Lower and Upper Concepción beds (N19-20) can be recognized by the presence of *Actinocythereis vineyardensis*, *Touroconcha lapidiscola*, and the abundance of *Hulingsina* sp. 1, *Henryhowella* ex. gr. *asperrima*, and *Puriana* spp. Encanto species persisting in the Lower Concepción beds indicate an upper bathyal to outer neritic environment. The Upper Concepción beds lack these species but instead possess abundant *Cyprideis* and *Perissocytheridea* spp., *Basslerites*? sp., *Malzella conradi* and *Echinocythereis margaritifera*. The Upper Concepción assemblage indicates an outer to middle shelf environment. The Filisola and Paraje Solo samples were barren of ostracodes. Their foraminiferal and mollusk fauna indicates nearshore and brackish environments. The Paraje Solo may be in part contemporaneous to the Agueguexquite. The Agueguexquite strata contain the youngest (middle N20), most abundant, and diverse fauna, indicating an inner neritic environment of deposition and representing a local marine transgression of short duration in the northern part of the basin. By upper Agueguexquite time brackish and continental conditions returned.

II. INTRODUCTION

The Isthmian Salt Basin is located in the states of Veracruz and Tabasco, México, between longitude 93°30′ and 95°10′W and from latitude 17°40′N to the Gulf of México, covering approximately 10,500 km^2 (Fig. 1). It is one of the major oil producing regions of México and detailed knowledge of its sediments is of great economic importance. From the geological point of view, it also represents a very interesting area as it shows a complex history influenced by the opening and evolution of the Gulf of México Basin and the development of the Middle American volcanic arc. As a consequence of this tectonic activity, great amounts of sediments and a rapid succession of environments are present in the basin. The recognition and understanding of these environments is of both scientific and economic importance.

Numerous studies of foraminifera, especially benthic ones, have been conducted

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Figure 1. Location map of México.

in the area; however, other microfossil groups are poorly known. The only study on ostracodes is a checklist of 32 species (Bold, 1978).

The samples used in this study were collected from Pliocene outcrops east and west of the Coatzacoalcos River, Veracruz (Fig. 2). Additional samples were provided by Dr. B. Kohl of Chevron Oil Company, by Dr. W. A. van den Bold of Louisiana State University and Drs. H. E. and E. H. Vokes of Tulane University. Sample locations and measured stratigraphic sections are shown in figures 3, 4, 5, 8, and 9 respectively; a list of locations and a list of species is given at the end of the paper.

III. ACKNOWLEDGMENTS

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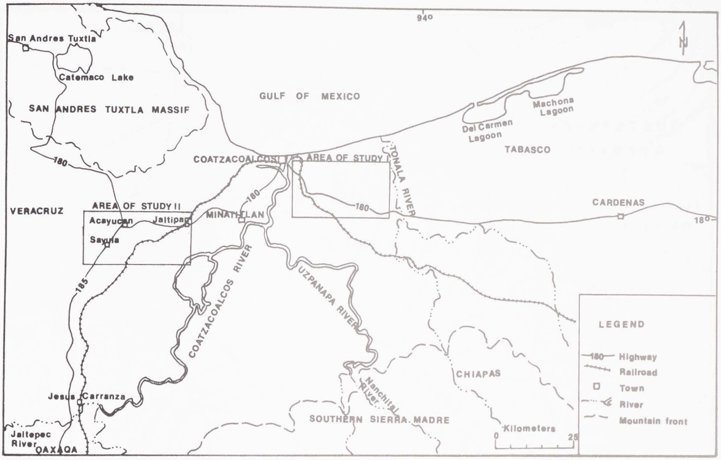

Figure 2. Location map of study area.

Ghiold and G. Rountree for their help with the word processor, and to E. Heydari and J. Dyson for drafting some of the figures and revising the manuscript.

IV. BIOSTRATIGRAPHY AND PALEOECOLOGY

The sediments outcropping in the Isthmian Salt Basin range from Triassic-Jurassic to Recent. The oldest units occur in the south in the Sierra Madre and the youngest to the north in the Gulf Coastal Plain. This study is confined to the Pliocene strata of the Basin.

The Pliocene deposits consist of the Encanto, Lower and Upper Concepción, Filisola, Paraje Solo, Agueguexquite, and Cedral "formations." As noted by other authors (Contreras, 1959, p. 411; Sansores adn Flores-Covarrubias, 1972, p. 6; Kohl, 1985, p. 5; Akers, 1981, p. 145), the term *Formation* is improperly used in the Basin for Neogene strata because they have been defined on paleontological not lithological basis. Most are therefore not mappable field units. However, they are widely cited in the literature and in the oil industry and for comparative purposes they will be referred here as "formations."

The environment and age determinations of the four fossiliferous units in the Isthmian Salt Basin (Fig. 6) indicate a gradual shallowing of the Basin from the upper middle bathyal (upper N18 - N19, Encanto) through upper bathyal – outer neritic (N19-20, Lower Concepción), through outer - middle neritic (N20, Upper Concepción), to inner neritic (N20, Agueguexquite).

However, between Upper Concepción and Agueguexquite beds we find Filisola of age N20 and Paraje Solo (brackish-continental) of unspecified age. This indicates a rapid uplift at the end of Concepción time (no inner neritic deposition) in the central and northern portion of the basin. By early Agueguexquite time a shallow, locally restricted transgression occurred, and by late Agueguexquite and Cedral times the brackish-deltaic depositional conditions returned.

ENCANTO (Gibson, 1936).

The Encanto strata represent the oldest unit sampled in this study. The lithology consists mainly of bluish-gray to yellowish-gray, fine-grained sandstone and silty clay, generally well stratified and up to 800 m

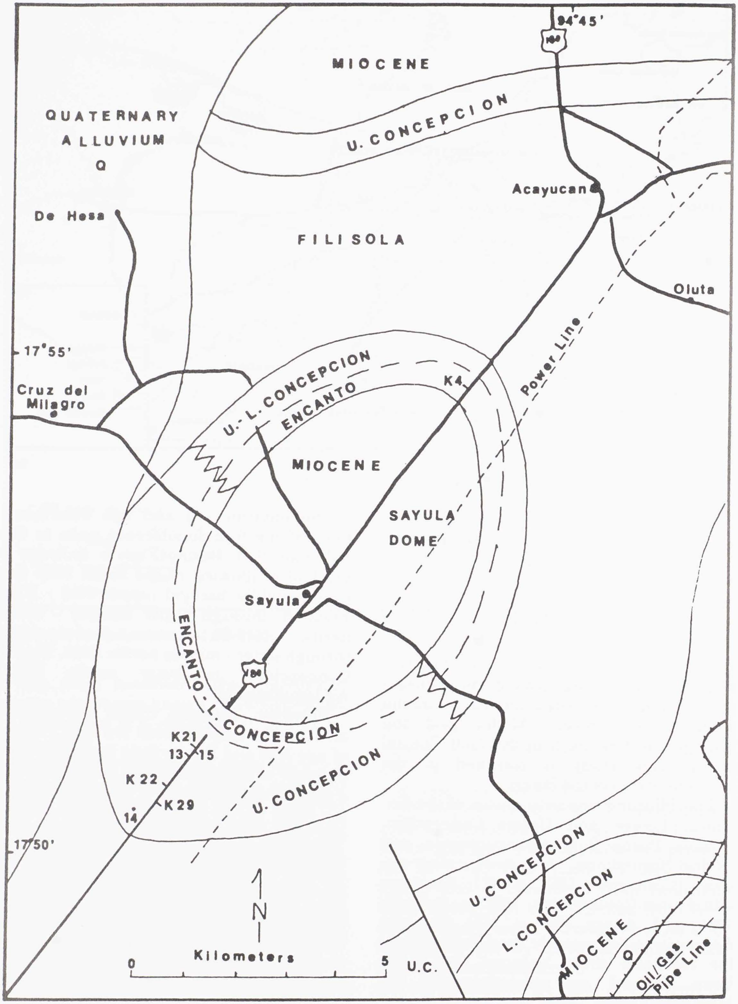

Figure 3. Geologic map and location of samples across Sayula Dome (after Kohl, 1985).

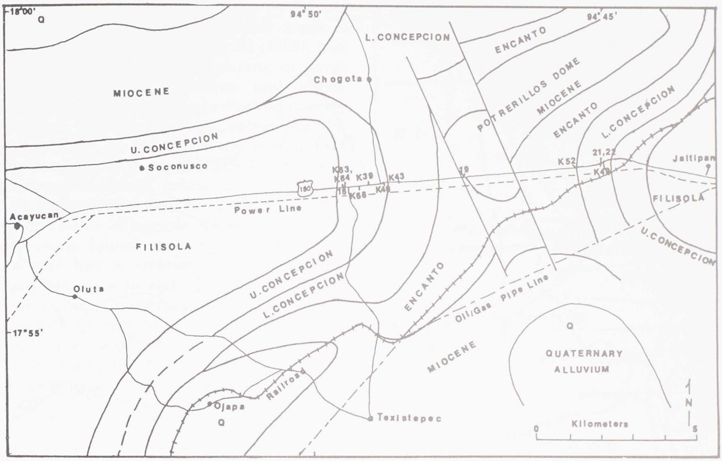

Figure 4. Geologic map and location of samples across Potrerillos Dome (after Kohl, 1985).

thick (Benavides, 1956). In the area of study these sediments generally consist of calcareous silty shale. The Encanto beds were assigned by Gibson (1936) to the Lower Miocene, were placed in the Middle Miocene by Sansores and Flores-Covarrubias (1972) and Akers (1972, 1979), and in the Lower Pliocene by Kohl (1985) and Akers (1984). Only a few samples from this unit yielded ostracodes: K4, (Fig. 3), K52, 19 (Fig. 4), 78, and 60 (Fig. 5).

Species characteristic of this "formation" are: *Krithe trinidadensis*, *Argilloecia posterotruncata*, *Parakrithe* spp., *Ambocythere* spp., *Bradleya normani*, and *Xestoleberis* sp. 2.

Age.

The presence of *Ambocythere caudata* (Early Pliocene to Recent), *Cytheropteron? yorktownensis* (Early Pliocene-Late Pleistocene), *Bairdoppilata* sp. aff. *B. victrix* (Pliocene), and *Parakrithe* sp. 2 (Early to Middle Pliocene), indicates an Early-Middle Pliocene age.

According to Kohl (1985) the planktonic foraminifer *Globigerina nepenthes* Todd "does become extinct near the top of the Encanto strata." Berggren (1973) placed the extinction of this species in the Lower Pliocene (later portion of Neogene Zone N19 of Blow, 1969) and assigned an age of 3.7 m.y. to it. Akers (1984) examined sample TU 1153, collected close to sample 19 of this study, and found a rich planktonic flora and fauna typical of the Lower Pliocene. He indicates that "the coincidence of *Globigerina nepenthes* with *Globorotaloides hexagona* and *Globigerinella calida* indicates a stratigraphic position in Zone N19 or the upper part of Zone N18."

Environment.

The environment of deposition can be deduced by the following species:

(1) *Krithe trinidadensis* has been recorded in upper to middle bathyal environments in the modern Caribbean. Although this species is also common in the Concepción strata, it is by far most abundant in the Encanto. Only one specimen has been recovered from the Agueguexquite beds.

(2) *Parakrithe* sp. 1 is a common species in the Encanto. Although it also occurs sparsely in the Lower Concepción, its peak

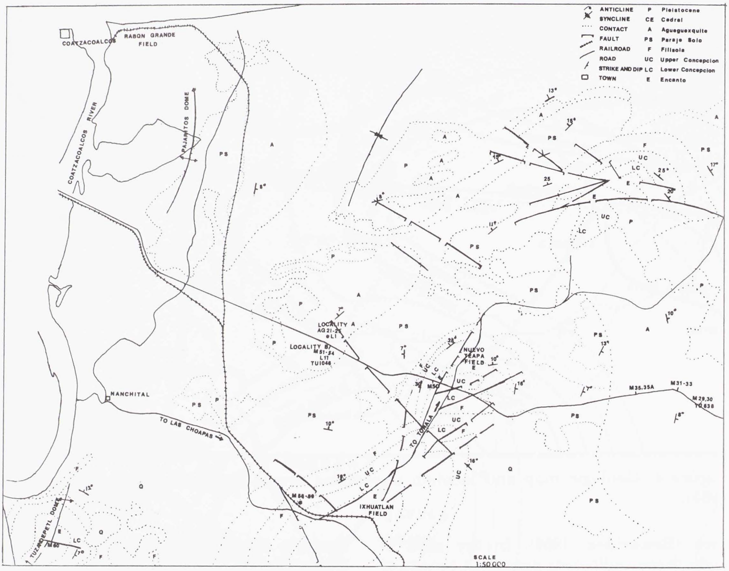

Figure 5. Geologic map and location of samples in eastern study area.

abundance is in the Encanto. It occurs only in a set of successive, closely spaced samples from the eastern flank of the Sayula Dome (Fig. 3), and its abundance increases towards the base of the section (increasing depth). *Parakrithe* sp. 1 is found in the Caribbean (Dominican Republic) Pliocene in probably upper slope sediments (Bold, per. comm.).

(3) *Parakrithe* sp. 2 is less abundant than *P.* sp. 1, but it is restricted almost exclusively to this unit; only two other specimens have been found in Lower Concepción strata. Van Morkhoven (1972) records this genus in the Recent Gulf of México from outer neritic to upper slope.

(4) *Argilloecia posterotruncata* is a species that occurs in all the units; however, it is very rare in Agueguexquite, rare in Concepción and has its peak abundance in Encanto beds, where it is a common species. *Argilloecia posterotruncata* is characteristic of middle - outer neritic to upper slope environments in the Caribbean Miocene to Recent.

(5) *Ambocythere caudata* and *Ambocythere* sp. cf. *A.* sp. *A* of Cronin (1983) have been reported by Bold and Cronin respectively from middle to upper slope environments in the Recent North Atlantic, and both are restricted to the Encanto, except for one specimen found in the Lower Concepción.

(6) *Bradleya normani* is a modern bathyal species (Benson, 1972) and it is found only in this unit. The presence of these species indicates an upper to middle slope environment for the Encanto strata.

The upper to middle slope character of the ostracode fauna is corraborated by the benthic foraminifera. Sansores and Flores-Covarrubias (1972) considered the depth of deposition of these beds to be between 500 and 2000 m. Kohl (1985) indicates that "the benthic foraminiferal assemblages of the Encanto 'biozone' imply ancient water depths of 300 to 700 m (upper to middle bathyal)."

An exception to the indicated depth is sample K4. According to Kohl (1985), this sample exhibits a faunal mixing of near-shore benthic foraminifera and upper bathyal ones, as well as reworked species of older, Middle Miocene, sediments. Interpretation of the ostracode assemblage shows a similar mixing. *Malzella conradi* is the most abundant species in the Isthmian Salt Basin. In the Encanto strata it is exclusively found in sample K4 except for one specimen found in sample 19. *Malzella conradi* has a stratigraphic range from Late Miocene to Late Pliocene, and it is found in strata interpreted as shallow shelf deposits by several authors; therefore, it seems that, along with the redeposition of older sediments there was also contemporaneous contamination at this locality, probably due to slumping of shallow shelf sediments.

Other species also considered as shelf indicators whose presence in Encanto is restricted to K4 include: *Radimella confragosa*, *Quadracythere? compacta*, *Paracytheridea tschoppi*, *Loxoconcha* sp. aff. *L. helenae*, *Mutilus*? sp., *Caudites nipeensis*, *Munseyella bermudezi louisianensis*, and *Buntonia* sp.

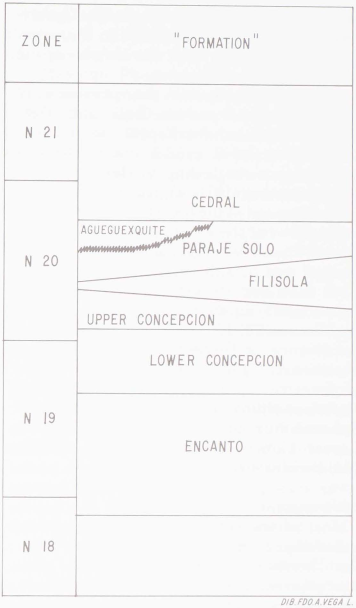

Figure 6. Stratigraphic column of the Pliocene sediments in the Isthmian Salt Basin (see text for lithology and thicknesses).

LOWER CONCEPCIÓN (Gibson, 1936).

Beds of the Lower Concepción consist of approximately 450 m of very fossiliferous gray and blue, poorly stratified silty shales with sandy layers of different thickness toward the top. This "formation" grades into the Upper Concepción; the contact between the two units is determined solely by microfauna. These strata contain a more diverse and abundant fauna than the Encanto: 55 species belonging to 36 genera were identified in the Lower Concepción. The most abundant are: *Henryhowella* ex. gr. *asperrima*, *Puriana* spp., *Echinocythereis* sp., *Hulingsina* sp. 1, and *Basslerites minutus*. Most of these species are characteristic of shelf environments. No species are restricted to these beds; however, some are restricted to Concepción strata (Lower and Upper): *Actinocythereis vineyardensis*, *Caudites rectangularis*, *Haplocytheridea-Peratocytheridea* molts, *Hulingsina* sp. 3, *Loxoconcha matagordensis*, *Perissocytheridea subrugosa*, and *Touroconcha lapidiscola*. Most of these are less abundant in the Lower than in the Upper Concepción.

Lower Concepción beds can be distinguished from Upper Concepción by the absence of certain species (see Upper Concepción), the smaller number of brackish water species and the presence of deeper water forms common in the Encanto (*Ambocythere caudata*, *Parakrithe* spp. and *Cytherella* sp. aff. *C. hannai* var.) that have their last appearance in the Lower Concepción.

Age.

The age indicated by the ostracode assemblage is not older than Early Pliocene, as determined by the following species: *Pterygocythereis inexpectata*, *Perisso-*

caudata (Early Pliocene-Recent), *Cytheropteron? yorktownensis* (Early Pliocene-Late Pleistocene) and *Parakrithe* sp. 2 (Early to Middle Pliocene).

Kohl (1985) reports the presence of *Globorotalia margaritae* Bolli and Bermúdez, *Sphaeroidinellopsis seminulina* (Schwager) and *S. subdehiscens subdehiscens* (Blow). According to Berggren and van Couvering (1974), *G. margaritae* has its last ocurrence at the top of zone N19 and *S. seminulina* at the end of N20. Akers (1981, fig. 1), however, indicates that *G. margaritae* and *S. subdehiscens subdehiscens* have their last ocurrences in the late N20. Akers (1979) studied the planktonic fauna and flora at TU 1025 and reported that "the occurrence of *Globorotalia (Turborotalia) acostaensis pseudopima* Blow, *Reticulofenestra pseudoumbilica* (Gartner), *Pseudoemiliania lacunosa* (Kampter) and *Sphenolithus abies* Deflandre dates the Lower Concepción beds at TU 1025 as Middle Pliocene, zone N20."

Environment.

Most of the ostracode species in these beds range from outer neritic to inner-middle neritic environments (*i.e.*, *Actinocythereis vineyardensis*, *Pterygocythereis inexpectata* etc.) and a few represent upper bathyal depths (*i.e.*, *Ambocythere spp.*, *Henryhowella* ex. gr. *asperrima*, *Parakrithe* spp., etc.). The absence or decreased abundance of upper slope species and the presence of characteristic shelf forms indicate that these strata were deposited at shallower depths than the underlying Encanto beds. On the other hand, the presence of the upper slope species and the comparatively small numbers of inner-middle shelf species indicate that the Lower Concepción deposits are deeper than those of the overlying Upper Concepción, and probably represent upper bathyal to outer neritic environments.

These conclusions are supported by a study of the benthic foraminifera by Sansores and Flores-Covarrubias (1972), who concluded that these beds were deposited between 200 and 500 m of depth (outer shelf to upper slope). Kohl (1985) suggests a water depth of 180-200m (outer neritic to upper bathyal) for these strata.

UPPER CONCEPCIÓN (Gibson, 1936).

Lithologically this unit consists mainly of massive grayish-blue silty clay, similar to that of the Lower Concepción, with occasional calcareous concretions. The sequence is about 200 m thick. Its lower and upper contacts are gradational; more shaley toward Lower Concepción and sandier toward Filisola; they are recognized solely by microfossils. The ostracode fauna does not contain a group of restricted species as the Encanto and Agueguexquite do; however, some species are more abundant here than anywhere else. These include *Hulingsina* sp. 1, *Basslerites minutus*, *Henryhowella* ex. gr. *asperrima* and *Haplocytheridea-Peratocytheridea* molts. The abundance of these species and the presence of *Malzella conradi*, *Echinocythereis margaritifera*, *Basslerites*: sp., etc., distinguish these beds from the Lower Concepción ones.

Age.

The age of the "formation" can be determined by the ostracode species *Perissocytheridea subrugosa*, *Pterygocythereis inexpectata*, *Cytheropteron? yorktownensis* and *Cyprideis mexicana*, which indicate an age of Early Pliocene or younger for these beds. An important species is *Loxoconcha* sp. *A*. (Hazel, 1977) that has only been found in zones N19 and N20 in Florida, North Carolina and Virginia.

Kohl (1985) found in these beds the planktonic foraminifera *Globorotalia margaritae*, *Sphaerodinellopsis seminulina* and *S. subdehiscens* and the calcareous nannoplankton *Sphenolithus abies*. *Sphaerodinellopsis subdehiscens* suggests a Middle Pliocene age, Neogene zone 20 of Blow (1969). *Sphenolithus abies* became extinct at about the middle portion of zone N20 (Blow, 1969) and *S. subdehiscens* became extinct at about 3.0 m.y.a. (Berggren, 1973). Therefore, the age of this unit should be the early part of Blow's zone N20 and slightly over 3.0 million years.

Akers (1979, 1981) also places this fauna in zone N20, based on the concurrence of the calcareous nannoplankton species *Pseudoemiliania lacunosa*, *Reticulofenestra pseudoumbilica* and *Sphenolithus* *abies*. He indicates that there is little if any difference between this assemblage and the one found in Lower Concepción.

Environment.

Most of the species found in these strata are characteristic of outer to middle shelf. The absence of deeper water species that occur last in the Lower Concepción suggests that these beds were deposited at shallower water depth than those of the Lower Concepción. The absence of inner neritic species found in the Agueguexquite strata, and the presence of *Henryhowella* ex. gr. *asperrima* and *Actinocythereis vineyardensis* indicate that these beds were deposited under deeper water conditions than the Agueguexquite beds.

However, there are several brackish water species found in these strata. *Cyprideis* sp. cf. *C. mexicana*, *C. salebrosa*, *Loxoconcha matagordensis* and *Megacythere repexa* are very rare, not more than three specimens per sample. *Perissocytheridea bicelliforma* and *P. subrugosa* are more abundant; however, they are mainly molts and badly preserved, which suggests an allochthonous origin from nearby low salinity environments.

The presence of brackish water species in the Concepción may be due to proximity of the area of deposition to a river mouth, to its location in the pathway of water currents bringing water and sediments from a river and marginal bays, or to slumping on a relatively narrow, steeply sloping shelf.

The outer to middle neritic environment of deposition suggested by the ostracode assemblage is also indicated by the foraminiferal fauna. Sansores and Flores-Covarrubias (1972) stated that the Upper Concepción strata were deposited between 100 and 200 m depth (middle to outer neritic), and Kohl (1985) determined a paleodepth of 50 to 180 m.

Age.

The following ostracode species indicate a Pliocene age (N19, N20) for these strata: *Pterygocythereis inexpectata*, *Kangarina ancyla* (Early Pliocene-Recent); *Cytheropton? yorktownensis*, *Microcytherura choctawhatcheensis* (Early Pliocene to Late Pleistocene); *Bairdoppilata* sp. aff. *B. victrix* (Pliocene) and *Loxoconcha* sp. *A* (N19 - N20).

Hazel (1983) indicated that the Yorktown Formation of North Carolina, which contains several of the most comon species of the Mexican Pliocene, is included in the *Orionina vaughani* Assemblage zone (N19-N20) with an age between 3.7 and 4.8 m.y. Cronin *et al.* (1984) extended the range of
river and marginal bays, or to slumping on a relatively narrow, steeply sloping shelf.

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FILISOLA (Gibson, 1936).

This unit consists mainly of 250 to 400 m of thick, fine- to coarse-grained quartzose sandstone beds, with sparse, thin, intercalations of soft bluish-gray shale toward the bottom. Fossils are rare and poorly preserved. As noted above, its contact with the Upper Concepción is transitional.

The samples collected from the Filisola strata were barren of ostracodes. However, scarce foraminiferal faunas reported by Sansores and Flores-Covarrubias indicate that these beds represent coastal deposits with deltaic influence. Akers (1979) examined a sample from the marine facies of this "formation" (TU 1141) outside the study area, near San Andrés Tuxtla, Veracruz (Fig. 2), and concluded that "the conjunction of *Globigerina bulloides apertura* Cushman, *Sphenolithus abies*, *Gephyrocapsa caribbeanica* Boudreaux and Hay and *Pseudoemiliania lacunosa* fixes the age of the Filisola Formation at the proposed type locality as middle Pliocene, Neogene zone 20."

PARAJE SOLO (Gibson, 1936).

This unit consists of 300 to 600 m of massive, thick, fine to coarse-grained sandstone with intercalations of silty clays and lignitic layers. It occasionally has a rare fauna of benthic foraminifera (*Elphidium* spp., *Ammonia becarii* Linné, *Eponides antillarum* (d'Orbigny) and mollusks, but most of the beds do not contain any fossils. It is considered to have been deposited under brackish or even freshwa-

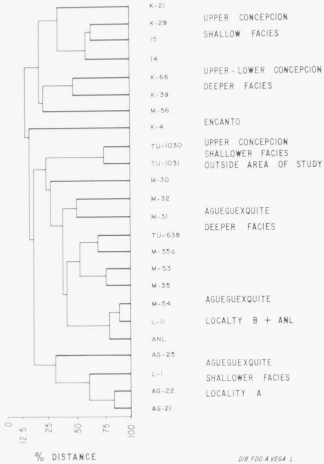

Figure 7. Cluster analysis dendrogram.

ter conditions. No ostracodes were found in these strata.

AGUEGUEXQUITE (Thalmann, 1935).

The Agueguexquite strata represent the last transgressive-regressive cycle and the end of marine deposition in the Isthmian Salt Basin. The unit consists of basal conglomerate, rich in microfauna, marine sands and silty shales that give way to continental lignitic sands and shales at the top. Five hundred meters of sediments have been reported in the subsurface. Only the lower part of the formation, including the basal conglomerate, yielded ostracodes, and presents the most diverse and abundant fauna: 63 species were identified. Of these, 20 are restricted to these beds: *Actinocythereis* sp. cf. *A. gomillionensis*, *Bairdia* sp. aff. *B. longisetosa* (except for one specimen in Upper Concepción), *Bairdoppilata* sp. aff. *B. victrix* (except for two specimens in K4), *Bairdoppilata* sp., *Cytherella vermilionensis*, *C.*, sp. aff. *C. pulchra*, *Cytherelloidea umbonata*, *C.* sp. cf. *C. umbonata*, *Cytheretta anderseni*, *Cytherura wardensis* (except for one specimen in Upper Concepción). *C.* sp. *A.*, *Gangamocytheridea? plicata*, *Hulingsina* sp. 2, *Kangarina ancyla*, *Loxoconcha wilberti*, *Luvula gigarton*, *Macrocyprina propinqua*, *Microcytherura choctawhatcheensis* and *Paracypris* spp.

Age.

The following ostracode species indicate a Pliocene age (N19, N20) for these strata: *Pterygocythereis inexpectata*, *Kangarina ancyla* (Early Pliocene-Recent); *Cytheropton? yorktownensis*, *Microcytherura choctawhatcheensis* (Early Pliocene to Late Pleistocene); *Bairdoppilata* sp. aff. *B. victrix* (Pliocene) and *Loxoconcha* sp. *A.* (N19 - N20).

Hazel (1983) indicated that the Yorktown Formation of North Carolina, which contains several of the most comon species of the Mexican Pliocene, is included in the *Orionina vaughani* Assemblage zone (N19-N20) with an age between 3.7 and 4.8 m.y. Cronin *et al.* (1984) extended the range of this zone to N21 with an age between 4.0 and 2.5 m.y.

Akers (1972) and Akers and Koeppel (1973) studied the planktonic fauna and flora of the Yorktown and Agueguexquite formations and found them very close in age and dated them as Zone N20 or top N19. Akers (1979, 1981) suggested that the presence in the Agueguexquite Formation of the nannoplankton species *Pseudoemiliania lacunosa*, *Reticulofenestra pseudoumbilica*, *Gephyrocapsa caribbeanica* and the absence of *Sphenolithus abies* indicate that "these beds were deposited just subsequent to the extinction of *R. pseudoumbilica* which may have occured higher in zone N20."

Berggren (1973) assigned an age of 3.0 m.y. to the extinction of *Sphaerodinellopsis subdehiscens*, which according to Kohl (1985) is approximately equivalent to the extinction of *S. abies*.

Environment.

The species found in these strata are characteristic of neritic environments and most of them decrease in abundance or are even absent in stratigraphically lower (deeper) units.

Malzella conradi is typically found in shallow water neritic environments. Hulings (1967) considered *M. conradi* along with *Cytherura wardensis*, *Bairdia gerda* (here *B. longisetosa*), *Pellucistoma mag-*

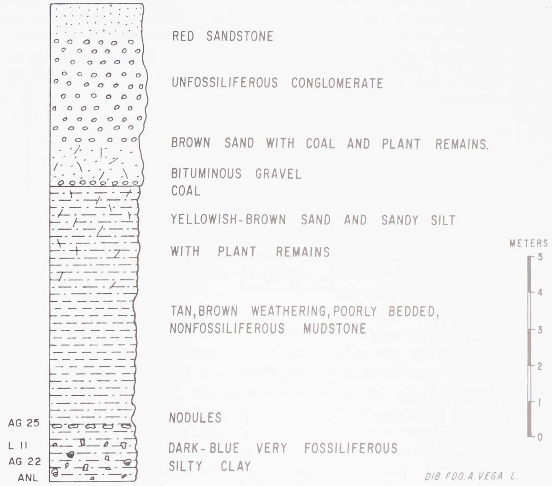

Figure 8A. Stratigraphic section of the Agueguexquite strata in locality *A* (pipeline), showing part of the lower to upper members of the "formation" and part of the Cedral Formation (see Fig. 5 for map location).

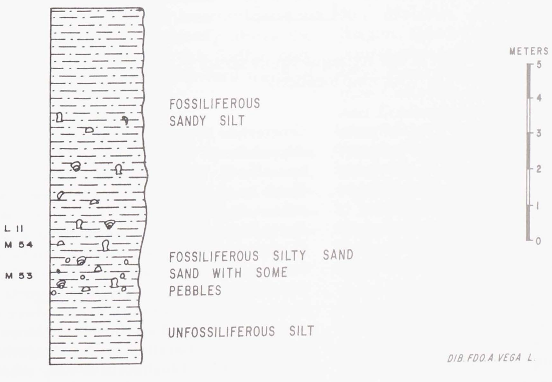

Figure 8B. Stratigraphic section of the lower strata at locality *B* (México Highway 180), showing part of the lower to middle Agueguexquite Formation (see Fig. 5 for map location).

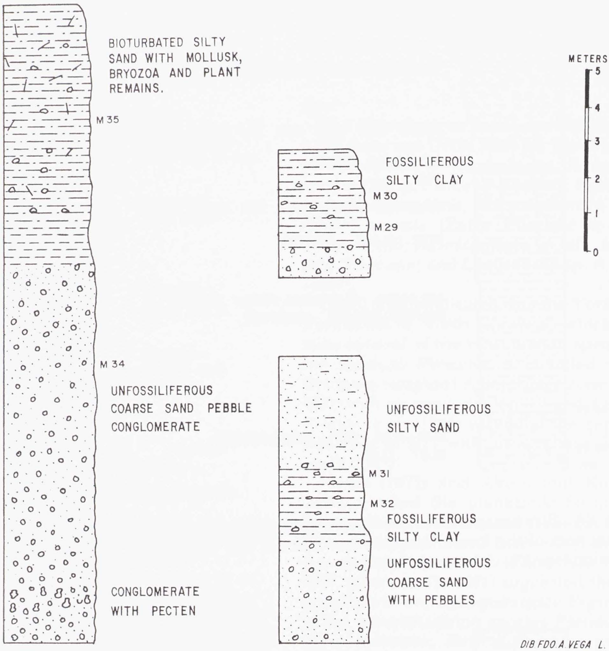

Figure 9. Stratigraphic section of the Agueguexquite strata in the eastern region, showing basal conglomerate (see Fig. 5 for map location).

niventra and *Pontocythere ashermani* (=*Hulingsina semicircularis*?) diagnostic of water depths less than 50 m. Puri and Vaanstrum (1969), indicated that "the occurrence of large total populations of *Puriana rugipunctata*, *Orionina vaughani* and *Aurila conradi* suggests stable environment conditions in shallow waters (less than 65 ft.)."

Cytherella vermilionensis has been reported by Kontrovitz (1976) in modern Louisiana inner neritic shelf sediments between 10 and 100 m, mostly between 10 and 50 m. *Cytherura sandbergi* has been reported by several authors from recent lagoonal and nearshore environments. *Cytherelloidea* sp. cf. *C. umbonata* was found by Teeter (1975) from a few centimeters to 10 m off the Belize's coast. *Bairdoppilata* sp. aff. *B. victrix* and *Cytherella* sp. aff. *C. pulchra* have been found by Bold in the Caribbean Pliocene shallow water sediments. Puri (1954) found that *Cativella navis*, *Cytheromorpha warneri*, *Cytheropteron (Microcytherura) choctawhatcheensis*, *Cytherelloidea leonensis*, *Loxoconcha wilberti*, and *Paracypris choctawhatcheensis*, among others, were characteristic of the Ecphora and Cancellaria facies of the Choctawhatchee Stage (inner-middle shelf). This fauna is very similar to the one in the Agueguexquite, therefore, the ostracofauna indicates that these beds were deposited in shallow, inner to possibly middle neritic environments.

Assemblages consisting of *Aurila* spp., *Basslerites minutus*, *Cativella*, *Orionina*, *Puriana gatunensis*, *Quadracythere producta*, and *Radimella confragosa*, occur concentrated in a belt from very near shore to a depth of about 20 m and generally paralleling the shoreline at a distance varying between 700 and 1200 m in the Gulf of Paria (Bold, 1974, Fig. 4). These conditions appear similar to the bathymetry of the Agueguexquite.

This interpretation agrees with the paleodepth suggested by the benthonic foraminifera found by Sansores and Flores-Covarrubias (1972), which represent an inner to middle neritic environment between 0 and 100 m.

The Bryozoa of these strata also confirm an inner neritic environment of deposition. Herrera-Anduaga (1983) found that autochthonous Bryozoa indicate a paleodepth of 0 to 55 m. Furthermore, she states that the bryozoans in the beds of the Pajaritos Dome along Highway 180 (locality B) are slightly deeper than those at locality A (see Figs. 5, 8B). This proposed difference in water depth for the two locations is supported by some differences in ostracode occurrence. *Basslerites minutus*, *Cytheretta choctawhatcheensis*, *Henryhowella* ex. gr. *asperrima*, and *Pterygocythereis inexpectata* do not occur at locality A (Fig. 8A) and their absence suggests slightly shallower conditions of deposition for these strata. As the ostracode bearing beds in locality A are stratigraphically above the ones along Highway 180, this further substantiates the shallowing-upward trend of the Basin.

CEDRAL (Castillo, 1955).

The Cedral "formation" consists of a series of yellowish-red and gray sand, shale and conglomerate with rare occurrences of the benthic foraminifera *Ammonia becarii* and *Elphidium* spp. It is considered to be of deltaic origin. No ostracodes were found in these beds.

V. CLUSTER ANALYSIS

In order to test the similarity among the samples taken from different formations, a Q-mode cluster analysis using Ward's method (SAS, 1982) and species proportions was performed. Species with over 2% in any sample and samples with over 100 specimens were used (of the Encanto and Lower Concepción samples, only one of each met this requirement).

Visual examination of the dendrogram in Fig. 7 reveals two major clusters each divided into two subclusters: (1) Cluster I comprises all of the Agueguexquite plus two Upper Concepción (TU 1030 and 1031) samples; (2) Cluster II consists of the Concepción samples.

The Agueguexquite samples are divided into two groups: (1) Subcluster Ia comprises all the samples from locality A, except the basal one (sample ANL). (2) Subcluster Ib is formed by ANL and the rest of the Agueguexquite samples.

The samples in subcluster Ib contain *Pterygocythereis inexpectata*, *Henryhowella* ex. gr. *asperrima*, *Cytheretta choctawhatcheensis*, and *Basslerites minutus*. These species are absent in the samples from locality A, and their presence indicates a slightly deeper environment.

The samples in locality B (Fig. 8B)(and probably the ones in the rest of the Agueguexquite localities), are stratigraphically below the ones in locality A; its deeper character agrees with the shallowing-upwards trend of the "formation."

Sample ANL is the lowest one in locality A (Fig. 8A) and it joins very early to samples L11 and M54 from locality B. These three samples contain abundant *Aurila* sp., *Malzella conradi*, *Radimella confragosa*, *Quadracythere compacta?*, *Orionina vaughani*, *Bairdoppilata* sp. aff. *B. victrix*, *Paracytheridea tschoppi*, and common *Cativella navis*, *Caudites nipeensis*, and *Echinocythereis* sp. It is possible that sample ANL represents the same conditions of deposition as samples L11 and M54, whereas the samples above them represent slightly shallower conditions.

The rest of the Agueguexquite samples (Fig. 9) seem to indicate a similar environment to the one in samples ANL, L11 and M54. Herrera-Anduaga (1983) found the same trend with Bryozoa. She reported a slightly shallower environment in the samples of locality A than for the ones in the rest of the localities.

Cluster II includes the Concepción samples. It is also divided into two groups: (1) Samples K66, K39, and M56, which joins later; (2) Samples 14, 15, K21 and K29.

The samples from subcluster IIb are all from the southern flank of the Sayula Dome (Fig. 3). They contain *Cyprideis* sp. cf. *C. mexicana*, *Loxoconcha matagordensis*, and *Haplocytheridea-Peratocytheridea* molts, which probably represent contamination from nearby shallow (or brackish) water environments.

Samples K66 and K39 were collected on the western flank of the Potrerillos Dome (Fig. 4). The presence of abundant *Echinocythereis* sp. and *Henryhowella* ex. gr. *asperrima*, and the absence of shallower cluster IIb species suggest that they represent a deeper environment. This agrees with the results obtained by Kohl (1985). He found that the benthic foraminifera of these samples indicate an outer neritic environment for the section in the western flank of the Potrerillos Dome, and an outer to middle neritic environment for the southern flank of the Sayula Dome.

Two of the Upper Concepción samples involved in the clustering procedure, TU 1030 and 1031 merge late with the Agueguexquite cluster. These samples are from outside the area of study and represent a shallower facies, as indicated by their high numbers of *Malzella conradi*, *Aurila* sp., *Orionina vaughani*, *Cytheropteron? yorktownensis*, and *Cytheretta choctawhatcheensis*. This assemblage may account for its merging (although late) with the Agueguexquite group. On the other hand, the absence of characteristic Concepción species such as *Hulingsina* sp. 1, *Actinocythereis vineyardensis*, *Buntonia* sp., *Cytherella* sp., *Megacythere repexa*, *Perissocytheridea* spp., and *Cyprideis* spp., accounts for its exclusion from that cluster. The lack of allochthonous brackish water species present in the other Concepción samples indicates that this contamination is locally restricted.

The Lower Concepción sample M56 remains independent joining late to cluster IIa, which contains the deepest water representatives of the samples analyzed (K39 represents a paleodepth close to upper bathyal).

The Encanto sample, K4, forms an independent entity, which joins very late to cluster 1. As mentioned before, this sample presents a mixed fauna of upper bathyal and inner shelf conditions, and since no other Encanto samples were used in the cluster (due to their low diversity and species abundance), its merging with the inner shelf Agueguexquite group seems logical.

VI. CONCLUSIONS

(1) The Pliocene strata in the Isthmian Salt Basin can be identified by their ostracode fauna.

(2) Each unit shows a characteristic assemblage:

(a) The Encanto beds can be recognized by the presence of *Ambocythere* spp., *Argilloecia posterotruncata*, *Bradleya normani*, *Krithe trinidadensis*, and *Parakrithe* spp. This fauna indicates a middle to upper bathyal environment and an age of Early to Middle Pliocene (upper N18 to N19).

(b) Concepción strata are distinguished by the presence of *Actinocythereis vineyardensis*, *Caudites rectangularis*, *Haplocytheridea-Peratocytheridea* molts, *Loxoconcha matagordensis*, and *Touroconcha lapidiscola*. Lower Concepción beds can be differentiated from Upper Concepción ones by the presence of *Ambocythere* spp. *Cytherella* sp. aff. *C. hannai* var., and *Parakrithe* spp. These species indicate upper bathyal to outer neritic environments and a Middle to Late Pliocene age (N19 - N20). Upper Concepción strata can be differentiated from Lower Concepción ones by the presence of *Malzella conradi*, *Echinocythereis margaritifera*, *Basslerites*? sp. and the abundance of brackish water species. This assemblage indicates outer to middle neritic environments and Late Pliocene (N20) age.

(c) Agueguexquite strata are characterized by abundant *Bairdia* and *Bairdoppilata* spp., *Cytherura* spp., *Cytherella vermilionensis*, *C.* sp. aff. *C. pulchra*, *Loxoconcha wilberti*, *Luvula gigarton*, and *Macrocyprina propinqua*. Their faunal assemblage indicates an inner neritic environment of deposition and a Late Pliocene (Middle N20) age.

(d) Samples from the Filisola, Paraje Solo, and Cedral strata did not contain ostracodes.

(3) The Pliocene depositional sequence of the Saline Basin shows a general shallowing-upward trend from middle to upper bathyal (Encanto) to upper bathyal – outer neritic (Lower Concepción), to outer - middle neritic (Upper Concepción) to nearshore and brackish conditions (Filisola + Paraje Solo). In the northern part of the Basin, a small transgression occurred and inner neritic marine sediments were deposited (Lower-Middle Agueguexquite) followed by the deposition of deltaic and continental deposits (Cedral).

(4) Clustering of the samples based on their specific content separated the Agueguexquite and Concepción strata.

VII. LOCALITY DATA

The samples used in this study came from a variety of sources, the abbreviations are:

K39, 40, 43, 49, 52, 63, 64, 66. Encanto and Concepción formations, Potrerillos Dome, coll. B. Kohl.

18, 19, 21, 22, Encanto and Concepción formations, Potrerillos Dome, coll. Machain and Bold.

K4, 21, 22, 29, Encanto and Concepción formations, Sayula Dome, coll. B. Kohl.

13, 14, 15, Upper Concepción Formation, Sayula Dome, coll. Machain and Bold.

AG21-25, Agueguexquite Formation, pipeline cut about 200 m north of Mexico Highway 180, km 13 (locality A), coll. Machain, Bold, Gío-Argáez and Herrera-Anduaga.

ANL, Agueguexquite Formation, same locality as above, collected at the base of the sequence, coll. Bold.

M29-54, Agueguexquite and Concepción formations, series of outcrops along Mexico Highway 180 from Coatzacoalcos, Veracruz, to Agua Dulce, Veracruz, coll. Machain, Bold, Gío-Argáez and Herrera-Anduaga.

M56-59, Lower Concepción Formation, hill at the El Chapo locality along the road from Nanchital to Las Choapas just after its crossing with the Southeastern Railroad, coll. Machain, Bold, Gío-Aráez and Herrera-Anduaga.

M60, Encanto Formation, Tuzandepetl Dome, coll. Machain, Bold, Gío-Argáez and Herrera-Anduaga.

M78, Encanto Formation, outcrop along México Highway 185, 14 km north of side road to Jesús Carranza.

Tulane University fossil locality numbers, coll. H. E. and E.H. Vokes.

638. Agueguexquite Formation, road cut, pipeline cut, and quarry on México Highway 180, 14 mi east of junction with side road into Coatzacoalcos, Veracruz.

1025. Lower Concepción Formation, first roadcut on east side of road between Nuevo Teapa and Ixhuatlán, 0.5 mi south of crossing of México Highway 180, Veracruz, México.

1030. Upper Concepción Formation, hill on left bank of Río Santo Domingo, just before its confluence with the Río Tonto, forming Río Papaloapan, just north of Tuxtepec, Oaxaca, México.

1031. Same locality as TU 1030 but about 7 m lower stratigraphically, river bank exposed at low water.

1046. Agueguexquite Formation, roadcuts on both sides of México Highway 180, 7.5 mi east of junction with side road into Coatzacoalcos, Veracruz, México.

1141. Filisola Formation, roadcut on north side of México Highway 180, 13 km west of San Andrés Tuxtla, Veracruz, México (= stop 10, 20th Geol. Congress, C-7, 1956).

1153. Encanto Formation, roadcut on México Highway 180, 16 km east of Acayucan, Veracruz, México.

VIII. LITERATURE CITED

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IX. APPENDIX – OSTRACODE SPECIES

1. *Actinocythereis gomillionensis* (Howe and Ellis, 1935)
2. *Actinocythereis* sp. cf. *A. gomillionensis* (Howe and Ellis, 1935)
3. *Actinocythereis vineyardensis* (Cushman, 1906)
4. *Ambocythere caudata* Bold, 1966
5. *Ambocythere* sp. cf. *A.* sp. A. Cronin, 1983
6. *Argilloecia posterotruncata* Bold, 1966
7. *Aurila* sp.
8. *Bairdia* sp. aff. *B. longisetosa* Brady, 1902
9. *Bairdoppilata* sp. aff. *B. victrix* (Brady, 1869)
10. *Bairdoppilata* sp.
11. *Basslerites minutus* Bold, 1958
12. *Basslerites*? sp.
13. *Bradleya normani* (Brady, 1865)
14. *Buntonia* sp.
15. *Cativella navis* Coryell and Fields, 1937
16. *Caudites nipeensis* Bold, 1946
17. *Caudites rectangularis* (Brady, 1869)
18. *Cushmanidea sagena* Benson and Kaesler, 1963
19. *Cyprideis salebrosa* Bold, 1963.
20. *Cyprideis* sp. cf. *C. mexicana* Sanberg, 1964
21. *Cytherella vermilionensis* Kontrovitz, 1976
22. *Cytherella* sp. aff. *C. hannai* Howe and Law, 1936

23. *Cytherella* sp. aff. *C. hannai* Howe and Law, 1936 var.
24. *Cytherella* sp. aff. *C. pulchra* Brady, 1866
25. *Cytherella* sp.
26. *Cytherelloidea leonensis* Howe, 1934
27. *Cytherelloidea umbonata* Edwards, 1944
28. *Cytherelloidea* sp. cf. *C. umbonata* Edwards, 1944
29. *Cytheretta anderseni* Butler, 1963
30. *Cytheretta bassleri* Howe, 1935
31. *Cytheretta choctawhatcheensis* Howe and Taylor, 1935
32. *Cytheromorpha warneri* Howe and Spurgeon, 1935
33. *Cytheropteron barkeri* Teeter, 1975
34. *Cytheropteron morgani* Kontrovitz, 1976
35. *Cytheropteron* sp. aff. *C. hamatum* Kontrovitz, 1976
36. *Cytheropteron? yorktownensis* (Malkin, 1953)
37. *Cytherura sandbergi* Morales, 1966
38. *Cytherura wardensis* Howe and Brown, 1935
39. *Cytherura* sp. A
40. *Echinocythereis margaritifera* (Brady, 1870)
41. *Echinocythereis* sp.
42. *Euctythere* sp. aff. *E. triangulata* Puri, 1954 of Howe and Bold, 1975
43. *Eucytherura* sp. 1 Howe and Bold, 1975
44. *Eucytherura* sp. 2 Howe and Bold, 1975
45. *Gangamocytheridea? plicata* Bold, 1968
46. *Haplocytheridea-Peratocytheridea* molts.
47. *Hemicytherid* molts.
48. *Henryhowella* ex. gr. *asperrima* (Reuss, 1849)
49. *Hulingsina semicircularis* (Ulrich and Bassler, 1904)
50. *Hulingsina* sp. 1.
51. *Hulingsina* sp. 2.
52. *Hulingsina* sp. 3.
53. *Kangarina ancyla* Bold, 1963
54. *Krithe trinidadensis* Bold, 1958
55. *Loxoconcha matagordensis* Swain, 1955
56. *Loxoconcha wilberti* Puri, 1954
57. *Loxoconcha* sp. aff. *L. helenae* Crouch, 1949
58. *Loxoconcha* sp. A Hazel, 1977
59. *Loxocorniculum tricornatum* Krutak, 1971
60. *Luvula gigarton* Bold, 1966
61. *Macrocyprina propinqua* Triebel, 1960
62. *Malzella conradi* (Howe and McGuirt, 1935)
63. *Megacythere repexa* Garbett and Maddocks, 1979)
64. *Microcytherura choctawhatheensis* (Puri, 1954)
65. *Munseyella bermudezi louisianensis* Kontrovitz, 1976
66. *Mutilus?* sp.
67. *Neocaudites scottae* Teeter, 1975
68. *Orionina vaughani* (Ulrich and Bassler, 1904)
69. *Paracypris* sp. cf. *P. choctawhatcheensis* Puri, 1954
70. *Paracypris* sp. cf. *P. franquesi* Howe and Chambers, 1935
71. *Paracytheridea tschoppi* Bold, 1946
72. *Paracytheridea* sp.
73. *Parakrithe* sp. 1.
74. *Parakrithe* sp. 2.
75. *Pellucistoma magniventra* Edwards, 1944
76. *Perissocytheridea bicelliforma* Swain, 1955
77. *Perissocytheridea subrugosa* (Brady, 1870)
78. *Pseudopsammocythere vicksburgensis* Howe and Law, 1936
79. *Pterygocythereis alophia* Hazel, 1983
80. *Pterygocythereis inexpectata* (Blake, 1929)
81. *Pterygocythereis* sp. 1.
82. *Puriana rugipunctata gatunensis* (Coryell and Fields, 1937)
83. *Puriana* sp. 1
84. *Puriana* molts.
85. *Quadracythere compacta* (Brady?) Bold, 1975.
86. *Radimella confragosa* (Edwards, 1944)
87. *Thalassocypria?* sp.
88. *Touroconcha lapidiscola* (Hartmann, 1959)
89. *Xestoleberis* sp. 1
90. *Xestoleberis* sp. 2

December 15, 1986

REVIEW

STORM DEPOSITIONAL SYSTEMS, by Thomas Aigner. Lecture Notes in Earth Sciences, 3: Published by Springer-Verlag, Berlin, Heidelberg, New York, and Tokyo, 1985, viii + 174 pp., illus., paper, $14.50

In this volume, the geological effects of storms and hurricanes are investigated and their role as tools in facies and paleogeographical analysis is explored. In part one, case studies of modern carbonate and terrigenous clastic storm sedimentation are presented. Models are derived which can be used in the interpretation of ancient analogues. Part two is an analysis of an ancient storm depositional system (the Muschelkalk) on a basin-wide scale.

–HCS