PALEOECOLOGIC AND BIOSTRAIGRAPHIC MODELS FOR PLEISTOCENE THROUGH MIOCENE FORAMINIFERAL ASSEMBLAGES OF THE GULF COAST BASIN

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ABSTRACT

Operationally oriented paleoecologic models for Pleistocene through Miocene foraminifera utilized in hydrocarbon exploration of the Gulf Coast Basin are developed, along with an updated, refined biostratigraphic chart. Estimated paleoecologic tolerances for major benthic and planktic foraminiferal markers are also presented. A number of rules and problems encountered in oil industry paleoenvironmental reconstruction are discussed.

Key benthic paleoenvironmental markers for particular depth zones of the Plio-Pleistocene and Miocene are graphically presented. Improvements over previous models include greater utilization of calcareous and arenaceous foraminiferal species not used, recognized, or reported in earlier studies.

Finer subdivisions of bathyal paleoenvironments are recognized and are of particular significance due to current Gulf of Mexico deep water exploration. Operationally, the abyssal environment is difficult to recognize due to the lack of abyssal zone markers and a reliance on faunal abundance to delineate abyssal from bathyal.

A number of genera and species are identified as having changed habitat preference through time. Some forms have moved progressively into deeper water (*Ceratobulimina*, *Cyclammina cancellata*, and *Nonion pompilioides*). Conversely, the movement of species into progressively shallower occurrences through time (*Pullenia bulloides*) appears to be less common.

The widespread occurrence of known Gulf of Mexico foraminiferal species from countries such as Mexico, Venezuela, Ecuador, Jamaica, Trinidad, Haiti, the Dominican Republic, and Cuba suggests that these models have direct application to Neogene and Pleistocene studies in Central and South America, and the Caribbean, as well as the US Gulf Coast.

A variety of deep water benthic marker foraminifera are introduced, many for the first time. These taxa help fill in gaps for deeper water sections where standard benthic marker foraminifera do not occur. This will help debunk the popular myth that benthic foraminifera are useless as markers in the exploration of deep water sections.

INTRODUCTION

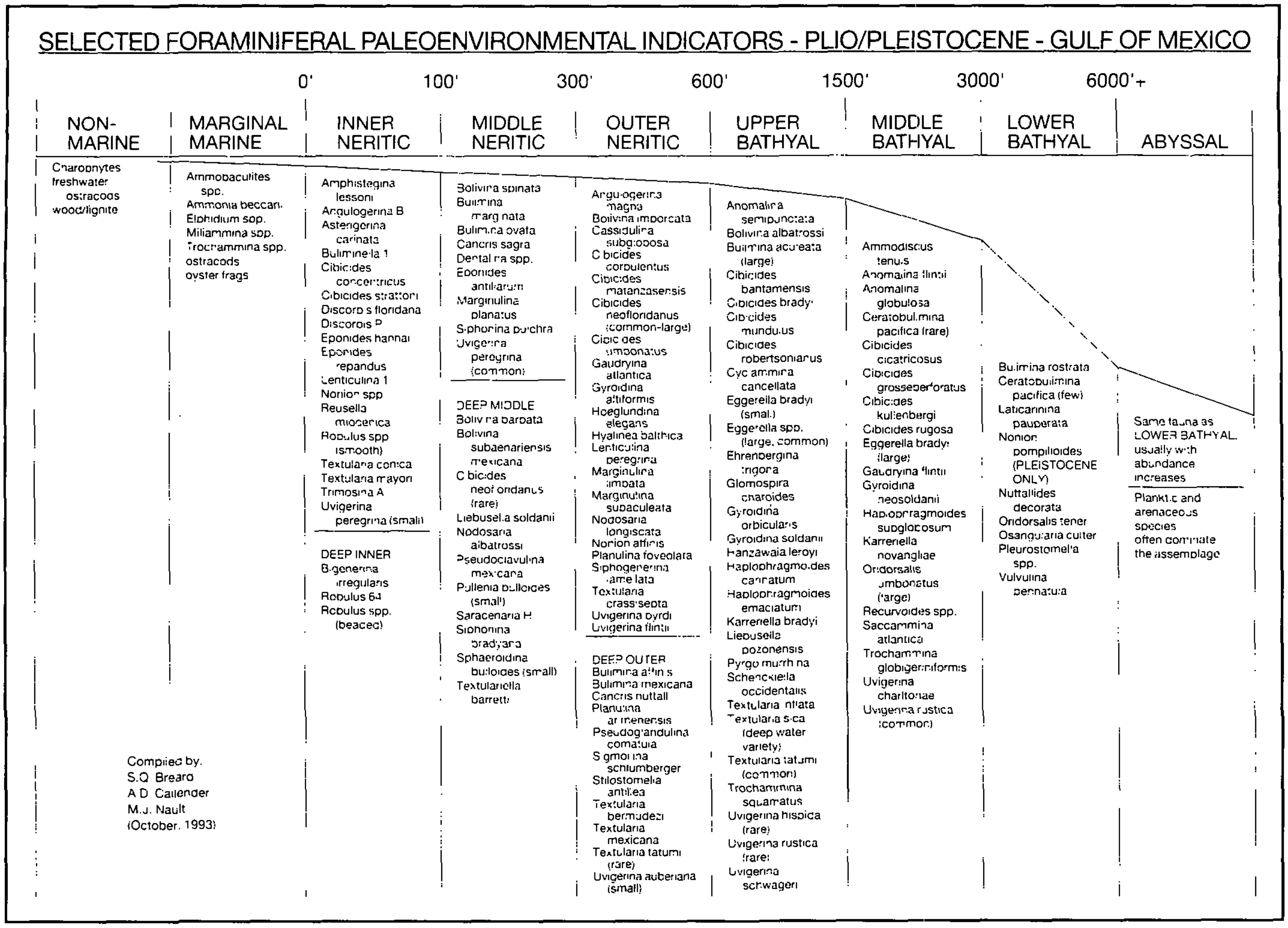
Over the years, numerous foraminiferal paleoecologic models have been proposed for the late Tertiary and Pleistocene strata in the Gulf Coast (Crouch, 1965; Albers et al., 1966; Poag and Valentine, 1976; Skinner, 1966; Smith, 1991). Drawing on these sources, plus the combined experience gained from various oil and gas exploration companies with which the writers have been employed (Amoco, Arco, BPX, Chevron, Sohio, Tenneco and Texaco), we present an updated model for foraminiferal ecology and biostratigraphy. Charts illustrating key paleoenvironmental marker species for Miocene, Pliocene, and Pleistocene strata are presented, as well as paleoenvironmental range charts for key biostratigraphic marker species. The Neogene and Pleistocene biochronostratigraphy is also updated for deep water zones.

Our objective is to provide operationally oriented models for determining environments from well cuttings. The models are based on a combination of literature (Phleger, 1960; Walton, 1964; Loep, 1965; Pflum and Frerichs, 1976; Lamb, 1981; Poag, 1981) plus thousands of (unpublished) observations from many hundreds of wells examined by the writers in the Gulf Coast Basin.

Improvements over previous models include greater utilization of arenaceous taxa, addition of more recently recognized deep water calcareous taxa, and finer subdivisions of the bathyal realm. Many of these improvements are drawn from recent experience with deep water biostratigraphy and paleoecology of the Flexure Trend and deeper areas of the Gulf of Mexico. The charts provided should prove useful to future generations of micropaleontologists,stratigraphers and geologists in domestic exploration and may also prove beneficial to international explorationists.

FORAMINIFERAL PALEOECOLOGY

The literature of foraminiferal paleoecologic studies is vast, much of that published being based on the modern Gulf of Mexico. A basic assumption to be addressed in a later section is that many of the ecologically relevant taxa have maintained that preference of environment through time. Although recognizing the fossil ecologic analogs of modern foraminifera can be a problem, it is diminished when dealing with species no older than the Miocene, when benthic and planktic communities began to modernize (Poag, 1977).



SELECTED FORAMINIFERAL PALEOENVIRONMENTAL INDICATORS - PLIO/PLEISTOCENE - GULF OF MEXICO

0' 100' 300' 600' 1500' 3000' 6000'+

NON-MARINE
- Charophytes
- freshwater ostracods
- wood/lignite

MARGINAL MARINE
- Ammobaculites spp.
- Ammonia beccarii
- Elphidium spp.
- Miliammina spp.
- Trochammina spp.
- ostracods
- oyster frags

INNER NERITIC
- Amphistegina lessoni
- Angulogerina B
- Asterigerina carinata
- Buliminella 1
- Cibicides concentricus
- Cibicides strattoni
- Discorbis floridana
- Discorbis P
- Eponides hannai
- Eponides repandus
- Lenticulina 1
- Nonion spp
- Reusella miocenica
- Robulus spp (smooth)
- Textularia conica
- Textularia mayori
- Trimosina A
- Uvigerina peregrina (small)

DEEP INNER
- Bigenerina irregularis
- Robulus 64
- Robulus spp. (beaded)

MIDDLE NERITIC
- Bolivina spinata
- Bulimina marginata
- Bulimina ovata
- Cancris sagra
- Dentalina spp.
- Eponides antillarum
- Marginulina planatus
- Siphonina pulchra
- Uvigerina peregrina (common)

DEEP MIDDLE
- Bolivina barbata
- Bolivina subaenariensis mexicana
- Cibicides neofloridanus (rare)
- Liebusella soldanii
- Nodosaria albatrossi
- Pseudoclavulina mexicana
- Pullenia bulloides (small)
- Saracenaria H
- Siphonina bradyana
- Sphaeroidina bulloides (small)
- Textulariella barretti

OUTER NERITIC
- Angulogerina magna
- Bolivina imporcata
- Cassidulina subglobosa
- Cibicides corpulentus
- Cibicides matanzasensis
- Cibicides neofloridanus (common-large)
- Cibicides umbonatus
- Gaudryina atlantica
- Gyroidina altiformis
- Hoeglundina elegans
- Hyalinea balthica
- Lenticulina peregrina
- Marginulina limbata
- Marginulina subaculeata
- Nodosaria longiscata
- Nonion affinis
- Planulina foveolata
- Siphogenerina lamellata
- Textularia crassisepta
- Uvigerina byrdi
- Uvigerina flintii

DEEP OUTER
- Bulimina affinis
- Bulimina mexicana
- Cancris nuttalli
- Planulina ariminensis
- Pseudoglandulina comatula
- Sigmoilina schlumbergeri
- Stilostomella antillea
- Textularia bermudezi
- Textularia mexicana
- Textularia tatumi (rare)
- Uvigerina auberiana (small)

UPPER BATHYAL
- Anomalina semipunctata
- Bolivina albatrossi
- Bulimina aculeata (large)
- Cibicides bantamensis
- Cibicides bradyi
- Cibicides mundulus
- Cibicides robertsonianus
- Cyclammina cancellata
- Eggerella bradyi (small)
- Eggerella spp. (large, common)
- Ehrenbergina trigona
- Glomospira charoides
- Gyroidina orbicularis
- Gyroidina soldanii
- Hanzawaia leroyi
- Haplophragmoides carinatum
- Haplophragmoides emaciatum
- Karreriella bradyi
- Liebusella pozonensis
- Pyrgo murrhina
- Schenckiella occidentalis
- Textularia inflata
- Textularia sica (deep water variety)
- Textularia tatumi (common)
- Trochammina squamatus
- Uvigerina hispida (rare)
- Uvigerina rustica (rare)
- Uvigerina schwageri

MIDDLE BATHYAL
- Ammodiscus tenuis
- Anomalina flintii
- Anomalina globulosa
- Ceratobulimina pacifica (rare)
- Cibicides cicatricosus
- Cibicides grosseperforatus
- Cibicides kullenbergi
- Cibicides rugosa
- Eggerella bradyi (large)
- Gaudryina flintii
- Gyroidina neosoldanii
- Haplophragmoides subglobosum
- Karreriella novangliae
- Oridorsalis umbonatus (large)
- Recurvoides spp.
- Saccammina atlantica
- Trochammina globigeriniformis
- Uvigerina charltonae
- Uvigerina rustica (common)

LOWER BATHYAL
- Bulimina rostrata
- Ceratobulimina pacifica (few)
- Laticarinina pauperata
- Nonion pompilioides (PLEISTOCENE ONLY)
- Nuttallides decorata
- Oridorsalis tener
- Osangularia culter
- Pleurostomella spp.
- Vulvulina pennatula

ABYSSAL

Same fauna as LOWER BATHYAL usually with abundance increases

Planktic and arenaceous species often dominate the assemblage

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(October, 1993)

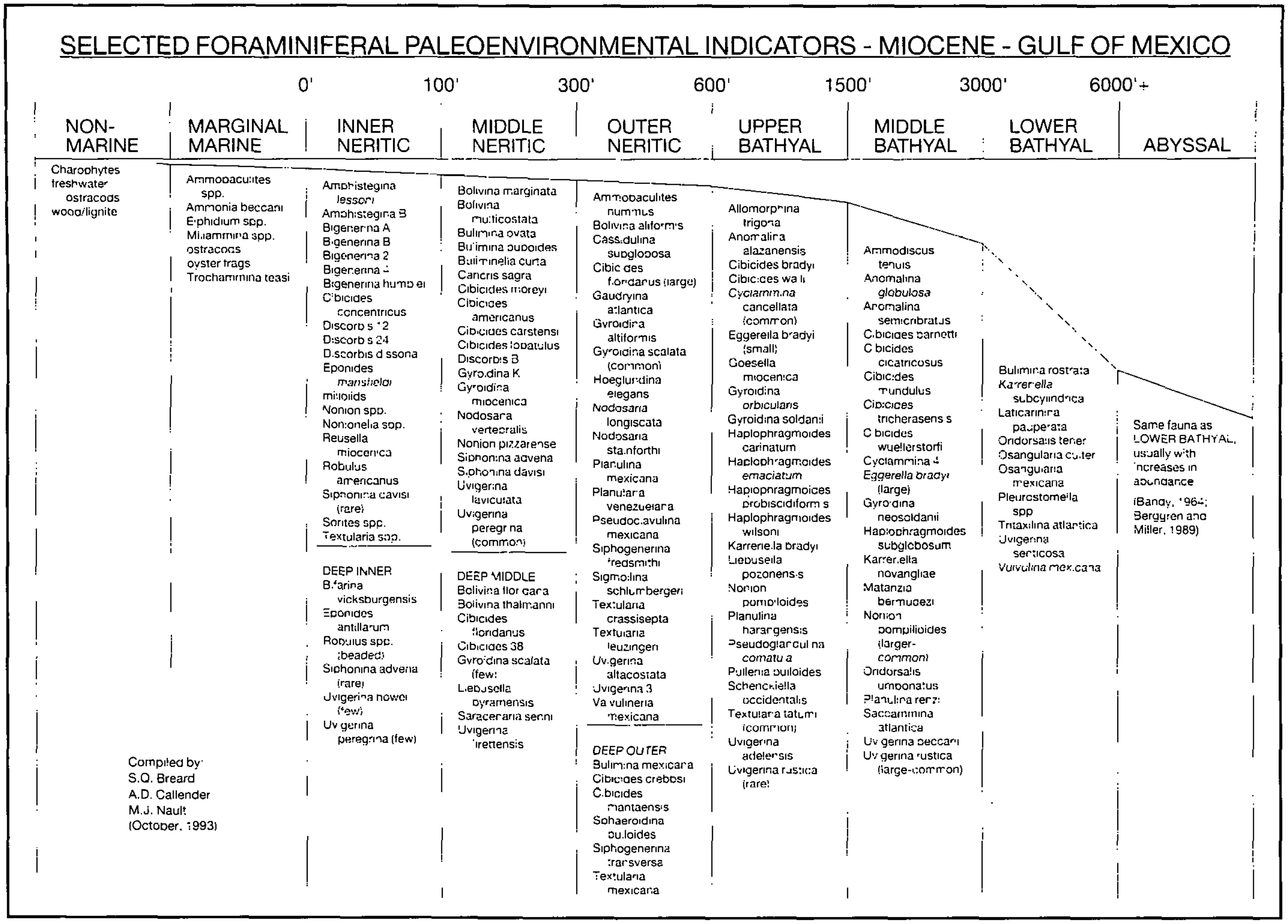
Figure 1. - Selected foraminiferal paleoenvironmental indicators for the Pliocene and Pleistocene of the Gulf Coast Basin.

Poag (1981) has shown that temperature and salinity are major factors in the distribution of living foraminifera. Other factors include substrate, food supply, and pressure to name a few. While most of these factors are difficult to measure, especially in more ancient sediments, the relative depth relationship of faunal assemblages and species are more easily determined. Crouch (1955) states that no exact depth relation is implied by his Miocene zonation. In other words, the assigned depth zones are relative - Zone B is deeper than Zone A. Consequently, an outer shelf zone in the lower Miocene may differ in exact depth limitations from an outer shelf zone in the Pleistocene. Changes through time in temperature, currents, sediment type, water mass, rates of deposition, and basin configuration all affect the microfaunal assemblages.

KEY ENVIRONMENTAL MARKERS VERSUS ASSEMBLAGES

Few foraminiferal species are limited to a single environment (Walton, 1964; Murray, 1974). Among the most valuable taxa are those with either very limited ecological tolerances (very rare, excepting some brackish water species), or those with known upper depth limits (Pflum and Frerichs, 1976). The enclosed environmental charts (Figs. 1 and 2) list Miocene and Plio-Pleistocene species identified either in the literature or by the writers as characteristic of particular zones. Zonations which rely on genera only (Culver, 1988; Smith, 1991) are less accurate from an operational vantage due to two factors: time limits for evaluation (short) and occurrence of genera with wide bathymetric ranges (most). For example, the benthic genus *Uvigerina* ranges from abyssal depths up into the inner shelf. Species within this genus have more specific ranges. For example, *Uvigerina rustica* ranges from abyssal to upper bathyal; *Uvigerina flintii* ranges from upper bathyal to outer neritic; and *Uvigerina howei* is typical only of the neritic zones.

Assemblages are very useful, probably being more accurate than key zonal markers, because of the mixed nature of well cuttings. A good example of microfaunal assemblages is provided by Puri (1953). Examining Figure 7 of that paper, it is possible for an experienced paleontologist to determine relative bathymetry (shallow vs. deep) by the figured species. By knowing general diversity and abundance trends of various species and assemblages (Walton, 1964), we are also able to estimate ranges for either new or unpublished taxa.



SELECTED FORAMINIFERAL PALEOENVIRONMENTAL INDICATORS - MIOCENE - GULF OF MEXICO

0' 100' 300' 600' 1500' 3000' 6000'+

NON-MARINE	MARGINAL MARINE	INNER NERITIC	MIDDLE NERITIC	OUTER NERITIC	UPPER BATHYAL	MIDDLE BATHYAL	LOWER BATHYAL	ABYSSAL
Charophytes freshwater ostracods wood/lignite	Ammobaculites spp. Ammonia beccarii Elphidium spp. Miliammina spp. ostracods oyster frags Trochammina teasi	Amphistegina *lessoni* Amphistegina B Bigenerina A Bigenerina B Bigenerina 2 Bigenerina 4 Bigenerina humblei Cibicides concentricus Discorbis 12 Discorbis 24 Discorbis dissona Eponides *mansfieldi* miliolids Nonion spp. Nonionella spp. Reusella miocenica Robulus americanus Siphonina davisi (rare) Sorites spp. Textularia spp.	Bolivina marginata Bolivina multicostata Bulimina ovata Bulimina puboides Buliminella curta Cancris sagra Cibicides moreyi Cibicides americanus Cibicides carstensi Cibicides lobatulus Discorbis B Gyroidina K Gyroidina miocenica Nodosaria vertebralis Nonion pizzarense Siphonina advena Siphonina davisi Uvigerina laviculata Uvigerina peregrina (common)	Ammobaculites nummus Bolivina aliformis Cassidulina subglobosa Cibicides floridanus (large) Gaudryina atlantica Gyroidina altiformis Gyroidina scalata (common) Hoeglundina elegans *Nodosaria* longiscata Nodosaria stainforthi Planulina mexicana Planularia venezuelana Pseudoclavulina mexicana Siphogenerina fredsmithi Sigmoilina schlumbergeri Textularia crassisepta Textularia leuzingeri Uvigerina altacostata Uvigerina 3 Valvulineria mexicana	Allomorphina trigona Anomalina alazanensis Cibicides bradyi Cibicides walli *Cyclammina* cancellata (common) Eggerella bradyi (small) Goesella miocenica Gyroidina *orbicularis* Gyroidina soldanii Haplophragmoides carinatum Haplophragmoides *emaciatum* Haplophragmoides probisciformis Haplophragmoides wilsoni Karreriella bradyi Liebusella pozonensis Nonion pompilioides Planulina harangensis Pseudoglandulina *comatula* Pullenia bulloides Schenckiella occidentalis Textularia tatumi (common) Uvigerina adelensis Uvigerina rustica (rare)	Ammodiscus tenuis Anomalina *globulosa* Anomalina semicribratus Cibicides barnetti Cibicides cicatricosus Cibicides mundulus Cibicides tricherasensis Cibicides wuellerstorfi Cyclammina 4 *Eggerella bradyi* (large) Gyroidina neosoldanii Haplophragmoides subglobosum Karreriella novangliae Matanzia bermudezi Nonion pompilioides (larger-*common*) Oridorsalis umbonatus Planulina renzi Saccammina atlantica Uvigerina beccarii Uvigerina rustica (large-common)	Bulimina rostrata *Karrerella* subcylindrica Laticarinina pauperata Oridorsalis tener Osangularia culter Osangularia mexicana Pleurostomella spp Tritaxilina atlantica Uvigerina senticosa *Vulvulina mexicana*	Same fauna as LOWER BATHYAL, usually with increases in abundance (Bandy, 1964; Berggren and Miller, 1989)
		DEEP INNER Bifarina vicksburgensis Eponides antillarum Robulus spp. (beaded) Siphonina advena (rare) Uvigerina howei (few) Uvigerina peregrina (few)	DEEP MIDDLE Bolivina floridana Bolivina thalmanni Cibicides floridanus Cibicides 38 Gyroidina scalata (few) Liebusella pyramensis Saracenaria senni Uvigerina irettensis	*DEEP OUTER* Bulimina mexicana Cibicides crebbsi Cibicides mantaensis Sphaeroidina bulloides Siphogenerina transversa Textularia mexicana				

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Figure 2. - Selected foraminiferal paleoenvironmental indicators for the Miocene of the Gulf Coast Basin

ABYSSAL PALEOENVIRONMENTS

In general, abyssal paleoenvironments are poorly known in the Gulf of Mexico (GOM) fossil record and rarely described from literature of the Gulf Coast Basin. Previously published abyssal zonations (Albers et al., 1966; Tipsword et al., 1966) list species with occurrence ranges into the bathyal, such as *Nonion pompilioides, Osangularia culter, Cibicides wuellerstorfi,* and *Uvigerina senticosa.* Earlier zonations (Crouch, 1955; Loep, 1965) did not separate abyssal from bathyal.

Pflum and Frerichs (1976) list nine sample stations in their GOM study below 6000 feet. All taxa listed have upper depth limits in the bathyal realm. Two species, *Uvigerina senticosa* and *Nonion pompilioides,* are listed as characteristic of the abyssal zone. While accurate for the modern GOM, we have observed *Uvigerina senticosa* in the lower bathyal and small *Nonion pompilioides* as shallow as upper bathyal in Miocene sections.

Bandy (1964) states that lower bathyal zone foraminiferal assemblages are generally about the same as the abyssal zone faunas. Berggren and Miller (1989) note that abyssal biofacies are distinguished from bathyal primarily upon abundances. As a matter of fact, **AB12**, the youngest abyssal zone of Berggren and Miller (1989), ranges from the base of **N12-N23**, which covers the entire Plio-Pleistocene and over a third of the Miocene, and lists no abyssal extinction markers for that lengthy zone (over 11 million years).

Although benthic foraminifera have been recorded from the hadal zone (16,000 feet or deeper) by Bandy (1967) and Haynes (1981), we lack knowledge of definitive abyssal-only marker species. From an operational viewpoint, we therefore submit that the abyssal zone in the Gulf Coast Neogene and Pleistocene section is too poorly known or defined to be recognized with confidence. It is probable that reliable markers for the abyssal zone will eventually be found among the arenaceous foraminifera (see Hemleben, et al., 1990).

GENERAL RULES FOR INDUSTRY PALEOENVIRONMENTAL DETERMINATION

A few general rules are applicable for accurate determination of paleoenvironments with well cuttings:

1. The more abundant or diverse the fauna, the greater the potential accuracy of the environment picked.
2. Generally, one should emphasize the deepest dwelling species of an assemblage.
3. Reworking of shallow water species into deeper settings is common, considering the nature and origin of turbidites (Bandy and Arnal, 1960). For example, it is

not unusual to find the brackish species *Ammonia beccarii* and lignite in bathyal faunal assemblages due to downslope transport.

4. It is common to encounter samples from sandy turbidite, storm or slump deposits within bathyal settings with scarce to near-absent microfauna (eg., diluted fauna of Trenchard, 1968).
5. It is felt that planktic/benthic ratios (or planktic abundance curves) are relative, but not precise, paleoenvironmental indicators (Grimsdale and van Morkhoven, 1955; Ventress, 1991). Although planktic floods have been considered to be slope and deeper (Smith, 1991), we have observed floods of *Globigerina* and *Globigerinoides* spp. on the shelf. However, floods of *Orbulina* do occur most commonly in the bathyal range.
6. Increases in relative abundance of foraminifera in sediments reflect not only deepening, but slower rates of sedimentation (Moore, 1955). These abundance increases often occur in association with maximum flood surfaces.
7. Sudden paleoenvironmental changes (for example, from middle to deep outer neritic) without expected intermediate environments are suggestive of faults, unconformities, or possible gouge (Glaessner, 1955; Poag, 1977; Ventress, 1991).

PROBLEMS IN INDUSTRY PALEOENVIRONMENTAL STUDIES

A number of factors, many involving drilling and sample quality, can inhibit accuracy in paleoenvironmental interpretation:

1. Drilling Mud Additives - A great variety of additives, including mica, barite, calcite, gypsum, bentonite, glass, lignite, silica beads, nutplug, sand, and gilsonite are found in well cuttings. Abundant additive influxes reduce or obscure the microfauna within a sample.
2. Casing Cement - Cement usually obscures microfauna 30 to several hundred feet beyond casing point.
3. Bypass - On occasion, well cuttings bypass the shale shaker; hence no sample and no environment (see Poag, 1977).
4. Downhole Contamination - As drilling mud circulates through the wellbore, it carries previously drilled and washed out formation fragments uphole, contaminating the well with younger sediments and microfauna. Failure to recognize "caving" can cause paleoecological calls to be inaccurate (Poag, 1977).
5. Environmental Mixing - Various physical processes (storms, turbidites, slumps, etc.) can mix species of different (shallower and deeper) assemblages together. With experience, biostratigraphers will usually recognize mixing. Jones (1956) lists several methods for recognition of ecologically or stratigraphically mixed faunas.

HABITAT CHANGE THROUGH TIME

Through millions of years of evolution and adaptation, various marine taxa have changed or readjusted to new habitats. Dunlap (1981) observes that, in spite of the study by Boltovsky (1980) indicating middle bathyal similarities of Oligocene and Quaternary faunas, a few exceptions do exist. Berggren and Miller (1989) state that a number of benthic foraminiferal species have changed depth distribution, migrating into deeper water niches over time. For example the Eocene Claiborne species *Melonis planatum* was found by Gaskell (1989) to be characteristic of and abundant in transitional zones between normal and brackish facies of the Wheelock Member, Cook Mountain Formation in Houston County, Texas. The closely related *Nonion* (*Melonis*) *affinis* of the Neogene is a characteristic outer shelf to bathyal species (Poag, 1981).

Robinson (1970) describes the bathymetric fluctuations of the arenaceous genus *Cyclammina*, observing that it extends into the neritic zone in Miocene sections, and becomes progressively rarer and deeper in Pliocene to younger faunas. Akers (1954) notes that recent *Cyclammina cancellata* occurs no shallower than 1,500 ft, considerably deeper than Miocene occurrences.

Documentation of the bathymetric travels of the calcareous benthic genus *Ceratobulimina* is revealing. Early species, such as *C. cretacea*, *C. perplexa* and *C. eximia* of the Late Cretaceous to middle Eocene, are limited to inner and middle shelf environs (Bandy, 1949; Tipsword, 1962; Sliter and Baker, 1972). *Ceratobulimina alazanensis*, which appears in the late Eocene, moves into outer shelf and possibly upper bathyal by middle Oligocene (Hackberry facies; Garrett, 1938). We have observed *C. alazanensis* (rarely) in middle shelf faunas of the lower Miocene. Whittaker (1988) documents *C. alazanensis* from Ecuador (**N7-N12**), but gives no paleoenvironmental data. By late Miocene, most occurrences of *Ceratobulimina* are limited to the bathyal. The species *Ceratobulimina pacifica* is restricted to middle and lower bathyal by Pliocene and early Pleistocene in the Gulf of Mexico, and is bathyal only in modern oceans (Barker, 1960).

Although *Nonion pompilioides* is typically considered a lower slope to abyssal species (Albers et al., 1966; Tipsword et al., 1966), we have documented Miocene occurrences of *N. pompilioides* in an upper bathyal realm, and small forms within outer shelf faunas having no other bathyal species. Berggren (1987) documents the fluctuations of *N. pompilioides*, ranging from outer neritic to upper bathyal (mid to late Oligocene), but as deep as lower bathyal to abyssal only since the middle Miocene. Late Pleistocene well sample occurrences of this species are usually lower bathyal, but in the recent Gulf of Mexico fauna, *N. pompilioides* is limited to the abyssal zone (Pflum and Frerichs, 1976).

An example of the reverse trend is provided by *Pullenia bulloides*. This species, which ranges into deep middle neritic in the Pleistocene, is more typical of upper bathyal to deep outer neritic in the Miocene (shallowest occurrences).

Berggren and Miller (1989) document the migration of several foraminiferal genera into the bathyal zone, including species of *Uvigerina*, *Melonis*, *Siphonina*, and *Planulina* in the Eocene, and Sphaeroidina in the Oligocene. To this list we can add *Ceratobulimina* in the late Miocene. While it is apparent that selected genera have migrated to new habitats through time, this does not diminish their value in paleobathymetric models.

As long as micropaleontologists carefully document the faunas, the overall assemblage should dictate the accuracy of the paleoenvironment in which these species occur.

APPLICATION BEYOND THE GULF OF MEXICO

One of the great values of the paleoecologic models presented here is its potential usage in areas outside the immediate Gulf Coast Basin. One clue to this potential is a perusal of the foraminiferal literature of Central and South America and the Caribbean region.

Several recent publications on Mexico (Sansores and Flores-Covarrubias, 1972; Kohl, 1985) list numerous Neogene species found in U.S. Gulf Coast sections. Literature on Venezuela (Hedberg, 1937; Franklin, 1944; Renz, 1948) list many species used in our models. Galloway and Morey (1929) and Whittaker (1988) are valuable references for microfaunal studies of Ecuador, listing many species common to both regions.

The various Caribbean islands have had many deep water faunas described. Countries with listings of many species common to both regions include Cuba (Hadley, 1934; Palmer and Bermudez, 1936), Jamaica (Cushman and Jarvis, 1930; Cushman and Todd, 1945), Haiti (Coryell and Rivero, 1940), the Dominican Republic (Bermudez, 1949), and Trinidad (Cushman and Stainforth, 1945; Bolli, 1957). These references have been especially useful for workers in the deep water sections of the US Gulf of Mexico, as few deep water faunas, excepting Leroy and Levison (1974) and Leroy and Hodgkinson (1975), have been described. The list of references presented here is by no means comprehensive. Kohl (1985) and Whittaker (1988) should be referred to for complete bibliographies.

Recent studies of bathyal foraminiferal fauna (van Morkhoven et al., 1986; Berggren and Miller, 1989) suggest widespread, if not global uniformity in deep water fauna. Therefore, our paleoecologic models would appear to have value in microfaunal studies of Central and South America and the Caribbean region, and the bathyal portion of the models may have a worldwide application.

MIOCENE THROUGH PLEISTOCENE MICROFAUNAL BIOSTRATIGRAPHY

Although a complete evaluation and description of foraminiferal biostratigraphy is beyond the scope of this paper, it is necessary to update previously described zonations and to introduce several deep water markers to fill in biostratigraphic gaps left by use of commonly known shelf-dwelling "tops". The combination of standard benthic markers, planktic foraminifera and nannoplankton extinctions with these bathyal horizons achieves greater resolution than previously possible. Recently published charts with which this zonation can be compared include Skinner (1972), Poag and Valentine (1976), Poag (1977), Stude (1984), Dunlap (1988), and Ventress (1991).

The basic zonation presented here (Figs. 3 and 4) differs little from above noted schemes other than integrating new markers, selected locals, and less frequently used planktic species. It is placed within a nannofossil framework similar to that of Dunlap (1988) and Ventress (1991). This zonation is by no means comprehensive. Many other local markers, acmes, and increases are known within the industry. Poag (1977) states that perhaps thousands of additional local zones are extensively used for correlation in the Gulf Coast Basin.

A relatively new marker, *Ehrenbergina* fauna, based on the local occurrence of *Ehrenbergina trigona* with other associated fauna, denotes the upper Pleistocene Sangamon interval in the bathyal zone. A faunal increase lacking *E. trigona* is characteristic for the same interval in the neritic zone. Another calcareous species, *Stilostomella antillea*, has been used as downdip equivalent (approximate) to *Trimosina* A, a neritic species. In bathyal sections, *S. antillea* occurs without *Trimosina* A. In sections where both species can be expected to occur, *S. antillea* will typically be found just below the **LAD** (Last Appearance Datum) or extinction of *Trimosina* A.

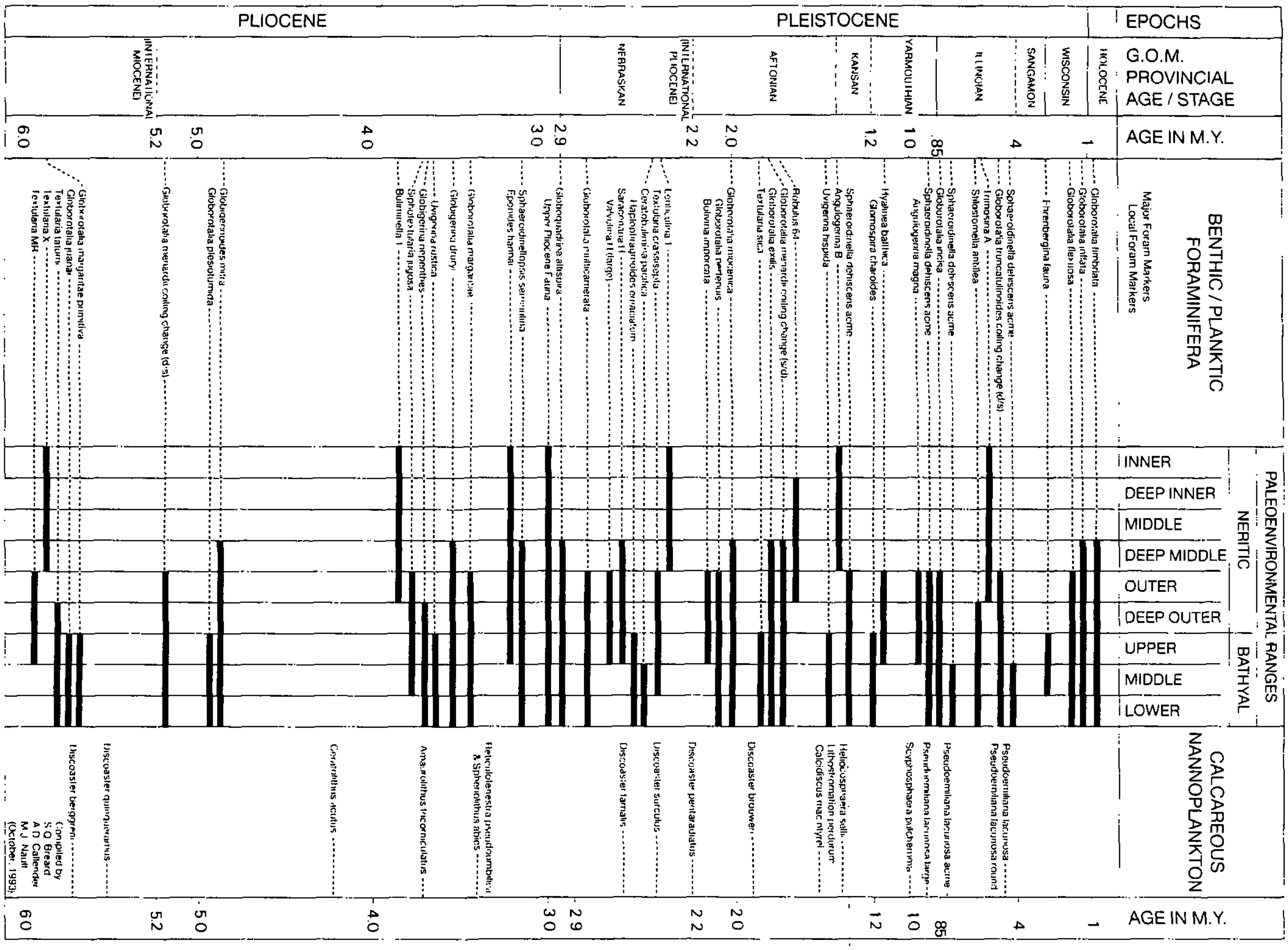
A local increase (acme) of *Glomospira charoides*, a bathyal arenaceous species, is noted in a number of downdip well, stratigraphically below the **LAD** of *Hyalinea balthica* in the Gulf of Mexico. This acme is absent on the shelf. Another bathyal species, *Uvigerina hispida*, occurs within a deepening of the Aftonian. It is a good bathyal equivalent for *Angulogerina* B, a neritic species, and often occurs with a planktic foraminiferal flood, especially *Sphaeroidinella dehiscens*.

The deep water morphotype of *Textularia sica* is very diagnostic of upper to middle bathyal deposits younger than the **LAD** of *Globorotalia miocenica*. The geographically widespread *T. sica* has been noted from East Breaks eastward to Mississippi Canyon in the Gulf of Mexico.

Two foraminifera, *Ceratobulimina pacifica* and *Haplophragmoides emaciatum*, are useful markers of expanded lower Pleistocene bathyal intervals. *Ceratobulimina pacifica* typically appears within a middle to lower bathyal deepening, as part of a significant faunal influx. Conversely, *Haplophragmoides emaciatum* usually appears within lower diversity, sand-rich expanded sections below the *C. pacifica* horizon. Arenaceous extinctions and local acmes have not been published as extensively in the Gulf Coast Basin. A recent exception is the paper by Rosen and Hill (1990), which employs arenaceous assemblages to define Pliocene sequences in the GOM.

Another bathyal species, *Uvigerina rustica*, helps delineate the *Globigerina druryi* - *Globigerina nepenthes* section of the Pliocene. Best developed in middle to lower bathyal waters, *U. rustica* becomes extinct with or just above the **LAD** of *G. nepenthes*. Floods of *Orbulina universa* may be locally correlative in lower to middle bathyal settings in the Pliocene and Miocene (Poag, 1977).

The GOM Miocene-Pliocene boundary is possibly the most contentious of any time-stratigraphic boundary worldwide. The two uppermost Miocene benthic markers in most industry schemes are *Robulus* E and *Bigenerina* A, both neritic species. In a slope setting, various planktic taxa, both foraminifera and nanno-



Compiled by
S.O. Breard
A.D. Callender
M.J. Nault
(October, 1993)

Figure 3. - Microfaunal biostratigraphy and paleoenvironmental ranges of marker foraminifera of Pliocene and Pleistocene strata of the Gulf Coast Basin

plankton, have been utilized. Rainwater (1964) contends that no valid criteria exist for determination of the Miocene-Pliocene boundary in the Gulf Coast. However, several lower bathyal benthic foraminifera occur near or just below the top of the Miocene, including *Planulina renzi*, and the somewhat older *Tritaxilina atlantica*. Another bathyal event, a local acme of *Nonion pompilioides*, appears to be a near equivalent to the neritic marker *Cristellaria* K. A number of bathyal benthic foraminifera became extinct in the Miocene (van Morkhoven et al., 1986; Berggren and Miller, 1989), and should provide biostratigraphers with future topics of study, as their relationships within established zonations are discovered, hopefully through continued deep water exploration.

PALEOENVIRONMENTAL RANGES OF MARKER SPECIES

Despite the extensive literature on foraminifera, no single published source exists for paleoenvironmental tolerance data of marker species of the Gulf Coast Basin. Tipsword et al. (1966) state that the best marker species are those with the greatest tolerance for many different environments, but poor as paleoecologic indicators. Tipsword (1962) describes key faunal components of marker faunas, but gives scant data on paleoenvironments. Dunlap (1988) notes that traditional benthic markers progressively disappear downdip, and must be replaced by planktic zonal indicators.

Because it is vital for all geologists and geophysicists to understand that marker species have environmental constraints, we have included in Figures 3 and 4, the usable paleoenvironmental range of each marker listed. The ranges presented are primarily based on many thousands of observations by the authors during the nearly 50 years cumulative experience with various oil companies and as consulting micropaleontologists/biostratigraphers. No such chart could claim complete accuracy, but as information documented here is based on a wealth of data from wells spanning the Gulf Coast Basin, both onshore and offshore, we feel it will be a valuable interpretive tool for exploration and production geoscientists in their search for the increasingly elusive hydrocarbon reservoir.

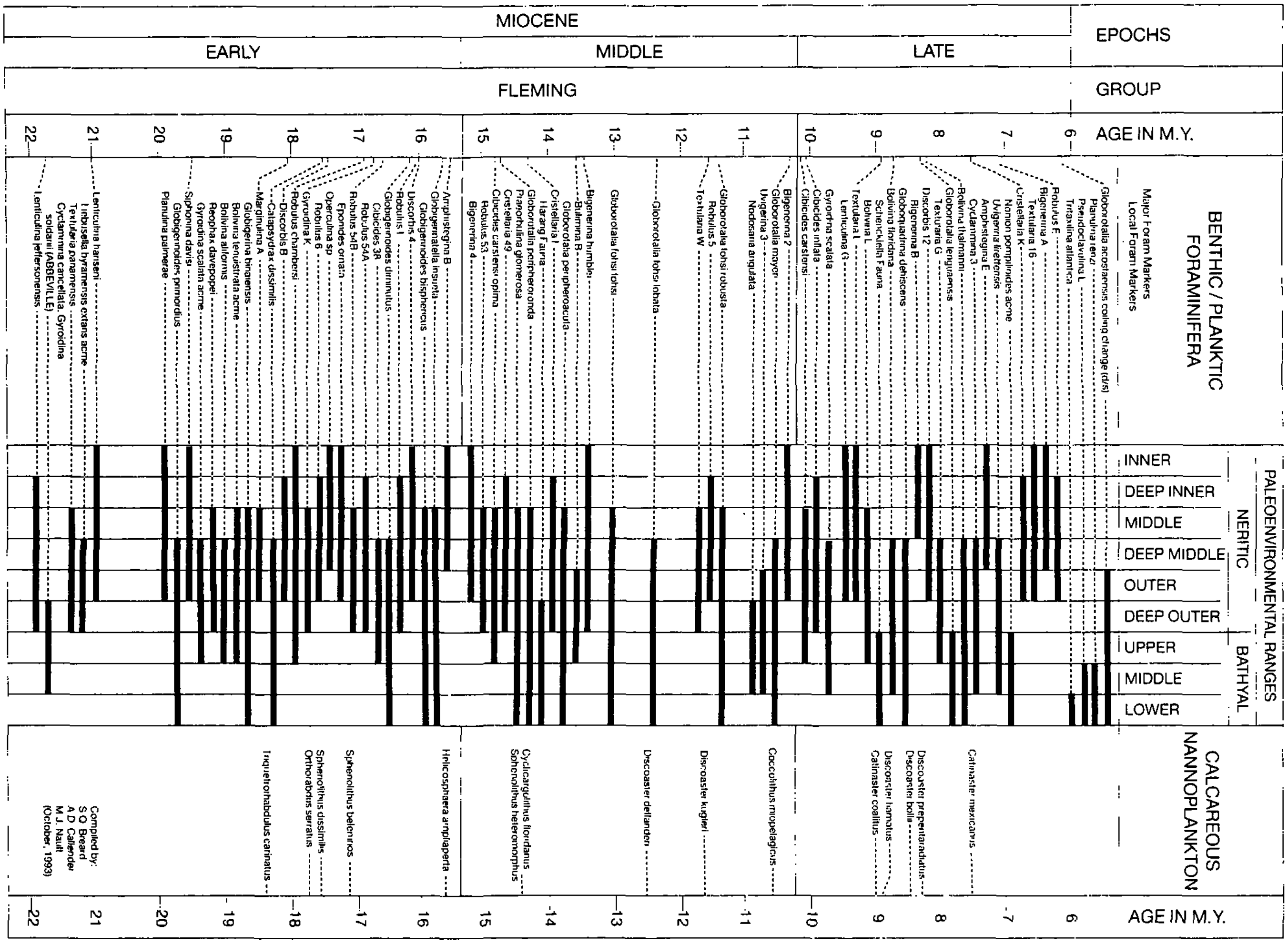


Figure 4. - Microfaunal biostratigraphy and paleoenvironmental ranges of marker foraminifera of Miocene strata of the Gulf Coast Basin

SUMMARY

1. Paleoecologic models for Plio-Pleistocene and Miocene foraminifera are presented. The widespread occurrences of Gulf Basin foraminiferal species suggests possible application to Central and South America and the Caribbean. Bathyal zonations may have cosmopolitan value.
2. The abyssal environment is judged to be too poorly defined to be recognize due to the lack of abyssal zone markers and a reliance on faunal abundances only. Arenaceous taxa may prove useful for splitting out this zone.
3. Through time, a number of foraminiferal genera and species have changed habitat preference, with several migrating into deeper water since the Miocene (*Cyclammina cancellata*, *Nonion pompilioides*, *Ceratobulimina* spp.). Migration into shallower water (*Pullenia bulloides*) is less common.
4. The Miocene through Pleistocene biostratigraphic zonation is updated, introducing a number of bathyal and local benthic markers. These tops fill in stratigraphic gaps and end the misconception that only planktic species are useful for downdip correlations.
5. Paleoenvironmental ranges are presented for all listed marker foraminifera. Because no such chart has been published previously, this represents a valuable new tool for geoscientists who should and must use foraminiferal marker zones in their work.

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