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Origin of Sulfate Minerals in San Andres and Grayburg Formations, Crane and Upton Counties, Texas

Analysis of four cores from Crane and Upton Counties, Texas, provides a basis for interpreting the origin of calcium sulfate minerals in Guadalupian-age carbonates. The San Andres and Grayburg Formations along the eastern margin of the Central Basin platform consist of basinward prograding supratidal to shallow marine carbonate facies. These units have undergone dolomitization and frequently contain large amounts of gypsum and anhydrite. Carbonate deposits are periodically interrupted by terrigenous clastic influx.

Investigation began with hand sample observation of core from Gulf Oil Corp. wells in the Dune and McElroy fields of Crane and Upton Counties. To define diagenetic fabrics better, core analysis was augmented by the preparing and observing 200 thin sections. Electron microscopy was performed on selected samples to provide a three-dimensional view of the nature of calcium sulfate pore fill and intergranular cement. In order to understand the relationship between dolomite and anhydrite/gypsum, detailed chemical analysis was conducted with the x-ray diffractometer and the electron microprobe.

Calcium sulfate minerals occur in a variety of forms in the San Andres and Grayburg Formations. The complex interrelationships between gypsum and anhydrite indicate multiple stages of dissolution, reprecipitation, hydration, and dehydration. The result of these processes is the occurrence of anhydrite and gypsum in the following forms: (1) nodules, (2) fracture fill, (3) pore fill/replacement, (4) poikilitic cement, and (5) a variety of gypsum and anhydrite intergrowths. The following occurrences of calcium sulfate minerals are evidence for their secondary origin: (1) replacement of carbonate grains and matrix, (2) pore filling along with pore filling of voids lined with secondary dolomite, (3) anhydrite filling of fractures connecting anhydrite nodules, and (4) occurrence of anhydrite nodules along stylolites.

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Relationship Between Morphological Variation and Environment in Holocene North Atlantic Benthic Foraminifera

Previous workers have found that morphological variability recognized in foraminifera is due in part to the effects of environment. The various environmental factors (water depth, temperature, salinity, etc) generally act interdependently, although one factor may be more influential than another in causing observed changes. C. E. Pflum and W. E. Frerichs suggested in 1976, that water depth may be most important in creating shape variation within a genus. Taxonomic problems are inherent, as species may be inaccurately named on the basis of form when, in reality, they actually represent a morphological continuum rather than several biological species.

The multiple rotation method of quantitative shape analysis is a new approach to measuring shapes of foraminifera. The outlines of many foraminifera are digitized, rotated to a standard orientation, and radial measurements are reduced to a few numerical descriptors by factor analysis. The relationship between quantitative morphological variation and environmental factors, such as water depth, are then determined by correlation analysis.

North Atlantic specimens of *Cibicides* and *Uvigerina* from 36 stations in 4 transects off Cape Cod were used in this study. Water depths ranged from 100 to nearly 4,200 m. The observed quantitative morphologic changes with depth tend to confirm previous hypotheses of the strong influence of environment. Results of this study may form the basis for a tool useful to paleontologists in making environmental interpretations from microfossil assemblages. Testing of the actual species boundaries is feasible, perhaps aiding in the solution of many taxononic problems.

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Crustal Structure and Tectonic Development of Gulf of Guinea Cul-de-Sac from Integrated Interpretation of New Aeromagnetic and Existing Geophysical Data

Data-acquisition difficulties and propriety restrictions on industry data have necessitated liberal extrapolations and generalizations in previous tectono-structural studies of the Gulf of Guinea cul-de-sac. This region is the locus of a postulated Late Cretaceous triple junction whose arms were the transform-dominated Equatorial Atlantic, the northward-propagating South Atlantic, and the Benue Trough aulacogen. Oceanic crust has been inferred to underlie most of the thick sedimentary wedge of the oil-prolific Niger Delta basin.

Integrated interpretation of new aeromagnetic data of the Geological Survey of Nigeria and existing geophysical data corroborates previous work on the general structure of the marginal basins. New aeromagnetic data, however, reveal a detail structure more complex than previously known. Low-frequency magnetic anomalies over the Niger delta indicate that oceanic crust extends northward to about Onitsha. From Onitsha, the edge of oceanic crust trends southwestward along the Benin hinge line (an apparent continental continuation of either the Chain fracture zone or a new Okitipupa fracture zone) and also wiggles southeastward (adjoined by a wide margin of transitional crust) toward the shelf break off Cameroon. Linear magnetic anomalies trending northeast indicate about 7 fracture zones beneath the Niger Delta basin. The region of high-frequency magnetic anomalies west of the Niger delta represent the Okitipupa basement ridge complex, which separates the Niger Delta basin from the Dahomey embayment. In this embayment, 2 wide bands of intervening high- and low-frequency aeromagnetic anomalies are interpreted to represent a basement high or ridge and a fault-bounded trough, respectively.

The change in the directions of fracture-zone trends (from east-northeast in the southeast, to northeast in most of the Niger delta area, and then to a more easterly direction over most oceanic areas) indicates 3 phases of tectonic evolution recorded as changes in sea-floor spreading directions in the Gulf of Guinea cul-de-sac.

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New Dense-Grid Aeromagnetic Map of Gulf of Guinea Cul-de-Sac, Northeastern Equatorial Atlantic Ocean

As part of a major project to procure miscellaneous geophysical coverage of the entire country, the Geological Survey of Nigeria has acquired aeromagnetic data, presented as contour maps at various scales, over the nation's 7 sedimentary basins. The coverage over the Nigerian continental margin, acquired at 2,500 ft above sea level, was flown at 4-km flight-line spacing in a north-northeasterly direction and at 20-km tie-line spacing in a west-northwesterly direction. Another tie line was flown along the coastline.

Twenty 1:250,000, one-degree square, total-intensity aeromagnetic contour maps covering the marginal basins down to the shelf break were assembled into a single aeromagnetic map of the Gulf of Guinea cul-de-sac. The map area lies within lat. 3°-8°N, and long. 2°-9°E. It covers the Nigerian portion of the Dahomey embayment, the Anambra and Niger Delta basins, and the southern portion of the Benue rift. The map covers the location of the postulated Late Cretaceous triple junction involving the Benue Trough aulacogen, the northward-propagating South Atlantic, and the transform-dominated Equatorial Atlantic. In addition to the region seaward of the continental shelf, the map covers the Niger Delta basin, the basement of which is also inferred to consist mainly of oceanic crust prograded by the thick sediments of the Tertiary Niger delta. This area is also the location of the Late Cretaceous coalescence of the North Atlantic and South Atlantic spreading systems hitherto separate from one another.

This new aeromagnetic map fills an important data gap (due to proprietary restrictions and acquisition difficulties) in previous studies of this oil-prolific and geologically unique province. The map would be useful in future structural and tectonic studies of the Gulf of Guinea cul-de-sac.

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Smackover Exploration in the 1980s Along Conecuh Ridge, Southwestern Alabama

Between 1982 and 1983, Smackover oil production was established at three new fields along the Conecuh ridge, southwestern Alabama, doubling the number of existing fields. Two of these discoveries (Huxford field and Appleton field) were a direct result of Texaco U.S.A.'s aggressive exploration program in Monroe, Conecuh, and Escambia Counties. Texaco also participated in the third field discovery, Lovett's Creek. During the last 4 yr, the company has controlled approximately 250,000 acres under lease and/or option, has shot 2,000 mi of seismic data, and has either drilled or participated in 18 wildcat wells in these 3 counties. Six successful Smackover oil completions, with initial gauges averaging 500 BOPD, yield a 33% success rate. Currently 3 wells are producing, 2 are awaiting production facilities, and 1 is being reworked.

Certain geological and geophysical factors complicated Texaco's Smackover exploration effort. First, the presence of near-surface Citronelle gravel frequently prevented successful transmittal of source energy to deep horizons and contributed both coherent and incoherent noise to the seismic data. Second, pervasive dolomitization in many places completely eradicated original rock texture, making environmental interpretation difficult. Third, facies changes and diagenetic changes in the reservoir rock were found to occur over very short distances, making development drilling high risk. Fourth, the presence of hydrogen sulfide in some successful wells substantially increased the cost of production facilities. However, even with these complications, a successful drilling program was achieved.

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Reworking of Sedimentary Pyrite on Euxinic Sea Floors, Devonian, Western New York

Basinal black and dark-gray facies of the lower Genesee Formation (uppermost Givetian) contain distinctive accumulations of exhumed and resedimented pyrite nodules, tubes, and steinkerns. Pyritic alloclasts occur at 2 stratigraphic levels; each horizon marks an erosional discontinuity overlain directly by anaerobic or marginally dysaerobic, basinal sediments. The most important level is the Leicester pyrite member, marking the base of the formation, where pyrite occurs in starved traction-lenses on or immediately above a widespread unconformity marking a major transgression. This relict pyritic deposit is regionally time-transgressive, as indicated by conodont data and diachronous shingling of lenses with basal Genesee black muds. Similar, but younger, pyritic lenses occur at the level of a diastem associated with the western margin of the Lodi limestone bed near Seneca Lake. Pyrite, chemically unstable in aerobic bottom settings, was apparently exhumed, transported, and concentrated under euxinic conditions. Lenses contain distinctive diagenetic pyrite structures (e.g., steinkerns, burrow tubes) from muds underlying both discontinuities. Erosional transfer of pyrite onto the sea floor is shown by mechanical breakage of pyrite grains, reorientation of geopetal stalactitic pyrite, and compactional features, plus alignment of burrow tubes by bottom currents. General absence of carbonate allochems in lenses is believed to reflect dissolution of carbonate grains, particularly in the lens intergrain environment.

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Geochemistry of Regionally Extensive Dolomites, Burlington and Keokuk Formations (Mississippian), Iowa and Illinois

The Burlington and Keokuk Formations (Mississippian) contain 2 major generations of dolomite throughout the several ten-thousand square kilometers of study area. Dolomite I (oldest) is luminescently zoned, Ca-rich, Fe- and Mn-poor, and has Mississippian $^{87}Sr/^{86}Sr$; dolomite II is unzoned, nearly stoichiometric, Fe- and Mn-rich, and has radiogenic $^{87}Sr/^{86}Sr$; dolomite III, a minor zone, is nonluminescent and very Fe-rich. Dolomites I and II formed before nonmarine calcite cements, and all 3 dolomites formed before Late Mississippian under shallow burial conditions.

Stable isotopes of dolomite I average +2.3 ‰ $\delta^{13}C$ and −0.3 ‰ $\delta^{18}O$ PDB. Dolomite I is slightly depleted in ^{13}C and ^{18}O with respect to estimated Mississippian marine dolomite. Thus, dolomite I may have formed in waters only slightly depleted in ^{18}O and ^{13}C compared with seawater at low temperatures (~25°C). Dolomite II averages −4.1 ‰ $\delta^{18}O$ PDB, +2.8 ‰ $\delta^{13}C$ PDB, and has a wide range of $\delta^{18}O$ (−0.5 to −6.6 ‰PDB) and a narrower range of $\delta^{13}C$ (+1 to +4 ‰). These data suggest that temperatures of precipitation were less than the 80°C-110°C ranges implied by the contained 2-phase fluid inclusions, unless the waters were isotopically heavy (~ +3 to 11‰ $\delta^{18}O$ SMOW). Dolomite II shows a regional geographic trend of decreasing $\delta^{18}O$ and increasing $\delta^{13}C$ from north to south. This trend can be accounted for by either a northward decrease in temperature or in ^{18}O content of diagenetic waters.

We suggest a model in which dolomite I precipitated in marine-dominated mixed waters at low temperatures, the bulk of the dissolved constituents being derived intraformationally. Dolomite II formed as a replacement of dolomite I in a system dominated by nonmarine waters and/or slightly elevated temperatures, deriving much of their constituents from sub-Burlington strata.

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Composition of Ultradeep Gas—Theoretical and Experimental Study

Increasingly greater numbers of wells are being drilled below 25,000 ft, and considerations of methane stability in the deep subsurface are becoming more important. We have calculated equilibrium gas compositions corresponding to conditions down to 40,000 ft for low, average, and high geothermal gradients, for hydrostatic and lithostatic pressures, and with and without graphite. Calculations have been made for sandstone reservoirs with various amounts and combinations of feldspars, clays, carbonate cements, and iron oxides with and without graphite, and for limestone and dolomite reservoirs with various combinations of clays, iron minerals, anhydrite, and sulfur, again with and without graphite. Natural gas shows considerable stability in sandstone reservoirs under most conditions, but its concentration in deep carbonates is much more variable and tends to a H_2S-CO_2 mixture except when an appreciable concentration of iron is present.

The thermodynamic predictions can (in principle) be checked by direct analysis down to the depth limit of available gas samples. In practice, considerable problems exist due to partial gas loss during sample retrieval. The analysis of gases trapped in fluid inclusions in late-stage cements offers one solution to this problem. This gas is being analyzed by thermally rupturing inclusions in the inlet system of a fast-scanning, computer-controlled mass spectrometer. Each bursting inclusion is analyzed separately, and several hundred individual inclusions can be analyzed using only 10 mg of sample. A wide variety of compositions, including water-rich, methane-rich, and H_2S-rich, is found in samples from below 20,000 ft.

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North Pecan Island Field: a Mature Trend Discovery in Miocene of Southern Louisiana

The Exxon 1 M. J. Epley discovery well for North Pecan Island field was completed in early 1982 as a discovery of significant new gas and condensate reserves in the mature Miocene trend of south Louisiana.

The field is located in Vermilion Parish within a large megablock between 2 major down-to-the basin growth-fault systems and is on the southern end of a south-plunging structural nose. Traps in 2 fault segments are formed in southeasterly dipping beds upthrown to 2 north-dipping, sealing faults. Six separate *Robulus chambersi* sandstones contain gas and condensate reserves.

Major gas and condensate reserves from sandstone reservoirs in the *R. chambersi* section were discovered in the mid-1960s 3.3 mi. west in the Pecan Island field and in the North Freshwater Bayou field, 5 mi northeast of the North Pecan Island field discovery. Several earlier dry holes just north of the discovery were drilled seeking to extend production from the upstructure Fire Island field (3 mi north), which produced a limited amount of gas and condensate from *R. chambersi* sandstones. Extensive structural and isopach mapping, aided by new high-resolution seismic data, revealed the North Pecan Island prospect to be structurally high to production at Pecan Island and that the prospective section was deposited over a growing paleostructure.

Four wells have been completed to date in the field, with flow rates as high as 30 MMCFGD. Current estimates place the new field recoverable at approximately 250 bcf of gas and 6 million bbl condensate.