

with superimposed overgrowths of authigenic clay minerals and etch pits.

Textural data were utilized in a variety of bivariate techniques and linear discriminant functions attempting to determine depositional environments for the St. Peter Sandstone. The results were inconsistent and nondefinitive. More consistent results were obtained by inspecting cumulative probability curves, following the techniques of Douglas, Sindowski, and Visser, which indicate a shallow-marine origin for the St. Peter Sandstone.

The classic textbook description of the St. Peter Sandstone as a very well-sorted sandstone with very well-rounded nearly spherical, and eolian frosted grains, is in error.

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SMACKOVER TREND FROM MEXICO TO FLORIDA

The Smackover trend within the United States extends approximately 1,000 mi from south Texas to western Florida. Prolific production has been obtained in east Texas, southern Arkansas, northern Louisiana, and eastern Mississippi. Continuing exploration is extending the productive areas eastward into Alabama and western Florida and promises to extend production into south Texas.

Most of the production has come from oolitic, pelletal, and skeletal carbonates of the upper Smackover. The 3 most important types of reservoir rocks are oomoldic dolomite, saccharoidal dolomite, and oolitic limestone with interoolite porosity. Reservoir porosity and permeability vary widely depending on the quality of the primary porosity, amount of secondary porosity development, and the magnitude of porosity destruction.

Low-relief anticlines, with up to about 400 ft of closure, are the most important structural traps in terms of present production. These closures are usually associated with Louann Salt swells which underlie the Smackover section. Fault traps, traps associated with high relief structures and salt piercements, and stratigraphic traps are of lesser importance at present, but it is anticipated that they will provide major reserves as exploration continues.

The search for low-relief anticlines will continue throughout the trend, but the importance of these features will be greatest in the sparsely drilled areas. Within well-developed areas, exploration will focus on the other trap types in order to find big new reserves.

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MICROPALAEONTOLOGIC INVESTIGATION OF EWOKORO AREA, SOUTHWESTERN NIGERIA

About 80 surface and subsurface samples from the Ewokoro limestone quarry and the Akinsinde borehole, approximately 10 mi south of the quarry, were examined for foraminiferal evidence bearing on the nature and vertical extent of the Ewokoro Limestone and the ages of the suprajacent and subjacent beds. A detailed bed-by-bed sampling of the section exposed at Ewokoro was carried out. Altogether, about 78 species of benthonic and planktonic Foraminifera were identified. Although some ostracods and Foraminifera have been studied previously in this area, the present investigation revealed the presence of additional Foraminifera species which either have not been recorded previously or

else were misidentified.

The undoubtedly early Eocene age of the shelly limestone commonly referred to as the "Ewokoro Formation" is substantiated by the presence of important index Foraminifera species including *Bolivina ottaensis* Reymont, *Globorotalia bollii* El-Naggar, and *Pseudohastigerina wilcoxensis* (Cushman & Ponton).

The biostratigraphic units established in the area have been correlated with equivalent units elsewhere in the western state. Detailed lithostratigraphic data in the form of charts and cross sections reveal the variability within the different units.

Data have led to the unmistakable conclusion that the deposition of the entire sequence referred to as "IMO Formation" occurred in a shallow-marine environment that succeeded the deposition of the Abeokuta Formation. The shelly limestone hitherto assigned a formational status is a member of the IMO Formation.

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TIME-TRANSGRESSIVE ASPECTS OF SOME CRITICAL PLANKTONIC SPECIES

The origin of *Globigerina bulloides* in temperate areas occurs in the middle Miocene in Neogene zones 9 or 10, whereas in tropical sections it appears in the upper Miocene in Neogene zones 16 or 17, a cool-water cycle. In both cases it could be represented as being derived from *Globigerina praebulloides*. The origin of the temperate *Globorotalia* (*Turborotalia*) *pachyderma*, dextrally coiled, occurs in Neogene zone 13 or just below in temperate areas, whereas it invaded subtropical areas only during the principal cold cycles subsequent to deposition of zone 13.

Forms of *Neoglobobadrina* lacking umbilical toothlike structures such as *N. dutertrei subcretacea* appeared in tropical and warm temperate areas in the late Miocene. *Neoglobobadrina dutertrei dutertrei* with umbilical toothlike structures appeared near the end of Pliocene or at the beginning of Pleistocene time in Neogene zone 22 in tropical areas, whereas the primitive forms continued into the Holocene in temperate areas. Thus, there is an apparent extinction datum plane of the primitive form near the end of Neogene zone 21 deposition in tropical areas but not in temperate areas. Coiling characteristics and form ratios distinguish this group from *Globorotalia* (*Turborotalia*) *pachyderma*.

Praeorbulina spp. appear initially in the lower Miocene Neogene zone 8 in tropical areas; isomorphs of this genus appear initially in temperate areas in Neogene zones 11 or 12. The earlier forms originated from species of *Globigerinoides* whereas those in temperate areas appear to have originated from *Globigerina*.

Ecologic-evolutionary relations are responsible for these and many other kinds of time-transgressive aspects of planktonic datum planes.

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NIAGARAN REEF EXPLORATION IN NORTHERN MICHIGAN BASIN

Silurian Niagaran reefs, a majority of which contain hydrocarbons, have been found in the northern part of the Michigan basin. These are pinnacle reefs similar to those in southeastern Michigan and Ontario and are present within a narrow belt along the northern flank

of the basin. Larger platform reefs may be present throughout a belt north of, and parallel with, the pinnacles. The productive trend, presently 15 mi wide and 150 mi long, was found as a result of renewed drilling activity in this exploration frontier. The high incidence of locating reefs is due mainly to detailed seismic evaluation. Significantly larger reserves could be contained in the platform reefs, but where found to date in the northwestern part of the current play, they are composed of nonporous dolomite.

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BIOSTRATIGRAPHY AND HISTORY OF CIRCULATION OF NORTH ATLANTIC

Distinct latitudinal control of the distribution of marine microfaunas in the North Atlantic Ocean began in the early part of the Tertiary (Paleogene) and is related to the opening of the North Atlantic to the Arctic region about 60 m.y. ago when the present deep-water circulation pattern was probably initiated. At that time a boreal zoogeographic province was established in the Atlantic Ocean for the first time. Caribbean and Mediterranean benthonic foraminiferal faunas exhibit a marked degree of similarity during the early Tertiary. The gradual displacement of west-east current migration routes into higher latitudes and the compression of Spain against North Africa brought an end to this amphiatlantic distribution pattern about 15 m.y. ago. Initiation of glaciation about 3 m.y. ago had a marked effect on circulation in the North Atlantic and temperature may have been the primary factor responsible for the many extinctions in planktonic Foraminifera.

Sediment cores and bottom photographs provide evidence of measurable bottom circulation within the Western Boundary undercurrent in the western North Atlantic. This contour current has played a major role in controlling fine-grained sediment deposition since the early Tertiary. Data from recent deep drilling suggest that during middle Cretaceous to early to middle Tertiary times extensive unconformities occurred, and during the early Tertiary a sudden onslaught of deep circulation coupled with wholesale erosion and redeposition of deep-sea sediments may have occurred. Currents gradually diminished in strength during the late Tertiary and are now flowing at moderate velocities apparently sufficient to transport and deposit sediment with only local erosion.

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PHYSICAL CHEMISTRY OF CARBONATES IN OCEANS

The common carbonate minerals found in oceanic sediments are aragonite and high and low magnesium varieties of calcite. A large proportion of deep seawater is undersaturated with respect to all three. This conclusion is based on laboratory studies of the effects of temperature and pressure on carbonate equilibria in seawater combined with shipboard measurements of water properties as well as upon actual measurements of dissolution rates of calcium carbonate samples held at various depths. Undersaturation is caused by biologic production of CO_2 at shallower depths and by the effect of increased pressure at greater depths on the solubility of CaCO_3 . The so-called "compensation depth" below which CaCO_3 disappears from deep sea sediments does not represent simply a downward change from supersaturated to undersaturated water.

This is proved by the presence of undersaturated water above the compensation depth and by the fact that the compensation depth may be thousands of meters below the depth where CaCO_3 begins to disappear from the sediments; *i.e.*, there is a zone of disappearance and not a single sharply defined depth. The rate of dissolution of CaCO_3 in undersaturated seawater is slowed by dissolved Mg and by dissolved organic matter and this helps account for the lack of dissolution where it is expected to occur.

Surface seawater, in contrast to deep water, is generally supersaturated with respect to both calcite and aragonite. However, inorganic precipitation rarely occurs due to the inhibiting effects of Mg^{++} and organic matter as dissolved species and as surface coatings on mineral grains.

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SOURCES OF SEDIMENT IN WESTERN BASINS OF ATLANTIC OCEAN

The Mid-Atlantic Ridge divides the Atlantic Ocean into two isolated north-south troughs. The western basin is subjected to intensified north-south moving currents because of the Earth's rotation. In addition to the surface currents such as the Gulf Stream and the Falkland Current, deep western boundary currents are presently identifiable as the North Atlantic Deep Water and the Antarctic Bottom Water. These currents affect the source and distribution of sediments in the western Atlantic basin.

In the western North Atlantic basin, bottom transport from high latitude sources is clearly seen by the contour of such mineral indicators as quartz, amphibole, and diagnostic "mixed-layer" clay minerals. The transporting agent is the North Atlantic Deep Water. In the western South Atlantic basin, bottom transport via the Antarctic Bottom Water from high southern latitudes supplies a major part of the sediments in the Argentine basin. The sediments came from glacial sources in Antarctica and from South Pacific volcanic sources. These volcanogenic sediments are carried eastward by the Antarctic Circumpolar Current. This is indicated in part by the mineralogy, but more so by the distribution pattern of the $\text{S}^{37}/\text{S}^{34}$ ratio in the detrital parts of the sediments. A diagnostic criterion for Antarctic glacial source relative to fluvial sources from southern Argentina is seen in the surface texture of quartz grains.

On the basis of material-balance calculations, much of the detrital sediment in the western Atlantic basin can be ascribed to high-latitude, glacially originating sources close to the continental margin; bottom transport from the shelf and slope also will contribute significant sediment.

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EXPERIMENTAL STUDY OF HEAVY MINERAL SEGREGATION UNDER ALLUVIAL FLOW CONDITIONS

In order to understand local alluvial flow sorting processes of grains of different densities, studies were made of 4 bed configurations in a large recirculating flume. These bed configurations included flat beds,