highly saline waters of thissubsiding basin, initiated rapid salt deposition by the brine-mixing method. Eastward rotation of Mexico into its present position deepened the Gulf of Mexico and peripheral rifting aided in continued submergence with normal marine deposition being established in Late Jurassic time.

DISTINGUISHED LECTURE ABSTRACTS

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New Views on Alpine Tethys Evolution Based on Joides Results

In the western central Atlantic, deep-sea drilling during Leg XI has revealed Late Jurassic to Cretaceous pelagic sediments that closely resemble Mesozoic sedimentary rocks exposed in the circum-Mediterranean orogens. This discovery is to be expected according to the concepts of plate tectonics because Alpine-type mountain ranges originate from the elimination and deformation of ocean basins and continental margins. In this context, the ophiolite belts of the central Mediterranean area are interpreted as remnants of oceanic crust and lithosphere which have been emplaced tectonically on the continental margins during Alpine orogeny. More specifically, close time correlations between the central Atlantic and Tethyan associations and palinspastic reconstructions suggest that the central Atlantic and the Alpine-Mediterranean Tethys had, during their early evolution, a parallel paleotectonic development and also were, at least from the Late Jurassic onward, connected directly to each other.

In the Alpine-Mediterranean region Mesozoic pelagic facies are present in both true oceanic and continental-margin settings. In the latter, these facies overlie Bahamian-type platform carbonate rocks lying ultimately on a continental crust. The oldest, Triassic, pelagic sediments were deposited in basins resulting from early rifting. Ophiolites of possible Late Triassic age reported from Turkey suggest that a small ocean was formed in the eastern Mediterranean area at that time.

During the Early Jurassic, the continental margins of the evolving Tethys were affected by block faulting and many of the former shallow-water sites were submerged; in these regions platform sedimentation was replaced by pelagic and turbiditic carbonate sedimentation and generally is analogous to the Cretaceous-to-recent geologic history in the Blake Plateau and the deeper troughs of the Bahamian region. Joides results and the magnetic-anomaly pattern suggest that this phase of block faulting 180 m.y. ago coincided with early rifting in the central Atlantic. The opening of this part of the Atlantic obviously implies translational movements between Africa and Eurasia and, in fact, a more or less synchronous opening in the central Mediterranean Tethys is confirmed by radiometric data and the age of the oldest sediments. Transform movements are suggested by the local abundance of tectonic breccias in the oceanic realm (ophicalcites) and by indications of compressive movements as early as Late Jurassic.

The oldest sediments recovered from the central Atlantic are greenish-gray and red, slightly nodular limestones of Late Jurassic age. These limestones are very similar to the Tethyan Ammonitico Rosso. However, the Ammonitico Rosso occurs in deeply submerged continental margin settings—different from what is observed generally; the first sediments deposited on the newly formed oceanic crust in the central Mediterranean were not pelagic limestones but radiolarites. As these radiolarites encroach locally on the deeply submerged continental margin, they may reflect a different current system resulting in a higher position of the calcite-compensation depth.

From the Tithonian onward, white and gray chalky limestones and nannoplankton oozes were deposited in the western Atlantic and most of the deep parts of the Tethys. The transitional contact with overlying black clays indicates that compensation depth was reached in the truly oceanic realm during the "middle" Cretaceous. However, the occurrence of ophiolitic olistoliths in the Mediterranean association indicates the tectonic emplacement of large ophiolite nappes in thelateEarly Cretaceous and a diverging history of central Atlantic and Tethys from that time forward.

A quantitative evaluation of the different plate movements in the Tethyan realm is still far from being reached, but comparisons of deformed and undeformed continental margins and ocean basins may help to provide some of the premises for such an attempt.

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Environmental Impact of Offshore Petroleum Operations

The state of Louisiana has more offshore petroleum platforms than all other states combined. The adverse environmental impact of these offshore "rigs" and their attendant operations is minimal, despite claims to the contrary by certain environmentalists, congressmen, and citizens.

Every day, many fishermen and divers leave the coastal Louisiana area and venture offshore to take advantage of some of the finest fishing and most interesting diving in the United States. Almost without exception, these fishermen and divers go to rig platforms because of the concentration of marine life near these structures.

Offshore platforms not only favor fishing because they provide food and shelter for marine life, but also offer protection to the recreationalist should a boat break down or severe weather endanger him, and give navigational aid to the mariner. The offshore petroleum industry has created these unique features in the Gulf of Mexico. Burning flares, abandoned platform locations, working rig sites, underwater completion installations, buried pipelines along the Gulf floor, and underwater vents which allow volatiles to bubble to the surface attract concentrations of, and become havens for, fish.

Both commercial and sport fishing have increased in the Gulf since the offshore petroleum industry was born in 1947 off Grand Isle, Louisiana. Gulf Coast fish tonnage doubled from 1940 to 1950 and again from 1950 to 1960. The tonnage increased 31 percent from 1960 to 1970. Louisiana, with her offshore platforms, has supplied the bulk of the fish production over the past five years—1969 through 1973—Louisiana's contribution to the total Gulf catch has ranged between 62 and 67 percent. Converted to percentage of total United States fish input for the same period, Louisiana has supplied between 21 and 28 percent of the entire United States catch of commercial fish.

No state surpasses Louisiana's annual catch. Because of its large fish concentration, offshore Louisiana is a growing attraction for fishing vessels from other states and nations too. Louisiana's fishing waters are so rich that new fisheries have been created for the United States. The Gulf trawl fishery for large croakers is one example.

Drilling production has not harmed permanently the marine life off the Louisiana coast, or the environment in which this life flourished. The petroleum industry is striving to insure that it can continue to make this claim.

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Plate Tectonic Models for Thrust Faulting in Southwestern United States

The Cordilleran orogenic belt of western North America is the product of sedimentational, magmatic, and tectonic processes along a continental margin initially formed by rifting in late Precambrian time. Deformation in the orogen is attributable to diverse interactions of the North American and various oceanic plates across that rifted margin. Phanerozoic deformation in the western United States largely has been due to convergent-plate interactions. As a consequence, thrust faulting is the most characteristic expression of pre-middle Tertiary Cordilleran orogenesis. Episodes of plate convergence may have been accompanied by important transcurrent components, but evidence for such components in the western United States is much less pronounced than in Canadian and Alaskan parts of the orogen.

Paleozoic, Mesozoic, and early Tertiary thrust faults in the southwestern United States display a distinct pattern of bilateral symmetry. In western parts of the orogen, thrust plates are characterized by a westward displacement relative to lower plate rocks and a westward decrease in age. Thrust plates in central and eastern parts of the orogen are, with few exceptions, east-directed and show an eastward decrease in age. Cordilleran thrust faults fall into three geographic and temporal groups, each of which can be characterized by a particular mode of plate interaction.

East-directed thrust plates can be divided into two distinct groups—those in central parts of the orogen formed during the Antler (Devonian-Mississippian) and Sonoma (Permian-Triassic) orogenies, and those of younger age, generally in areas to the east. The Antler and Sonoma orogenies represent progressive stages in the closure of a marginal basin located between the continent and an offshore Klamath-Sierran island arc which developed in Ordovician time. Episodic closure of the basin occurred during times of accelerated plate convergence in the arc region. Antler and Sonoma allochthons consist of sedimentary and volcanic rocks from the marginal basin and slices of their oceanic basement displaced eastward across the continental shelf. Closure of the marginal sea was accompanied by subduction, probably eastward, of the bulk of the oceanic crust on which the basin fill had been deposited. Complete closure resulted in accretion of the island arc to the western margin of the continent.

East-directed thrust plates of post-Sonoma age are intracontinental, having developed within the North American plate, east of the Andean-type Mesozoic-early Tertiary igneous complex. Subduction-related magmatism produced a thermally controlled zone of high-crustal ductility along the western leading edge of the American plate. Eastward intraplate yielding by thrust faulting was localized largely across the eastern boundary of this ductile zone as cooler, more rigid parts of the plate moved westward into and beneath it. The geometry of yielding also was influenced by stratigraphic anisotropy in thick sedimentary accumulations (Belt Supergroup and Cordilleran miogeosyncline). Eastward migration of thrusting occurred in response to an eastward shifting of plutonism and the zone of high-ductility contrast.

Thrust faults in the western part of the orogen are products of eastward subduction of oceanic lithosphere, initially beneath the Paleozoic Klamath-Sierran arc but also beneath the continental margin after Triassic accretion of the arc to the continent. The westward shifting of these thrust faults from Devonian through early Tertiary time reflects westward shifting of subductive activity by growth of melange wedges and accretion of oceanic and island arc rock assemblages to the continental margin.

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Influence of Eustatic Sea-Level Changes in Oil and Gas Accumulations in Appalachian Basin

Regional stratigraphic studies indicate a minimum of 23 eustatic sea-level fluctuations in the Appalachian region from New York to Alabama. A eustatic fluctuation is interpreted if the stratigraphic and sedimentologic records on two or more sides of the Appalachian basin show evidence of a similar simultaneous shift in relative sea level within the limits of temporal resolution by fossils, intertonguing facies, or bentonite chronology. Simultaneous sea-level shifts affecting different lobes of ancient delta complexes built into the Appalachian basin from eastern sources also are considered eustatic. For analysis of a hypothetical single basin, a eustatic sea-level change is one which affects the entire basin. The cause may be large-scale tectonics of the continental area containing the basin, or a true sea-level shift related to glaciation or rate of sea-floor spreading.

Timing on the sea-level variation curve is related closely to ages of strata with hydrocarbon production in the Appalachian basin. Changes in sea level result in shifting of sand deposition along shorelines, solution porosity in carbonate rocks exposed along basin margins, or modifications of reef growth. The clearest relations to hydrocarbon production are in the well-explored oil and gas fields in the Devonian and Silurian, where the sea-level shifts can be used to explain permeability distribution. Superposing sea-level shifts onto sedimentary tectonics in a basin of known shape allows prediction of exploration trends.

The largest fluctuations of sea level are at the base of the Sauk sequence (Cambrian transgression), the Owl Creek discontinuity (base of the Middle Ordovician), the Wallbridge discontinuity (end of the Early Devonian), and the discontinuity at the base of the Absaroka sequence (beginning of Pennsylvanian). Fluctuations associated with the Wallbridge discontinuity are related to deposition of the Oriskany Sandstone, which is the largest Appalachian gas producer. Lesser sea-level changes are related to other production, notably oil and gas from the Upper Devonian fields which were the birthplace of the American petroleum industry, and gas from the Silurian Newburg sandstones.

The eustatic sea-level curve from one basin such as the Appalachian area should be compared with other basins to identify worldwide patterns and to help to focus petroleum exploration in distant basins. The major level drops at the end of the Early Ordovician, end of the Early Devonian, and the beginning of the Pennsylvanian seem established. The sea-level drop in the Appalachians at the end of the Ordovician appears related to continental glaciation centered in the African Sahara. The rise in sea level at the end of the Precambrian is possibly a result of an increase in rate of sea-floor spreading as the proto-Atlantic Ocean opened. Recognition of true global changes should permit more precise intercontinental correlations because eustatic sea-level change is not related to distribution of faunal provinces or local tectonic processes.

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Geothermal Energy—Viable Energy Resource

Interest in geothermal energy is increasing. In all countries which have been affected by the energy crisis, the quest for indigenous sources of energy which would reduce dependence upon importation of fuel has taken a tremendous surge. Geothermal energy is abundantly available along plate boundaries, as shown through examples from the United States, Ethiopia, Kenya, Nicaragua, and Indonesia.

Geothermal power plants are in operation in about half a dozen countries at a cost which is economically competitive with other forms of energy. The environmental impact of geothermal energy is especially low when it is used directly for heating or cooling. At the same time, geothermal heat is most attractive economically when used for nonpower uses. Desalination and mineral extraction are other uses that may be made of geothermal power.

The total stored heat to a depth of 7.5 km is equivalent to 3 million billion barrels of oil. This is equivalent to 7,500 megawatt-years or 21 million tons of oil per square kilometer of the earth's surface. Even if only a very small fraction of the total resource base is ever utilized, it could provide energy equal to, or greater than, all currently known fossil-fuel reserves.

Examples of geothermal energy utilization from a number of countries are shown and discussed.

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Emerging Geothermal Resources Exploration Technology

Exploration for geothermal energy requires reevaluation of existing exploration techniques and development of new ones.