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.

DENNISON, JOHN M., Dept. of Geology, Univ. North Carolina, Chapel Hill, N.C.

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.

MEIDAV, TSVI, Geonomics, Inc., Hempstead, N.Y.

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.

MEIDAV, TSVI, Geonomics, Inc., Hempstead, N.Y.

Emerging Geothermal Resources Exploration Technology

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

The suites of techniques being employed in geothermal exploration are different from those in either mineral or petroleum exploration.

Geologic reconnaissance techniques involve the mapping of hot springs, fumaroles, and volcanoes. Plate margins typically delineate the broader zones in which economic geothermal reservoirs may occur. Empirical correlation exists between the rate, the angle of subduction, and the spatial occurrence of active volcanoes providing a general guide for exploration. Andesites are more commonly associated with productive geothermal fields than are the more basic rocks.

Geochemical thermometry, coupled with hydrogeologic studies, provides useful clues as to the probable last equilibrium temperature of geothermal reservoirs. However, dilution and continuous rock-water interaction often obfuscates the true reservoir temperature.

Geophysical techniques have become indispensable in narrowing down the targets to be tested by drilling. Foremost among the geophysical techniques is the electrical resistivity method and all of its variants, including deep electromagnetic soundings, tellurics, magnetotellurics, and audio-magnetotellurics. Microearthquake activity has been shown to have empirical correlation with the more productive parts of geothermal fields. Temperature gradient and conductive heat-flow measurements are important tools in detailed exploration, but oversimplified interpretation of the data therefrom can result in grievous disappointment.

Gravimetry may be employed in both direct, as well as indirect exploration for geothermal steam, depending upon the specific circumstances. Magnetometry may be useful in identifying very high temperature zones (greater than about 500°C) by virtue of loss of magnetism beyond the Curie Point.

Other techniques which are employed occasionally include ground noise mapping, SP, seismic refraction and reflection, and radioactivity mapping.

Each of the above listed techniques has certain merits and weaknesses. A proper combination of techniques, which must be individually tailored for the given region under investigation, could result in success, as shown by examples from a number of localities. Overly simplistic interpretation or overinterpretation of limited data have resulted in exploration failures, as documented in other cases.

MILTON, DANIEL J., U.S. Geological Survey, Menlo Park, Calif.

Comparative Geology of Inner Solar System

No abstract available.

PRICE, LEIGH C., U.S. Geological Survey, Denver, Colo.

Solubility of Petroleum in Water and Its Significance to Petroleum Migration

The aqueous solubilities of individual hydrocarbons, petroleum, and petroleum fractions increase with temperature, the rate of increase being gradual to 100°C and drastic thereafter; eventually cosolubility will be reached at high temperatures. Mass-balance calculations show that the formation of petroleum deposits can be accounted for by a molecular-solution primary-migration mechanism at temperatures greater than 180°C. Temperature decrease and salinity increase cause drastic exsolution of hydrocarbons from the aqueous phase. Thus the pronounced decrease in solubility of petroleum at higher salinities and lower temperatures present at shallow basin depths releases dissolved hydrocarbons during upward movement of deep-basinal waters. Faults provide the main pathway for this vertical movement. Eventually the fluids are collected into shallower sandstones when the fault becomes impermeable to further vertical fluid movement.

The model is supported by geochemical-geologic evidence. At depths of 14,000-18,000 ft (4.27-5.49 km), 15-20 percent water remains in clastic sediments, which is more than sufficient to carry the required volumes of petroleum. Experimental and field evidence has shown the almost total conversion of "kerogen" to extractable organic matter in fine-grained rocks at temperatures greater than 300°C. On the other hand, studies in Tertiary-Mesozoic basins have shown that, at depths shallower than where these temperatures are present the "kerogen" has not thermally degraded at all, and the extractable organic matter in shales is immature and unlike crude oil. Microspore and pollen particles in crude oils are derived from sediments much deeper in the section than where the oils are found. Thermodynamic equilibrium temperatures calculated for crude oils are much higher than reservoir temperatures and are in the range predicted by this model.

The model predicts specific geologic and geographic controls on petroleum occurrence. Examination of petroleum deposits and basins confirms the predictions and indicates that this model can be used as a powerful tool in petroleum exploration. The model's essence is a search for the first trap off a major fault into the area of greatest sediment thickness. The model can be used for exploration in Tertiary depocenters (Gulf Coast, Niger delta), wrench basins (Los Angeles), upthrust basins (Rocky Mountains), thrust basin (Western Canada), and shelf plays (Western Canada; Mid-Continent).

Another implication of the model is the possible existence of a huge new energy resource—crude oil dissolved in hot deep waters of petroleum basins. The possibility exists of tapping these geothermal waters for heat as well as dissolved crude oil. Minimum estimates by mass-balance calculations put the reserves of this resource in range of the trillions of barrels.

SMITH, J. H. STUART, J. C. Sproule and Associates, Ltd., Calgary, Alberta

Geology of Northern Greenland

Most of extreme northern Greenland is formed by rocks deposited in the North Greenland geosyncline, an extension of the better known Franklinian Geosyncline of the Canadian Arctic. Across the northeastern corner of Greenland, outliers of beds of late Paleozoic to Tertiary age are present and provide evidence for the existence of a basin of that age off the eastern coast of the island.

The Paleozoic beds of northern Greenland were apparently deposited in two basins that retained their separate identities from Late Proterozoic to late Silurian times. This is well demonstrated by the lithologies of the beds in the two basins. The Cambrian in the western basin is formed dominantly of carbonates; in the eastern basin, a black shale and sandstone sequence is conspicuous. The Ordovician in the west contains a thick bed of anhydrite which is absent or unrecognizable in the east. Thick reefs dominate the Silurian of the west but do not crop out in the east where a thick siltstone sequence lies above the carbonates. To account for the variations in lithology, which do not appear to be gradational, it is postulated that a north-trending crystalline basement "high" separated the two areas throughout sedimentation. Evidence for the presence of this feature can be obtained in the field and from geophysics.

Following a phase of folding in post-Silurian time, sedimentation commenced in a basin toward the east from the present northeastern coast of Greenland. Rocks of all eras have been recognized, but much work remains to be done in this area. It is exceptionally remote.

Analyzing the area in terms of plate tectonics can provide interesting data.