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.