REVIEW OF OUTER 1,000 KILOMETERS OF EARTH

(No abstract submitted)

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EVALUATION OF GEOTHERMAL STEAM RESERVES

Early evaluation of geothermal steam reserves is a key step toward rapid and proper development of such reserves. The term "reserves" indicates the quantity of geothermal fluid which can be produced at an acceptable rate and for a period of time sufficient to make the development investment reasonable and profitable. Unfortunately, there has been a general belief among technologists that reservoir-engineering methods developed in oil and gas production are not applicable to geothermal fluid production. Although some modification of existing reservoir-engineering methods is necessary, basic principles are to a large extent applicable.

Many geothermal fluid reservoirs currently being produced are believed to be dominated by fracturing and to be in communication with aquifers recharged by surface water. Many such oil and gas reservoirs have been recognized, and methods for forecasting their behavior have been developed in the last two decades. One very useful body of literature exists in connection with oil and gas well test analysis. The effects of fractures, production limits, fluid sources, and other pertinent reservoir features have been thoroughly documented. Such tests and their interpretations can be utilized, much more than has been appreciated, in geothermal wells.

The heat transmission involved in geothermal fluid production is a complication not commonly involved in reservoir engineering. However, the development of processes involving the subsurface combustion of crude oil and the displacement of crude oil by steam and hot water injection led to important literature concerning reservoir and well-bore heat flow. Application of existing and new reservoir engineering techniques to geothermal fluid production should lead to better understanding of this class of reservoirs and to more rapid development of this significant resource.

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GEOLOGY OF WYNOOCHEE VALLEY QUADRANGLE OF SOUTHWEST WASHINGTON

In the Wynoochee Valley quadrangle of southwest Washington, a sedimentary sequence of Tertiary rocks approximately 15,000 ft thick overlies the middle Eocene volcanic rocks of the Crescent Formation. These strata range in age from late Eocene to at least late Miocene and include unnamed beds of late Eocene age and the Lincoln Creek, Astoria(?), and Montesano Formations. At least three major periods of deformation are recorded: (1) post-Crescent and prelate Eocene; (2) post-Astoria and pre-Montesano; and (3) following Montesano deposition. A few major strike-slip faults trending northeast and several associated normal faults trending northwest are the result of pre-Montesano deformation. Post-Montesano deformation is confined mainly to moderate folding and limited faulting.

Potential source rock for petroleum is represented by the thick Lincoln Creek Formation and possibly by parts of the Astoria(?) Formation. Widespread sandstones of the Montesano Formation and some parts of the Astoria(?) Formation are possible reservoir rocks. Several major anticlines and several other smaller folds, together with conditions for stratigraphic as well as fault traps, are present in the Wynoochee Valley quadrangle.

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ORIGIN OF *Pseudohastigerina* IN PALEOCENE AND LOWER EOCENE STRATA OF CALIFORNIA

In the analysis of planktonic Foraminifera, true phylogenetic lineages are difficult to assess because of the small number of morphologic characters and convergence due to similar ecologic stress. However, the development of the planispirally coiled genus *Pseudohastigerina* is well documented in Paleocene strata from California. The origin of *Pseudohastigerina* has been traced in the type Lodo Formation section at Lodo Gulch. In the lowermost Lodo Formation (*Heliolithus riedeli* Zone), *Globorotalia chapmani* gives rise to a form transitional with typical *Pseudohastigerina* in the overlying strata (*Discoaster multiradiatus* Zone). This lineage transition involves the migration of the extraumbilical-umbilical aperture onto the spiral side of the test with further development of bilateral symmetry. A similar lineage transition has been observed in the upper Santa Susana Formation of the Poison Oak Canyon section from Simi Valley. Typical *Pseudohastigerina wilcoxensis* specimens, which show a more perfect planispirality and a more nearly equatorial aperture, occur in the middle of the Lodo Formation (lower *Discoaster tribrachiatus* Zone).

In the Paleogene, other genera of the Hantkenininae evolved from *Pseudohastigerina*, all serving as important biostratigraphic indicators. The first occurrence of *Pseudohastigerina*, the so-called *Pseudohastigerina* (or *Globanomalina*) datum, is a useful criterion for distinguishing lower Eocene from upper Paleocene in strata from California and throughout the world.

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NEW PETROLEUM PROSPECTS, SHALLOW AND DEEP BERING SEA

Recent geological and geophysical investigations by the United States Geological Survey and cooperating institutions have outlined three areas of possible interest for petroleum prospecting in the Bering Sea: (1) intrashelf basins, (2) an outer-shelf sediment-draped basement high, and (3) a continental borderland, Umnak Plateau, seaward from the continental slope.

1. Although the possibility of subshelf oil deposits has long been recognized in the thick sequence of Cenozoic sediments underlying Bristol Bay, published geophysical data seemed to indicate that elsewhere the shelf is underlain by only a thin blanket of Cenozoic sedimentary deposits overlying a basement of crystal-

line and deformed sedimentary rocks of Mesozoic and older ages. However, the writers' seismic-reflection studies reveal that large areas of the shallow Bering shelf are underlain by intrashelf basins containing several thousand feet of Cenozoic deposits. For example, at least 3,000 ft of sedimentary section overlies basement in western Norton Sound. Nunivak, St. Lawrence, and the Pribilof Islands are basin-bounding structural highs; these may be flanked by oil-bearing Cenozoic deposits.

2. Reflection records reveal that the outer edge of the shallow Bering shelf is underlain by a discontinuous basement high. The basement is composed in part of well-indurated sedimentary rocks of probable Mesozoic age. Cenozoic strata are draped over the shelf-edge basement high and bury the landward-facing flank, which is thought to be the scarp of a normal fault in some areas. The high may be of some interest to petroleum geologists but possible stratigraphic and structural traps within the overlying Cenozoic section are more obvious locations for petroleum prospects.

3. Deep-water drilling techniques ultimately will be required to explore adequately the petroleum possibilities of Umnak Plateau—the borderland which lies at a depth of 6,000 ft in the triangular area formed by the intersection of the Bering continental slope and the Aleutian ridge. The plateau is underlain by at least 5,000 ft of Cenozoic deposits that have accumulated over a differentially downwarped part of the basement platform underlying the shelf. The structure of the plateau is broadly domical, but moderate folding and faulting have deformed its edges; thus the flanks of the plateau may be the best location for future petroleum prospecting.

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Large-Scale Thrusting and Migrating Cretaceous Foredeeps in Western Brooks Range and Adjacent Regions of Northwestern Alaska

Large-scale, low-angle thrust sheets mapped within a 30,000-sq-mi region have been grouped tentatively into five tectonic units, each characterized by multiple northward thrusting of a distinctive rock sequence.

Rock sequences which distinguish the tectonic units in the De Long Mountains are informally designated as follow:

1. *Foothills unit* (northernmost and structurally lowest).—(a) Permian(?), Triassic, and Jurassic chert, shale, and limestone, (b) Early Cretaceous (Valanginian) shale with *Buchia*-bearing coquinoid limestone, and (c) late Early Cretaceous (early? Albian) graywacke and shale.
2. *Wulik unit*—(a) Mississippian dark carbonate, chert, and shale, (b) Permian(?), Triassic, and Jurassic(?) varicolored chert, shale, and limestone, (c) Valanginian quartzitic sandstone and shale containing *Buchia*, and (d) early? Albian graywacke and shale.
3. *Kelly unit*—Subunit A: Devonian and Mississippian detrital rocks; Subunit B: (a) Mississippian light carbonate and terrigenous rocks, (b) Permian(?) and Triassic chert and shale, and (c) earliest Cretaceous (Berriasian and Valanginian) graywacke and shale.
4. *Ipnavik unit*—(a) Devonian carbonate, (b) Mississippian dark chert, shale, and carbonate intruded by numerous mafic sills (Jurassic?), and (c) Berriasian graywacke and shale.
5. *Misheguk unit*—(structurally highest): (a) Jurassic(?) tabular, mafic igneous complex several thousand feet thick, and (b) Devonian carbonate.

The five internally thrust tectonic units are juxtaposed and separated by important low-angle thrusts, some of which have a minimum northward displacement of more than 20 mi. Cumulative northward displacement of all thrusts in the region may exceed 150 mi.

The major episode of thrusting was probably Aptian to early(?) Albian; however, three other phases of less intense Cretaceous deformation also are postulated. All four episodes were accompanied by deposition in adjacent foredeeps (exogeosynclines), which are progressively younger northward. The ages of the preserved foredeep rock sequences are: (1) Berriasian and Valanginian; (2) early(?) Albian; (3) later Albian (Nanushuk Group); and (4) Late Cretaceous (Colville Group).

The contrast between the north-trending grains of the Lisburne Peninsula and the southwest-trending structures of the De Long Mountains may have resulted from latest Cretaceous or Tertiary bending of the regional structural grain.

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Stratigraphy and Structure of Middle Paleozoic Section, Independence Quadrangle, Inyo Mountains, California

The middle Paleozoic section in the central Inyo Mountains is represented by slightly more than 2,000 ft of dark-colored hornfels with beds of limestone, impure chert, sandstone, and conglomerate near the base. Four formations have been differentiated: a previously unrecognized Middle Devonian unit, and the Perdido Formation, Chainman Shale, and Hamilton Canyon Formation of probable Late Mississippian age. The Middle Devonian rocks lie unconformably on beds ranging in age from Early Devonian to Middle Ordovician. A second unconformity separates the Middle Devonian section from the Perdido Formation. In the northern half of the Independence quadrangle, the upper part of the Chainman Shale, Hamilton Canyon Formation, and overlying carbonates of the Permo-Pennsylvanian Keeler Canyon Formation are complexly folded, whereas the underlying rocks apparently lack this deformation. This suggests that the upper part of the sequence has been involved in a *décollement*.

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Movement Along Faults in Central Inyo Mountains, Eastern California

A large anticline and syncline located near the mouth of Mazourka Canyon and formed during the early Mesozoic are broken by several faults of Tertiary age. These faults are almost parallel with the scarp formed at the time of the 1872 Owens Valley earthquake. Reconstruction of folds indicates that the best-exposed fault is normal and that vertical movement east of Kearsarge has exceeded 10,000 ft. Little