stage origins for most of the deposits and emphasized the important roles of both mantle and continental crust in metal-concentrating processes. A. Sutherland Brown also advocated multi-stage origins for the systematically zoned deposits of the Canadian Cordillera, suggesting that the metals were derived from 'neighboring space in the crust' rather than directly from the mantle.

In a well-ordered analysis, C. Nichiwaki, H. Ohmachi, and I. Kobayashi pointed out consistencies between metallogenic trends and inferred behavior of crustal plates in the sea-island-arc complex of the Japan region. A contrasting point of view was expressed by Yu. M. Pushcharovsky, P.L. Bezrukov, Yu. K. Burlin, L.I. Krasny, and B.A. Sokolov, who suggested that plate tectonics fails to account for the geological and structural fractures shown on recent USSR maps of the Pacific Ocean and its margins. They described a broadly concentric zonation of metalliferous deposits in the parts of Asia and North America adjacent to the Pacific Basin. These and other samples of differences and disagreements appeared to reflect current deficiencies in data rather than in imagination, and it was heartening to note little expression, during these sessions, of attempts to force-fit elements of metal occurrence into antecedent genetic models.

A large chunk of the eastern Pacific Ocean floor in effect was neatly packaged (possibly for future plate consumption), by Cyrus W. Field and several co-investigators, who reported on the Nazca Plate Project. Sediments on this plate are notably enriched in Fe, Mn, Cu, Ni, Zn, Ag, Mo, and Pb along and near the East Pacific Rise, and geological, geochemical, and geophysical data suggest that the metals were deposited mainly by interaction between volcanic contributions and sea water, and by precipitation from sea water alone. Attempts to relate these oceanic metal concentrations to known Andean deposits on the South American continent via processes of subduction, anatexia, and remobilization thus far have yielded conflicting results—another refreshing admission of needs for growth in the data base.

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coal

In this session, 6 papers described coal resources of Alaska, Australia, Western Canada, Japan, Korea and Taiwan. The coal ranges from Carboniferous to Neogene in age, and from lignite to anthracite in rank, and total reserves are estimated at more than 400,000 million tons; most of it is evenly balanced on opposite sides of the Pacific in Australia, Alaska and Canada.

Edward N. Milligan of Utah Development Co. pointed out the spectacular increase in Australian coal production in the last decade, after the discovery of premium-grade metallurgical coal in the Bowen Basin of central Queensland. This state's annual coal production has risen from less than 3 million tons in 1964 to 18 million in 1973 (and is expected to reach 34 million tons in 1974), and is going to both European and Japanese mills. National re-assessment of coal reserves has resulted in drastically upgraded estimates to 100,000 million tons for New South Wales and a comparable amount for Queensland.

George Gryc and Edward Cobb of the U.S. Geological Survey showed that there are vast reserves of low-sulfur coal in Alaska, very conservatively estimated at 130,000 million tons—possibly twice as much. About 110 million tons of the coal is subbituminous to lignite, and most of the rest bituminous, but unfortunately little of it is suitable for metallurgical purposes. Annual production recently has been less than a million tons, used for electric-power generation.

To the south, however, an important Jurassic-Cretaceous coal belt extends for 600 miles through Canada along the eastern edge of the Rocky Mountains. Much of this is high-quality coking coal, and at present some 8 million tons is being shipped annually to Japan (about 15% of her requirements). Bernard Latour of the Geological Study of Canada estimated that the Canadian Cordillera contains 87,000 million tons of coal of all ranks in beds more than 5 ft thick.

Bong K. Kim of Seoul National University said that the high-rank anthracite reserves of South Korea, amounting to some 1,400 million tons, are being produced at the rate of 10 to 14 million tons a year, a rate expected to rise to 20 million tons by 1980. In Taiwan, lenticular coal seams up to one meter thick and averaging less than a half meter, which would be considered uneconomical in many countries, are now being mined, as described by Patzen Wu of the Department of Mines. Remaining coal reserves have been placed at 465 million metric tons, of which 220 million is considered recoverable at present.

An important study of the conditions of formation of Japanese coals by Toshio Shimoyama of Mitsui Mining Co. and Azuma Iijima of Tokyo University shows that coalification of bituminous coals probably takes place between 85 and 125° C and is controlled mainly by temperature. Tuffs interbedded with the coals contain temperature-sensitive zeolite assemblages whose temperature zonation has been determined from deep-well data.

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geothermal

The circum-Pacific 'ring of fire' may prove to be an enormous source of heat that man in the future will use for his benefit. The theme common to all 14 papers in this session was the geothermal energy potential of Quaternary and active volcanoes. In country after country the 19 authors zeroed in on current geological, geophysical, and geochemical programs of investigation of tectonovolcanic areas of potential for geothermal-energy development. The areas discussed included New Zealand, Indonesia, Philippines, Taiwan, Japan, Alaska, western United States, Mexico, and Nicaragua.

In the overview paper, James Healy stressed that 1) in the Pacific region a close relation exists among producing geothermal fields, thermal springs, and Quaternary volcanism, and 2) all tend to be situated over subduction zones or over spreading ridges, indicating a common, large, deep source

heat. He also stressed that a growing body of evidence reveals that cations of hot water and vapor systems are strongly affected by regional ground-water movement, and concluded that more attention should be devoted to geohydrologic studies in geothermal areas.

M. Hayakawa reported progress in continuing basic research into the amount of heat that has been generated in several igneous stages since the Miocene in Japan. Ages and heat content of different-size heat sources can be estimated from analysis of wave lengths of heat-flow-profile data. This in turn should be related to the amount of geothermal energy available for use in Japan.

Economic and environmental aspects of geothermal-energy use were reviewed by R.G. Bowen, who emphasized that compared to the production cycle of coal, oil, or nuclear fuels, the geothermal steam cycle 'has fewer steps, fewer energy inputs, and fewer hidden subsidies, thus lowering net costs' and resulting in a net reduction of adverse environmental impact.

The results of the first deep well ever drilled into the summit area of an active volcano were reviewed by J.V. Keller. The research hole was drilled to 1,262 m beneath the summit of the active Kilauea volcano on the island of Hawaii for 2 purposes: 1) to derive engineering data on the energy potential of a basaltic volcano, and 2) to obtain scientific data on the inner workings of Kilauea. The rocks remained cool down to the water table encountered at 490 m (remarkably high!), then temperatures kicked up to 279°F at bottom hole. Certainly numerous volcanoes in the circum- and intra-Pacific region await such deep—and deeper—studies for scientific and economic reasons.

One of the most exciting, albeit futuristic, ideas on extracting the Earth's heat and harnessing it for mankind was outlined by J.L. Colp in a paper entitled 'Magma Tap—Ultimate Geothermal Energy Program'. The idea is to locate by very deep drilling a circulating magma pool and to extract energy directly from it by inserting a fully closed heat-exchanger system that would deliver heat to the surface; there, conventional techniques would convert it to electricity with minimum environmental insult. If this engineering project becomes feasible the circum-Pacific region may provide nearly limitless power in the future.

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hydrocarbons

The 25 papers on hydrocarbons covered a wide range of offshore areas that have not yet been explored for hydrocarbons but have substantial potential. These areas are off the west and north coast of Taiwan, in the Aleutian/Bering Sea region, off the coast of British Columbia, and off the west coast of Colombia, Ecuador and Peru. In addition, papers concerning Alaska and the Amazon Basins of Colombia, Ecuador and Peru show that although hostile environments prevented exploration there in the past, now, with the advent of new technology, exploration is proceeding and new reserves of hydrocarbons are being discovered that may rank with the major oil basins of the world.

David W. Scholl of the U.S. Geological Survey displayed geophysical evidence of a thick sedimentary section in the deeper part of the Bering Sea where inferences may be drawn from seismic data that gas is presently being generated and accumulated. In addition, Scholl reported on the discovery of large sedimentary basins on the edge of the Bering Shelf that have the potential to contain large hydrocarbon reserves. He pointed out that the Aleutian/Bering Sea region is twice the size of Alaska, thus giving an idea of the magnitude of reserves that might be expected in the sedimentary basins below the Bering Sea.

Fernando Zuniga, of Petroleos del Peru (Petroperu), in a paper read by Russel Travis, estimated potential petroleum reserves in the Amazon sedimentary basins of Colombia, Ecuador and Peru at 45 billion barrels, and said that in the Amazon region of Peru early exploration drilling had already discovered reserves on the order of 800 million barrels.

Most current hypotheses postulated to interpret the structural history of the circum-Pacific region revolve around the concept of plate tectonics. Peter Montecchi, of Gulf Research & Development Co., presented a wealth of geophysical evidence in the western Pacific showing the relative motion between land masses and ocean basins. Although earlier workers concluded that sediments in the ocean trenches are flat-lying and undisturbed, Montecchi believes that along the landward wall of ocean trenches sediments are scraped off the crystalline substratum and compressed and buckled into a sedimentary mélange. An abrupt boundary separates this mélange in the tectonic front from the yet-undisturbed trench sediments. Montecchi pointed out that, although hydrocarbons may be generated within the mélange along the trench wall, reservoir and seal conditions can be expected only in the undisturbed part of the trench sediments.

In another thought-provoking paper, Maurice Terman of the U.S. Geological Survey related plate tectonics to oil accumulations on the Chinese mainland. In his plate model Terman indicated that contemporaneously with subduction along the oceanward margin of an individual plate a structural sag or sink occurs along the plate's back or landward boundary. This sink evolves into a sedimentary basin, and such sinks are coincident with the petroliferous basins of mainland China.

The ever-increasing quality of seismic data by 3-dimensional ray-path models, bright-spot analysis, and improved stacking methods have enhanced exploration substantially. Worldwide examples of such improvements were shown by B.S. Flowers of Shell Oil Co.

That the accuracy of forecasting the petroleum potential of basins, countries or provinces is directly proportional to the amount of exploration activity became evident in 2 regional papers: R.W. Murphy, Esso Exploration Co., Singapore, underscored this premise in his discussion of the structural evolution of Tertiary basins in southeast Asia; Achabulti Pulungono, of Petmina, Indonesia, also said that intense exploration activity had resulted in the discovery of substantial new reserves in Indonesia.

T.L. Thompson, Amoco, reviewed concepts of plate tectonics and pointed to the significance of convergent plate boundaries in the makeup of the circum-Pacific continental margins, and their potential for hydrocarbon accumulations. Of particular significance in such margins is the early achievement of hydrocarbon generation from potential source rocks and their subsequent uplift to shallow levels as exemplified by the carbonization degree of Pleistocene rocks in the trench wall off the Aleutian trench.

That volcanics in an arc related basin are not necessarily a deterrent