soluble in ground fluids, practically non-adsorbable, highly mobile, and a direct product of radioactive decay.

The technique can be applied by collecting soil, soil gas, water or bottom sediment samples in reconnaissance, and semi-detailed and detailed arrays under a wide range of environmental conditions. Helium analyses are made by gas-source mass spectrometry. The resultant data are interpreted and presented with the aid of computers. In interpreting the helium data, it is necessary to consider the effect of some parameters which must be determined for each sample.

Helium anomalies have been found in near-surface soil and soil gas over known sandstone-type deposits in New Mexico, Texas, and Wyoming; hydrothermal(?) ore in Washington; unconformity-type mineralization in the Athabasca basin; and pegmatitic ore zones in Ontario. Anomalies have also been detected in lake bottom water and sediment overlying these types of deposits and in the groundwater recovered from wells and boreholes located close to them. The results from resurveys over several of these deposits indicate that even though the magnitude of the helium anomalies may vary from season to season, the anomalies themselves persist and hence define the location of the mineralization. This technique therefore seems to offer great promise as an economical indicator of deeply buried uranium deposits in a wide range of geologic environments.

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Oil and Metals in Ordovician and Devonian Kerogenous Marine Strata of Central Nevada

Kerogen-rich mudstone, siltstone, dolomite, and chert units as much as 50 m thick in the Vinini (Ordovician) and Woodruff (Devonian) formations contain potential resources of syncrude oil, V, Zn, Mo, Se, Ag, and Cr. Most kerogenous rocks originally consisted of organic-rich siliceous muds, slimes, and oozes. Organic matter is mostly amorphous, flaky, and stringy sapropel composed of planktonic organisms. The strata are within strongly deformed eugeosynclinal Paleozoic marine rocks of the Roberts Mountains allochthon.

Many fresh black rocks are low-grade oil shales which, upon pyrolysis, yield <40 l of oil per metric ton of rock; some thin layers yield as much as 125 l per metric ton. In these rocks, solid bitumen and liquid oil commonly fill voids and microfractures. Such early-phase hydrocarbons probably were released during diagenesis and formed without any major thermal degradation of the kerogen. Geochemical data suggest that the organic matter is thermochemically immature to mature and has not been subjected to temperatures above 60°C since deposition. Hydrocarbon contents (<100 to 5,400 ppm) and organic carbon contents (<1 to 25 weight %) vary widely.

V, Mo, Se, Ag, and Cr in fresh black rocks occur chiefly in organic matter; Zn occurs as sphalerite and Ni in iron sulfides. Concentrations are as much as 5,000 ppm V, 18,000 ppm Zn, 1,000 ppm Mo, 100 ppm Se, 20 ppm Ag, 150 ppm Ni, and 600 ppm Cr in unoxidized rocks. Enrichment of V and Se and depletion of Zn, Mo, Ni, and organic matter occur in oxidized rocks.

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Oil and Gas Potential of Wyoming-Utah-Idaho Overthrust Belt—Relation to Canadian Foothills Province Analog

The Cordilleran orogenic belt is generally considered to be a single tectonic element extending from northern Alaska to Central America. Two segments of the North American part of this element are oil and gas producers—the Canadian foothills thrust belt and the Wyoming-Utah-Idaho Overthrust belt.

Turner Valley was the first field discovered in the Canadian foothills. In the 55 years since that discovery, 32 fields have been found containing 9.3 Tcf of initially recoverable gas, 143 million bbl of natural gas liquids and 132 million bbl of oil. The first significant field discovery in the U.S. Overthrust belt was made in 1975 at Pineview. By the end of 1979 eleven new fields had been found, containing an estimated 500 million bbl of recoverable oil and 5.5 Tcf of recoverable gas, plus natural gas liquids.

The Canadian province is considered to be an appropriate geologic analog to the U.S. Overthrust belt, based on a number of characteristics common to both provinces. These include general structural configuration, trap types, reservoirs, stratigraphy, timing of migration of hydrocarbons, depth of burial, and age of tectonic movement. However, significant differences include age of major source rocks and paleothermal histories.

The future potential of the immaturely explored Wyoming-Utah-Idaho Overthrust belt is assessed by using a volumetric method, wherein hydrocarbon yields in barrels of oil and cubic feet of gas per cubic mi of sediments are established for the more densely explored Canadian foothills. These yields are applied to the less densely explored U.S. Overthrust belt. The usefulness of this method lies in the correct interpretation and analysis of similar, as well as dissimilar, geologic characteristics of the analog province. In addition, the assessment of the U.S. Overthrust belt is further refined by using the southerly productive part of this province as an "internal" analog which is applied to the remaining area of the province.

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Algal-Metazoan Bioherms of Lower Ordovician Age—St. George Group, Western Newfoundland

Bioherms are common in the St. George Group, a sequence of shallow-water carbonate rocks deposited on the western continental shelf of Iapetus Ocean. The cores of these bioherms are composed of thrombolites (unlaminated, branching, columnar stromatolites), "calcareous algae," and corals. On the basis of framework-building components, three types are distinguished: (1) thrombolite mounds, (2) *Lichenaria*-thrombolite mounds, (3) thrombolite-*Lichenaria-Renalcis* reefs. Associated with these structures is a diverse fauna of burrowing invertebrates, trilobites, nautiloids, pelmatozoans, brachiopods, gastropods, rostroconchs, and archaeoscyphiid sponges.

Thrombolite mounds are circular in plan, up to 2 m in diameter and thickness, with an estimated depositional relief of 0.3 m at most. Individual mounds commonly coalesced form circular and linear patch reefs, or banks with grooved margins. Large archaeoscyphiid sponges and *Pulchrilamina* (encrusting sponge?) contribute in a minor way to the framework in scattered horizons. Rare small mounds are composed of an intergrowth of thrombolites and *Lichenaria* corals.

Large thrombolite *Lichenaria-Renalcis* reef complexes, up to 12 m thick, with an estimated depositional relief of up to 1.5 m, occur in the lower part of the St. George. One particularly well developed complex is composed of vertically superimposed reef stages composed of *Lichenaria,* thrombolites, and the "calcareous alga" *Renalcis.* The framework is surprisingly complex, with abundant cavities and a demonstrably uneven growth surface. Cavity walls are commonly coated by algalaminites and internal sediments are burrowed. Some cavities are sediment conduits. *Renalcis* occurs as free-standing heads of varying shapes, as encrusting walls on small thrombolite mounds, and as manes in cavities under corals.

These bioherms span a critical time gap in the development of reefs, the transition period from algal-dominated bioherms of the Precambrian and Cambrian to the metazoan-dominated bioherms of the Middle Ordovician and remaining Phanerozoic.

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Early Guadalupian (Permian) Bank Margin Erosion Surfaces, Guadalupe Mountains, Texas

Two basin-sloping erosion surfaces occur in the early Guadalupian carbonate rocks on the western Guadalupe Mountains escarpment. Their longitudinal profile resembles a slump scar. Each truncates (with 20 to 40° dips) 70 to 100 m of flat-lying bank-top strata, and then flattens basinward. The younger surface, previously unreported and virtually inaccessible because of sheer cliffs, sharply truncates about 70 m of upper Grayburg shelf strata at its headwall. It flattens basinward and appears to more gradually truncate the uppermost part of the Getaway (also Grayburg) bank. Initiation of the characteristic high-angle foreslope deposits of the Goat Seep and Capitan "reef" began at this 70-m-high headwall. Early Goat Seep foresets, contrasting with later Goat Seep and Capitan, have little rock equivalent in a gentler-dipping toe-of-slope section. The older erosion surface is the regional unconformity at the base of the Brushy Canyon Sandstone. At its headwall (the Brushy Canyon pinch-out) about 100 m of Cutoff and Victorio Peak Formations are truncated abruptly.

The two Guadalupian erosion surfaces somewhat resemble the closely associated late Leonardian basin-sloping (5 to 10°) surface that truncated 200+ m of Victorio Peak bank in pre-Cutoff time. We believe all formed in a submarine environment. Conceivably they are "half-channels" with their south or southwestern side eroded or kilometers away. We believe they were formed by shelfward retreat of the depositional bank margin. The erosion agent and mechanism are enigmatic. We believe the Victorio Peak and probably the Grayburg were rock when eroded, but we are uncertain regarding pre-erosion lithification of the Cutoff Formation.

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Hydrocarbon-Trapping Structures in Southern Canadian Rockies Segment of Cordilleran Foreland Thrust Belt

The hydrocarbon reservoirs consist of upper Paleozoic platformal carbonate rocks in northeasterly verging, imbricate, listric thrust-fault wedges, and in related flexural-slip folds. They formed in Maestrichtian to early Paleogene time, after these rocks had been buried under more than 5 km of Late Jurassic to Paleogene molasse. Both the generation and entrapment of the hydrocarbons result from subduction of the floor of the Cordilleran miogeocline.

Palinspastic reconstructions of the foreland thrust and foldbelt, based on balanced structure sections that take into consideration the deep crustal structure as outlined by seismic refraction, magnetic, gravity, and geomagnetic depth sounding data, show that: (1) there has been about 200 km of net horizontal convergence between the Mesozoic magmatic arc of the eastern Cordillera and the autochthonous cover on the North American craton; (2) the convergence is expressed at a shallow level, in the eastern, more external zone, by horizontal compression and vertical thickening within supracrustal rocks that overlie an unbroken basement of cratonic continental crust; but at deeper levels, in the western, more internal zone, it involved the subduction of the former basement of the miogeocline; (3) the Cordillean miogeocline is a northeasterly tapering wedge of craton-derived sedimentary rocks that accumulated outboard from the edge of the continental craton, on oceanic or tectonically attenuated continental crust; (4) the foreland thrust and foldbelt is a shallow subduction complex that was tectonically prograded northeastward as the miogeoclinal, platformal, and exogeoclinal supracrustal rocks were scraped off the underriding slab and accreted to the overriding slab; (5) subsidence in the migrating foredeep was due to flexure of the lithosphere under the weight of the encroaching subduction complex, and of the molasse itself.

The first of two main pulses of subduction occurred outboard from the craton, during Late Jurassic and Early Cretaceous time. It involved outward verging thrusting and folding on either side of the uplifted core of the miogeocline, and it produced a thick wedge of molasse that covered the western craton. The hydrocarbon reservoirs formed during the second pulse, in Late Cretaceous and early Paleogene time, as the cratonic cover rocks were deformed and accreted to the growing subduction complex, while the continental craton moved under the detached miogeocline.

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