of Mississippian carbonate rocks. Trap capacity is governed by horizontal displacement, vertical uplift, convergences of allochthonous and autochthonous structural strike, and probable seal quality to the thrust planes. Approximately 18 significant gas-bearing structures containing 5 tcf marketable reserves have been discovered.

The surface geology of the Inner Foothills is characterized by outcrops of Paleozoic carbonate rocks and relatively undeformed Mesozoic strata. Usually two or more thrust sheets are stacked in a general anticlinal form and provide multiple objectives. To date, 14 gas-bearing structures have been discovered in this zone containing approximately 5.5 tcf of gas. The gas-bearing structures in the Waterton-Carbondale and Moose Mountain Panther River areas are typical. The gas-bearing post-lower Paleocene structures probably are related to the time of maturation of the major source rock and the west-to-east deformation of the southern Canadian Rocky Mountains. Despite the large areas of the Alberta Foothills belt in which exploration is restricted, it is estimated that 6 to 14 tcf of gas may still be found.

GRETENER, P. E., Univ. Calgary, Calgary, Alberta, Canada

On the Use of the Modified Lopatin Method

The modified Lopatin method (detailed description in AAPG Course Note Series 17) can provide quick estimates of the state of organic metamorphism. To do so, it is necessary to evaluate the thermal history of a potential source rock. Under favorable conditions, such as uniform burial in an environment of constant geothermal gradient, it is possible to approximate the actual thermal history by a linear temperature rise. For such simple situations, the method yields essentially instantaneous results without the help of any artificial aids. The method is equally applicable to more sophisticated models, but those require a careful analysis of the burial history and an evaluation of the possible changes of the terrestrial heat flow during the lifetime of a source rock.

Examples of the use of the method will be shown and the current limitations imposed by various uncertainties and approximations will be discussed.

GRIES, ROBBIE, AMAREX, Inc., Denver, CO

North-South Compression of Rocky Mountain Foreland Structures

Petroleum exploration beneath Precambrian on the flanks of Rocky Mountain foreland structures has revealed substantial throw on east-west-trending thrusts which has not been predicted by underthrust models of west-directed tangential compression. Recognizing this north-south compressional component in the foreland necessitates a new look at the forces that formed these structures.

Initial compression that developed foreland structures was dominantly from east to west and was caused by westward movement of the North American plate during the opening of the Atlantic Ocean in Late Cretaceous. Atlantic spreading progressed to the North Atlantic and Arctic Oceans in Late Cretaceous and early Tertiary. It is proposed that movement of the North American plate evolved from west to southwest to south, causing not only significant southwest and south movement on several foreland basement-involved thrusts, but also termination of movement in the detached Idaho-Wyoming-Utah thrust belt.

Major east-west-trending foreland structures include the Owl Creek Range, the south flank of the Wind River Range and the south flank of the Granite Mountains in Wyoming, the Uinta Mountains in Utah, and the north flank of North Park basin in Colorado. North-west-trending foreland thrusts, such as the southwest flanks of the Casper arch, and Gros Ventre and Wind rivers in Wyoming developed during the transition from east-west to north-south compression.

GRIFFITH, ROLAND LYLE, JR., Univ. Maryland, College Park, MD

Investigation of Beasman Prospect, Sykesville Mining District, Maryland, with a Proton Precession Magnetometer

The Sykesville copper-iron district is centrally located in the Piedmont upland of Maryland. Extending through the northeastern half of the district is the Monroe and Beasman prospect, where magnetite-quartz veins occur in steeply dipping faults or shear zones. To find the locations and configurations of the veins, traverses parallel and perpendicular to the strike of known localities of magnetite have been made using the proton precession magnetometer. A magnetic anomaly map with profiles will be developed and interpreted using the dipole system method and known geology of the area. Preliminary results suggest that the veins are discontinuous parallel to strike and dip toward the southeast.

GROVER, G., JR., Gulf Oil Exploration Co., Midland, TX, and J. F. READ, Virginia Polytechnic and State Univ., Blacksburg, VA

Near-Surface to Deeper Burial Cementation Patterns and Foreland Basin Evolution, Middle Ordovician Ramp Carbonates, Virginia

Middle Ordovician ramp carbonates, Virginia, were deposited in a subsiding foreland basin bordered by developing tectonic highlands. Ramp carbonates are largely occluded by nonferroan, clear rim, and equant cements which contain cathodoluminescent zones consisting of nonluminescent (oldest), bright and dull (youngest) cements. The zonation largely relates to increasingly reducing conditions of pore waters. Zoned cements in peritidal beds have complex zonations, pendant to pore-rimming fabrics, and are associated with vadose silt (which abuts all cement zones); these cements are vadose to shallow phreatic. Major cementation of subtidal facies occurred under burial conditions. Zoned burial cements have a simple zonation reflecting progressive burial (up to 3,000 m) of carbonates. Shallow burial nonluminescent cement formed from oxidizing, meteoric waters which expelled anoxic, connate marine waters; meteoric waters were carried by aquifers from tectonic upland recharge areas. Deeper burial, bright and dull cements formed at depths (2,000 to 3,000 m) and temperatures (75 to 135°C) associated with hydrocarbon emplacement during the Late Devonian or Mississippian. Final, clear dull cement fills tectonic fractures and was emplaced during late Paleozoic deformation. Deeper burial diagenesis appears to be genetically linked to late Paleozoic, Mississippi Valley-type mineralization. Zoned peritidal and burial cements are mainly confined to southeastern parts of the ramp, where cementation was influenced by meteoric waters from developing uplands on the southeastern margin of the foreland basin and carried northwest by aquifers. Cements in northwestern peritidal and subtidal ramp facies are dominated by nonzoned dull cements, where cementation was little influenced by upland-source meteoric waters. The close association of zoned cements and regional uplands in the Middle Ordovician sequence indicates the importance of assessing regional geology, geologic history, and tectonics in understanding regional cementation patterns and cementation processes of ancient carbonate platforms.

GROW, J. A., W. P. DILLON, and J. S. SCHLEE, U.S. Geol. Survey, Woods Hole, MA

Late Mesozoic Carbonate Banks and Reefs Along U.S. Atlantic Margin

A paleoshelf-edge complex of Late Jurassic and Early Cretaceous age rocks observed in seismic profile off the United States east coast probably represents a group of carbonate banks and/or reefs. The paleoshelf-edge lies 10 to 15 km seaward of the present shelf edge in Georges Bank, 20 to 30 km in the Baltimore Canyon trough, 30 to 150 km in the Carolina trough, and 150 to 300 km in the Blake Plateau basin. Refraction studies of the margin observed velocities of about 5 km/sec at depths of 2 to 3 km beneath the outer continental shelf and upper continental slope that correspond to the top of this paleoshelf-edge complex.

Drilling results from COST wells in Georges Bank basin and in Baltimore Canyon trough indicate that a carbonate-evaporite depositional regime was dominant behind the paleoshelf-edge during the Jurassic. Lower Cretaceous algal reef debris has been sampled in Heezen Canyon (Georges Bank slope). DSDP Site 390 also drilled back-reef carbonates of Early Cretaceous age along the seaward edge of the Blake Plateau, and recent submersible dives have recovered Albian-Aptian rudist reefal materials along the Blake Escarpment.

While strong evidence exists for carbonate bank and algal reef deposits all along the paleoshelf edge, the evidence for rudist reefs is presently restricted to the Blake Plateau basin. Erosional retreat of the ancient shelf edge, especially in the Blake Plateau basin, resulted in the removal and breaching of the Lower Cretaceous-Jurassic carbonate bank or reef margin at some locations.

GUBER, ALBERT L., and HIROSHI OHMOTO, Pennsylvania State Univ., University Park, PA

Sedimentary and Structural Setting, Kuroko Ore Formation, Hokuroku District, Japan

The Kuroko massive sulfides are thought to have formed on the sea bottom during middle Miocene time. The deposits are interstratified with a highly variable sequence of volcaniclastic and detrital sediments, some of the latter bearing foraminifera. Our studies of the paleontological and sedimentological characteristics of the sediments place the following constraints on models of the sedimentologic-tectonic setting before, during, and after ore genesis. (1) Contrary to previously accepted ideas, ore genesis in the Hokuroku district (a 30 by 30 km area) was not contemporaneous and may have spanned as much as 6 million years as is suggested by the planktonic foraminifera. (2) Most previous ideas embodied a shallow-sea origin for the ores, but benthic foraminifera indicate that the ores formed at great depths (about 3,500 m). (3) The district subsided from subaerial to deep submarine during the early Miocene, when the late Paleozoic metamorphic basement was lowered along high angle faults. Rapid subsidence is suggested by thick-bedded, poorly sorted sedimentary breccias and sandstones on the downfaulted blocks. (4) Middle Miocene detrital turbidite muds are common in the district, and a mixing ratio of benthic foraminifera from different depths is used to determine turbidite source areas. (5) Further high angle faulting during the middle Miocene produced a large scale submarine topography which limited the distribution of the muddy turbidites. These fault-generated submarine highs are relatively free from turbidite influence and contain most of the ores.

HALBOUTY, MICHEL T., Consulting Geologist and Petroleum Engineer, Houston, TX

A New Philosophy for Petroleum Exploration

Worldwide reserves of oil and gas must be increased substantially within the coming decades to meet critical energy demands as the global transition from fossil fuels to alternate energy sources continues. The easier-to-find supplies have been located and the challenge now is for the petroleum explorationist to focus his efforts toward innovatively searching for the world's remaining deposits of oil and gas.

Petroleum exploration concepts and technology have advanced greatly from the days of random drilling and strict adherence to the anticlinal theory. Surface and subsurface mapping, core drilling, magnetic and gravimetric prospecting, the reflection and refraction seismograph, and computer technology have added to the overall effort. Geologists and geophysicists are encouraged to search for subtle trap accumulations of petroleum, those which are stratigraphic, unconformity-associated, or paleogeomorphic. Remotely sensed data from land satellites and spacecraft are also aiding the explorationist in his search for petroleum.

Bold new ideas are needed to stimulate even bolder exploration. By using the best of past exploration theories, using the tools and ideas of today, and being willing to accept innovative methods the petroleum explorationist can make the crucial decisions called for by today's soaring petroleum energy demands. The philosophy concerning these items is discussed.

HALFMAN, SUSAN E., MARCELO LIPPMANN, and REUBEN ZEWLER, Lawrence Berkeley Laboratory, Berkeley, CA

Interpretation of Well Logs at Cerro Prieto Geothermal Field

The Cerro Prieto geothermal field is located 35 mi (56 km) south of Mexicali, Baja California, Mexico. The subsurface geology of Cerro Prieto is typical of a deltaic depositional environment. Logging data from more than 70 wells have been analyzed. A comparison of the data derived from these logs with surface geophysics, mineralogic, and stratigraphic information leads to a model of subsurface fluid flow.

Cross sections have been constructed using the values obtained from resistivity and density logs. The resistivity cross sections are consistent with the model derived from surface dipole-dipole resistivity measurements, lithology, production, and mineralogic characteristics. The density cross sections show good agreement with the location of a self-potential anomaly and the location of micro-earthquake hypocenters.

Interpretation of these well logs leads to estimates of porosity, salinity, temperature, and permeability. High porosities are probably due to secondary dissolution. The salinity distribution shows that relatively fresh water extends from near the surface to depths of 4,000 to 5,000 ft (1,220 to 1,525 m) in the eastern part of the field and to shallower depths in the western part. Water of higher salinity underlies the fresh water. Permeability has been hard to estimate because of conflicting evidence from the well logs.

In the proposed model of hydrothermal flow, hot brines enter