Thermal Contraction and Petroleum Maturation in Michigan Basin

Surface cooling of heated continental crust imposes a load on the lithosphere which causes subsidence as the basement rocks contract. Accumulation of sediments in the resulting depression forms a sedimentary basin. Studies of the geometry of sedimentary basins with horizontal dimensions of a few hundred kilometers suggest the lithosphere responds to loads by regional flexure of a strong elastic or viscoelastic upper lithosphere.

A three-dimensional model for flexure of the lithosphere due to thermal contraction is applied to the Michigan basin. Using the observed depth to basement and assuming a continuously filled basin, the magnitude of the thermal contraction load is calculated for each effective flexural rigidity of the lithosphere. For a sediment-mantle density contrast of 0.69 g/cu cm and a thermal decay constant for the lithosphere of 50 m.y., the subsidence record of the sediments and the observed free-air gravity anomaly are most satisfactorily explained by an elastic lithosphere with an effective flexural rigidity of 2×10^{28} dyne-cm or a viscoelastic lithosphere with an effective flexural rigidity of 10^{31} dyne-cm for a viscosity of 10^{25} poise.

The temperature history of stratigraphic horizons during basin development is determined from the excess temperature due to the thermal anomaly and the predicted burial history of the sediments. For an equilibrium temperature gradient of 22°C/km, a surface temperature of 10°C and an equilibrium surface heat flow of 1.1 HFU, the maximum paleotemperature and surface heat flow for both the elastic and viscoelastic models are 100°C and 2.5 HFU, respectively. These estimates are consistent with limits set by paleomagnetic studies. The low value for paleotemperature results from the concentration of the thermal anomaly below 15 km.

Once the thermal history of the sediments is specified, the oil potential of the basin can be determined from laboratory derived kinetic equations for the degradation of kerogens to petroleum. For the Michigan basin, temperature conditions sufficient for kerogen conversion have existed only in the Middle and Upper Ordovician and the Lower Silurian sedimentary rocks in the central section of the southern peninsula of Michigan. Published geochemical studies confirm this origin of the petroleum.

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Cross-Bedded Sandstone Reservoirs—Geologic Modeling of Geometry of Reservoir Units and Permeability Anisotropy Using Well Logs

A worldwide study of sandstone formations with large-scale cross-bedding reveals that the majority of these originated as transverse bed forms. It is possible to recognize the transverse origin as well as the geometric shapes of the depositional surfaces of some other bed forms. Investigations by K. Weber and others have aided in the understanding of the areal distribution of eolian transverse genetic units and thus allow for geologic modeling. Unfortunately, the genetic units may have cemented parts and thus may not produce as single reservoir units. By relating the petrophysical analysis of these sandstone sequences to a bedding evaluation, it is often possible to infer the nature and geometric distribution of the porous reservoir units and non-porous elements. Thorough geologic reservoir modeling may be derived from (1) a dipmeter survey and porosity logs, or (2) petrophysical core analysis and oriented bedding studies from full, continuous cores, or both. At least one is necessary.

With either data base it is possible to determine the presence and areal significance of permeability anisotropy controlled by the texture, fabric, and diagenesis of bedding lamina. The geometric determinations of dip angle and azimuth, combined with the genetic interpretation of areal extent of the reservoir unit, allow borehole formation evaluation to be geologically projected into the reservoir area between wells. Such a geologic modeling and analysis are important in completion practices, field development, water flooding, and reservoir analysis.

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Bowdoin Dome Area, North-Central Montana—Example of Shallow Biogenic Gas Production from Lower-Permeability Reservoirs

Natural gas is currently being produced from shallow, low-permeability, low-pressure reservoirs in the Bowdoin dome area, Phillips and Valley Counties, Montana. Most of the biogenic gas is stratigraphically entrapped in thin, discontinuous siltstones and sandstones that are enclosed in a thick sequence of shales of Late Cretaceous age. There is some structural influence on the accumulations in more porous zones. The reservoirs and the associated shales were deposited on a shallow-marine shelf and thus present different mapping and recovery problems from most low-permeability reservoirs of nonmarine origin.

Early development, prior to 1960, was on the structurally high part of the dome and covered an area of about 200 sq mi (520 sq km). Production was from depths ranging from 800 to 1,000 ft (240 to 300 m). With the advent of higher gas prices and improved completion technology in the 1970s, the field now includes an area greater than 600 sq mi (1,560 sq km). The reservoirs in the expanded area are lower in permeability, occur at depths ranging from 1,200 to 1,800 ft (360 to 540 m), and require stimulation to provide economic flow rates.

Most of the recent wells have been drilled using conventional rotary rigs and mud systems designed to minimize formation damage. The wells are hydraulically fractured using sand, carbon dioxide, and water. A combination of sonic, neutron, and density logs is an aid in reservoir evaluation, although better logging tools are needed. Production history, which is limited, will probably prove to be the best method of estimating recoverable reserves.

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Trace-Element Content of Bituminous Coal from Appalachian and Eastern Interior Regions and Rocky Mountain Coal Province—Data as of 1979

We have studied 2,035 samples from the Appalachian bituminous coal beds, 370 samples from the eastern interior coal beds, and 362 samples from the Rocky Mountain coal beds.

The coals analyzed range in rank from high-volatile bituminous to low-volatile bituminous; the Appalachian coals have the lowest mean volatile-matter and moisture contents and the highest fixed-carbon content and Btu value. The Rocky Mountain coals have the highest mean ash content and lowest fixed-carbon content and Btu value. The average Appalachian coal has a much higher rank than does coal from either of the other regions.

Of the 19 elements reported, seven (Cu, F, Mn, Pb, Sb, U, and V) have mean values that vary less than twofold among the three areas. Of these, U is the most uniformly distributed. Other elements (Co, Ni, Zn, and S) have about a fourfold variation, whereas As is 6.5 times as abundant in Appalachian coal as in Rocky Mountain coal. In average, the other elements are 2 to 6.5 times as abundant in some coals from the three areas as in others.

Table 1.--Statistical summary of data on Appalacian, Interior, and Rocky Mountain bituminous coals.

(Mean contents of all elements except sulfur are in parts per million, sulfur and ash contents are in weight percent, calorific values are in Btu's per pound, Gm = Geometric mean, Gd = Geometric deviation.)

	Rocky Mountian		Eastern Interior		Appalachian	
	Gm	Gd	Gm	Gd	Gm	Gd
As	1.4	2.6	6.9	2.9	9.1	3.6
Be	.87	2.3	2.4	1.8	1.9	1.9
Cd	.12	2	.19	4.2	.08	2.5
Co	1.5	2.1	4.3	2.1	5.5	2
Cr	5	2.3	12	1.7	14	2
Cu	7.7	1.8	10	1.8	14	2
F	73	2.2	55	1.7	68	2.1
Hg	.05	2.5	.09	2	.13	2.8
Li	9.3	2.3	7.3	2.2	15	2.5
Mn	15	2.9	23	2.5	15	2.7
Mo	1.1	2	2.7	2.5	1.8	2.3
Ni	3.2	2.2	14	2.3	11	2
Pb	5.2	2	9.1	3.1	6.7	2.2
Sb	.40	2.2	.73	2.8	.68	2.4
Se	1.2	1.9	2.2	1.7	2.9	2
U	1.4	2.2	1.3	2.3	1.2	2
V	12	2.1	15	3.3	17	2.5
Zn	8.6	2.4	32	3.3	13	2.5
Ash (550°C)	11	1.8	9.4	1.6	10	1.9
Calorific value	10,690	1.2	11,630	1.1	12,620	1.1
Sulfur	.67	1.7	2.8	1.8	1.6	2.2

The Rocky Mountain coals have the lowest mean contents of 15 of the elements listed in the table; only U and F mean contents are slightly higher in this area. The eastern interior coals have the highest mean contents of nine of the elements, and the Appalachian coals have the highest mean contents of eight of the elements.

As the average rank of the coals increases, the average contents of As, Co, Cr, Cu, Hg, Se, and V also increase; however, the distribution of most other elements is not related to rank. In general, the trace-element content of coal is influenced largely by the depositional environment and does not depend on rank.

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Overview of Geothermal Energy Developments

Exploration for geothermal resources includes evaluation of the volcanic history, regional geology and hydrology, geochemistry of hot springs, and use of selected geophysical methods to determine temperature, heat flow, and structure of prospective areas.

Geothermal energy is primarily used for electric power generation. At the Geysers field in northern California, geothermal energy has proved to be a viable, mechanically reliable, and environmentally acceptable resource. The field competes economically with alternative forms of power generation such as oil, gas, nuclear, and hydroelectric. The Geysers field is an example of a vapor-dominated geothermal reservoir. The field produces 630 Mw, with a total capacity estimated to be about 2,000 Mw. It is the only geothermal field used to generate significant quantities of electricity in the United States.

Other areas experiencing active development are the Imperial Valley of California, Baca area of New Mexico, and Roosevelt area of Utah. Overall, plans have been announced for nine power plants at seven sites, with a total generating capacity of 300 Mw. The new areas are all liquid-dominated systems.

The Department of Energy estimates that 15,000 to 20,000 Mw of geothermal power can be developed in the western United States in the next 2 decades. With improved exploration, drilling, and utilization technology, it has been estimated that several times this amount of power can be developed, provided that delays due to environmental and legal/institutional issues can be resolved.

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San Juan Basin of New Mexico and Colorado, Classic Area of Stratigraphic Exploration

The San Juan basin of northwestern New Mexico and southwestern Colorado is a Laramide structural basin with a maximum thickness of 15,000 ft (4,572 m) of Paleozoic to Eocene sedimentary rocks. The basin is elongate north-south, approximately 125 × 100 mi (201 × 161 km); it is structurally asymmetrical, with the deepest part in the north near the New Mexico-Colorado line. Monoclinal basin rims are especially prominent.

Petroleum occurs in Pennsylvanian carbonate rocks,