spectral resolution (seven spectral channels distributed throughout the visible and infrared portions of the electromagnetic spectrum), improved spatial resolution (30 × 30 m [98 × 98 ft] ground resolution), and improved sensitivity (256 gray levels in each spectral channel). Experimental studies with airborne Thematic Mapper simulators tentatively indicate that these measurement capabilities will have a major payoff in terms of our ability to detect variations in clay mineralogy and abundance, to map bleaching effects in surficial rocks and soils that may be produced by hydrocarbon seepage, and to detect variations in the distribution and vigor of natural vegetation that are also related to seepage phenomena. The improved spatial resolution of the Thematic Mapper will enable photogeologists to identify smaller scale landforms and drainage features which will also contribute to improved structural mapping capabilities. Research is currently underway to determine the utility of Thematic Mapper measurements for geologic mapping in complex areas characterized by large relief and extensive vegetation. Recent experimental results have underscored the need for improved spectral resolution in the next generation of visible and infrared sensors.

Radar imaging techniques also represent an important source of information concerning geological conditions at the earth's surface. Imaging radars artificially illuminate the earth at an angle of incidence and azimuthal direction that can be controlled by the radar operator. Variations in radar backscatter intensity observed at different angles of incidence are largely governed by areal variations in surface relief and roughness. Exploration geologists have made extensive use of airborne radar surveys for terrain analysis and structural mapping, particularly in tropical environments. However, it is difficult to obtain quantitative information on surface roughness conditions from airborne surveys because of the large variation in incidence angle that occurs across the radar's ground swath. Spaceborne radar systems offer the unique advantage of being able to illuminate large areas at a nearly constant angle of incidence due to their much greater elevation above the earth's surface. A Shuttle Imaging Radar Experiment (SIR-B), which will be conducted in August 1984, is designed to acquire multiple images of selected regions at different radar incidence angles. In principle, the coregistration of these images will enable researchers to differentiate surficial materials on the basis of their roughness characteristics in much the same way that multispectral measurements at visible wavelengths are used to detect variations in surface pigmentation. Experimental studies tentatively indicate that variations in surface roughness detected in orbital radar surveys can be related to subtle differences in the lithology of sedimentary rock units. Orbital radar techniques may provide an important new tool for mapping facies variations within sedimentary basins. Additional orbital experiments are being planned during the latter 1980s to evaluate the geological utility of radar imagery obtained at multiple frequencies and multiple polarizations.

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Secondary Porosity in Sandstones

Secondary porosity in sandstones is caused by dissolution and fracturing, and is common in the sedimentary record. Secondary porosity commonly develops in the deep subsurface and thus provides an opportunity to extend exploration to depths traditionally considered unsuitable for exploration.

Two contrasting routes of diagenesis exist in nature: porosity reduction and porosity enhancement. Porosity reduction is commonly caused by compaction and cementation, whereas porosity enhancement is primarily caused by dissolution of carbonate minerals. The dissolution of carbonate minerals in the deep subsurface can be attributed to release of carbon dioxide during thermal maturation of kerogen. Clay-carbonate reaction and flushing of undersaturated meteoric water from erosional unconformity are equally important mechanisms in generating secondary porosity at various depths.

Two basic types of primary pores (intergranular and intragranular) and four basic types of secondary pores (grain fractures, rock fractures, intergranular, and intragranular) can be differentiated on the basis of (1) position of pores, (2) timing of origin, and (3) processes of origin. The proposed classification system is useful in inferring reservoir quality.

Various types of secondary porosity are recognized using a comprehensive set of 20 criteria. The various criteria are based on manner of breakage, pore geometry, grain geometry, products of dissolution, and sediment packing. Examples of secondary porosity gathered in part from investigation of 2,000 thin sections will serve as a guide for recognizing secondary porosity in outcrop, in hand specimen, under the scanning electron microscope, and most importantly, under the petrographic microscope.

New evidence suggests that silicate minerals, including quartz, dissolve more commonly than have been reported. The abundant occurrence of secondary porosity in reservoir sandstones emphasizes the importance of secondary porosity in evaluating deep reservoirs.

Since the first recognition of secondary porosity by Nutting in 1934, Chepikov in 1959 and 1961 not only developed the first set of criteria for recognition of secondary porosity but also introduced the concept in which development of secondary porosity is related to arrival of oil.

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Numerical Model of Shale Compaction, Aquathermal Pressuring, and Hydraulic Fracturing

Clastic sediments, which are fine-grained or clayey, are capable of retaining fluids at pressures considerably greater than hydrostatic. The excess pressures can be induced by any of several mechanisms. A numerical model is developed which considers simultaneously the effects of compaction disequilibrium and aquathermal pressuring. Energy transport of conduction only is used to provide temperature profiles. The pressure and temperature dependency of isobaric thermal expansivity and isothermal compressibility are integrated in the solution. Simulations were conducted for a variety of heat flux, permeability, stratigraphic, and sedimentation conditions.

It is shown that, while compaction disequilibrium itself explains the general pressures in Gulf Coast sections, aquathermal pressuring can lead to fluid pressures greater than lithostatic. Fluid release by hydraulic fraturing must then occur. This combination of processes provides an explanation for the observed variations in shale bulk density, excess pressure, and thermal gradient. A Mohr failure diagram, using a two-part failure envelope combined with horizontal versus vertical stress data provides a means of determining when fracturing is initiated and the orientation of the fractures. A variety of stress conditions that result in both horizontal and vertical fractures are considered. The depth of fracture initiation is highly dependent on the sedimentation rate, the sand versus shale ratio of the sediments, and on the tensile strength and hydraulic conductivity of the shale.