United States consist of at least 50% carbonate rock. Hydrocarbon resources of lacustrine depositional systems are greatest in the People's Republic of China (several billion barrels of recoverable oil). Hydrocarbon resources are also significant in the ancient lake basins of Brazil, Angola, Cabinda, and United States. Currently developed Chinese oil fields in nonmarine rocks are primarily in structural traps, those of South America and Africa are in combination structural and stratigraphic traps, whereas those of the United States are principally in stratigraphic traps.

Available data suggest that hydrocarbons in the more deeply buried strata are contained in secondary pores which received oil or gas subsequent to significant episodes of cementation and/or compaction, and dissolution of minerals. Reservoir rocks with abundant primary porosity are most commonly preserved at relatively shallow burial depths, and many are intercalated with immature source units. Primary pores contain hydrocarbons that have migrated to reservoirs from mature source rocks (more deeply buried?). In China, oil is recovered in great quantities from sandstones with abundant primary porosity, particularly in those basins with high geothermal gradients. The oil apparently migrated to the primary pores from nearby source beds which reached thermochemical maturation at relatively shallow depths of burial and before significant early cementation and compaction of the sandstone units. Matrix porosity and permeability in sandstone units are best developed and preserved in those rocks composed of chemically stable minerals and few labile grains.

Fluid-pressure gradients may be abnormally high in those lacustrine systems that have reached the stage of thermochemical maturation. In these cases, oil and/or gas are generated and expelled in quantities great enough to locally increase fluid pressures faster than pressure is released to adjoining rocks. Abnormally high fluid-pressure gradients in lacustrine units also occur in those impermeable hydrocarbon-bearing strata that have apparently been elevated at a rapid rate. In such a system, equilibration between fluid pressures in beds of low matrix permeability in the deep subsurface and permeable beds near the surface is restricted. In both cases, fractured overpressured rocks of low matrix permeability may yield oil and/or gas from pools whose boundaries are not restricted to local structures. Rather, they are restricted by relatively permeable beds that have provided access to the surface for pressure and fluid release (and invasion of water). Local avenues of permeability in overpressured rocks are greatest along natural, open fractures.

Although reservoir rocks for fields developed in lake basins are commonly described as being of a lacustrine origin, others were formed from sediment deposited at the edge of a lake or in settings well removed from a lake. Principal reservoir rocks in the Uinta basin, Utah, represent the basal parts of coalesced fluvial channels formed at the fluctuating margin of lake Uinta. Red-colored oil-bearing strata in some Chinese fields whose reservoir rocks are channel-fill sandstones formed from sediment deposited on an alluvial plain several kilometers from the lacustrine shoreline. Lacustrine turbidite, bar, and deltaic rocks are important reservoirs in Brazil, Africa, United States, and China. Petroliferous sedimentary rocks formed in lake basins are known over much of the world where they contain many billion barrels of recoverable oil and offer the promise of more.

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Geologic History of Reefs

A reef, whether fossil or modern, is the physical expression of a community of calcium carbonate-secreting organisms which grew in one place for an extended period of time, forming either isolated structures or cores of complex buildups. These sea-floor highs are not only sites of rapid carbonate fixation and accretion but also locales of internal sedimentation, synsedimentary lithification, and active bioerosion—attributes which set them apart from most other sedimentary deposits.

The core facies of large and complex fossil reefs generally illustrate a succession of growth stages, each of which is characterized by specific lithologies and invertebrate taxa. These stages, now recognized in reefs throughout the geologic record, are generally referred to as the pioneer (stabilization), colonization, diversification, and domination (climax) phases of reef growth. They record the transition from shoals of skeletal sand populated by small, rooted invertebrates and/or algae to thickets of branching or lamellar organisms to complexes made up of many different taxa with varied growth forms and life habits to a cap comprising only a few, generally lamellar to encrusting skeletons.

Just as the development of any one reef is dependent upon inherently biological factors so the history of reefs in general reflects the evolution of Phanerozoic marine invertebrates. For a reef illustrating all stages to develop, a prerequisite is the existence of metazoans capable of secreting large skeletons of variable growth form. At those times in geologic history when only small, prone, branching sessile invertebrates occur, buildups called reef mounds are present that illustrate only the first two stages of growth. Thus there are times when no reefs occur, periods when reef mounds are the norm, and periods when complex reefs dominate.

Although the attributes that characterize all reefs are present in the very earliest Cambrian bioherms, against the backdrop of geologic time, there are two general cycles of reef growth. Each begins with reef mounds which are subsequently populated by sponges and then gradually transformed into complex reefs by the appearance of corals and/or stromatoporoids. The first cycle begins in Early Cambrian time and culminates in the Late Devonian (240 m.y.); the second cycle begins in the Mississippian and has continued to the present (340 m.y.). During the early phases of these cycles reef mounds occur on or around shoal-rimmed platforms; in the latter stages reefs commonly form the rim facies, and control platform evolution.

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Geological Evaluation of Fractured Reservoirs

Effective evaluation of fractured reservoirs involves both qualitative and quantitative data of various levels of complexity. This paper attempts to describe those geological and petrophysical data necessary in making an early evaluation of a fractured reservoir, during either exploration or early development phases. As such, prediction rather than detection will be emphasized.

Early in the evaluation of a fractured reservoir the majority of predictions are based on direct observations of a combination of geological and rock data. Those observations are generally made by geologists and/or petrophysicists, and are used to determine: (1) fracture origin and distribution, (2) the reservoir characteristics of the fracture system, (3) the interaction of the fracture and matrix porosity systems, and (4) the type of fractured reservoir, based on the contribution of the fracture system to overall reservoir quality. Each of these determinations is discussed, including the general types of geological interpretations and rock property analysis required.

Subsequent to those early determinations and predictions by geologists, larger scale, more quantitative data detecting the effect of reservoir fractures are made by the reservoir engineers. Techniques such as pressure transient analyses and interference testing allow the extrapolation of small scale geological and petrophysical data to larger scale reservoir flow predictions using large mathematical reservoir flow models.

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Shales—Their Sedimentology and Geology

Shale and mud form at least 60% of the world's sediments and have been deposited throughout geologic history. They occur in every major depositional basin. They are major source beds for hydrocarbons, hosts for metallic minerals, sources of ceramic materials, cause unstable foundation conditions, and produce soils for our food. Yet the study of shales has lagged far behind that of other sedimentary rocks. However, the following general observations can be made about these important rocks.

More studies have been made of recent muds than of ancient shales. Clay mineralogy, geochemistry, and paleontology of muds and shales are better understood than their stratigraphy, petrology, and sedimentology. Most shales occur in marine sequences and are associated with deltaic depocenters. They are more commonly geosynclinal than cratonic, and are most commonly deposited in deep water as distal turbidites and pelagic muds. Cratonic shales occur as widespread, thin sheets distal from their source land.

Sedimentology

Most muds are transported in suspension and are commonly deposited as aggregates of floccule or fecal pellet origin. Floccule formation is sensitive to water chemistry—salinity, organic compounds, and turbulence. Mud aggregates are commonly deposited under higher hydraulic energy conditions than previously assumed for muds. Size analyses for mud and shales are generally useless for interpretation of depositional hydraulics. Vertical variations in bedding properties, texture, color, organic content, mineral composition, fossil content, and bioturbation are the most useful parameters for the deduction of depositional environments of shales and muds. These, integrated with basin geometry, hold the most promise for future studies.

Stratigraphy

Shales almost always have an internal stratigraphy that is well-expressed on wire-line geophysical well logs. Thin beds of high or low density, different lithologies and organic content, and fossil zones or concretions within shale sequences are commonly widespread and are good markers for internal stratigraphy. Most shales have a clinoform internal stratigraphy that can be related to basin geometry and can be observed in seismic profiles.

Diagenesis

Muds compact more than other sediments and hence expel more fluids. Pore water chemistry, mineralogy, thickness, and density all change as pore water is expelled. Water expulsion concentrates hydrocarbons and metals in interbedded porous reservoirs. Seismic response, heat flow, and our perception of original shape of shale bodies all change with burial compaction.

Tectonics

The concept of "lutokenesis"—mud makes its own tectonics—applies. Where deposition has been rapid, buried shales are overpressured and undercompacted. Undercompacted shales can form diapiric structures. Shales thin over rising structures and thicken into synclines and subsiding basins. In large-scale overthrusts, bedding-plane faults form fold trains; shear and flow occur mostly in shale units.

Source Beds

Shales are major source beds of hydrocarbons. Total organic content is sensitive to the original circulation in the basin, biogenic productivity, and influx of fine terrigenous and carbonate muds—a dilution factor. Preservation of organic matter is best in muddy basins because density stratification inhibits vertical mixing and oxidation—rapid burial inhibits biodegradation. Best indicators of thermal history of shaly basins are kerogen, conodonts, vitrain, and clay minerals.

Relating Sedimentology of Shales to Resources

Establish internal stratigraphy and facies distribution. Relate every resource variable to internal stratigraphy, and make an isopach map and relate facies distribution of basin. For gas, relate primary and secondary porosity (fracturing and permeability) to maturation, facies, and internal stratigraphy. For oil, correlate kerogen content to internal stratigraphy and maturation. For uranium, correlate kerogen to internal stratigraphy.

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Modern Wetlands and Their Potential as Coal-Forming Environments

An array of modern wetlands, including swamps, marshes, bogs, etc exists on nearly every continent. The wetlands range from essentially dry upland shrub-moss communities to forests which exist on a constantly submerged substrate. Some wetlands are common to arctic regions, others are found only in the tropics. Each wetland has developed a variable and fascinating assemblage of plant species that have adapted to the peculiar physical and chemical properties of their environment.

The great variety of wetlands provides us with an opportunity to study an assortment of depositional settings, some of which are suitable analogs to ancient, coal-forming environments. Some wetlands, such as kettle swamps and bogs, or karst swamps and marshes may have occurred so infrequently in the past as to have been unimportant in coal formation. Other wetlands, such as back-barrier lagoon swamps, deltaic swamps, and inland river swamps have unquestionably been responsible for deposition of our most extensive coal deposits.

An overview of modern wetlands illustrates the tremendous complexity of these plant communities, and dispells the idea that modern swamp/marsh deposits (i.e., peats) and, hence, coal deposits are simple. The physical and chemical compositions of peats and coal beds have changed with time, as different environments have dominated areas of the globe and plants have evolved in response to those environmental changes. The study of modern wetlands is receiving increased emphasis as