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 further comparison of modern and ancient deposits improves our means of mining and utilizing coal.

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Wrench Fault Tectonics

Relations among basin formation, sedimentation, and uplift in response to wrench faulting are well documented, especially in California, and together with rock and clay model laboratory studies, the California examples provide considerable insight to the mechanics of wrench fault tectonics in both space and time.

Wrench faults are produced in both pure and simple shear deformation, but it is the unique nature of strain in simple shear which leads to the characteristic en echelon arrangement of related folds and faults, structures which constitute the principal traps for hydrocarbons along wrench faults in many parts of the world.

Coalescing and rotated fractures combine within the length of the fault zone to form a braided arrangement of faults around lozenge-shaped, uplifted, and downdropped blocks. Whether an uplift or basin develops depends on the bending geometry of the fault segments and the sense of slip across the wrench fault zone itself. Adjacent highlands along such tectonically active zones may shed great volumes of generally coarse sediment into these equally tectonically active basins, and such basins are typified by unusually thick sequences of coarse clastic sediments stacked in a shingled or Venetian-blind-like arrangement.

The structure along the edges of the uplifted blocks may be complicated in detail, involving the geometrical interplay of steeply and gently inclined strata together with variable components of dip and strike separation on faults of diverse attitudes. It is along these complicated fault block margins, however, where favorable traps for hydrocarbons can be anticipated and have yet to be explored in many areas.

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Prediction of California's Next Earthquake

A great earthquake, centered near Los Angeles or San Francisco, has the potential to be the greatest natural catastrophe ever to strike the United States in historic time. According to some estimates, as many as 10,000 people could be killed, 100,000 could be injured, and up to $40 billion damage could occur.

Against this threat, many state and federal agencies, universities, and private consultants are working overtime in California to fathom the riddle of how and why earthquakes occur, in the hope of gaining understanding of the earthquake process, and leading to timely predictions to reduce the loss of life and property.

Following examples which have been variously successful in the People's Republic of China, Japan, and the Soviet Union, American seismologists are designing, testing, and studying a wide variety of instruments and initiatives they hope will be successful in making predictions routine. Techniques and instruments range from traditional seismographs, tiltmeters, and creepmeters, to monitoring changes of gravity, magnetic field, and resistivity, to observing behavior of kangaroo rats, emission of radon gas, and measuring levels of water wells.

Results have been mixed. No one has issued a formal prediction, which demands that the time, place, magnitude, and estimated effects be specified, but several earthquake alerts have been given. To confound matters, however, earthquakes have happened in the center of heavily instrumented areas without a shred of precursory warning. One statistician has said that at the rate we are progressing, we shall not have another chance to predict a great earthquake in California for 100 years if we miss the next one, which some experts say will happen in the next decade.

This lecture gives an overview of the problems and techniques of predicting California's next earthquake, together with a discussion of the status quo which, at the time this abstract was written, included a possible volcanic eruption a few hours' drive from downtown Los Angeles.

AAPG-SEG-SEPM PACIFIC SECTION MEETING

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Abstracts of Papers

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Lithic Wackes of Early-Middle Eocene Lookingglass Formation, Southwest Oregon

The early to middle Eocene Lookingglass Formation is exposed over a wide area in southwestern Oregon. The formation contains a thick sequence of turbidite deposits consisting dominantly of very coarse to fine-grained lithic wackes, with minor amounts of pebbly sandstone, siltstone, mudstone, or shale. Sediments, mainly from the Klamath region on the south, and partly from a volcanic arc on the east, were deposited in a north-trending fore-arc basin approximately 125 by 155 mi (200 by 250 km) in size.

Within the lower part of the sequence, the lithic wackes are mainly thick-bedded, normally graded, pebbly sandstones and very coarse to coarse sandstones that contain a shallow-water marine fauna. Channel-fill conglomerate lenses occur within some of the thick beds of sandstone. This part of the sequence is interpreted as a proximal submarine-fan deposit. The lithic wackes of the upper part of the sequence, however, generally form sheets of thinner bedded, medium to fine-grained sandstone with more matrix. They contain deeper water marine fauna and are devoid of channel-fill conglomerate lenses. This part of the sequence is interpreted as a distal submarine-fan deposit. Sedimentation took place at a high rate and was accompanied by rapid subsidence of the basin.

The lithic wackes have undergone fairly intense diagenetic alteration, which includes cementation by calcite, silica, chlorite, and clay minerals; the replacement of feldspar grains, lithic fragments, and matrix materials by calcite and chert; and the recrystallization of chlorite. Cementation and compaction have considerably reduced the porosity of these sandstones.

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Application of Nonlinear Constraints to Processing of Seismic Data