a top seal will also be a lateral seal. Stratigraphic traps and faulted prospects have substantial seal risks. Hydrocarbons are not distributed randomly or arbitrarily on complexly faulted structures. Their distribution follows simple physical principles, and preferential hydrocarbon distribution can be predicted, given adequate data. Improvements in assessing seal risk for an exploration prospect directly affect the estimation of exploration success.

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Mediterranean Miocene Carbonates: Facies Models and Diagenesis

Miocene carbonates can bridge the gap between Holocene and older carbonate sequences, thus enhancing understanding of depositional and diagenetic patterns. Miocene carbonates can bridge this gap because of their similarity to Holocene counterparts and the ease of using these carbonates to reconstruct tectonic, paleogeographic, and paleoclimatic settings. In the Mediterranean, the Miocene provides a superb set of exposures and a wide variety of facies models in different geologic settings.

Mediterranean Miocene carbonates contain three major types of platform facies: coral reefs, macroforaminifer-rodolithic carbonates (rodalgal facies), and molluscan-bryozoan-foraminifer calcarenites (foramol facies). A combination of interrelated factors (e.g., water depth, temperature, and nutrients) control the distribution and lateral vertical transitions of these platform types. The rodalgal facies is widespread and occurs as a transition between the coral reef platform and the foramol platform. Modern carbonate sedimentation in the Mediterranean provides instructive analogies for many varieties of foramol and rodalgal facies. The most extensive porosity type is a combination of secondary intergranular and moldic porosity with chalky microporosity, locally in association with minor primary integranular porosity. This porosity is normally associated with dolomitization and is interpreted as having originated in intermediate burial environments.

Miocene coral reefs were particularly abundant and well developed in the late Miocene, before and during the Messinian salinity crises and basinal evaporite deposition. These events implied drastic variations in sea level, water chemistry, and nutrients, and coincided with high sedimentation rates in coastal areas. To survive these adverse conditions, coral reefs grew very fast, with spacially successful colonial morphologies and intense carbonate cementation. Many coral reef sections present marked cyclicity with repeated intercalations of exceptionally well-developed stromatolitic carbonates. Present outcrops record details comparable to Quaternary reefs, as well as details of the facies geometry of the different reef complexes and their responses to Miocene sea level oscillations.

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Unconformities, Paleokarst Facies, and Porosity Evolution

The study of unconformities and paleokarsts from the perspective of modern facies analysis and modeling offers potential advantages in terms of organizing and guiding observations, comparisons, interpretations, predictions, and hydrodynamic considerations.

Karsts that developed at major unconformities may result in karst facies and profiles different in many respects from those of meteoric diagenesis in Quaternary carbonates in tropical areas (e.g., the Caribbean). Many paleokarsts developed on mud-supported carbonates after mineralogical stabilization, deep burial, and tectonic deformation, but without the diffuse recharge and flow characteristics of the Caribbean model or the influence of a coastal marine mixing zone. The general concepts of water table and vadose and phreatic regimes need careful review when applied to heterogeneous permeability networks.

Karst facies and profiles are controlled by (1) previous permeability networks of the affected formation, (2) balance and interaction of climatic, biologic, and hydrologic environments that enhance or reduce these permeability networks, and (3) timing, rate, and succession of environments, and stages of evolution. Karst facies, facies associations, and their profile arrangements generally vary, and may be complicated by relict and rejuvenated features common in evolved karst profiles. In detail, karst facies are defined in terms of (1) corrosion-erosion morphologies, (2) diagenetic overprints, (3) karst sediments and cements (speleothems), and (4) biologic associations.

A common, mature, authigenic karst profile consists of the following zones. (1) Soil, infiltration zone—down to the limit of root penetration. (2) Percolation zone—with vertical passages and abundant sedimentation, collapse, and cementation, commonly containing relict features (cave levels) from deeper horizons or local saturation zones. (3) Oscillation zone—characterized by periodic water saturation and, in terms of lithofacies, commonly indistinguishable from the permanent lenticular zone (shallow phreatic); predominantly horizontal passages with bedding-plane control and erosional features are the key characteristics of this zone; cave sediments show evidence for reducing depositional environments; many well logs show a characteristic kick in the gamma ray (B marker), together with a decrease in the sonic activity. And (4) deep phreatic zone—characterized by incipient, slow corrosion and/or cementation and grading into the unaffected formation.

In most places, a rock formation is first exposed to the deep phreatic zone and evolves through the shallow phreatic into the vadose as a result of the dismantling of the upper part of the profile. In this way, the classic concepts of youth, maturity, and senility can apply to parts of the karst profile or to the entire profile, and can provide a basis for comparing other profiles of the same karst system. Base level changes are commonly sharp and produce repeated horizontal cave levels that are abandoned in the vadose part of the profile. In many paleokarsts, those relict cave levels have been confused with repeated surfaces of subaerial exposure.

Correlating different karst profiles and the structural-lithologic patterns of the affected formation offer the possibility of reconstructing the evolution of drainage patterns during major unconformities. This karst facies modeling can also provide a basic tool for reservoir evaluation in exploration and production.

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A Dry Hole or Reservoir Damage? What We Need to Know

Stories abound in the industry about the oil or gas field drilled and abandoned by one company, only to be "discovered" by a second company that evaluated the data from a different perspective. The Elmworth field (Canada), and Beeville, North Resenberg, and Running Duke fields (Texas) are all examples where the initial well penetrated the hydrocarbon column but was not completed, or was completed, tested, and abandoned.

Numerous explanations exist as to why fields are abandoned and then rediscovered. Often contributing to this cycle is a lack of understanding of the reservoir's pore geometry, and of the effects of drilling or completion-induced damage on production or pressure performance measured by drill-stem tests, repeat formation testers, and well logs. Additionally, the inability to tell the difference between a low-permeability noncommercial reservoir and a damaged commercial reservoir results in a lot of missed field discoveries.

In my lecture, I discuss the causes of formation damage, as well as factors that signal the reservoir's vulnerability to damage (e.g., small pore throats, authigenic clays, low reservoir pressure). I also include case examples of conventional tests that, by routine analysis, show the zone to be noncommercial when, in fact, the well was completed and produced commercially.

Understanding the type of reservoir system being tested and using all available tools and data are the key to determining reservoir behavior.

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Carbonate Facies and Reservoir Heterogeneity—The Value of Modern Analogs

Secondary and enhanced processing of hydrocarbon fields requires a critical understanding of reservoir heterogeneity by both geologists and engineers. Carbonates have more varied facies and diagenetic patterns than their siliciclastic counterparts, thus offering a greater challenge to reservoir evaluation. This challenge is illustrated by American Petroleum Institute data showing average primary plus secondary recovery efficiencies of carbonate reservoirs of only 32% original oil in place. Studies of modern analogs are valuable because they constrain interpretations and lend predictability to unraveling facies patterns in reservoirs. These patterns help to understand the lateral continuity of stratification, variation within layers, heterogeneity, and performance of reservoir examples.

An appreciation of facies variability and depositional processes for carbonates can come from examination of modern environments of deposition. Common patterns in structural, textural, and diagenetic trends can be summarized from several modern settings for reefs and mounds, sand shoals, and lagoons and tidal flats. The lessons learned from detailed studies of modern examples center on several important points: (1) the trend and continuity of facies belts vary, but the patterns are orderly when the setting is understood; (2) typically, carbonate deposits form in localized ovoid or elongate thicks, not in widespread sheets; (3) the depositional systems contain complex, highly variable facies patterns in map view; (4) a predictable sequence of sediments, although not fully developed throughout the depositional environment, typifies the setting; (5) the stratigraphy as revealed by sediment coring is highly variable, recording a short-lived, but exceedingly complex geologic history; and (6) early diagenesis related to evolving depositional environments can significantly alter the porosity and permeability of the sediments.

Carbonate depositional systems, as shown by modern examples, are complex from the scale of a producing field right down to that of a pore throat. This fact, coupled with frequent control by facies over subsequent diagenesis, imparts the great heterogeneity to carbonate reservoirs. Log response and reservoir quality are directly related to facies and diagenesis, with varying grain size a major control over permeability amounts in porous intervals. Permeability affects recovery efficiency and thereby links the depositional facies through sediment texture to reservoir performance.

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Depositional Environments and Petroleum Geology of Jurassic Eolian Deposits (Norphlet Formation), Eastern Gulf of Mexico Area

Jurassic Norphlet sediments in the eastern Gulf of Mexico area accumulated under arid climatic conditions. The accumulation of thick Jurassic salt deposits, anhydrites, and red beds in association with Norphlet sandstones indicates that arid climatic conditions were prevalent during Norphlet deposition. Usually an association of salt deposits, anhydrites, and red beds is characteristic of arid climatic conditions, and eolian sands can be expected to accumulate under such depositional conditions.

The Appalachian Mountains of the eastern United States extended into southwestern Alabama and provided a barrier for air and water circulation during the deposition of the Norphlet Formation. These mountains produced the topographic conditions that contributed to the arid climate. In the region, Appalachian structural features are recognized as basement ridges and arches, such as the Conecuh and Pensacola ridges and associated Wiggins arch. These paleohighs affected Norphlet sedimentation and acted as local sediment sources.

Norphlet paleogeography in the eastern Gulf coastal plain was dominated by a broad desert plain, rimmed to the north and east by the Appalachians, and to the south by a developing shallow sea. The desert plain extended westward into eastern and central Mississippi.

Norphlet sedimentation began as a result of basin subsidence accompanied by erosion of the southern Appalachians. Norphlet conglomerates were deposited in coalescing alluvial fans near an Appalachian source. The conglomeratic sandstones grade downdip into red beds that accumulated in distal portions of alluvial fan and wadi systems. Quartz-rich sandstones were deposited as dune and interdune sediments on a broad desert plain. The principal source of the sand was updip alluvial fan and plain and wadi deposits. Wadi and playa lake sediments also accumulated in the interdune areas. A marine transgression during the late phase of deposition of the Norphlet Formation resulted in the reworking of previously deposited Norphlet sediments.

To date, 35 Norphlet oil and gas fields have been established in the region. Petroleum traps discovered are principally structural traps involving salt anticlines, faulted salt anticlines, and extensional fault traps associated with salt movement. Although basement highs also have potential as petroleum traps in the area, salt movement is the critical factor in forming a petroleum trap. Numerous Norphlet fields are located along the regional peripheral fault trend, particularly in association with the Pollard-Foshee fault system in southern Alabama and the Florida panhandle. Other onshore Norphlet petroleum traps include salt anticlines, such as Copeland, and salt grabens, such as the Mobile graben. In Mississippi, several Norphlet fields are located near the Jackson dome, a Cretaceous igneous intrusion. The Norphlet fields discovered in offshore Alabama are along the Lower Mobile Bay fault trend. The petroleum traps in the offshore area include a series of generally east-west-trending salt anticlines.

Reservoir rocks consist primarily of quartz-rich sandstones of eolian, wadi, and marine origin. The average composition of these quartz-rich sandstones is 72.5% quartz, 15.0% feldspar (plagioclase, microcline, and orthoclase), 4.4% rock fragments (chert, shale, phyllite, schist, and quartzite), 3.8% cement (carbonate, quartz, and anhydrite), 3.2% authigenic clay, and 1.1% accessory minerals. Porosity includes primary intergranular and secondary intergranular, and intragranular developed as a result of decementation and grain dissolution. Porosity in Norphlet reservoirs can exceed 25%.

The primary source of hydrocarbons in the Norphlet reservoirs is Smackover carbonate mudstones. Norphlet shale samples analyzed were found to be low in total organic carbon (0.1-0.2%). Smackover carbonate mudstones are locally rich in algal and amorphous kerogen. The geochemical and carbon isotopic composition of Norphlet crude oils compares favorably with the composition of Smackover crude oils and Smackover carbonate mudstones.

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Capitan Reef Complex (Permian), Guadalupe Mountains, Southwestern United States: A Classic Sedimentologic Model in Flux

The Capitan reef complex of west Texas and New Mexico has been an important sedimentologic model since a reef origin was proposed for the Capitan Limestone in 1929. The Capitan's magnificent exposures in the Guadalupe Mountain area; its large scale; its variety of carbonate, sandstone, and evaporite facies; and its relationship to major petroleum resources of the Permian basin have made it a justly famous sedimentary geologic model for academic and industrial geologists alike. Since 1950, extensive research has yielded markedly contrasting sedimentologic interpretations of key features, such as the nature and origin of the Capitan massive ("reef wall"); the back-reef pisolite, sandstone, and evaporite facies; the depositional profile of the shelf and shelf edge; the importance and magnitude of sea level fluctuations; and the role of submarine, vadose, and phreatic diagenesis.

Early views of a barrier reef depositional profile have been replaced by a shelftop marginal mound profile, in which the mound's gentle crest coincided with the backreef pisolite and tepee facies. The Capitan massive, earlier considered an ecologic barrier reef, is now interpreted as an outstanding example of massive limestone formed at a submerged shelf edge where extensive submarine cementation lithified sponge wackestones and formed massive cement boundstones. Permian vadose diagenesis, earlier accorded much importance and inferred as being related to major sea level falls, appears negligible. Phreatic diagenesis by mixed meteoric and marine fluids was at least locally important in the Capitan massive and foreslope strata. The famous Guadalupe pisolite, interpreted until the mid-1960s as lagoonal, and then widely accepted as Permian caliche of vadose origin, is now reinterpreted as largely synsedimentary, formed by subaqueous precipitation from hypersaline waters of a peritidal shelf crest; associated vadose fabrics are minor, overprint isopachous pisolite fabrics and are unrelated to major intraformational erosion surfaces.

Subaerial erosion surfaces within the reef complex are largely localized high on the shelf marginal mound. Unequivocal evidence of emergence of the Capitan massive or its underlying foreslope has not been recognized, suggesting that any sea level lowering during Capitan deposition did not exceed a few tens of meters. Although a sabkha origin of the back-reef evaporites and eolian transportation of sand across a sabkha surface has conceptual appeal, a lagoonal origin of the evaporites and subaqueous deposition of the back-reef sandstone sheets better fits the available field evidence. Vast amounts of siliciclastic sand had to bypass the Capitan massive and upper foreslope facies, but neither channels nor scoured erosion surfaces have been identified.

The Capitan reef complex can serve not only as a "world class" sedimentologic model, but also as a much studied model not yet well understood. The model is one whose scientific investigators have frequently been afflicted by over-reliance on Holocene models ("modern model mesmerism"), by overthrust of established authorities or dogma ("dogma reverence"), by uncritical acceptance of new concepts ("bandwagonitis"), by overuse of superficial "look-alike" features for