from the upgoing reflections by f-k filtering. The downgoing wave field can be used as signatures to deconvolve the upgoing wave field as the best estimate of the primary reflections in the vicinity of the borehole. VSP processing preserves the polarity and amplitude of reflections, and after deconvolution, a trough corresponds to a positive reflection coefficient. These reflections can be shifted to their two-way traveltime and stacked to produce a VSP extracted trace (VET), which is used to correlate to the CDP data.

An important application of a VSP is to correlate the reflection character to depth and the stratigraphy observed in the borehole. The direct downgoing arrival contains the two-way time to depth relationship and the enhanced primary reflections contain the reflection character. Any formation top in the VSP survey can be correlated to time using these features.

VSP reflection character indicates the significant features in the sonic log velocities that produce the reflections observed in the surface seismic data. Sonic logs and VSPs attempt to measure the same velocities and reflectivity near the borehole but with significantly different resolution. The sonic log only penetrates a short distance into the formation but provides detailed velocity information vertically. A VSP, however, has poor vertical resolution (50 to 100 ft [15 to 30 m] intervals) but samples a large area around the borehole similar to CDP data. Therefore, the VSP correlates well with CDP data because they have the same resolution. It also correlates well with the synthetic seismogram because they both contain primary reflections without multiples.

Finally, multiples in the CDP data are easily identified utilizing the VET and synthetic seismogram. In addition, the depth of origin and periodicity of multiples in the processed VSP can be observed directly because they are generated by downgoing multiples and not by the direct arrival.

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Iodine—A Pathfinder for Petroleum Deposits

The relationship between oil and gas fields and high concentrations of iodine in water is well known. Iodine is a good, indirect surface indicator of areas favorable for oil and gas accumulations. Humic substances are the main initial source of iodine in subsurface waters. At the high temperatures achieved during burial, structural degradation of large molecules of unsaponified organic matter and of insoluble residues and bitumens also provide a source of iodine. Although the iodine background content in formation waters of different geologic ages varies widely, it has no apparent effect on the use of iodine as a pathfinder for potential oil and gas prospects.

Samples are taken from the top 2 to 4 in. (5 to 10 cm) of the soil and are analyzed for total iodine content. In the analysis for iodine, the total iodine content—iodine that is firmly retained by humic soils and iodine that is contained in soluble iodide form—is expressed in weight percent. Depth appears to influence the extent of iodide fixation by clay soils. For example, in arid and humid-temperate soil clays, the extent of iodide fixation increases with the decrease of soil depth. Clays obtained from different depths of soils located within the water table do not record any difference in iodide fixation; however, identification of the sand/clay ratio in the 170 mesh soil sample is important.

High iodine concentrations occur about the perimeter of a surface geochemical anomaly. This surface expression of the reduction chimney, the so-called halo effect, is associated with oil and gas anomalies. A typical anomaly exhibits values greater than two standard deviations above the statistical mean.

Iodine is an effective pathfinder in surface prospecting because of: (1) the simplicity of taking and non-critical handling required of the surface samples, (2) the ability to integrate a detailed survey into an earlier reconnaissance survey, and (3) relatively low-cost analysis permits a greater sampling density, which provides better identification and definition of anomalies.

Iodine, as all geochemical parameters, should not be used by itself, but rather in combination with other geochemical techniques, and the results should be cross-correlated for an optimum confidence level. Iodine analyses are a good cross-check on the validity of radiometric anomalies or magnetic anomalies. They are also a good geochemical tool to use in the reconnaissance mode prior to using more expensive hydrocarbon analyses in the detailed phase of an exploration program.

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Depositional Architecture and Reservoir Characterization of Late Paleozoic Submarine Slope and Basin Depositional Systems—Midland and Delaware Basins, Texas

Upper Pennsylvanian and Lower Permian slope sandstones of the Eastern shelf (Midland basin), Permian Spraberry and Dean fan sandstones and siltstones (Midland basin), and Delaware Group basinal sandstones (Delaware basin) were deposited by slope-accelerated density currents and illustrate a spectrum of intracratonic submarine slope and basin depositional styles. Each depositional system also contains several large reservoirs (cumulative production exceeding 10 million bbl) and numerous smaller reservoirs constituting three prolific oil plays.

The Eastern shelf submarine-slope fan system was deposited along the margin of an actively prograding clastic shelf. Downslope sediment transport was by turbidity currents, and deposits are scale-models of larger oceanic submarine fans. Spraberry/Dean reservoirs were largely deposited by relatively nonturbid, saline density currents flowing off of shallow, restricted shelves and platforms. Reservoir geometries reflect the increasing importance of channelized flow across the basin floor. Delaware sandstones were deposited by saline density currents originating on surrounding broad, evaporitic reef-barred platforms. Elongate, lenticular geometry and textural maturity characterize Delaware Sand reservoirs. Despite the variations in specific sand-body genesis, reservoirs of each system display numerous similarities. (1) Reservoir facies are embedded in organic, oil-prone source rock basinal mudrocks. (2) Entrapment is largely by the updip or uplap pinch-out of porous fan facies that is inherent in the depositional architecture of submarine slope systems. (3) Porosity and permeability range from fair to poor, and proximal-to-distal variations decrease as saline density currents assume the dominant role in sediment transport. (4) Water saturation and residual oil saturation are high. (5) Solution gas drives dominate reservoirs; consequently, waterflood and pressure maintenance are necessary for efficient recovery. (6) Great internal facies complexity of the slope channel and suprafan deposits, combined with low to moderate permeabilities, results in low recovery efficiencies. Because of the internal and external stratigraphic complexity of these slope system reservoirs, the potential remains for discovery of new reserves and significant improvement in recovery of the 12 billion bbl of known oil-in-place.

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Deep-To-Shallow Carbonate Ramp Transition in Viola Limestone (Ordovician), Southwest Arbuckle Mountains, Oklahoma

The Viola Limestone (Middle and Upper Ordovician) of the southwest Arbuckle Mountains was deposited on a carbonate ramp within the southern Oklahoma Aulacogen. Depositional environments include (1) anaerobic, deep-ramp setting represented by microfacies RL, CH, CGL, and A, (2) dysaerobic, mid-ramp setting represented by microfacies B, and (3) aerobic, shallow-ramp setting represented by microfacies C and D.

Deposition in the deep- and mid-ramp environments was dominated by bottom-hugging currents produced by off-platform flow of denser waters. These currents moved down a broad slope that was locally incised by gullies. Deposits of the broad slope, microfacies A and B, originated from a line-source and are found throughout much of southern Oklahoma. Primary sedimentary structures include millimeter-size laminations, starved ripples, and concave-up and inclined erosional surfaces. Shelly benthic fauna are rare in A and B; trace fossils are common only in B. Deposits associated with the line-source gully, microfacies RL, CH, and CGL, are laterally confined; they have been observed only in the southwest Arbuckle Mountains. Primary sedimentary structures present in RL include wavy and ripple-cross laminae. Microfacies CH, contained within RL and interpreted as a submarine channel deposit, is present only at one locality. Primary sedimentary structures present in CH include an erosional base and several internal erosional surfaces, lateral accretionary sets, and imbricated, locally derived intraclasts.

Deposition in the aerobic, shallow-ramp setting (microfacies C and D) was dominated by storm processes and intervening periods of bioturbation. An increase in both size and abundance of pelmatazoan fragments is the characteristic feature of these microfacies.

High total organic carbon (TOC) values have been reported for the lower Viola. TOC values of 1% have been reported from microfacies A, and TOC values of 5% have been reported from microfacies RL. These high values suggest that A and RL may act as hydrocarbon source rocks. Recognition of these microfacies in the subsurface will contribute to our knowledge of the Viola Limestone as an exploration target.

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Tectonics, Stratigraphy, and Petroleum Potential of Tripura-Mizoram Folded Belt, Northeast India

The folded belt of the northeast Indian states of Tripura and Mizoram and the adjoining parts of Assam (Cachar district) and Manipur constitute a part of the Assam-Arakan geosynclinal basin and lie between the present-day foredeep of Bangladesh and the hinterland of Burma. This region, with its characteristic succession of synorogenic ridges and valleys, can be subdivided into a frontal subbelt of Tripura and south Cachar comprising narrow, boxlike, and cuspate anticlines separated by wide, flat synclines, and an inner mobile subbelt of Mizoram and west Manipur consisting of tight, linear, commonly isoclinal anticlines and synclines, festooned into salients and reentrants. Passing from east to west, deformation in this belt becomes progressively younger and less intense. The anticlines are commonly bounded on one or both flanks by longitudinal listric reverse faults. The individual structures are internally segmented by cross faults and oblique faults of multiple alignments, some of which have strike-slip components and have offset anticlinal axes and flank faults. These multidirectional trends combine at places to form doglegs and trap doors, disrupting a more general north-south relay pattern, and indicate polyphase deformation with structural styles grading from those associated with basement-involved compressive block-faulting to detached thrust-fold assemblages and further modified by shale flowage. Such compressional tectonic styles are characteristics of areas close to convergent plate boundaries.

The Tripura-Mizoram region exposes mainly Neogene-age clastics of molassic facies, comprising about 6 km (20,000 ft) thick, poorly fossiliferous succession of alternating shales, mudstones, siltstones, and sandstones in varying proportions, which have been lithostratigraphically subdivided from the bottom upward into Surma (Miocene-Pliocene), Tipam (upper Pliocene), and Dupi Tila (Pleistocene) Groups, with conditions of deposition ranging from shallow marine/deltaic at the bottom to fluviatile/lacustrine at the top.

Numerous surface and subsurface manifestations of oil and natural gas in Tripura, Cachar, and Mizoram areas, occurrence of gas fields in the neighboring areas of Bangladesh, and a favorable geologic history indicate the existence of conditions conducive to petroleum generation in this region. On the basis of geochemical studies, it has been concluded that there are good prospects of striking gas in the relatively shallower zones and both oil and gas in the deeper zones in several structures of Tripura and Cachar. The expected hydrocarbon traps include discrete culminations and trap doors in individual anticlines, cross-faulted noses, subsidiary flexures in synclinal areas, subthrust warps against block-bounding faults, and various associated stratigraphic traps, as well as combination traps resulting from clay diapirism. However, on account of logistic constraints, unfavorable subsurface conditions (including steep dips and high pressures), inherent stratigraphic and structural complexities, and a paucity of seismic data, exploratory operations conducted in this region have had limited success. An accelerated exploration program with the help of improved techniques and additional resources is being initiated.

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Lower Eocene Carbonate Facies of Egypt—Paleogeographic and Tectonic Implications

The northern Arabo-Nubian craton witnessed a major Late Cretaceous-early Tertiary marine transgression that culminated in the deposition of widespread shelf-sea carbonates during Early Eocene (Ypresian) time. In Egypt, these Early Eocene strata (the Thebes Limestone and its equivalents) crop out over more than 100,000 km^2 (38,610 mi^2), and reveal a mosaic of carbonate facies consistent with the general model of "epeiric clear water sedimentation" proposed by Irwin in 1965.

"Outer shelf" facies characterize exposures in central Egypt (Assiut, Luxor, Kharga), and are composed primarily of rhythmically interbedded chalk and micritic limestone with minor intercalated marine hardgrounds. To the south (Kurkur-Dungul), these fine-grained lithologies give way to "inner shelf" foraminiferal wackestones and grainstones, typical Tethyan "Nummulitic" facies. Missing in southern Egypt is the restricted dolomitic evaporitic facies predicted by the Irwin model and observed in the lower Eocene of the Sirte basin to the west and the Arabian Platform to the east. The absence of this marginal marine evaporite belt in Egypt is presumably the result of post-Ypresian uplift and removal.

Comparing the areal distribution of these lower Eocene carbonates to coeval facies developed across the remainder of northern Africa and Arabia reveals the presence of a broad marine embayment which extended through central and eastern Egypt into northern Sudan during Ypresian time. The widespread subsidence that resulted in the development of this feature may have been an effect of regional crustal attenuation preceding the rifting of the Red Sea.