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Practical Consideration in Using Velocity, Frequency, and Phase in Stratigraphic Seismic Exploration

Since recent rediscovery of the role which amplitudes can play in seismic exploration, potential information content in other attributes has been suspected. Attempts to use these attributes have been directed essentially toward special problems (thin beds, fracture porosity) and/or special displays (instantaneous frequency, phase, etc). In fact, there are simple methods and displays which relate closely to more or less conventional approaches and make significant use of attributes such as velocity, frequency, and phase. The insights which can be developed are of particular value in stratigraphic studies, especially on land where amplitudes embody so much greater uncertainty.

Key results which can be readily established include an appreciation that large scale velocity changes are often directly indicated by stacking velocity slope changes. High frequency reflections can often delineate major changes in lithological sequence and point out with clarity "specular" reflecting boundaries such as lava sills and fluid contacts. Finally, study of phase properties makes clear that synthetic seismogram rather than the inversion section is the proper place to note phase differences and to make adjustments.

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Fan-Deltaic and Marine Siliclastic Facies of Laborcita Formation, Northern Sacramento Mountains, New Mexico

Fan-deltaic sequences in the Laborcita Formation, northern Sacramento Mountains, New Mexico, form a clastic wedge that prograded north and west. These Penn-Permian (Virgilian-Wolfcampian) deposits represent a facies tract of proximal to distal alluvial fan and fan-deltaic facies. Associated nearshore and shelf siliclastics are also developed.

Red bed conglomerates interpreted as braided and ephemeral fluvial channel fills are the most proximal deposits. These limestone cobble conglomerates crop out near the Fresnal Canyon fault and are syntectonic deposits. Northern quartzite cobble conglomerates are less proximal and form more continuous sheet-like units. These thick (10 m, 33 ft) and laterally extensive (6 km, 4 mi) conglomerates that contain trough cross-bedded coarse sand lenses associated with intrachannel bars are interpreted as midfan deposits.

Shales and thin (20-40 cm, 8-16 in.) progradational distal sands under conglomerates are highly variable in total thickness (20-60 m, 65-200 ft). The thin sandstones show evidence of marine processes and are interpreted as fan-deltaic foreset deposits. Gray limestone and chert conglomerates deposited directly on limestones are thin (0.5-2 m, 1.5-6.5 ft), deposited subaqueously, and exhibit reworking by marine processes.

Northern sands are disassociated with conglomerates. These green arkosic sands are relatively thick (3 m, 10 ft) and contain landward (east) accreting tangential foresets. Geometry, stratigraphic position, and minor upward coarsening indicate shelf-bar deposition.

Fan-delta source areas shifting during Laborcita deposition. Initial deposits were from the southeast and characterized by limestone/chert conglomerates. Later quartzite/rhyolite porphyry cobble conglomerates prograded from the east and northeast. Ultimately, alluvial fan red beds of the Abo Formation prograded over Laborcita fan-delta and shelf-bar deposits.

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Reexploration in Recôncavo Basin, Brazil

The Recôncavo basin, a major oil and gas rift basin in northeast Brazil, has reached exploration maturity relative to traditional structural trap prospects. The basin has gone through 2 phases: an initial phase from 1940 to 1960 when the major existing fields were discovered, and a development phase from 1960 to 1980, during which addition of new field reserves was small, recovery factors of the major fields were increased, and production decline began. In the early 1980s a third phase, one of reexploration, was initiated, with exploration oriented toward prospects not systematically tested before, and exploitation strategies aimed at increasing recovery from existing fields.

In the past, the exploration in Recôncavo was for structural highs with two targets: a basal Jurassic prerift fluvial section brought into structural contact with a core of lacustrine source beds, and a supra-core Cretaceous deltaic section that is part of the rift fill. Discoveries of stratigraphic traps in the intermediae turbiditic rift section were commonly fortuitous, made while testing structural highs. Current structural and stratigraphic analysis of this tract of the rift fill shows that it consists of turbiditic and non-turbiditic sublacustrine fans, and indicates that the more prospective areas tend to be the structural lows of the prerift section. A major element of the reexploration strategy is testing these combined structural-stratigraphic prospects in the rift section.

Ultimate recovery from existing Recôncavo reservoirs, based on conventional development practices, is estimated to be 33% of oil in place. An estimated 450 million m^3 (2.8 billion bbl) is left unrecovered, of which above 60% is residual oil requiring advanced tertiary techniques for recovery, and about 40% is a target for strategically deployed conventional recovery. Additional recovery depends on detailed reservoir characterization identifying isolated zones and internal heterogeneities that control fluid behavior. With these strategies, overall recovery can be increased from an average of 33-42%, leading to a doubling of current remaining reserves, rated at about 60 million m^3 (377 million bbl).

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Uranium Distribution and Sandstone Depositional Environments—Oligocene and Upper Cretaceous Sediments, Cheyenne Basin, Colorado

Wyoming-type roll-front uranium deposits occur in the Upper Cretaceous Laramie and Fox Hills sandstones in the Cheyenne basin of northeastern Colorado. The location, geometry, and trend of specific depositional environments of the Oligocene White River and the Upper Cretaceous Laramie and Fox Hills formations are important factors that control the distribution of uranium in these sandstones.

The Fox Hills Sandstone consists of up to 450 ft (140 m) of nearshore marine wave-dominated delta and barrier island–tidal channel sandstones which overlie offshore deposits of the Pierre Shale and which are overlain by delta-plain and fluvial deposits of the Laramie Formation. Uranium, which probably originated from volcanic ash in the White River Formation, was transported by groundwater through the fluvial-channel deposits of the White River into the sandstones of the Laramie and Fox Hills formations where it was precipitated.

Two favorable depositional settings for uranium mineralization in the Fox Hills Sandstone are: (1) the landward side of barrier-island deposits where barrier sandstones thin and interfinger with back-barrier organic mudstones, and (2) the intersection of barrier-island and tidal channel sandstones. In both settings, sandstones were probably reduced during early burial by diagenesis of contained and adjacent organic matter. The change in permeability trends between the depositional strike-oriented barrier sandstones and the dip-oriented tidal-channel sandstones provided sites for dispersed groundwater flow and, as demonstrated in similar settings in other depositional systems, sites for uranium mineralization.

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Turbidite Facies and Facies Associations of Cretaceous and Paleocene Gottero Sandstone, Northern Italy

Turbidites of the Gottero Sandstone were deposited as a small deep-sea fan in a trench-slope basin. The Gottero is as thick as 1,500 m (4,900 ft), had an original radius of 30-50 km (19-30 mi), and in the early and middle Cenozoic was thrust northeastward onto the Italian peninsula. The Gottero Sandstone is stratigraphically part of the Vara Supergroup, which has an ophiolite at its base and forms one of several stacked allochthonous sheets in the Ligurian Apennines southeast of Genoa. The Gottero, which contains foraminifers ranging in age from Albian to Paleocene that indicate deposition at bathyal depths, consists chiefly of feldspathic sandstone thought to be derived from the largely plutonic Corsican-Sardinian continental block to the southwest. The Gottero rests on tectonically disrupted shale that contains intercalated olistostromes. To the northwest, northeast, and southeast, it pinches out into and is overlain by basin-plain turbidites. An outward-radiating paleocurrent pattern suggests northeastward transport of sand through a single major inner-fan-channel complex, succeeded by radial downfan dispersal to smaller middle-fan channels, outer-fan lobes, and fan-fringe deposits. Sandstone-to-shale ratios are 99:1 in inner-fan-channel deposits, 10:1 in middle-fan-channel deposits, 2.5:1 in middle-fan-levee deposits, 1.3:1 in middle-fan-interchannel deposits, 11:1 in outer-fan-lobe deposits, 2.6:1 in fan-fringe deposits, and 0.25:1 in basin-plain deposits. Orderly and progressive downfan changes in most sedimentary parameters, such as maximum clast size, thicknesses of fining- or coarsening-upward cycles, facies, and facies associations permit the growth history of the fan to be determined. The Gottero Sandstone provides a useful model for petroleum exploration in small deep-sea fans characterized by a mixture of grain sizes and deposited adjacent to tectonically active, convergent continental margins.

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Comparison of Tectonic Framework and Depositional Patterns of Hornelen Strike-Slip Basin in Norway and Ridge and Little Sulphur Creek Strike-Slip Basins of California

Deposition in basins that develop adjacent to strike-slip faults can yield thick nonmarine sequences with similar facies and geometry. In this paper, we compare 3 basins of different age and size whose tectonic and depositional characteristics suggest a similar origin and history.

The Hornelen basin developed during the Middle Devonian in western Norway. The basin is bounded on the north and south by east-west trending faults; the northern fault is considered to have been a zone of major right-slip movement. The basin is 60-70 km (38-43 mi) long, 15-25 km (9-16 mi) wide, and about 1,250 km^2 (480 mi^2) in areal extent; its 25,000 m (82,000 ft) of fill accumulated at an estimated rate of 2.5 m/1,000 yr (8 ft/1,000 yr). The Ridge basin developed during the Miocene and Pliocene between the right-lateral San Gabriel and San Andreas faults in southern California. The basin is 30-40 km (20-25 mi) long, 6-15 km (4-10 mi) wide, and about 200 km^2 (80 mi^2) in areal extent; its 7,000-11,000 m (23,000-36,000 ft) of fill accumulated at an estimated rate of about 3 m/1,000 yr (10 ft/1,000 yr). The 3 Little Sulphur Creek basins probably developed 4-2 m.y.B.P. along the east side of the right-lateral Maacama fault zone in northern California. These basins cumulatively are about 12 km (7 mi) long, 1.5-2 km (0.9-1.2 mi) wide, and about 15 km^2 (6 mi^2) in areal extent; their 5,000 m (16,000 ft) of fill accumulated at an estimated rate of about 2.5 m/1,000 yr (8 ft/1,000 yr).

Coarse angular sedimentary breccia, which constitute a relatively small volume of the basin fill, was deposited in each of these basins along the active right-slip-fault margins as talus, landslide, and small but steep debris-flow-dominated alluvial fans. Along other margins of the basin, a much larger volume of the fill accumulated as larger streamflow-dominated alluvial fans, braided-stream, meandering-stream, fan-delta, and deltaic deposits. Lacustrine deposits that include turbidites and local chemical precipitates accumulated in the centers of the basins. The basin floors are generally tilted toward the active right-slip-fault margins so that the basin axes and the depocenters are subparallel to and shifted toward this margin. Sediment was transported toward the basin axis from surrounding highlands and then longitudinally down the basin axis. The basin fills were syndepositionally folded and faulted, and postdepositionally folded into large plunging synclines. The basins lengthened over time and contain thicknesses of sediment that are comparable to or greater than their widths.

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Retardation of Vitrinite Reflectance in Green River Oil Shales, Piceance Creek Basin, Northwestern Colorado

Vitrinite reflectance (R_0) of coaly inclusions in the otherwise alginitic rocks of the Green River Formation, northwestern Colorado, is greater in sandstones, marlstones, and organic-lean oil shales than in adjacent organic-rich oil shales. The R_0 of the coaly inclusions in these organic-lean rocks increases from about 0.30% for samples with a maximum burial depth of less than 1,000 m (3,300 ft) to 0.55% for samples with a maximum burial depth of more than 1,500 m (5,000 ft). The higher R_0 in the organic-lean rocks (oil yield < 10 gal/ton with the modified Fischer assay method) thus appears to record the thermal history of the area more precisely. In contrast, coaly inclusions from oil shales (yields > 10-15 gal/ton) all have lower R_0 values—typically in the range 0.20-0.27—regardless of depth of burial. This retardation effect appears to be very localized and has not altered the vitrinite in coaly material as close stratigraphically as 30 cm (12 in.) to rich oil-shale beds.

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In-Place Barrier Drowning on Louisiana Continental Shelf

An extensive data set consisting of vibracores, seismic reflection profiles, surface sediment sampling, bathymetry, and historical maps and bathymetric charts strongly suggests that the two major shoals on the western Louisiana shelf, Ship Shoal and Trinity Shoal, originated through the in-place drowning of earlier barrier-island systems. The last barrier remnants were still visible in the early 1800s.

The island systems originated as delta-flank barriers during the abandonment of Holocene lobes of the Mississippi delta. The islands probably developed through rapid shoreface retreat and transgression of deltaic distributary-mouth bar sands along the central part of the abandoned "headland." Flanking these headlands, regressive barrier spits and islands developed in response to a high rate of sediment supply from the eroding headland. These barriers prograded into the progressively deeper water of old interdistributary bays. Rapid, local, relative sea level rise, due to delta lobe subsidence, prevented the destruction of these flanking barriers by the erosional effects of the retreating shoreface. Consequently, the barriers drowned in place and the shoreline was "instantaneously" displaced approximately 15-20 km (10-12 mi) landward.

Ship Shoal and Trinity Shoal provide the only convincing case of recent barrier island in-place drowning along the United States coastline. An additional, possible example may exist in the western extension of the Maguire Island chain off Prudhoe Bay, Alaska.

Barriers subject to in-place drowning have the potential of preserving thick reservoir sands in the geologic record. These Louisiana shelf shoals, in particular, may be rapidly buried by the prodelta muds of a new phase of delta progradation. In contrast, barrier islands along coastlines with a slower relative rate of sea level rise, such as the United States east coast, are generally completely removed by the eroding shoreface. Their sand is transported seaward into an inner-shelf sand sheet. This sand sheet may subsequently be molded into linear sand ridges by contemporary storm-generated shelf currents. Such ridge sands are stratigraphically and sedimentologically distinct from the drowned barriers.

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Carbonate Pore Systems: Porosity/Permeability Relationships and Geologic Analysis

The porosity/permeability relationships of the common carbonate rock types have been studied, with emphasis on the variety of pore types in upward-shoaling grainstone sequences including: Smackover, Lansing, Salem, and San Andres Formations. A result of these studies is an improved conceptual understanding of permeability gained from the cross-plotting of porosity and permeability data from plugs and whole cores accompanied by textural and fabric analyses of rock samples, thin-sections, serial sections, and pore casts. Importantly, many depositional rock types cross-plot as distinctly different populations, commonly yielding linear trends on semi-log paper. These trends indicate a degree of order in the seemingly chaotic pore systems of carbonate rocks which have undergone cementation and/or compaction. For grainstone samples, there appears to be a change in the slope of this trend between the compaction and cementation phases of diagenesis.

Once the depositional texture and fabric of the rock are defined in terms of porosity and permeability, the evaluation of fractures and secondary porosity can be addressed. The secondary porosity is observed to be as high as 14% of the rock volume in the Smackover example and 21% of an oolitic sample from the Lansing Formation. Pore casts and serial sections reveal that the grain-moldic porosity is poorly connected to the intragranular pore system and contributes little to the permeability of the rock. This insight allows quantitative estimates of this type of secondary