dom if ever used as an exploration tool. The problem with these previous studies is that they concentrate on grain-size parameters for individual samples, and fail to recognize that various depositional environments are characterized by a number of discrete facies, each with its own characteristic sedimentary structures and grain-size populations. For that reason, vertical progressions in grain-size data are far more diagnostic of depositional environment than are scatter diagrams in which one grain-size parameter is plotted against another.

Grain-size progressions for ancient sequences of the Upper Cretaceous Point Lookout formation and Eocene Queen City Formation demonstrate the value of the technique. The data show that distinctions can be made between fluvial, estuarine/tidal distributary, flood-tidal delta, foreshore, and shoreface sandstones. More importantly, our method relies on analysis of samples collected at random intervals (generally 2 ft or .6 m), so that it is applicable where sidewall cores are available. Diagenetic complications (other than those resulting from silica cementation) do not appear to threaten the sensitivity of the method. Using automated settling analysis, these data are obtained rapidly and can aid in subsurface correlation as well as determining the depositional environments of sandstones.

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A Model for Evolution of Small Pull-Apart Basins

A preliminary model for the evolution of small extensional or pull-apart basins is presented. The very rapid subsidence, sediment accumulation, and hydrocarbon maturation observed in many basins of this type are explained using a McKenzie-type approach. Lateral heat loss is shown to be a critical factor in controlling the rate of heat loss in basins of finite width. In a simple two stage model where stretching and cooling are assumed to occur as separate processes, more than one-third of the total thermal subsidence occurs in the first 200,000 yr of cooling for a basin 30 km (20 mi) across. This allows for the accumulation of over 2 km (6,500 ft) of sediment. Because the time required for a 10-km (6-mi) long block to be stretched to 30 km (20 mi) is substantially greater than 200,000 yr, much of the cooling and subsidence must take place during stretching. This simultaneous stretching and cooling is approximated by alternating short periods of stretching and cooling.

The resulting model is applied to the development of the basins associated with the San Andreas fault in southern California. These basins have recently (Miocene to Present) undergone rapid (up to 6 km, 4 mi) subsidence and sediment accumulation as well as rapid maturation of hydrocarbons. They appear to have been initiated in an extensional regime along irregularities in the strike-slip motion of the fault, even though some of the basins have been modified by subsequent compression. These basins are therefore excellent candidates for testing the proposed model.

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Multi-Disciplinary Approach to Biostratigraphic Mapping—Two Case Studies: Bass Basin, Australia, and North Soldado, Trinidad

Palynologic zones were used to subdivide the Late Cretaceous to late Eocene beds in the Bass basin, Tasmania, Australia and the Late Miocene to Pliocene beds in the S.484/S.498 area, North Soldado, Trinidad. These zones are related to discrete genetic sedimentary cycles bounded by unconformities which are marked by abrupt changes in the environment of deposition. In both areas, the environments range from shallow marine to continental.

Owing to wide sample spacing (up to several hundred feet in some wells), it was impossible to locate precisely each biostratigraphic boundary, based on palynological data alone. The composite use of sedimentology, wire-line log characteristics, dipmeter interpretation, and reservoir fluid properties was integrated with the palynologic data, providing a practical technique that was used to delineate the sequence boundaries in wells where spore-pollen data was inadequate.

This method enabled the development of accurate zonation and a detailed correlation between wells within both the Bass basin and the S.484/S.498 area.

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Distribution of Organic Richness in Time and Space

Distribution of organic facies is related to interaction between productivity and preservation, both the consequence of environmental factors. The environment also controls the amount and type of the organic matter present and its potential to yield hydrocarbons.

A conceptual model for predicting organic richness in time and space is based on predictions of the geographic location of high marine organic productivity by upwelling systems during intervals of optimal preservational potential within transgressive cycles. Whether or not the marine organic matter is in fact preserved in the rock record depends on the spatial relationship of the upwelling system to potential environments of preservation. The problem of preservation is addressed at two levels. The first is whether or not a depositional basin was in the proper geographic position to receive the organic matter during a sediment accumulation cycle, and second, whether or not that organic enriched interval is preserved in the stratigraphic sequence of the basin.

Prediction of basin location is derived from plate tectonic reconstructions. Prediction of productivity is based on paleogeographic and paleoclimatic models. Presence or absence of potentially organic-enriched rock units is evaluated by examination of the stratigraphic record of the basin being studied. Measuring actual levels of organic content of the rocks must be done with sample analysis.

The conceptual model for predicting the temporal and spatial distribution of organic richness derived from marine upwelling systems is simplistic by necessity. It focuses on primary parameters and addresses only a few secondary parameters. Success or failure in making predictions with this model in basins already understood can test the validity of the model and which parameters are most important.

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Oblique-Slip Sedimentation and Deformation in Nonacho Basin (Early Proterozoic), Northwest Territories, Canada

The Nonacho basin shares several traits with molassoid basins formed in oblique-slip settings: (1) great thicknesses (about 9 km, 6 mi) of siliciclastic sediments deposited in alluvial fan, fan-delta, braided stream, beach, deltaic, and lacustrine environments; (2) synsedimentary faults which activated nearby sources; (3) rapid sedimentation and subsidence; (4) telescoped facies transitions, particularly adjacent to active faults; (5) extremely variable thicknesses of lithostratigraphic units; (6) diachronous sedimentation resulting from the migration of source areas and sites of sedimentation along deformation fronts; (7) mobility of deposition and deformation such that early sediments were uplifted, cannibalized, and redeposited; (8) paleocurrents directed basinward near basin margins, and longitudinally in axial regions; (9) lower greenschist facies metamorphism; (10) paucity of volcanic rocks; and (11) complicated structural geometries. However, these features alone are not diagnostic of oblique-slip origin; all are compatible with rift, aulacogen, impactogen, retroarc, peripheral, intramontane, and broken foreland settings. More reliable indicators of an oblique-slip tectonic setting for the Nonacho basin are: (1) anastomosing pattern of near-vertical, en echelon faults which delineate rhomb-, wedge-, and rectangular-shaped semi-independent subbasins and basement uplifts; (2) stretching lineations of shallow to moderate plunge along shear zones; (3) folds and near-vertical penetrative fabrics, related to shear zones, but at angles of 20°-30° to these zones. The Nonacho basin fill is interpreted as a foreland molasse of the Trans-Hudson orogene. Deposition and deformation probably occurred in response to convergence accommodated by oblique slip, analogous to the Tarim and Tsaidam basins of China, which developed in the late stages of India-Eurasia collision, north of the Tibetan Plateau.

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Dakota Sandstone Facies, Western Oklahoma Panhandle

The Cretaceous Dakota Sandstone in Cimarron County comprises three sandstone units and intervening mudrocks; it overlies the Kiowa

Shale Member of the Purgatoire Formation. Deposits include shoreface, beach (foreshore) and dune, estuarine and tidal channel, marine marginal bay and swamp/marsh in a generally progradational sequence associated with marine regression in the Western Interior.

The shoreface sand, characterized by ripple lamination, bioturbation and the trace fossils *Teichichnus* and *Thalassinoides*, is fine-grained, 5-10 m (15-30 ft) thick and grades into the underlying Kiowa Shale. Beach and associated dune deposits are 2-5 m (6-16 ft) thick, medium to fine-grained, medium to thick-bedded, tabular-planar cross-bedded, and lenticular; cross-bed paleocurrent headings are northeasterly and northwesterly. Estuarine channel deposits are 3-5 m (10-16 ft) thick, trough to tabular-planar cross-bedded, and medium to coarse-grained with local conglomerate overlying the scoured base which commonly cuts into the Kiowa Shale or overlying shoreface sandstone; rip-up clasts and wood pieces are common but trace fossils are rare; southeasterly and southwesterly paleocurrents predominate.

Tidal channel deposits are thinner (up to 2 m or 6 ft) and finer grained (medium to fine-grained) than the estuarine channel deposits; they occur within fine-grained sandstone and mudrock sequences, are trough cross-bedded, and commonly contain trace fossils (e.g., *Skolithos*) and wood fragments. Marine marginal (tidal flat or bay?) deposits comprise fine-grained sandstone, siltstone and interbedded shale, that are 1-3 m (3-10 ft) thick with abundant burrows, small ripple marks, and parallel lamination. These grade into the fine to very fine-grained sandstones, siltstones, shales, and coals of the swamp/marsh deposits that are 1-5 m (3-16 ft) thick and contain ripple marks, burrows, other trace fossils, and parallel lamination.

AYDIN, ATILLA, Purdue Univ., West Lafayette, IN, and AMOS NUR, Stanford Univ., Stanford, CA

Role of Stepovers in Strike-Slip Tectonics

We show that the key to understanding the tectonic complexity of large strike-slip fault systems is fault stepovers. Secondary structures such as folds, thrust or reverse faults, cracks, dikes, normal faults, or smaller strike-slip faults, known to occur in strike-slip environments, localize in stepovers between en echelon faults. Two types of en echelon geometry are recognized: (1) strike-slip faults that are en echelon in map view with discontinuities along the strike of faults; (2) strike-slip faults that are en echelon in cross-sectional view with discontinuities along the dip direction of faults.

Depending on the sense of stepover, discontinuities along the strike of faults result in pull-apart basins and push-up ranges, several examples of which are presented to illustrate the associated structures and their complexities. Discontinuities along the dip direction of strike-slip faults are poorly known because of the lack of field observations. Data from seismicity, however, can be used to fill this gap. One example of such en echelon fault geometry is found along the Calaveras fault, California. It is inferred that stepovers along the dip direction of strike-slip faults may produce secondary strike-slip faulting on inclined planes connecting the en echelon segments of the major fault. As the amount of overlap increases, features similar to pull-apart basins or push-up ranges are expected to occur.

Causes for the formation of discontinuities and control of the sense of stepover are not well known. Some possible factors are: spatial variability of the coefficient of friction, spatially variable elastic moduli, high pore pressure, and interaction between neighboring faults in an array of faults. The first two would give rise to both senses of stepover, whereas the last two lead only to one sense of stepover, which induces pull-apart basins.

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Lithofacies Control of Lignite Distribution and Ground-Water Quality, Wilcox Group (Eocene), East-Central Texas

Deep lignite resources (200-2,000 ft; 61-610 m) were evaluated regionally using 1,470 geophysical well logs to interpret lithofacies, lignite occurrence, and resistivity (water quality). The regional distribution of lithofacies indicates that in the region, the Wilcox Group is a fluvial-deltaic system. The primary fluvial system entered the Wilcox coastal plain west of Waco, Texas, trended southeast, and supplied a 75-mi (120-km) wide fluvial-deltaic system comparable in size to the Mississippi system.

Lignites are most abundant in the Calvert Bluff Formation (upper Wilcox). Lower Calvert Bluff lignites are thickest and most extensive southwest of the Navasota River, whereas those of the upper Calvert Bluff are thickest northeast of the Brazos River. In the shallow subsurface, Calvert Bluff lignites are found in dip-elongate low-sand areas (flood plains) between channel-sand belts. Basinward, laterally continuous lignites coincide with high net sand areas comprised of distributary channel sands indicative of a delta-plain setting.

The Wilcox Group is a major aquifer. Maps of resistivity values show that Wilcox channel sands are conduits for ground-water flow. High values of formation resistivity (low total dissolved solids) exist in recharge areas at outcrop and around salt domes. Elongate trends of high resistivity values extend tens of miles basinward and coincide with axes of major sands. Resistivity values decrease basinward and the 20 ohm-m contour delineates the downdip limit of fresh water.

Lithofacies and lignite occurrence maps are guides to exploration for deep lignite. Resistivity maps can be used to explore for ground-water resources.

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High-Potential Geothermal Energy Resource Areas of Nigeria and Their Geologic and Geophysical Assessment

The widespread occurrence of geothermal manifestations in Nigeria is significant because the wide applicability and relative ease of exploitation of geothermal energy is of vital importance to an industrializing nation like Nigeria. There are two known geothermal resource areas (KGRAs) in Nigeria: the Ikogosi Warm Springs of Ondo State and the Wikki Warm Springs of Bauchi State. These surficial effusions result from the circulation of water to great depths through faults in the basement complex rocks of the area. Within sedimentary areas, high geothermal gradient trends are identified in the Lagos subbasin, the Okitipupa ridge, the Auchi-Agbede area of the Benin flank/hinge line, and the Abakaliki anticlinorium. The deeper Cretaceous and Tertiary sequences of the Niger delta are geopressured geothermal horizons. In the Benue foldbelt, extending from the Abakaliki anticlinorium to the Keana anticline and the Zambuk ridge, several magmatic intrusions emplaced during the Late Cretaceous line the axis of the Benue trough. Positive Bouguer gravity anomalies also parallel this trough and are interpreted to indicate shallow mantle. Parts of this belt and the Ikom, the Jos plateau, Bauchi plateau, and the Adamawa areas, experienced Cenozoic volcanism and magmatism.

Geothermal gradients indicate that steam would be encountered at a depth of about 6,000 ft (1,800 m) in the Lagos and Auchi-Agbede areas, and at about 4,250 ft (1,300 m) in the Abakaliki area. A combination of heat-flow measurements and analysis of existing aeromagnetic data would provide a basis for the determination of geothermal gradients in the undrilled resource areas and the determination of depths to Curie isogeotherm (about 570°C, 1,058°F) in the basement complex and the intrusive areas from thermal attenuation of the remanent magnetic field. The separate but preferably combined application of gravity analysis, and electrical, refraction-seismic, electromagnetic, and telluric methods would help in the accurate delineation and evaluation of Nigeria's known and suspected geothermal resource areas for future detailed investigations and possible exploitation.

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Printer-Posted Maps from a Well-Data File

A series of microcomputer programs have been written to aid the geologist in building a well-data file, selectively retrieving data from the file, and generating posted maps on a printer. The system uses an IBM PC with 64K of memory, one disk drive, and an Epson MX 100 printer. The programs are written in BASICA to run under DOS 1.1. The system has been used to conduct regional geologic studies in the Michigan basin and to make field studies.

The data files contain well-identification information such as well names, location, API number, completion date, elevation, and total