be acquired by open-cut, adit, or test drilling. Core logging is particularly important for determination of the engineering characteristics of rocks. Structure-contour, isopach, overburden, and interburden maps are required in mine design, and ultimately in mine development. Reclamation requires determinations of overburden and interburden chemistry.

Cost and time advantages result if hydrologic and soils/rock quality data are collected early, thereby saving time in the permitting process, and reducing the ultimate cost of reclamation.

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Application of Cingulum Index to *Dinogymnium* in Hilliard Shale, Southwestern Wyoming

The cingulum index (CI) was defined for fossil dinoflagellates of the genus *Dinogymnium* as a two-digit number expressing the distance from the middle of the cingulum to the apex divided by the total length of the test and multiplied by 100. This morphologic statistic, which is independent of specimen size, was interpreted as a character of interspecific taxonomic importance. Analysis of CI values of specimens of *Dinogymnium* sp. from the Hilliard Shale (Upper Cretaceous) of southwestern Wyoming suggests that the CI has biostratigraphic significance.

CI values were calculated for *Dinogymnium* from the Hilliard Shale at Cumberland Flats, Lincoln County, Wyoming. When plotted against stratigraphic position of samples, mean and maximum CI values for successive populations show an increasing trend upward through the formation. Population size and sample spacing are variable, and it is uncertain whether evolution or paleoecology is the controlling factor, but the progressive change through more than 1,000 m is useful for biostratigraphic zonation of the formation. The cumulative frequency distribution for all specimens measured in this study is quadramodal, suggesting that four morphologic variants, indistinguishable by transmitted light microscopy, are present.

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Stratigraphic Relations of Permian Formations in Parts of Colorado and Utah

This study suggests that the Permian rocks in northwestern Colorado and northeastern Utah were deposited in shallow-marine shelf, transitional, and terrestrial environments. The Wolfcampanian and early Leonardian upper layers of the Weber formation are predominantly eolian quartz sandstones deposited in a broad coastal area of low relief. This coastal area was at the northwestern end of the ancestral Uncompahgre uplift, and was intermittently covered by seawater as indicated by the few thin marine carbonate rocks. The upper Weber intertongues with the Grandeur Member of the Park City Formation in the study area. The carbonates and cherts of the Grandeur were deposited in shallow-marine waters during a transgressive cycle which was probably caused by a crustal downwarping of the shelf.

The Meade Peak Member of the Phosphoria Formation was deposited on top of the Grandeur by cold, phosphorous-rich, upwelling water as a result of continued Early Permian transgression. Landward from the phosphorites, carbonates were contemporaneously deposited, and further landward, siltstones.

Regression near the end of Leonardian shifted the depositional environment belts westward and resulted in deposition of the Franson Member carbonates and cherts on top of the phosphorites. Maximum regression during the Guadalupian produced very shallow and highly saline waters in the area and subaerial exposure for long periods, combined with a significant increase of terrestrial, fine-grained sediment supply. These conditions led to the deposition of interstratified gypsum, silt, and shale of the Mackentire Tongue redbeds.

The eastern half of the study area is characterized by greenish-gray and tawny beds which are partly time-equivalent of the Meade Peak, Franson, and Mackentire. The environments of deposition are interpreted to be those of a reducing, restricted marine embayment. These beds are more closely related to the Goose Egg Formation in central Wyoming than to any other formation in the area and are so designated.

Extensive regression beginning in late Guadalupian continued into the Triassic and caused the deposition of the Moenkopi red beds.

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Sedimentology of Lower Cretaceous Subtidal Sand Complex, Woburn Sands, Southern England

The Lower Cretaceous Woburn sands have long been considered a transgressive and partly open marine tidal sand deposit. They form a 60-m thick, northward-wedging sandstone body between Jurassic shales, which they unconformably overlie, and a transgressive marine clay which oversteps them northward.

Our studies identify three southward-imbricated, erosionally bounded sand units as follows.

Orange Sands (oldest) comprise alternations of cross-bedded, channel-fill sands and thinner bedded, bioturbated, heterolithic sands. Bidirectional paleocurrents show a dominant northeasterly flood direction.

Silver Sands are characterized by tabular cross-bed sets (up to 3 m thick) which overlie subhorizontal, low-angle (4 to 8°) or concave-upward erosion surfaces. Bidirectional paleocurrents reflect a slight dominance of the southwesterly ebb direction.

Red Sands (the youngest) are structurally similar to the Silver Sands but are distinctive on the basis of abundant detrital ferric oxide and strong horizontal burrowing. Northeasterly dipping cross-bedding is relatively uncommon, producing an overwhelmingly dominant southwesterly, ebb-directed paleocurrent mode.

The interfingering of high-energy tidal channel-fill deposits and heterolithic beds is typical of subtidal estuarine deposits. Furthermore, the upward decrease in the proportion of heterolithic facies and burrowing intensity, the upward increase in the proportion of large-scale cross-bedding and channel width/depth ratios, and the upward transition from flood to ebb dominance are interpreted as reflecting the onlap of estuary-mouth sands over inner estuarine channel/shoal deposits.

The closest modern analogs to this type of transgressive sequence are the estuarine retreat sand complexes on the eastern United States shelf.

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Understanding Field Development History Using 3-D Seismic Survey

A mature oil and gas field in south Louisiana produces from multiple pay zones having various fault-related traps, simple closures, and stratigraphically controlled sands. Seismic understanding of the field is complicated by an ancestral river channel, its tributaries, and surface variances such as lakes, marshes, and canal levees. Surface access restrictions include wells, flow lines, tank batteries, and oyster beds. A careful study indicated the field to be complex, thus opening the possibility of further development if the significant subsurface parameters could be better defined. A 3-D seismic survey was planned and conducted to explore this possibility.

The 3-D survey was implemented using dynamite as the source with a "3-D swath" layout of shot-and-receiver locations. Approximately 4 sq mi (10.4 sq km) of 6-fold subsurface control was obtained with depth-point spacing equal to 82 ft (25 m) in both directions. This closely spaced control provided adequate subsurface definition of the proposed objectives. A 3-D migration algorithm was used for proper subsurface imaging of the data and yielded good fault definition. The regularly spaced 3-D migrated data were displayed in a series of equally spaced horizontal sections and printed in a movie format. These data were used by interpretive personnel to generate a set of depth maps that compare favorably with those generated in a conventional manner. Subsequent drilling in the field has demonstrated the validity of the technique.

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Trace-Makers as Historians in Large-Scale Cycles of Western Interior Cretaceous Strata

Previously established stratigraphic framework and gross depositional history have permitted analysis of nature and distribution of trace fossil assemblages from western margin to basin center for upper Albian to lower Maestrichtian deposits of the western interior sea. Cluster analysis of trace variety and density reveals distribution patterns which represent habitats similar to those determined previously for mollusks. Trace fossil "habitats" were, however, controlled more closely by substrate nature and events related directly to sedimentation than were the habitats determined by body fossil analysis. Changes in sediment type, depositional rate, and early diagenetic phenomena were recorded with greater accuracy by these groups of trace-makers, which may be used to elucidate the more detailed history of the study interval. The analytical method was applied to several bioturbated carbonate beds of the Greenhorn Limestone that are traceable over large areas of the basin. Bed-by-bed analysis suggests that subtle changes in depositional parameters and/or nature of overlying water column were imparted to certain beds with distinct and characteristic trace fossil assemblages. Basin-wide analysis and mapping of trace fossil assemblages from such beds can be used to improve environmental resolution of this part of the Upper Cretaceous.

Despite great utility of these trace fossil assemblages for environmental analysis, gross interpretations (e.g., water depth) based on trace fossil assemblages alone, must be made with caution. Traces from "deep-water" Upper Cretaceous carbonate rocks are compared to traces in texturally similar but clearly shallow-water Illinois basin Mississippian carbonate rocks. Environmental parameters such as salinity or oxygen availability, that are less readily suggested by lithology, may be largely responsible for such trace fossil assemblage similarities.

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Organic Facies—Stratigraphic Concept and Exploration Tool

An organic facies is a mappable subdivision of a stratigraphic unit, distinguished from the adjacent subdivisions on the basis of its organic matter (OM), without regard to the inorganic aspects of the sediment. Both the concept of organic facies and its usefulness to explorationists are based on the following facts: (1) OM in sediments consists of several types which can be distinguished by microscopic and geochemical techniques; (2) different types of OM generate and migrate different amounts and types of oil and gas; (3) the same types of OM, and consequently similar generation products, commonly extend over thousands of square miles laterally and hundreds of feet vertically; (4) the distribution of organic facies is not capricious, but is determined by the origin of the organic remains and the free oxygen of the depositional environment; (5) organic facies can be mapped and extrapolated; and (6) the organic facies concept is a major exploration tool because it aids in understanding and predicting both the location and types of oil and gas deposits.

Several organic facies are defined by the microscopic, geochemical, generation, and migration characteristics of their OM, and examples are given of their geologic setting, vertical and horizontal distribution, and their economic significance.

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Trace Fossils and Stratigraphy of Devonian Black Shale in East-Central Kentucky

In recent years trace fossils have been studied in carbonate and siliceous rocks. Shales have largely been ignored. This study describes trace fossils from the "anoxic" Upper Devonian black shale in east-central