forming in a coastal salina (Halite Lake) less than 2 km (1 mi) from the area where the thickest Coorong dolomites are forming. Obviously evaporite filled ponds can occur in an ancient Coorong-type facies mosaic, and the distribution of evaporites versus dolomites could be a good palaeoslope indicator.

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Variability of Internal Geometry of Duplexes

Duplexes are imbrications of the footwall of a thrust fault (or series of connected thrust faults) in which the minor faults connect to or intersect with the master thrust surface at both their leading and trailing edges. Within this closely constrained definition, there is considerable geometric variation. The current classification scheme recognizes the variation in postdeformational arrangement of horses in two dimensions, but ignores variations in the size and shape of the horses and in the displacement on the imbricate fault surfaces. Compilation of the geometric arrangement of horses in known duplexes shows that such variations are common and result in several geometric variations that do not fit into the current classification. Additional geometric variations can be found in 3-dimensional framework.

These geometric variations can be correlated with mechanical properties of the footwall material in which the duplex formed. Since the deformational style within the horses is also controlled by the same mechanical factors, the internal structure of the horses can be correlated with the gross geometry of the duplex. Recognition of the range of duplex geometries and the correlation with deformational patterns should aid exploration in complex thrust belts.

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Calcareous Nannofossil Paleobiogeography of the Cretaceous Greenhorn Sea

Two distinctive, laterally traceable bentonite beds were used to construct two isochronous time slices through the marine sediments of the Upper Cretaceous Greenhorn cyclothem of the United States Western Interior basin. Calcareous nannofossil assemblages from these time slices were examined from more than 40 outcrop localities. Nannofossil presence and assemblage diversity and composition were statistically analyzed to examine the paleooceanographic conditions within the basin.

The lower time slice (X bentonite) is at the stratigraphic horizon which approximately corresponds to the time at which free communication between the basin and open oceanic systems first occurred. The most striking trend in the nannofossil distribution is delineated by the presence or absence of nannofossils. The presence of common to abundant nannofossils in the center of the basin (i.e., near the hingeline of the basin) and the absence of nannofossils from the eastern and western basin margins indicate that open marine conditions conducive to significant standing crops of calcareous phytoplankton occurred only in a narrow, centrally located zone. Conditions at the basin margins were probably unsuitable for large populations due to environmental instability. Evidence indicates that *Watznaueria barnasae* was the most ecologically tolerant form.

The upper time slice (HL-3 bentonite) samples the nannofossil distributions at a point at or near the maximum transgression of the Greenhorn Sea. Similar, basinward increases in diversity and abundance are evident but more subtly expressed. Paleolatitudinal differences in diversity and the relative abundances of some taxa indicate contributions from both tropical and boreal oceanic water masses.

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Submarine Fans in a Developing Extensional Regime—Their Significance in the North Sea Hydrocarbon Province

The North Sea is a major hydrocarbon province with estimated proven recoverable reserves of approximately 23 billion bbl of oil and 50 tcf of gas. A significant proportion (22%) of these reserves occurs in reservoirs interpreted as submarine fan deposits. These include both oil and gas fields that are among the largest discovered in the province.

The North Sea basin provides a classic example of long-term development of an extensional basin. Major tectono-sedimentary sequences can be broadly matched to pre-, syn- and post-rift phases of the Viking and Central grabens. Development of submarine fan systems within the basin can in turn be related to this framework.

Submarine fans developed in the Viking graben within the syn-rift tectonic setting during the late Jurassic. The major controlling factor at this time is considered to be internal tectonics of the graben with subordinate influence from sea level changes. Small, coarse, scarp-fed fans formed a sediment apron along the fault-controlled graben margins. Finer-grained, rather better developed fan systems were also formed during this period, reflecting the relative importance of different controlling influences.

The post-rift cycle in the North Sea basin is characterized by Late Cretaceous-Tertiary thermal subsidence of the graben as well as the former rift margins. The major influences on fan development in this phase were external tectonics in the source area, and, of equal importance, sea level changes which controlled sediment input to deeper parts of the basin. Late Paleocene and early Eocene fans developed in association with major prograding delta systems.

The variability in space and time of submarine fan types in the North Sea highlights the importance of identifying the most appropriate fan model. This is critical to reservoir distribution in field development, as well as in future exploration where predictive models will be required to identify time periods and areas most likely for the development of submarine fans.

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Computer-Assisted Attribute-Coincidence Mapping (ACM) in the Search for Massive-Sulfide Exploration Targets in Appalachian Devonian Rocks

Attribute-coincidence mapping (ACM) is a powerful tool commonly used by geologists when they visually compare map data from diverse sources by use of a series of transparent overlays. The same geologists using computer-assisted ACM (particularly the MAPSS = MAGIC software system) can consider, evaluate, and replot or store for later retrieval many more kinds of data with less time and effort than with manual methods. Because the MAPSS = MAGIC system organizes and manages information by orthogonal patterns, standard CRT terminals or high-speed line printers enable users to view complex grid-cell patterns of derivative maps almost instantaneously, and thus facilitate rapid decision making.

ACM with the MAPSS = MAGIC system can be used at any scale to compute, analyze, and plot derivative patterns. For regional analysis the standard U. S. Geol. Survey 7½-minute quadrangle is used as the information cell for data manipulation. A demonstration of the system shows map patterns of some of the various attributes of sediment-associated massive-sulfide ore deposits that have been combined through ACM to identify potential exploration targets in Appalachian Devonian rocks. The massive-sulfide model was developed by the West German Federal Geol. Survey and recently modified by Wedow for computer use by the U. S. Geol. Survey. This ACM study of the Appalachian Devonian has revealed several significant exploration targets.

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A View on Oil Shale Development

An examination of energy statistics shows clearly that the United States is on the edge of an impending energy crisis. This appears preposterous in the face of a world oil glut and probable world oil price decreases over the next year or so. However, oil supply, oil demand and United States economy statistics support the scenario of a rapidly occurring energy crisis in the United States should oil imports be shut off even partially. This is not an unlikely happening under present world tensions.

Oil and gas exploration and production statistics support the view that domestic oil reserves will continue to decline even if concentrated oil exploration activity were maintained.

The shortest avenue for United States energy independence is through the development of synthetic fuels. However, a detailed study shows that, under present technology, synthetic fuels cannot be produced economi-

cally regardless of the price of crude oil. One exception to this economic situation is shale oil coproduced with other minerals from the vast "Saline Zone" oil shale resource of northwest Colorado.

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Wattenberg Field, Denver Basin, Colorado

The most important mineral resource activity in Colorado during the past decade has been the discovery and development of the Wattenberg gas field. Located north of Denver near the axis of the Denver basin, Wattenberg is estimated to have reserves of 1.3 tcf in the tight J Sandstone reservoir over an area of 600,000 acres (2,400 km^2), at depths between 7,600 and 8,400 ft (2,310 and 2,560 m). Net pay thickness varies from 10 to 50 ft (3 to 15 m), porosity ranges from 8 to 12%, and permeability varies from 0.05 to 0.0005 md.

The J is interpreted as a fluvial-deltaic sandstone with the principal production from widespread delta-front sandstone. Drilling for gas in the Cretaceous J Sandstone has resulted in multiple pays in overlying strata. The Spindle field, situated in the southwest portion of the Wattenberg field, produces from two marine bar complexes (Hygiene and Terry) in the middle portion of the Pierre Shale. Since 1971, total production is in excess of 36 million bbl of oil and 164 bcf of gas from depths of 4,000 to 5,000 ft (1,220 to 1,525 m).

For the past 2 years, the Codell Sandstone, approximately 500 ft (152 m) stratigraphically above the J Sandstone, has been developed as a new petroleum-producing zone. More than 100 discoveries have been made within and marginal to the outlined Wattenberg field area. The Codell is a tight bioturbated marine-shelf sandstone generally without a central-bar facies. Net pay thickness ranges between 3 and 25 ft (0.9 and 7.6 m), porosities range between 8 and 24% (with the average 10–12%), and permeabilities less than 0.5 md. Because of rapid decline in production and economic uncertainties, potential reserves from the Codell are unknown.

All petroleum accumulations in the Wattenberg area are regarded as stratigraphic traps. Variation in pay thickness and reservoir quality is related to the original environments of deposition and paleostructure which locally influenced unconformities, fracturing and diagenesis.

WHITE, BRIAN, KAREN A. KURKJY, H. ALLEN CURRAN, and KIMBERLY A. BESOM, Smith College, Northampton, MA

Shallowing-Upward Sequence in a Pleistocene Coral Reef and Associated Facies, San Salvador, Bahamas

Excellent exposures of a well-preserved Pleistocene coral reef (dated 120 to 140 thousand years B.P.) extend along the shore northwest of Cockburn Town on the island of San Salvador, which lies at the eastern edge of the Bahamas platform 600 km (375 mi) east-southeast of Miami, Florida. The reef was buried sequentially by nearshore marine and terrestrial carbonate sands during a lowering of sea level. This shoaling produced a vertical sequence of carbonate rocks that represents a progressive change from shallow subtidal through beach to dunel environments.

Acropora palmata, A. cervicornis, Diploria sp., and *Montastrea annularis* are found in growth position up to 2 m (6 ft) above present mean sea level (MSL). Coral rubble, composed principally of *A. cervicornis* and *A. palmata*, commonly occurs subjacent to, adjacent to, and up to 80 cm (31 in.) above the in-situ corals. Gullies in the coral rudites are filled by coarse skeletal calcarenites, which in some places contain well-preserved, irregular boxworks of *Ophiomorpha* sp. and *Skolithos linearis* burrows. The calcarenites extend upward and outward from the gullies to overlie the corals and coral rudites; lowermost beds commonly have trough cross bedding extending up to 3.6 m (12 ft) above MSL. Upward, the calcarenites become finer grained, skeletal, intraclastic, peloidal, and oolitic, with gently seaward dipping planar cross beds and beachrock clast breccias occurring up to 4 m (13 ft) above MSL. Fine-grained eolianites with abundant rhizocretions and some paleosols occur higher than 4 m (13 ft) above MSL, and this elevation marks the maximum height of sea level during the development of the Cockburn Town reef. Following this high stand, lowering of sea level produced this fine Pleistocene example of a shallowing-upward carbonate sequence.

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Fluvioglacial Sandstone Reservoirs and Deposystem Analysis in Hydrocarbon Exploration of Permian Gidgealpa Group, Southern Cooper Basin, South Australia

The sedimentology of the Permian Gidgealpa Group of the southern Cooper basin currently is being evaluated to ascertain the tectonosedimentologic evolution of the basin and to determine the architecture of the clastic suite in order to generate exploration plays.

The study has produced a new understanding of the relationship between the hydrocarbon-rich Tirrawarra Sandstone, of dominantly fluvial origin, and the, as yet little explored, glacigenic Merrimelia Formation. The facies states and transitions of both formations interdigitate, and typical porous Tirrawara-type fluvial facies are clearly evident within glaciolacustrine Merrimelia-type sediments.

The Merrimelia Formation was examined regionally in 29 cored wells. The formation attains a maximum thickness of 300 m (1,000 ft), and representative facies include glaciofluvial outwash, terrestrial and subaqueous diamictites, and glaciolacustrine, wave-affected, and ripple-laminated sandstones, with thick, monotonous mudrock sequences containing clay-dominant rhythmite horizons.

The Tirrawarra Sandstone, analyzed in 32 cored wells, comprises four major facies associations throughout its maximum 75 m (250 ft) thickness. These associations indicate a temporal and spatial evolution of a fluvioglacial to predominantly fluvial system. Initial deposition on low slope, outwash fans, where braided processes operated is indicated. This sedimentation style evolved into a low sinuosity, bedload-dominant, sandy braided system, with high width-to-depth ratio channels. Allocyclic control mechanisms are invoked for "late Tirrawarra" sedimentation as the facies reveal proximal-distal patterns and the fluvial style changes to a mixed-load channel system.

The interfacing and evolutionary pattern of the deposystem indicates that additional reserves potential exists for reservoirs developed locally within the Merrimelia Formation.

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Salt Domes, Anoxic Brines, and Organic-Rich Sediments in Intraslope Basins

The origin of organic-rich sediments and their potential relationship to petroleum source beds remains problematic despite the development of models relying primarily on oceanographic mechanisms. We outline instead a model that involves salt dome development under a prograding shelf-slope and has a modern analog in the hypersaline anoxic Orca basin on the Texas-Louisiana continental slope. We believe the model may explain the occurrence of some ancient black shale sequences by a mechanism which is not dependent on either intensification of the mid-water oxygen minimum, enhanced marine productivity, or circulation-induced bottom water anoxia. In our working model, salt diapir movement structurally produces sedimentary basins in the intraslope region. Dissolution of the salt inhibits oxygen replenishment in the deep parts of the basin. As oxygen levels and bioturbation in the basin are diminished, finely laminated sediments with high organic carbon contents result. Gradual evolution of the basin to complete anoxic conditions leads to the accumulation of fine-grained, fluid-rich, black muds which, upon burial and dewatering through compaction, resemble black anoxic shales. Infilling and burial of the basin with clastic and hemipelagic sediments from glacio-eustatic-driven climatic episodes subsequently provide source beds and reservoir rocks for potential exploration plays. Lerche and O'Brien have recently shown that the high thermal heat capacity of salt domes (≈ 5 times $>$ sediment) produce predictable thermal anomalies in the surrounding sediments. Thermal maturation rates of the organic-rich source beds are enhanced near the top of the salt dome and suppressed on the lower flanks. The negative thermal anomaly on the lower flanks of the salt dome inhibits overmaturation and thus enlarges the hydrocarbon window. As overburden increases, the density contrast between the salt (≈ 2.2 gm/cm^3) and surrounding compacted sediments (2.6-2.7 gm/cm^3) eventually becomes such that upward diapirism resumes. The present model, although preliminary, may have wide applicability in sedimentary basins other than the Gulf of Mexico. Further work on the Orca basin and other sedimentary sections near salt displacement should prove beneficial in future modeling of organic-rich sediments.