common in dark gray shales, siltstones, fine to very fine sandstones, and silty, calcareous mudstones deposited in basinal, slope, and deeper shelf setting below effective wave base. In the Lituolacea, the Hormosinidae, Lituolidae, Textulariidae, Trochamminidae, and Ataxophragmiidae include only a few late Paleozoic genera, which locally are abundant in dark to medium gray, silty shales, siltstones, silty sandstones, and carbonate wackestones and packstones; all deposited near wave base.

Miliolina: Late Paleozoic representatives are primitive (tubular, nonseptate) genera of Hemigordiopsidae, Fischerinidae, and Nubeculariidae. These occur mainly in shallow, warm water calcareous wackestones.

Fusulinina: These were the most taxonomically diverse of the late Paleozoic foraminifera and were adapted to a wide range of depth habitats. Parathuramminacea locally were very abundant in deeper water, dark gray calcareous wackestones formed in basins and slopes below wave base. Endothyracea (s.l.) included many genera and families that dominated most of the Early Carboniferous shallow water, calcareous depositional environments. Nodosinellidae preferred open shelf facies and may have extended to depths below wave base. Colaniellidae, Ptychocladiidae, Paleotextulariidae, Tetrataxidae, Tournayellidae, Endothyridae, Loeblichiidae, and Lasiodiscidae locally were common in shallow shelf, shoal, and lagoonal carbonate wackestones, packstones, and as displaced fossils in some grainstones, such as oolites. Bradyinidae were globose, had pseudoalveolar walls, and were widely scattered in a number of different lithologies suggesting a pelagic or planktonic habitat. Archaediscidae, which have recrystallized wall structure, were common in shallow water, carbonates and calcareous shales.

Fusulinacea, most of which probably had photosynthetic symbionts, were adapted to shallow carbonate depositional habitat at depths less than 15 to 20 m (49 to 66 ft). Carboniferous Fusulinidae and Ozawainellidae apparently occupied most of this depth range because of their adaptation to Middle Carboniferous cool surface waters. Permian Schubertellidae and Oazawainellidae became adapted to shallow, warm water lagoons and shelves. Verbeekinidae and Neoschwagerinidae were common in reef cores and upper flank deposits of Permian Tethyan reefs. Schwagerinidae also adapted to shallow to very shallow water carbonate environments, such as reef edges, shallow lagoons, tidal flat channels, margins of algal shoals and banks, and other shallow nearshore areas. For example, *Eoparafusulina* formed extensive skeletal grainstones in many cross-bedded, subtidal deposits.

Several globose lineages within the Fusulinacea possibly were pelagic, such as *Robustoschwagerina, Pseudoschwagerina, Verbeekina,* and many of the Permian Staffellidae.

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Regional Inventory of Peace River Oil Sands, Alberta, Canada

The Peace River oil sands of northwestern Alberta contain an estimated 92 billion bbl of bitumen trapped in an updip pinch-out of the Lower Cretaceous Bluesky and Gething Formations. The geologic reservoir characteristics of the Peace River oil sands are being mapped on a regional scale through the use of core and geophysical logs. Four wells per township are used wherever possible. A computerized data file on each well consists of basic well data, tops of the Bluesky and Gething Formations, and oil sand reservoir and the underlying pre-Cretaceous unconformity, and a coded lithology log. The lithology log is kept simple due to the limits of geophysical log interpretation but attempts to quantify sand, shale, interbedded sand and shale, oil, and water. Logs have been calibrated wherever possible with core control. Because the data are stored as a log of the well, a wide variety of useful maps can be generated by the computer. These include maps showing structure, sand/shale ratios, gross and net pay thicknesses, basal water, top water, lean zones, and uninterrupted pay.

Recognition of four major facies including continental, tidal flat, shoreline and shallow marine, and tidal channel deposits has led to the proposal of an estuarine model for sedimentation within the Gething Formation. Isopach maps from the top of the Bluesky and Gething Formations down to the pre-Cretaceous unconformity show a regional southeast to northwest drainage trend on the unconformity surface. Similar trends are seen in the main sand bodies. Coordination of computer-generated maps with the facies model highlights areas which satisfy specific criteria that may be critical in determining the applicability of a particular in-situ recovery method.

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Depositional and Exploration Models for Cretaceous Lower Mannville Fluvial Sandstones of South-Central Alberta

Production of hydrocarbons from fluvial strata of the lower Mannville Formation in the Taber–Milk River area of south-central Alberta occurs primarily from combination structural-stratigraphic traps situated on subtle north-northwest trending anticlinal features. Lower Mannville sediments were deposited in a north-trending valley that formed when sea level lowered and shorelines receded to the edge of the continent during the Late Jurassic and Early Cretaceous. The river that cut this valley shifted eastward in response to rising of the Cordilleran highlands, producing a west-facing escarpment. We regard this escarpment as a southward extension of the Fox Creek Escarpment of west-central Alberta. In latest Neocomian or earliest Aptian time, the river system began to aggrade as a result of southward transgression of the Boreal sea. The basal aggradational valley fill, the Sunburst Sandstone, is generally the coarsest, best sorted, and texturally most mature of the sandstones in the Mannville Group. Stratigraphic traps in the area are the result of: (1) updip pinch-out of the Sunburst Sandstone against the north-trending Fox Creek Escarpment (e.g., Horsefly Lake field); (2) general eastward-thinning of the Sunburst Sandstone within tributary valleys east of the Fox Creek Escarpment (e.g., Chin Coulee field); and (3) updip interruption of blanket fluvial sandstone units by clay-filled, abandoned reaches of the river system that deposited the lower Mannville sandstones (e.g., Taber field). A logical exploration strategy both in the Taber–Milk River area and in areas to the north and south would be to pursue the trends of the Fox Creek Escarpment and its tributary valleys.

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Sedimentology of Spearfish Formation

The Permo-Triassic Spearfish Formation of the southeastern Black Hills, South Dakota, consists of evaporite, clastic, and carbonate sediments which formed as the result of the complex depositional history.

The lithologies that occur as the result of primary deposition are (in decreasing order of abundance) gypsum, siltstone, shale, sandstone, conglomerate, limestone, dolomite, and a highly organic-rich marlstone (oil shale). The gypsum and limestone were precipitated in a low energy, hyper-saline, subaqueous environment, while the shale and organic-rich marlstone were deposited in a relatively fresh, low energy, subaqueous environment. The siltstone and dolomite were deposited in intertidal to supratidal conditions. Sandstone and conglomerate were deposited in a high flow regime fluvial environment. Although salt casts are common, no halite was observed in the area. Breccias occur as the result of post-depositional processes.

During the late Middle Permian, the depocenter of the Minnekahta sea shifted westward causing the beginning of Spearfish deposition in the area. Subsequent local fluctuations of the shoreline altered environments from shallow marine to terrestrial. Throughout accumulation of the formation, deposition continued in this fashion, similar to conditions currently observed in the Persian Gulf region.

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Evaluation of Ancient Aragonite Cements and Their Temporal Distribution

Literature on carbonate diagenesis has, in general, suggested that cements of virtually any geologic age and morphology were derivable from alteration of aragonite precursors similar to modern submarine aragonites. That interpretation requires for the fibrous fringe cements in many Jurassic and Mississippian oolites, for example, an inference of pseudomorphing of fibrous aragonite by fibrous calcite. Such an assumption of pseudomorphing is unsupported by any examples from calcitization of known aragonite cements (botryoids), ooids, or skeletons. Aragonite relics in calcitized botryoidal cements in the Pennsylvanian of Kansas are comparable to relics in calcitized ooids and skeletons. This underscores the similarity of calcitization behavior of aragonites of diverse origins.

Radiaxial-fibrous (RFC) and fascicular-optic (FOC) calcites are generally interpreted as replacement, by two different modes, of fibrous cement precursors. Those supposed precursors are often inferred to have been aragonite, based on the common fibrous habit in modern aragonite cements. Samples of the Pleistocene Ryukyu limestone (Japan) contain a cement fringe of randomly mixed RFC and FOC on aragonite skeletal substrates and sometimes as a second generation cement on a loose fringe of acicular aragonite. This indicates that RFC and FOC are not distinctive in genesis, and they cannot have originated by replacement of aragonite by proximal to distal migration of a thin film diagenetic front. Geometric considerations also indicate that that generally accepted model is untenable.

Ancient cements whose original aragonite mineralogy can be confidently recognized show a non-random, clumped distribution with respect to geologic time. Bases for such confident recognition of original aragonite include preservation as still aragonite or as replacement calcite irregularly crosscutting original structure and containing relic aragonite inclusions and/or elevated strontium content (with or without distinctive original external morphologies, such as botryoids or square-end rays). Such cements occur in rocks of the Lower Cambrian and Upper Mississippian to Upper Triassic and perhaps Lower Jurassic. Cenozoic cements have not been very closely investigated, and the Cenozoic picture may be rather complex. Nevertheless, the general pattern which emerges appears to parallel that I have found for ooids: aragonite restricted to the Cenozoic, Late Mississippian to Early Jurassic, and Early Cambrian (and late Precambrian).

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Euxinic Biofacies in Anoxic Basins: San Pedro and Santa Barbara Basins, California Continental Borderland

As part of an ongoing study of anoxic California continental borderland basins, the relationships between dissolved oxygen content, sediment fabric, biogenic structure distribution and size trends, and species richness in the San Pedro and Santa Barbara basins were examined. Results of these analyses are essentially identical to those of a previous study of the adjacent Santa Monica basin. The relationships observed in these basins will be useful as criteria for the reconstruction of ancient anoxic basins, the strata of which have high potential as hydrocarbon source beds.

Six sediment fabric types, subjectively classified on the basis of degree of preservation of primary sedimentary structures versus degree of destruction by biogenic activity, were observed in box core x-radiographs. These are distributed concentrically around the centers of the basins with a progressive trend toward increased preservation of primary structures with depth and decreased oxygen content. Intermediate sediment fabric types are formed by the short-term fluctuations of the position of the dysaerobic-anaerobic boundary in the water column.

Box core x-radiograph analysis of biogenic structures indicates that most burrow types occur over a wide range of depth and dissolved oxygen content. However, burrow diameter analysis indicates that burrow size decreases with a decrease in dissolved oxygen content. Bottom photograph analysis of surface biogenic structures indicates that aerobic and upper dysaerobic environments are characterized by abundant tracks and trails, lower dysaerobic environments are dominated by burrow openings, and anaerobic sea floor lacks any visible biogenic structures. Size trends of burrow openings indicate a decrease in size with decreased oxygen. However, organism-sediment interactions and environmental energy also exert a control on burrow-opening size.

Bottom photograph analysis of visible organisms shows that aerobic and upper dysaerobic environments are dominated by urchins, while lower dysaerobic environments are characterized by holothurians, polychaetes, small arthropods, and the small gastropod, *Mitrella permodesta*. Anaerobic surface environments are essentially devoid of visible macrobenthic organisms. Although these trends reflect changes in dissolved oxygen content, evidence suggests that grain size also exhibits control on organism distribution.

Species richness data from the upper portion of box cores indicates that diversity of macrobenthic organisms generally decreases with decreased oxygen content. The greatest decrease in diversity is coincident with the shelf break rather than the aerobic-dysaerobic boundary (1.0 mL/L dissolved oxygen). A loss of macrobenthic organisms that significantly affect sediment fabric occurs at the dysaerobic-anaerobic boundary.

Although observations made in these modern basins support parts of previously developed biofacies models designed for use in reconstruction of ancient anoxic basins, several aspects of these models now appear to be invalid. In particular, there appears to be no definitive change in any of the studied parameters at the aerobic-dysaerobic boundary. The use of sediment fabric, biogenic structure trends, and fossil evidence may aid in the reconstruction of ancient basins providing that controlling factors other than oxygen are thoroughly considered.