Facies of the Waltman depositional system, in basinward progression, include distal alluvial-fan, proximal fan-delta, delta-front, and prodelta. This sequence of facies exhibits an increasing influence of lacustrine over fluvial processes. Depositional environment of each facies is interpreted through examination of outcrop and subsurface characteristics, and supported by analogy with other ancient and modern depositional systems.

Sedimentation was largely controlled by the tectonic behavior of the source area and receiving basin. Rapid subsidence of the basin relative to the source area resulted in three vertically stacked fan-delta lobes in the study area. Uplift of the source area relative to the basin subjected preexisting formations and facies to erosion and redeposition. Climate and basin morphology (which controlled storm activity), stream runoff, waves, currents, basin slope, water depth, and water salinity were also factors which influenced sedimentation within this depositional system.

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Integrated Exploration: Frustration, Fulfillment, or Fun?

The development of optimum integrated exploration has both technical and humanistic aspects. Experience in the borehole-geophysics field with integration of measurements shows the connotations for integration of measurement systems (e.g., seismic and borehole) on more ambitious scales. It is concluded that many of the technical tools needed for effective integration are already available. The challenges and opportunities posed by the humanistic aspects are considered. Modes of integrated exploration suggested by experiences of organizations and conclusions to be drawn from these experiences are reviewed.

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Carbonates, Evaporites, Red Beds, and Organic Shales—Global Tectonic Model for Their Chemical Cycling and Hydrocarbon Potential

The partitioning of oxidized and reduced species of exogenic carbon and sulfur, as calculated from secular Phanerozoic trends in $\delta^{34}S$ and $\delta^{13}C$, suggests a strong coupling between major reservoir transfers and global changes in sea level due to geotectonic mechanisms. The stoichiometry of the major reservoir transfers can be approximated by two tectonic-geochemical end-member scenarios.

Scenario I—high ridge volume, high spreading rates, high global sea level:

$$Me^{2+}CO_3 + SiO_2 + 8CaSO_4 + 2Fe_2O_3 + 15CH_2O \rightarrow Me^{2+}SiO_3 + 4FeS_2 + 8CaCO_3 + 15H_2O + 8CO_2.$$

Scenario II—low ridge volume, low spreading rates, low global sea level:

$$Me^{2+}SiO_3 + 4FeS_2 + 8CaCO_3 + 15H_2O + 8CO_2 \rightarrow Me^{2+}CO_3 + SiO_2 + 8CaSO_4 + 2Fe_2O_3 + 15CH_2O.$$

Scenario I tends to be a time of globally widespread carbonates, elevated carbon dioxide, warmer temperatures (greenhouse effect), extensive iron sulfides, light $\delta^{13}C$ and heavy $\delta^{34}S$. Conversely, scenario II represents a time of globally widespread evaporites, red beds, reduced carbon, carbon dioxide consumption, more frequent glaciation, heavy $\delta^{13}C$ and light $\delta^{34}S$.

These secular trends which track the first-order sea-level curve have important bearing on global hydrocarbon-reservoir and source-rock strategies. Owing to elevated carbon dioxide in scenario I, the widespread carbonates on the flooded shelves would tend to be composed of allochems and marine cements of metastable aragonite and/or Mg calcites greater than 8 mole % Mg. Such compositions are vulnerable to becoming excellent secondary porosity reservoirs. The carbon dioxide concentrations might also enhance the "anoxic" preservation of source-rock organic matter in areas where slow depositional rates would normally lead to oxidation of reduced carbon before burial. Scenario II, on the other hand, would yield less favorable conditions for carbonate reservoir development. This would be a result of both a decrease in areal extent (lower sea level, increased clastic input) and a general decrease in potential secondary porosity development owing to the lower carbon dioxide levels which lead to a dominance of more stable non-aragonite Mg calcitic (less than 8 mole % Mg) allochems and marine cements. However, the source-rock potential at this time would tend to be generally favorable owing to the greater global storage of reduced carbon. Furthermore, scenario II would also represent a time of widespread areas for the potential application of a variety of evaporite and red-bed play concepts.

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Residual Temperature Analysis—Tracking Subsurface Fluid Migration

Positive temperature anomalies associated with fluid-migration paths are expected effects within a compacting and dewatering sediment pile. However, temperature anomalies are also produced by lateral variations in thermal conductivity of the sediments. Using established relations between thermal conductivity and seismic velocity, an estimate of regional heat flow, and average surface temperature, it is possible to estimate the local geothermal gradient (due to solid state, one-dimensional conduction) from sonic logs or downhole velocity surveys. Subtraction of such calculated temperatures from corrected bottom-hole or log temperatures produces mappable residual temperature anomalies which can be interpreted as effects of active upward fluid migration. Mapping of such residual temperature anomalies and comparison with structural setting provide a stronger tool for interpreting routes of water (and perhaps hydrocarbon) migration, than using temperature values without removal of conductive effects. The procedure is analogous to removing a predicted regional gravity field to produce residual gravity anomaly. Interpretations are strengthened by mapping calculated fluid pressure and salinity anomalies which might also be attributable to fluid movement.

Examples from the Louisiana Gulf Coast Miocene illustrate the application and promise of the technique. Residual temperature anomalies occur close to faults, suggesting the potential importance of such structures as routes for fluid escape. The method also provides a means of interpreting correspondence of thermal highs with structural highs as products of either conductive focusing or fluid movement up structure, though two- or three-dimensional modeling is required.

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Classification of Onshore Sedimentary Basins in Brazil

The major sedimentary basins of Brazil range in age from late Proterozoic to Cenozoic. They overlie a stable Precambrian craton consolidated by several orogenic events. Two major regions can be distinguished in this basement: the relatively calm Amazonic Province and the strongly tectonized Atlantic Province, welded together 900 to 1,200 m.y. ago.

The oldest of the major superimposed basins is the Bambui (Sao Francisco) basin, whose sedimentary sequence was, especially along the margins, slightly folded and metamorphosed during the Braziliano-Panafrican orogenic-thermotectonic event 450 to 750 m.y. ago.

Large Paleozoic basins are superposed both over the Amazonic craton (Amazon basin) and over the Atlantic craton (Maranhao and Parana basins). They were subjected to regional cratonic subsidence and broad regional arches separate several subbasins. The architectural framework and shape of the basins (saucer or elongated trough) allow them to be classified either as remote interior basins (Middle and Lower Amazon, Maranhao, and Parana) or as near interior basins (Upper Amazon), the latter being affected by the Hercynian orogeny.

In westernmost Brazil, the Acre basin forms part of the mobile subandean belt and displays intense deep-focus (500 to 700 km) seismic activity. Its architecture and tectonic behavior are that of a typical intracontinental cratonic composite basin.

In Early Cretaceous time, intense faulting marked the breakup of the Gondwana supercontinent. A series of rifts opened along the present Atlantic coast, with characteristic horst-and-graben system. Some rifts remained aborted "aulacogens" (Takutu, Marajo, Reconcavo-Tucano) whereas others developed into the pull-apart basins of the widening South Atlantic Ocean.

The Cenozoic basins can be divided into two groups: (1) those of southeastern Brazil along the Serra do Mar and the Serra da Mantiqueira where half-grabens formed through vertical reactivation of faults following Precambrian lines of weakness, and (2) those of central Brazil (Pantanal and Bananal) where large interior basins are being formed through slow cratonic subsidence.

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Geology of Willow Creek Foreland Thrust Play, Moffat County, Colorado

Exploration for potential oil and gas traps in subthrust zones along the thrusted forelands of a number of Rocky Mountain uplifts has gained renewed interest by the oil industry. In the past, two drawbacks to identifying and drilling these traps were: (1) they are obscured by burial beneath overthrust Precambrian crystalline or metasedimentary rocks, and (2) drilling through an appreciable thickness of these Precambrian rocks is expensive, time-consuming, but necessary to reach younger rocks in the subthrust zone.

The Willow Creek thrust is an example of this type of foreland subthrust exploration play. It is about 7 mi (11.3 km) north of the giant Rangely oil field (production from the Permian-Pennsylvanian Weber Sandstone), and forms the south flank of the Blue Mountain anticline, south of the Uinta Mountains, in northwestern Colorado. This foreland subthrust play was drilled in 1960 by Tennessee Gas and Oil Co. (now Tenneco), and was also studied through a combination of surface and photogeologic mapping, minimum subsurface well control and pre-multichannel seismic data. Structural closure was mapped on subthrust Weber Sandstone in fault contact with overthrust Precambrian rocks. Drilling of more than 2,000 ft (600 m) of Precambrian was required to penetrate the Weber Sandstone. Although the test had good oil shows in Triassic and Permian rocks, it was a dry hole. However, it confirmed the overall original structural interpretation, identified the presence and angle of the main thrust fault, and successfully penetrated an appreciable thickness of Precambrian rocks to reach the Weber.

The Willow Creek thrust may well be a type model of a foreland thrust play, and some of the geologic concepts involved in this study could be used as additional exploration tools to help find these elusive, prospective subthrust traps.

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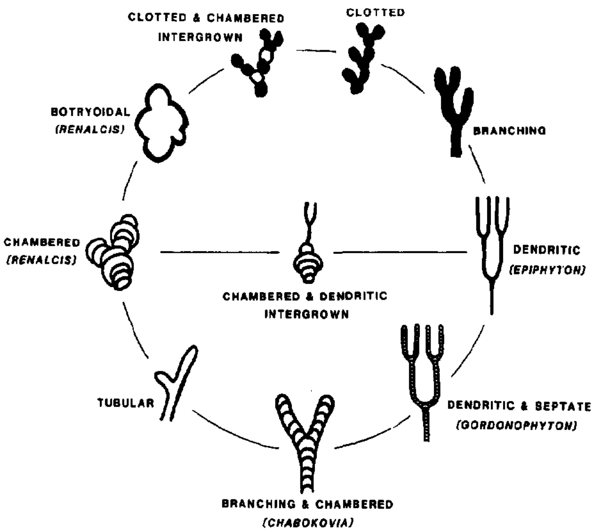
Epiphyton and *Renalcis*—Diagenetic Microfossils from Calcification of Coccoid Blue-Green Algae

Epiphyton and *Renalcis*, and related microfossil genera, are very important but enigmatic framebuilding and encrusting components of many Paleozoic reefs. Study of numerous North American occurrences of various ages (Early Cambrian to Late Devonian) suggests that *Epiphyton* and *Renalcis* are end members of a continuous spectrum of diverse morphologies that commonly occur adjacent to or intergrown with each other. Salient morphotypes include (1) dendritic forms (typified by *Epiphyton)*, (2) dendritic forms with finely septate branches (*Gordonophyton*), (3) robust branching forms with chambers (*Chabokovia*), (4) large unchambered branching tubes, (5) chambered and botryoidal aggregates (typified by *Renalcis*), and (6) arborescent grapelike clots which often lengthen into stubby branches. Particularly noteworthy among common intergrowths and co-occurrences are *Epiphyton* branches attached to (sprouting from?) *Renalcis* chambers. Many well-preserved micrite walls, branches, and clots exhibit a faint dense peloidal microstructure.



The continuum of shapes and intergrowths indicates that these microfossils were likely not genetically distinct organisms. It is proposed that these fossils represent precipitation of high-Mg calcite around and within clumps of coccoid blue-green algal cells soon after death of the algae and in the environment of growth. Inferred rates of chamber addition and growth of branch tips suggest that many cells grew, died, and rotted away between successive times when biogeochemical conditions were right to promote calcite precipitation. The various forms, genera, and species resulted from environmentally related size variation of cells and cell clumps and whether or not calcification was episodic. These microfossils are therefore "diagenetic taxa" and, in a sense, can be considered "microstromatolites."

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Time as Factor in Organic Metamorphism and Use of Vitrinite Reflectance as an Absolute Paleogeothermometer

The only evidence that time is a factor in organic metamorphism lies in the works of Karweil, Lopatin, and Connan. All three attributed the high degree of organic diagenesis in geologically older areas to today's presently low geothermal gra-