inland sabkha with episodic inundations intercalating intertidal dolomite and lagoonal "black shale" with the sabkha sediments. Prolonged periods of exposure allowed migration of eolian dunes across the region. The broad sabkha surface was an area of eolian bypass with only isolated patches of dunes being trapped by rare topographic relief. The bulk of the migrating sand was transported south and west into the sand seas of the Tensleep, Weber, and Casper Formations. Sand was supplied from the north probably by eroded Tyler and older Paleozoic sandstones. In the present-day Hartville uplift area, an Upper Pennsylvanian trough known as the Lusk embayment modified Leo sedimentation. This trough introduced open marine waters into the southwestern corner of the Leo region, resulting in deposition of crinoidal limestone (in lieu of evaporites and carbonaceous shale) interbedded with eolian dunes.

Criteria suggesting windblown deposition of the majority of Leo sandstone include deflationary lag surfaces, low-amplitude ripples, subcritically climbing translatent cross-stratification, and sand-flow toes. Isolated eolian sandstones provide excellent stratigraphic traps for hydrocarbons generated in the organic-rich shales. The current flurry of Leo drilling that began in 1978, has affirmed the inherent potential of this play. Definition of paleodepositional trends and seismic recognition of isolated dunes are the keys to Leo exploration success.

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Trapper Canyon Deposit, Eastern Big Horn Basin, Wyoming: Tar Sand or Heavy Oil?

The Trapper Canyon Deposit (Battle Creek Deposit in U.S. Bureau of Mines Monograph 12) is located on the western flank of the Bighorn Mountains approximately 30 mi (48 km) east of Greybull, Wyoming. The petroleum occurs in the upper eolian sequence of the Pennsylvanian Tensleep Sandstone which dips from 5° to 8° to the southwest. The deposit was initially reported by N. H. Darton in U.S. Geological Survey Professional Paper 51 in 1906. A characterization study was made on the deposit which included mapping the deposit and surrounding area, measuring three stratigraphic sections in the Tensleep Sandstone, and sampling 13 outcrop localities. Thickness of the deposit ranged from 0 to 22.5 ft (6.8 m) in the 13 sample localities. Preliminary analyses of outcrop samples indicate API gravities and viscosities consistent with the definition of a tar sand. Oil properties are similar to those published for Phosphoria-sourced oils produced from the Tensleep Sandstone in fields to the west. Lateral pinch-out of the deposit, tight characteristics of upper and lower bounding units, and the lack of any apparent structural controls in the area, are all evidence for a stratigraphic trapping mechanism. Recoverable reserves are estimated at 1.96 million bbl over a 67-acre (27 ha.) area.

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Thermal Infrared Survey of Sunlight Basin, Park County, Wyoming

Thermal infrared surveys were flown over the Sunlight mining region and Sulphur Camp area of the Sunlight basin to substantiate whether reported fumaroles are indicative of contemporary geothermal activity in the area.

Thermal infrared imagery shows areas of warm ground along and warm water discharge into Sunlight Creek and Sulphur Lake. Sulphur deposits are found on north- and south-facing hill slopes associated with a second warm ground anomaly adjacent to Gas Creek. Warming is also manifested in the thermal characteristics of vegetation, and several fumaroles are identifiable. Aeromagnetic data show a 200 gamma low at Sulphur Camp which cannot be explained topographically.

Major northeast-trending lineaments provide potential conduits for thermal fluids from the magma plume in Yellowstone National Park, 50 km (30 mi) to the southwest. The floor of the Yellowstone caldera is topographically higher and could provide the necessary hydraulic head to move the fluids outward. Other geothermal resources may exhibit the same characteristics. This example suggests that geothermal resources may occur at considerable distances from a heat source.

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Comparison of Western Facies of Thermopolis, Muddy, and Mowry Formations with Other Areas of the Early Cretaceous Seaway, Northern Rocky Mountains and Great Plains Region

The Thermopolis, Muddy, and Mowry formations were deposited in environments associated with an Early Cretaceous sea in the area of the modern Northern Rocky Mountains and Great Plains. The sea advanced into the western interior from the north temporarily joining a northward-transgressing Gulf sea. A regressive period followed, and the southern margin of the sea retreated at least as far north as Wyoming. Studies of depositional environments in the central and eastern parts of the seaway indicate that a second Early Cretaceous transgression followed. However, evidence for the second transgression is not apparent in the study area (Madison and Gallatin Ranges of southwestern Montana). Eastward progradation of marginal marine environments continued on the western side of the seaway despite the sea's second advance. Fluvially dominated delta systems developed on the western side with only minor reworking by marine processes. The western side also received significant amounts of volcaniclastics producing additional lithologic and environmental differences across the seaway.

Facies of the Thermopolis, Muddy, and Mowry formations on the western side of the seaway are compared with other parts of the seaway through compilation of regional paleogeographic maps for five Early Cretaceous episodes. These comparisons show that significant differences in sediment source, amount of sediment input, and tectonic setting existed from one side of the seaway to the other. The following are some of the changes in the Thermopolis, Muddy, and Mowry formations which occur across the Early Cretaceous seaway as a result of the following differences. (1) The lower, informally designated "rusty beds member" of the Thermopolis Shale is more calcareous on the western side of the seaway. Paleozoic carbonates provided sediment from the west while siliciclastic sediment was shed into the seaway from the east. (2) The Thermopolis Shale was subaerially exposed on the eastern side of the seaway is separated from overlying Muddy Sandstone by an unconformity. In contrast, the depositional sequence is continuous on the western side. (3) An unconformity separates lower, regressive Muddy Sandstone deposits from overlying transgressive Muddy Sandstone deposits in the central and eastern parts of the seaway. The Muddy Sandstone on the western side of the seaway is a continuous regressive deposit. (4) The transgressing sea reworked lower Muddy Sandstone into extensive winnowed bar deposits in the eastern and central parts of the seaway. These excellent oil and gas reservoirs apparently are not present on the western side of the seaway. (5) The Mowry Shale was deposited in offshore marine environments in most of the Northern Rocky Mountains and Great Plains region. However, in most of southwestern Montana, the Mowry Shale and equivalents were deposited in nonmarine environments. (6) Siliceous claystone is the dominant lithology of the Mowry Shale deposited in marine environments on the western side of the seaway. Much of the sediment on the western side was derived from volcanic sources. The Mowry Shale is less siliceous to the east, probably because volcanic sediment decreases eastward. Organic carbon content is higher to the east, increasing the petroleum source potential of the Mowry Shale on the eastern side of the seaway.

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Depositional Environment of Bullion Creek Formation (Paleocene) in Southern McKenzie County, North Dakota

The environment of deposition of the Bullion Creek Formation in western North Dakota has been variously ascribed to lacustrine, meandering fluvial, and marginal marine deltaic environments with the latter three being favored by most workers. The purpose of the present study is to evaluate these previous models through careful field observations on a local scale, more specifically T145 and 146N, R102W of McKenzie County, North Dakota.

The Bullion Creek Formation rests conformably atop the Slope Formation (nonmarine) in the southwest quarter of the state and is conformably overlain by the Sentinel Butte Formation. The Tongue River Member of the Fort Union Formation is the lateral equivalent of the Bullion Creek Formation in Montana, Wyoming, and South Dakota. The Bullion Creek Formation is composed primarily of flood-plain sediments, including unconsolidated sands, silts, and clays. Freshwater limestones and thin, discontinuous lignites (with the exception of the thick and laterally extensive HT Butte lignite which has been defined as the upper contact of the Bullion Creek) are also present. The carbonates are of two types: most common are the discontinuous pods of laminated lime mud, which are mudcracked at the top and may indicate evaporative ponds; more rarely, a gastropod-pelecypod-fishscale wackestone occurs near the top of the formation, and represents a small (≈ 1 mi^2, 3 km^2) lacustrine deposit.

Channeling in the Bullion Creek is of special interest. Paleochannels have a low width to depth ratio and appear laterally stable as evidenced by lack of lateral accretion or point bar deposits and vertical stacking. In map view, channels of equal stratigraphic position converge with and diverge from each other.

The preponderant flood-plain sediments, lignites, and carbonates, as well as channel configuration would seem to indicate deltaic sedimentation; however, the deposits contain fauna which are strictly fresh water, thereby making this interpretation tenuous. A possible alternative to this deltaic interpretation is the anastamosing fluvial model. This model, proposed by Smith and Putnam in 1980, has a dominance of vertical accretion, producing channel deposits which are thick, narrow, and laterally stable, as well as extensive inter-channel wetlands and lakes. Hanley and Flores in 1983 proposed a similar depositional picture for part of the Tongue River Member in the Powder River basin in northeastern Wyoming. Anastamosis in the Williston basin is probably the result of greater relative local subsidence of the basin than in the downstream reaches.

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Corals of Madison Group (Mississippian), Williston Basin, North Dakota

Coral faunas studied from subsurface cores of the Mississippian Madison Group in the Williston basin of North Dakota indicate that Sando's coral zones for outcrops in western North America can be extended into the subsurface of North Dakota. Coral zones II and III are recognized as corresponding roughly to lower and upper Mission Canyon strata, respectively. These data were obtained from 12 wells along the northern border of North Dakota in Divide, Burke, Renville, and Bottineau Counties, and two wells near the center of Williston basin in Dunn and McKenzie Counties.

Coral faunas appear to show a relatively low diversity of 13 species distributed among the following genera: *Syringopora*, *Vesiculophyllum*, *Sychnoelasma*, *Amplexizaphrentis*, *Lophophyllum*, *Cyathaxonia*, *Lithostrotion* (*Siphonodendron*), *Diphyphyllum*, *Michelinia*, and *Stelechophyllum*. *Vesiculophyllum*, *Sychnoelasma*, and *Syringopora* are the most abundant genera of the Madison Group in North Dakota.

Corals found in dark argillaceous crinoid-skeletal wackestones representing "deeper" waters are robust, and this may infer a hospitable environment for their growth. However, evidence from the coral and lithologic associations refute the pervading dogma that the occurrence of corals is strictly facies controlled. Abundant smaller corals have been found from buff-colored skeletal wackestones and algal mudstones which alternate with subaqueous anhydrites representing a marginal marine environment. In addition, corals have been found in buff-colored skeletal and peloidal grainstones of adjacent shoals and in brown pisolitic-oolitic packstones-wackestones of possible tidal ponds. These latter deposits may represent allochthonous accumulations, but the amount of time involved in transport of corals would not invalidate their usefulness as biostratigraphic tools.

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Paleotectonic Control of Depositional Facies, (Devonian), Southwest Montana

Deposition of the Jefferson Formation occurred on a shallow carbonate platform that extended westward to the Antler foreland basin. The distribution of facies and porosity trends was controlled by the structural trends imposed on the area during the late Precambrian and the relative movement of these paleostructural elements during Jefferson deposition. Isopach values (formation "thins") suggest the presence of paleohigh structural elements identified as the Alberta shelf, Tendoy high, and Beartooth shelf, separated by formation "thicks" in the paleolow structural elements (troughs), identified as the Central Montana trough and Ruby trough.

The Jefferson Formation is a moderately thick cyclical sequence of dolomitized carbonate rocks deposited in an extensive tidal flat-lagoonal environment similar to modern tidal flats of Andros Island and the sabkha-lagoonal regions of the Persian Gulf. Normal marine, restricted marine, and evaporite platform facies are recognizable in the Jefereson, and occur in repetitious fining-upward cycles, which are generally capped by the evaporite facies. Evaporitic facies are predominant in the areas of paleohighs, whereas restricted and normal marine facies predominate in paleolows. Dolomitization was probably contemporaneous in areas of paleohighs, and resulted in microcrystalline dolomite associated with evaporites. Areas marginal to the paleohighs and in paleolows were originally the sites of restricted and normal marine limestone deposition. Subsequent dolomitization has locally destroyed all primary structures.

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Codell Sandstone, Denver Basin—Frontier Exploration in a Mature Basin

The Codell Sandstone Member of the Carlile Shale is a new exploration target for oil and gas in the northern Denver basin. The Codell interval ranges in thickness from a wedge edge to approximately 100 ft (30.5 m), the average being 15 to 20 ft (4.5 to 6.1 m). The Codell is well developed in the southern Denver basin, is absent in a broad northeast-trending area in the central Denver basin, and is sporadically developed in the northern Denver basin.

The variation in geographic distribution and thickness results from regional unconformities at the base and top of the Codell. The Carlile Shale (50 to 200 ft, 15.3 to 61 m, thick) in the Denver basin and marginal outcrop has four members which, in ascending order, are the Fairport Chalk, Blue Hill Shale, Codell Sandstone, and Juana Lopez Limestone. The unconformity at the base of the Codell Sandstone has a hiatus which increases in magnitude to the west across the basin. The sandstone is transitional with the overlying Blue Hill in central Kansas but it rests on Fairport equivalents over most of the Denver basin and underlying Greenhorn Formation along the northwest flank of the basin. The unconformity at the top places the Fort Hays Limestone Member of the Niobrara in erosional contact with either the thin (1 to 3 ft, 0.3 to 0.9 m) Juana Lopez or the Codell Sandstone.

Outcrop and core studies clearly show three types of sandstones which developed during sea level changes of late Turonian and early Coniacian age. The Codell is related to processes in three different environmental settings. (1) Marine (or shoreline) bars, which have a transitional base with the underlying Blue Hill Shale. The sandstones have good porosity and permeability and a sheetlike distribution. These sandstones occur in Kansas and the southern Denver basin and are not currently productive of petroleum. (2) Tight bioturbated and reworked marine shelf sandstones generally without a central-bar facies. These sands may also be associated with thin, irregular, relict, or palimpsest shelf deposits which locally are coarse grained and conglomeratic. Recent petroleum discoveries have been made in this sandstone facies in the west-central portion of the Denver basin. Productive depths range from 4,000 to 8,000 ft (1,219 to 2,438 m). Net pay ranges from 3 to 25 ft (0.9 to 7.6 m). Porosities range from 8 to 24%. Permeabilities are generally less than 0.5 md. Trapping of petroleum appears to be stratigraphic. (3) Tight sandstones of marine origin(?) filling large scour depressions (valleys?) which were eroded into underlying Fairport or Greenhorn strata. Although these sandstones are the thickest found in the Codell, they are generally tight and occur mainly in the Wyoming portion of the basin. Only minor production has been found in this facies.

Variation in thickness and reservoir quality is related to original environmental control, paleostructure which locally influenced the unconformities, fracturing, and diagenesis. Where fracturing is important to reservoir quality, the Codell and overlying Fort Hays Limestone may be a commingled reservoir.