els of listric-normal faulting occur in the Boulder-Greeley area. These tectonic sensitive intervals are present in the following Cretaceous formations: Laramie-Fox Hills-upper Pierre, middle Pierre Hygiene zone, and the Niobrara-Carlile-Greenhorn. Documentation of the listric-normal fault style reveals a Wattenberg high, a horst block or positive feature of the greater Transcontinental arch, was active in the east Boulder-Greeley area during Cretaceous time. Paleotectonic events associated with the Wattenberg high are traced through analysis of the listric-normal fault systems that occur in the area. These styles are important to recognize because of their stratigraphic and structural influence on Cretaceous petroleum reservoir systems in the Denver basin. Similar styles of listric-normal faulting occur in the Cretaceous in many Rocky Mountain foreland basins.

DAW, TERRELL B., ARCO Exploration, Denver, CO

Use of Seismic Stratigraphy for Minnelusa Exploration, Northeastern Wyoming

The Powder River basin in northeastern Wyoming has long been a productive oil province. Abrupt lithology changes of the Upper Pennsylvanian-Permian Minnelusa Formation have provided a variety of hydrocarbon traps. However, these same abrupt changes have also yielded many surprises to the hopeful explorationist.

The upper Minnelusa is composed mainly of sands, dolomites, and anhydrites, and was deposited in sabkha environment. Unconformably overlying the Minnelusa is the supratidal Opeche shale. Hydrocarbon traps in the upper Minnelusa sands are usually stratigraphic in nature, and are of two common types. In one, a porous sand is trapped by an updip facies change; in the other, thick Opeche deposits in interdunal areas provide an updip seal for the porous sands.

The C-H field area, located in Campbell County, Wyoming, was chosen for initial study. Abrupt updip termination of the thick productive upper Minnelusa sand appeared to provide an ideal situation for a stratigraphic-seismic study. Sonic logs used to construct a geologic cross section showed a significant difference in the sonic response of porous upper Minnelusa sand versus no sand. Synthetic seismograms were then produced from these wells and, when organized in cross-section form, they again showed an obvious difference in response from sand to no sand conditions.

A "pilot" seismic line tying these wells was acquired. From this data, a good correlation between synthetic and actual seismic data was achieved. The updip termination of the productive Minnelusa sand was clearly identifiable on the seismic data.

The drilling phase of our exploratory program yielded mixed results. Some excellent development wells were drilled, one being completed for 625 BOPD. Although we were 70 to 80% successful in predicting the presence or absence of porous upper Minnelusa sand, only 20% of our extension or wildcat wells were productive.

Two major problems were soon discovered: (1) the seismic response from a thick, relatively low velocity Opeche shale is very difficult to distinguish from an upper Minnelusa sand; and (2) thin, porous Minnelusa sands are difficult to identify seismically, thus updip trap limits are not easily defined.

A variety of seismic trace attributes were examined in hopes that subtle amplitude and frequency differences would help distinguish thick Opeche shale from Minnelusa sand. This approach produced very limited success. Better results were achieved on the second problem, that of thin bed resolution. Accentuating the upper portion of the seismic frequency spectrum (40 to 80 Hz) did allow better mapping of thin Minnelusa sands.

In conclusion, through a closely coordinated geologic-geophysical effort, a useful methodology was developed which can be applied to a variety of stratigraphic-seismic exploration projects. The basic steps involved are as follows. First, determine if known lithologic changes can be seen on sonic or density logs. If successful, can the changes on logs be seen on synthetic seismograms? If successful, can the change be seen on a pilot seismic line? Finally, prepare for some complications and failures.

DE VRIES, JANET L., Hotline Energy Reports, Casper, WY

Evaluation of Low-Temperature Geothermal Potential of Cache Valley, Utah

This research is a continuation of the assessment of low-temperature geothermal resources of Cache Valley, Utah, initiated by the Utah Geological and Mineral Survey. The study area is the southern part of a narrow, north-trending graben located in north-central Utah and southern Idaho.

Tools used for evaluating the low-temperature geothermal resources are ground-water temperatures, thermal gradients, silica and Na-K-Ca geothermometers, and mixing models for estimating reservoir temperatures.

Ground-water temperatures range from 9.9 to 50.0°C, with a background temperature of about 13.0°C. The three areas in the study area with anomalous water temperatures are: (1) North Logan, 16.0 to 25.1°C; (2) Benson, 13.5 to 23.0°C; and (3) Trenton, which has evidence for past and present warm spring activity, with temperatures ranging from 22.9 to 50.1°C.

Thermal gradients generally range from 15° to 52°C/km, approximately the same as the average thermal gradient for the Basin and Range province, 35°C/km.

The silica and Na-K-Ca geothermometers, when applied to the groundwater of Cache Valley, Utah, show varying degrees of agreement, with estimated reservoir temperatures averaging 50 to 100°C. When the mixing models are applied to the water in the Trenton area, estimated reservoir temperatures are 30 to 200°C.

The function, $F(T) = \log(Na/K) + B\log(\sqrt{Ca/K})$, is used as an exploration tool to indicate a possible geothermal anomaly when the value is less than 2.00. The Trenton area is a possible geothermal anomaly located using this method.

Warm water in Cache Valley, Utah, appears to be the result of groundwater which has migrated from depth, is warmed by the normal thermal gradient, rises quickly along permeable fault zones, and either mixes with near surface recharge water or is forced to flow horizontally because of a less permeable confining layer. Both of these models mask the higher temperatures at depth.

Considering measured surface temperatures, calculated reservoir temperatures, thermal gradients, and the local geology, most of the Cache Valley, Utah, area is unsuitable for geothermal development. However, the areas of North Logan, Benson, and Trenton have anomalously warm ground water in comparison to the background temperature of 13.0°C for the study area. The warm water has potential for isolated energy development but is not warm enough for major commercial development.

DIXON, JOE S., Champlin Petroleum, Englewood, CO

Regional Structural Synthesis, Wyoming Salient of Western Overthrust Belt

Surface geologic mapping, regional and high-density reflection seismic data and information from approximately 370 wells are combined to describe geometrically that area of the western Overthrust belt between the Snake River Plain and the Uinta uplift. Particular care has been taken to two-dimensionally verify interpretations of multiple thrust sheets by linear restoration. By establishing equivalence of pre-thrust lengths of affected beds, one can gain confidence in interpreted structural geometrics as well as generate data in regard to internal shortening and deformation intensity. Due to irresolvable geometric problems within sections, 47 cross sections were developed at roughly 6-mi (10 km) spacing to help verify changes in displacement or placement of key structural elements. Displacements of 0 to 32 mi (51 km) have been demonstrated, and both structure of faults and subcrop relations of Absaroka and younger thrusts are described. Jurassic to Paleocene (Sevier) thrusts were active across a previously deformed cratonic shelf terrane and interacted with active structural elements such as the Uinta uplift, Gros Ventre Range, and Moxa arch. Thrusts are progressively younger to the east, except for the Darby-Prospect pair in which the Darby system is younger.

DODGE, HARRY W., JR., U.S. Geol. Survey, Denver, CO, and THOMAS M. CRANDALL, U.S. Bureau Mines, Pittsburgh, PA

Depositional Environments of Upper Cretaceous Fox Hills Formation, Niobrara and Weston Counties, East-Central Wyoming

The Upper Cretaceous Fox Hills Formation on the southeastern flank of the Powder River basin, Wyoming, was deposited along a regressive, northeast-trending, low-energy, tidally affected, wave-dominated coastline. The Fox Hills Formation consists of rocks deposited successively in marine transitional-lower shoreface, upper shoreface, foreshore, and tidal-flat environments.

The marine transitional-lower shoreface beds are characterized by generally highly bioturbated, very fine-grained sandstone and silty claystone with interbedded siltstone, silty shale, and shale. The amount of sandstone in them increases landward. Portions of all of these strata include hummocky cross-bedding, unidentified tracks and trails, traces of *Rhizocorallium* and small *Ophiomorpha*, and glauconite layers. The lower shoreface portion of this environment has a ledgy appearance due to the alternation of sandstone and finer grained sediments.

The upper shoreface deposits consist dominantly of sandstone and have minor amounts of siltstone, silty claystone, and shale. The sandstone generally becomes coarser and better sorted upward. Highly bioturbated beds are common throughout the upper shoreface strata. Low-angle planar cross-bedding and some parallel bedding are the major sedimentary structures. Trace fossils of *Ophiomorpha* and *Arenicolites*, and body fossils of pelecypods and gastropods appear in upper shoreface rocks.

The deposits of the foreshore (intertidal) consist of moderately sorted to well-sorted fine-grained sandstone that has seaward-dipping wedge-planar cross-bedding. *Arenicolites* and large, generally vertical, traces of *Ophiomorpha* are common in these rocks. Irregular polygonal weathering patterns are common on outcrop surfaces.

Tidal-flat deposits are common in the upper part of the section in the northern part of the study area. At one locality, these deposits consist of at least 75 ft (23 m) of intercalated fine-grained sandstone and claystone that have lenticular to flaser bedding. The majority of these deposits show a high degree of bioturbation and are considered to be intertidal. These sediments are overlain by approximately 15 ft (4.5 m) of fine-grained silty sandstone and claystone which have plant root casts and a high content of carbonaceous material, and which could represent supratidal deposits. Overlying these deposits is a 12-ft (3.7 m) sandstone bed having a scour base, lag of clay clasts and woody fragments, parallel bedding that grades upward into trough cross-bedding, and a 6-ft (1.8 m) bed of oyster shells near its top. This sequence represents an ancient tidal-channel deposit.

DOLLIVER, PAUL, Geomap Co., Denver, CO

Upper Mission Canyon (Mississippian) Cyclicity and Hydrocarbon Occurrence, North-Central North Dakota

The upper Mission Canyon Formation along the east flank of the Williston basin represents several upward-shoaling cycles within an overall regressive marine sequence. Individual cycles grade from offshore shelf carbonates eastward into restricted marginal marine evaporites. This depositional pattern and subsequent diagenesis have produced numerous prolific hydrocarbon traps.

The relationship of hydrocarbon occurrence to facies distribution, paleostructure, and porosity development is discernable by constructing a variety of isopach, lithofacies, and porosity maps. Two areas in the vicinity of Chola-Mackobee Coulee and Glenburn fields permit detailed analysis of the Bluell, Sherwood, Mohall, and Glenburn cycles.

Anhydrite distribution and thickness variation within individual Mission Canyon cycles most closely correspond to the pattern of hydrocarbon occurrence. Other major factors governing such occurrence include the lateral distribution and succession of carbonate bank, dolomite, anhydrite, and siliciclastic lithofacies.

DOLSON, JOHN, Amoco Production Co., Englewood, CO

Depositional Environments and Reservoir Properties, Lonetree Field, Southern Denver Basin, Colorado

Significant accumulations of oil and gas are stratigraphically trapped in the Lower Cretaceous "J" sandstone in the southern Denver-Julesburg basin of Colorado. Lonetree Field (T3S, R59W) provides a typical example of trapping mechanisms and reservoir properties. Examination of 5 cores and 75 wire-line logs within the field resulted in several conclusions.

The deltaic J sandstone at Lonetree can be divided into three genetic units; a lower delta front (J-3), a middle delta plain sequence (J-2), and overlying destructional marine (J-1). Production at Lonetree is primarily from channel and crevasse splay sandstones of the J-2 interval. Traps are formed by the updip pinch-out of quality sandstone.

Channel sandstones are characterized by a coarse to very fine-grained upward-fining sequence. Trough cross-beds predominate at the base, and ripples and rootlets at the top. Carbonized wood is ubiquitous throughout. These northeast-southwest-trending channels attain thicknesses of 15 to 50 ft (4.5 to 15 m) and widths up to 2,500 ft (760 m).

Crevasse splay deposits show extreme lateral and vertical variation. Both coarsening and fining upward deposits are possible. Maximum thicknesses of 15 ft (4.5 m) are developed only in close proximity to channel sandstones. Rooted zones and ripple cross-stratification are common.

Porosity in both channels and splays is secondary in nature, resulting from the dissolution of feldspars and calcite cement. This overprinting of secondary porosity on a complex depositional system has created numerous separate reservoirs within the field. Porosity in producing zones is commonly 13 to 20%, with permeabilities in excess of 75 md. Kaolinite is abundant in pore throats, and may present completion problems associated with brushpiling of fines during treatment.

Little petrographic or petrophysical differences appear to exist between productive splay and channel sandstones. Typical cumulatives to date are 100,000 bbl of oil per well from splay sandstones, while channels contribute 125,000 bbl of oil per well. The 17 producing wells are expected to yield 2.4 million bbl of oil and 4 bcf of gas.

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Early Cretaceous Stratigraphy, Paleontology, and Sedimentary Tectonics in Paris Overthrust Foredeep (Western Wyoming and Southeastern Idaho) Compared with Quaternary Features of Indo-Gangetic Plain

Fluviatile clastics of the nonmarine, Early Cretaceous Gannett and Wayan groups were deposited on wet alluvial megafans and on intervening interfan piedmont slopes which declined eastward into more poorly drained lowlands from a western highland source area uplifted episodically by movements of the Paris overthrust. The deposits accumulated in the tectonic foredeep depressed by that thrust. The Gannett alluvial fan deposits (earliest Cretaceous) graded eastward into nonmarine lowland alluvial plain deposits of the Cloverly Group. Subsequent Wayan alluvial fan clastics (Early Cretaceous) graded into Bear River, Aspen, and lower Frontier mixed nonmarine, brackish, and marine facies. Lacustrine episodes of deposition intercalated Peterson and Draney limestones with Gannett fluvial clastics. Westward marine transgressions (Skull Creek, Mowry) intercalated mixed lacustrine and brackish facies (Smiths and Cokedale formations) into Wayan fluviatile clastics. Newly discovered fossil vertebrate and invertebrate materials (all fragmentary but identifiable) include: Gannett Group—large reptiles including turtles; Thomas Fork Formation—freshwater gastropods and unionid pelecypods, gastroliths(?), two types of turtles, large reptilian fragments (dinosaur?), and abundant dinosaur eggshell fragments; Wayan Formation—perennially aquatic snails, turtles, unidentifiable large reptiles, two types of crocodilians, an iguanodontid dinosaur (Tenontosaurus), an ankylosaurian dinosaur, a large ornithopod dinosaur, gastroliths(?), abundant and ubiquitous dinosaur eggshell fragments (numerous types and sizes), and miscellaneous unidentifiable small vertebrate bone fragments. The dinosaurs are the first reported from Idaho and from these stratigraphic units.

Faunal, sedimentologic, and stratigraphic data indicate perennially wet, upland (proximal fan) lithotopes and biotopes on a deposurface of much lower gradient than characterizes semiarid or arid fans.

A census of analogous modern reptile reproductive behaviors supports the conclusion that the Wayan, and probably also the Gannett, alluvial fan environments were used as upland breeding grounds by dinosaurs and perhaps other reptiles. Comparison of these Early Cretaceous data with observations on the tectonic setting, sedimentology, and biology of the Quaternary indo-gangetic plain suggests many close analogies between the two sedimentary tectonic settings.