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**ANNOTATED BIBLIOGRAPHY OF SELECTED REFERENCES ON
SHORELINE BARRIER ISLAND DEPOSITS WITH EMPHASIS ON
PATRICK DRAW FIELD, SWEETWATER COUNTY, WYOMING**

Topical Report

**By
Viola Rawn-Schatzinger
Richard A. Schatzinger**

July 1993

Performed Under Cooperative Agreement No. FC22-83FE60149

**IIT Research Institute
National Institute for Petroleum and Energy Research
Bartlesville, Oklahoma**

**Bartlesville Project Office
U. S. DEPARTMENT OF ENERGY
Bartlesville, Oklahoma**

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**Prepared for
U.S. Department of Energy
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ANNOTATED BIBLIOGRAPHY OF SELECTED REFERENCES ON SHORELINE BARRIER ISLAND DEPOSITS WITH EMPHASIS ON PATRICK DRAW FIELD, SWEETWATER COUNTY, WYOMING

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INTRODUCTION

This bibliography contains 290 annotated references on barrier island and associated depositional environments and reservoirs. It is not an exhaustive compilation of all references on the subject, but rather selected papers on barrier islands, and the depositional processes of formation. Papers that examine the morphology and internal architecture of barrier island deposits, exploration and development technologies are emphasized. Papers were selected that aid in understanding reservoir architecture and engineering technologies to help maximize recovery efficiency from barrier island oil reservoirs. Barrier islands from Wyoming, Montana and the Rocky Mountain basins are extensively covered.

A. GREATER GREEN RIVER BASIN INCLUDING PATRICK DRAW FIELD

The Greater Green River Basin is a large area in southern Wyoming, northwestern Colorado and northeast Utah. The basin is bounded on the west by the Wyoming Thrust Belt and on the north by the Wind River Thrust Belt. The eastern boundary is formed by the Sierra Madre and Park Range uplifts. The southern boundary is the Axial Basin Uplift and the Unita Mountain Thrust Fault. Five smaller subbasins within the Greater Green River Basin include; Hoback, Green River, Great Divide, Washakie and Sand Wash. Structural features within the Greater Green River Basin that separate the individual basins are the Rock Springs Uplift, Moxa Arch, LaBarge Platform, Pinedale Anticline, Wamsutter Arch and Cherokee Ridge. The area covers more than 51,000 km² (Law, 1984).

Rocks in these areas encompass Cambrian through Tertiary sedimentary deposits. Characteristic fill includes Permian age Phosphoria Formation, Triassic-Jurassic Nuggett Formation, Upper Cretaceous Mesaverde Group and equivalent age rocks topped in some areas by the Paleocene Fort Union Formation and Eocene deposits. The emphasis in this bibliography is papers that deal with the geology, dynamic processes and hydrocarbon recovery of barrier island reservoirs.

Annon., 1973, Oil Characteristics in the Greater Green River Basin: Wyoming Geol. Assoc. Guidebook, 25th Field Conf., p. 12-18.

Tables give field name, location (township and range), county, formation, depth, number of wells, color of sediments, API oil gravity, viscosity, and percentages of sulfur, carbonate, and nitrogen, cumulative oil, and cumulative gas production.

Arp, G. K., 1992, An integrated interpretation for the origin of the Patrick Draw oil field sage anomaly: AAPG Bull. 76, no. 3, p. 301-306.

Remote sensing methods have been used at Patrick Draw Field, Wyoming for nearly 10 years. Patrick Draw is a stratigraphic trap. The surface is covered with sage brush. Remote sensing has detected an anomaly in the growth of the sage over Patrick Draw. The controversy is whether this anomaly, first observed in 1978, is related to the underlying oil field. Sage die-out results from the upward migration of injected gases and water. The soil becomes high pH, high in salinity, and toxic to the sage.

Asquith, D. O., 1966, Geology of Late Cretaceous Mesaverde and Paleocene Fort Union oil production, Birch Creek, Sublette County, Wyoming: AAPG Bull., v. 50, p. 2176-2184.

South Birch Creek is located on the La Barge Arch in western Green River Basin, northwest of the Rock Springs Uplift. It is part of the Big Piney-La Barge producing complex. The close association of oil and most of the gas production from the Paleocene Fort Union shales suggests that this shale is the source of hydrocarbons for the associated reservoirs. Close association of production in Mesaverde reservoirs with an unconformity above it at the overlying shale, absence of distinct chemical differences in oils between Cretaceous and Paleocene reservoirs, and lack of significant production from areas lacking or with poorly developed Paleocene shale suggests that the source of hydrocarbons produced from Mesaverde reservoirs may be the Paleocene lacustrine shales rather than the underlying Cretaceous marine shale and siltstone.

Asquith, D. O., 1968, Origin of large kaolinite crystals in the lower Almond Formation in southwest Wyoming: Jour. Sed. Petrol., v. 38, p. 948-949.

Large kaolinite books, up to 3-mm in diameter from near Rock Springs (WY) are present as a 1-3 in. underclay in the lower nonmarine portion of the Almond. Grain size, crystallinity, and lack of abrasion of books indicate diagenetic rather than detrital origin.

Asquith, D. O., 1975, Petroleum potential of deeper Lewis and Mesaverde sandstones in the Red Desert, Washakie and Sand Wash Basins, Wyoming and Colorado: RMAG Symposium, p. 159-162.

Almond (Upper Mesaverde) was deposited during a local regression in the overall transgression of the marine Lewis Shale over the Mesaverde. Production trend includes Patrick Draw, Table Rock, and Desert Springs fields on the western flank of the Washakie Basin and Red Desert Basin.

Baptist, O. C., E. J. White, and C. S. Land, 1964, Laboratory predictions of water sensitivity compared with field observations of well damage - Patrick Draw, Wyoming: SPE Paper 839 (preprint), 6 p.

Actual formation damage due to invasion of fresh water is estimated from interpretation of DST's and rates of injection into two pilot waterflood wells where fresh water was injected into 1 well and brine into the other.

The results are indecisive. Damage ratios from DST are high for gas sands, but damage is rapidly removed by production. Damage ratios are less in oil sands than in gas and are even less in water sands. Injection rates for fresh water were about the same as for brine. Rates of brine injection are close to those calculated from laboratory relative-permeability curves.

Barlow, J. A., Jr., 1961, Almond Formation and Lower Lewis Shale, east flank of Rock Springs Uplift, Sweetwater County, Wyoming: *in* Wyoming Geologic Association Symposium of Late Cretaceous Rocks, 16th Ann. Field Conf. Green River, Washakie, Wind River and Power River Basins, p. 113-115.

The Almond Formation is the uppermost formation of the Mesaverde Group. The relationship of the Almond to the overlying Lewis Shale and other associated strata is analyzed with stratigraphic correlations, cross sections and maps.

Brock, W. G. and J. Nicolaysen, 1975, Geology of the Brady Unit, Sweetwater County, Wyoming: Rocky Mountain Assoc. Geol. Symposium, *in* Deep Drilling Frontiers of the Central Rocky Mountains: eds. D. W. Bolyard, p. 225-237.

Initial drilling into a deep seismic structure west of the Washakie Basin has produced hydrocarbons from multiple pay zones. Production has been from the Upper Cretaceous Dakota Formation, the Jurassic Entrada and Nugget formations, the Permian Phosphoria Formation and the Pennsylvanian Weber Formation.

The Dakota sandstones are fluvial and distributary channel deposits. The Entrada and Nugget sandstones are the most porous and continuous reservoirs at Brady Unit. Thin carbonate facies in the Phosphoria limits production. The porosity and permeability of the Weber and Phosphoria formations are discontinuous and cause problems in production.

The structural feature at the Brady Unit reflects Precambrian faulting in the basement rocks. A thick sedimentary layer is draped over the fault, dying out in the higher stratigraphic layers.

Bryant, W. A., 1984, Paleoenvironmental interpretation based on foraminifera of coal-bearing Almond Formation, Little Snake River Coalfield, Wyoming (abst.): AAPG, Bull., v. 68, p. 933.

The Almond is about 450 ft thick and divided into two informal members, both of which contain coal. Coals in the upper 100 ft of the upper member are thin; however, coals in the lower member include several thick beds. Coal-bearing portions of both members are characterized by repetitive coarsening-upward bay-fill deposits of mudstone and sandstone, commonly overlain by coal. A major coarsening-upward sequence in the lower part of the upper member is capped by sandstone interpreted as marine shoreface.

Fine grained rocks in both members contain forams. The three foram assemblages are: (1) low diversity agglutinated benthic assemblage interpreted as a hyposaline saltmarsh fauna from fine grained rocks of the lower member, (2) a high diversity mixed agglutinated and calcareous benthic assemblage interpreted as a hyposaline bay to lagoonal fauna in shales in the lower part of the upper member, (3) a moderate-diversity agglutinated benthic assemblage in fine-grained rocks in the upper part of the upper member interpreted as a hyposaline salt marsh to interdistributary bay fauna.

Burton, G., 1961, Patrick Draw area, Sweetwater County, Wyoming: Wyoming Geol. Assoc., 16th Ann. Field Conf., p. 276-279.

An early field analysis of Patrick Draw Field and nearby Table Rock Field. Patrick Draw oil field is approximately 8 miles long and 3 miles wide. Oil is coming from stratigraphic traps in the Almond Formation. Seismic data collected thus far revealed no structural configuration conducive to hydrocarbon accumulation.

Cox, J. E., 1962, Patrick Draw area, Sweetwater County, Wyoming: Billings Geol. Soc., Paper no. 1, p. 1-17.

A detailed field study of Patrick Draw Field. The geology is based on core data, and expressed in maps and cross sections.

Davis, J. R., 1966, Stratigraphy and depositional history of upper "Mesaverde" Formation of Southeastern Wyoming: Ph.D. thesis, The University of Wyoming, 124 p.

The Mesaverde Formation outcrops in the Laramie, Carbon, Hanna, and Kindt basins of Wyoming. The sequence in these basins includes the Steele Shale, Pine Ridge Sandstone, and the Almond. The Mesaverde is overlain by the Lewis Shale. Descriptions of the depositional environments include details on the marine fossils, sedimentary structures, grain size analyses, and facies. The Almond Member was deposited as a barrier bar during a early transgressive phase of the Lewis Sea. The Almond becomes progressively thicker (600 ft) in the western portions of the basins. Several transgressive-regressive cycles are represented by the Almond, and a long period of stable strandlines allowed for diverse transitional environments.

Dickinson, R. G., 1992, Table Rock Field-Frontier Formation, an overpressured reservoir: Wyoming Geol. Assoc. 43rd Field Conf. Guidebook, p. 139-144.

Data from a test well in the Table Rock unit of the Frontier Formation drilled in 1991 is presented and analyzed. Initial gas production was 4,300 MCFD from highly overpressured layers. The bottom hole pressure at 14,400 ft is 11,100 psi. Wells in the Table Rock Field into Nugget, Weber and Madison units have greater porosity and permeability than those drilled into the Frontier. The effective permeability and the hydrostatic pressure are major factors in continuing gas production from the Frontier Formation in the Table Rock Field

Douglas, W. B., Jr., and T. R. Blazzard, 1961, Facies relationships of the Blair, Rock Springs, and Ericson formations of the Rock Springs Uplift and Washakie Basin: Wyoming Geol. Assoc., 16th Annual Field Conf. Guidebook, p. 81-86.

This paper suggests revisions for nomenclature in the Rock Springs Uplift: rocks formerly correlated with the Rock Springs Formation are shown to be laterally equivalent with the Ericson Formation. From bottom to top the formations of the Mesaverde Group are Blair, Rock Springs, Ericson and Almond.

Finley, R. J., 1983, Comparison of depositional systems and reservoir characteristics of selected blanket-geometry tight gas sandstones (abst.): AAPG Bull., v. 67, p. 460-61.

The upper Almond Formation of the eastern Greater Green River Basin may contain more shallow marine and offshore bars than barrier strand-plain facies. The upper Almond occurs at depths of 6,000-15,000 ft, with a net pay of 14-18 ft.

Flores, R. M., 1978, Barrier and back-barrier environments of deposition of the Upper Cretaceous Almond Formation, Rock Springs Uplift, Wyoming: The Mountain Geologist, v. 25, p. 57-65.

Depositional environments identified in the upper Almond of Rock Springs Uplift include shoreface, barrier island, tidal inlet, tidal delta, washover fan, tidal flat, lagoon, tidal creek, overbank, pond, and marsh. Tidal delta, tidal-inlet-channel, washover fan, and tidal-creek deposits significantly affected back-barrier accretion and lagoon filling. The complete filling of the lagoon led to coalescing of marsh on the back side of the barrier island with the marsh on the landward side of the lagoon. Thin, discontinuous coal beds that rapidly grade into carbonaceous shale formed in the marsh in close proximity to the barrier island. Thin to thick, laterally extensive coal beds that locally grade into carbonaceous shale formed in the marsh on emergent levee, overbank, and bayfill deposits at the landward side of the lagoon. Deposition of the above detrital deposits, as well as tidal-creek channel sandstones, caused splitting and merging of the coal beds.

Garcia-Gonzalez, M. and R. C. Surdam, 1992, Coal as a source rock of petroleum: a comparison between the petrology of the Mesaverde Group coals, in burial and hydrous pyrolysis: Wyoming Geol. Assoc. Guidebook, 43rd Field Conf., p. 237-244.

The composition and textural changes in coal were studied at different stages of maturation from samples taken from the Almond Formation coals in the Greater Green River Basin of Wyoming. Samples were taken from the surface to a depth of 11,000 ft. Samples of Lance Formation coal were studied at different temperatures under hydrous pyrolysis. Composition and textural changes brought about by burial show a pattern. First there is a loss of the original laminated texture, followed by formation of a porous texture which evolves to a vesicular texture. At greater burial depth and pressure quantities of exsudatinite (a precursor to petroleum) is formed. Micrinite forms from liptinite while at the same time desmocollinite becomes homogenized, and the semifusinite and fusinite content increases with temperature increase related to burial depth. Charts and tables explain and compare the coal maceration stages, and compare samples from different outcrops and core depths.

Gosar, A. J., and J. C. Hopkins, 1969, Structure and stratigraphy of the southwest portion of the Rock Springs Uplift, Sweetwater County, Wyoming: in Lindsay, J.B., ed., Geologic Guidebook of the Uinta Mountains, Utah's Maverick Range, 16th Ann. Field Conf., Intermountain Association of Geologists, p. 87-90.

A short summary of the stratigraphy of the area with structural interpretations is presented.

Greer, P., J. K. King, and A. J. VerPloeg, 1987, Preliminary map of known surficial structural

features for the Rock Springs 1 x 2 Quadrangle: Wyoming Geol. Surv., Open File Report 87-1N.

Includes a listing of all the reference maps used to compile the Rock Springs Quadrangle map.

Hawkins, C. M., 1980, Barrier bar sands in the Second Frontier Formation, Green River Basin, Wyoming: *Stratigraphy of Wyoming: 31st Ann. Wyoming Geol. Assoc. Field Conf. Guidebook*, p. 155-161.

Results are based on logs and core cuttings from the gas production area on the crest and flanks of the Moxa Arch at 7,000 to 12,000 ft. Presents interpretation of a classical upward coarsening, marine, shoreface, foreshore, dune, lagoonal package. This was a subsurface study of a gas productive barrier.

Heasler, H. P. and R. C. Surdam, 1992, Pressure compartments in the Mesaverde Formation of the Green River and Washakie Basins, as determined from drill stem test data: *Wyoming Geol. Assoc. 43rd Field Conf.*, p. 207-220.

Drill stem tests were used to study the pressure in the Mesaverde Formation of the Green River and Washakie basins. Initial and final shut in pressures were graphed to analyze the relationships and evaluate pressure zones. Anomalous pressure zones were mapped on potentiometric surface maps. These anomalous pressure zones in both the Green River and Washakie basins are on the scale of individual oil fields.

Hendricks, M. L., 1983, *Stratigraphy and tectonic history of the Mesaverde Group (Upper Cretaceous), east flank of the Rock Springs Uplift, Sweetwater County, Wyoming*: unpublished Ph.D. thesis, Colorado School of Mines, Golden, Colorado, 213 p.

The Mesaverde Group in southwestern Wyoming includes 4000 ft of sediments of the Blair, Rock Springs, and Ericson Formations. The Upper Blair is a prodelta sequence of shales and thin sandstones. The Rock Springs Formation is a cyclic deposit of marine and non-marine sandstones, shales and coals. The Lower Ericson is a thick unit of fluvial sandstones interbedded with thin carbonaceous shales.

The Rock Springs Formation was deposited as a wave-dominated delta. Two faults in the Rock Springs Formation indicate penecontemporaneous movement during deposition. Coal layers in the Rock Springs Formation are associated with prograding delta lobes. Illustrated with numerous photos of textural features, and maps showing structural and stratigraphic developments.

Irwin, D., 1976, Arch and Monell Units, Patrick Draw-Table Rock area, Sweetwater County, Wyoming-upper Almond Sandstone study: *in* Unpublished Union Pacific Resources Co. Data Files.

This report separates the Almond Formation at Patrick Draw in four sandstone units. They are in descending order UA-5, UA-6, UA-7, UA-8. These sandstone units are

separate by marine shales. Units UA-5, UA-6, and UA-7 are subdivided into A and B, and unit UA-6 sometimes has a C. These units are recognizable on log and in core analysis. The sandstones were deposited as shallow water and barrier beach sands along the edge of the Cretaceous sea. Units UA-5 and UA-6 are less than 40 ft. thick and have been deformed somewhat.

Unit UA-5 is the primary producing zone Patrick Draw Field for both the Arch and Monell areas. UA-5B is an excellent reservoir and is 35 ft. thick in the center of Patrick Draw Field. A Y-shaped tidal channel dissects the UA-5 sandstone. The sand isolith map indicates that Table Rock was present as a paleostructure influencing patterns at the time of deposition. A coal unit underlies unit UA-5, and marine shales overlie it.

Irwin, D. C., 1986, Upper Cretaceous and Tertiary cross sections, Moffat County, Colorado: *Rocky Mountain Assoc. Geol. Symposium*, p. 151-155.

Three cross sections across the Sand Wash Basin in the southern part of the Greater Green River Basin are presented. The Sand Wash Basin is bounded on the south by the Uinta Mountains, in the north by the Cherokee Arch (along the Colorado-Wyoming state border), on the east by the Park Range and on the west by the Hiwatha Sugar Loaf Anticline. Over 30,000 ft of sedimentary deposits from Cambrian to Tertiary age fill the basin. The cross sections were chosen to display Upper Cretaceous facies relationships and show the correlations of Tertiary formations. The source for the Mesaverde Group rocks in the basin is suggested as southerly to southwesterly based on core data.

Iverson, W. P., 1992, Oil and gas production and reserves, Mesaverde Group, Green River Basin, Wyoming: *Wyoming Geol. Assoc. 43rd Field Conf. Guidebook*, p. 245-252.

A summary and analysis of hydrocarbon production from the Mesaverde Group in the Greater Green River Basin. Over 11% of the gas produced in Wyoming comes from the Greater Green River Basin which contains only 5% of the state's wells. Production decline curves are calculated based on current production and a 575 Bcf gas reserve is estimated. Fracturing has aided production from tight gas sands by connecting the numerous sands.

Jacka, A. D., 1965, Depositional dynamics of the Almond Formation, Rock Springs Uplift, Wyoming: *Wyoming Geol. Assoc., 19th Field Conference Guidebook*, p. 81-100.

Upper Almond cycles display the following sequence of deposits from the base upward: (1) marine and/or lagoonal shale, (2) barrier-island sandstone, (3) marsh or mudflat deposits, and 4) lagoonal-bay deposits. These sequences reflect the lateral shifting of three contemporaneously existing depositional entities: (1) marine environment in which surfzone and infra-surfzone sands, and offshore muds

accumulated; (2) the barrier-island environment consisting of foreshore beach, backshore beach, and fringing marsh or mudflat deposits; (3) the lagoonal-bay environment in which predominantly fine-grained sediment, carbonaceous shale, and oyster reefs accumulated.

Evidence indicates that seaward growth of barrier islands was accompanied by expansion of lagoons that resulted in a progressive flooding of the landward margins of the barrier. Thus, positions previously occupied by a barrier island were successively blanketed with lagoonal deposits. As the distance between a seaward-advancing barrier island and the mainland increased, a threshold limit was approached beyond which the volume of sand supplied to the seaward face was insufficient to permit further seaward growth. The operation of negative processes (subsidence, compaction, erosion, and possibly an independent rise in sea level) soon brought about the submergence or drowning of an abandoned barrier island.

Jacka, A. D., 1970, Principles of cementation and porosity-occlusion in Upper Cretaceous sandstones, Rocky Mountain Region: Wyoming Geol. Assoc., 22nd Ann. Field Conf. Guidebook, p. 265-285.

Upper Cretaceous sediments from the Rockies were chosen because they constitute good models for humid-subhumid climates, swampy coastal plain, barrier island-lagoon-bay, and deltaic facies with established structural and geological histories; and, outcrops and subsurface data which may be compared.

Vadose cementation is restricted to hot arid and semi-arid regions where carbonate (caliche) is concentrated, and hot regions with wet-seasons. Rapid, evaporation-triggered precipitation of carbonates, hydroxides, and oxides results in initial precipitation of finely crystalline grain coating cement films, which separate grains, causing an expanded or floating fabric, and which later replace terrigenous grains to form concretions.

Cementation below the water table in fresh or sea water occurs slowly resulting in coarsely crystalline cement that tends to fill pore bodies. Soon afterward, burial silica is precipitated as syntaxial overgrowths on quartz grains at shallow to moderate depths under conditions of low temperature, and slightly acidic pH. At greater depths, silica cementation is followed by calcite precipitation and replacement of quartz under higher temperature and pH. Silica, mobilized at depth by replacement and solution of quartz, diffuses upward and carbonate diffuses downward where it precipitates on prior calcite "seeds".

Transportation of cementing material by opposing diffusion gradients occurs slowly through nearly static interstitial waters which overcome inadequacies inherent in supposition of transport by abnormally large volumes of water (as required by water from compacting clays).

Jacka, A. D., 1970, Sediment economics of Upper Cretaceous sandstones Rocky Mountain Region: Wyoming Geol. Assoc., 22nd Ann. Field Conf. Guidebook, p. 187-219.

The Upper Cretaceous in the Rocky Mountains commonly display the following sequence: (1) marine and/or lagoonal shale; (2) barrier island sandstone; (3) marsh-mudflat deposits; (4) lagoonal-bay deposits; (5) alluvial-coastal plain sediments. The sequence displays seaward progradation of coastal plain in response to a large sediment supply. The Gulf Coast Barrier Island/Coastal plain is proposed as an analogue for Upper Cretaceous (especially Almond Formation) in the Rocky Mountains.

The paper is based primarily on investigation of environments, paleogeography and depositional history of the Upper Cretaceous Almond Formation of the Rock Springs Uplift.

Jackson, S., et al., 1993, Integration of the Geological/Engineering Model with Production Performance for Patrick Draw Field, Wyoming: DOE Report NIPER-634, 122 p.

A integrated geological/engineering model for production performance is based on barrier island reservoirs from Patrick Draw Field, Wyoming and Bell Creek Field, Montana. The objectives were: (1) to identify heterogeneities that influence the movement and trapping of fluids within the reservoirs; (2) to characterize methods to quantify reservoir architecture and to predict mobile oil saturation distribution for application to Enhanced Oil Recovery processes; and (3) to summarize reservoir and production characteristics of shoreline barrier systems.

Hydrogeochemical analytical techniques were found to be an inexpensive reservoir characterization tool. Formation water salinity in Patrick Draw Field varies across the field and can cause errors in the estimation of oil saturation. CO₂ flooding was more successful in the Monell Unit at Patrick Draw Field than in the Arch Unit. Horizontal drilling has the best potential for additional oil recovery in the Arch Unit.

Keighin, C. W., B. E. Law, and R. M. Pollastro, 1989, Petrology and reservoir characteristics of the Almond Formation, Greater Green River Basin, Wyoming: in Coalson, E.B., et al., eds, Petrogenesis and Petrophysics of Selected Sandstone Reservoirs of the Rocky Mountain Region, RMAG, Denver, p. 281-298.

Production through 1986 was 100 MM bbl oil and seven TCF gas. SEM and thin section analyses indicated that pores in fine to very fine Almond Formation sandstones are small (< 20 μ) and formed in part by dissolution of framework grains and authigenic cements. Intergranular micropores occur between crystals of authigenic clay. Sandstone contains 15 to 30% clay, which is dominantly illitic. Local concentrations of kaolinite occur, but chlorite is rare. Smectite clay minerals were not detected.

Distribution of cements, as well as detrital feldspars, is variable.

Not only porosity, permeability, and depth, but also vitrinite reflectance seem to be related in both conventional and unconventional (tight) Almond reservoirs. It may be possible to define an approximate depth at which overpressuring may occur based on these data.

Krueger, M. L., 1960, Occurrence of natural gas in the western part of Green River Basin: Wyoming Geol. Assoc. 15th Annual Field Conference Guidebook, Overthrust Belt of Southwestern Wyoming and Adjacent Areas, p. 195-209.

The Green River Basin is one of the largest of the Rocky Mountain intermountain basins. Its maximum north-south dimension is approximately 180 miles; its maximum east-west dimension, near its southern end, is 90 miles. The basin is bounded on the northeast by the Gros Ventre-Wind River Mountain Range, on the east by the Rock Springs Uplift, on the south by the east-west trending Uinta Mountains, and on the west by the east thrust fault (Disturbed Belt) of the Hoback-Wyoming Range.

Krystinik, L. F., 1990, Characteristics of cores from a wave-dominated barrier/tidal inlet deposit: Cretaceous Almond Formation, south-central Wyoming (abst.): in Davis, R.A., D. Nummendal, and R. Tillman, eds., Tidal Inlet and Related Sand Bodies Modern and Ancient: SEPM Research Conference San Juan Basin, New Mexico, pages unnumbered.

East of Table Rock Field in Sweetwater County, the UA-8 sandstone is a north-south trending barrier/lagoon complex which has been cored at several localities in barrier and back-barrier facies. In the Union Pacific Railroad Corporation Robinson Siding No. 1 well (11-19N-97W), a 59-ft continuous core was cut through a sandstone body interpreted to be a tidal inlet deposit. The tidal inlet is laterally equivalent to wave-dominated shoreface deposits along strike and to back-barrier lagoonal deposits to the west.

The tidal inlet deposit is a 45 ft thick, blocky- upper-fine to lower-medium-grained sandstone body. The inlet has a sharp basal scour on older lagoonal deposits, and the inlet fill is composed of a basal oyster-shell lag which grades upward into clean, massive to medium-scale trough cross-stratified sandstone. A number of oyster-shell lags occur within the cross-stratified inlet fill, and these slightly inclined horizons may mark lateral accretion surfaces, as observed in field exposures of Almond formation inlets. The cross-stratified sandstone becomes more massive to planar-laminated toward the top 3 ft of the sandstone body and may record foreshore deposition as spit accretion filled the inlet. The upper 6 ft of the core is composed of *Ophiomorpha*-burrowed sandstone which grades upward

into a transgressive unit composed successively upward of burrowed argillaceous sandstone, gritty mudstone and black silty mudstone.

Land, C. B. Jr., 1972, Stratigraphy of Fox Hills Sandstone and associated formations, Rock Springs Uplift and Wamsutter Arch area, Sweetwater County, Wyoming: A shoreline-estuary sandstone Model for the Late Cretaceous: Quarterly of the Colorado School of Mines, v. 67, no. 2, 69 p.

The Upper Cretaceous Fox Hills Sandstone which outcrops on the east flank of the Rock Springs Uplift is a regressive sequence of sandstone and siltstone which was deposited along a barrier island coastline in littoral, shallow neritic, and estuarine environments. It overlies and intertongues with marine Lewis Shale; and it is overlain by, and intertongues with, the nonmarine Lance Formation. Depositional environments: An earlier report by Weimer interpreted the Fox Hills as a barrier island sequence similar to the modern barriers along the Gulf Coast. Weimer interpreted the shoreline to have been generally north-south oriented with lagoons and coastal swamps to the west and a deeper neritic environment to the east. Land is generally in agreement, but points out some minor differences of interpretation:

1. Sands deposited in migrating estuaries was important in Fox Hills. The scour at base of Weimer's upper "G" sandstone is the base of migrating estuary channel.
2. Lenses of *Ostrea* are reinterpreted as lag deposits in estuary channels.
3. Subsequent subsurface control indicates that shoreline trend is northeast-southwest.
4. Weimer (1961) compared Fox Hills environments to the Gulf Coast Barriers- where the barriers are separated by broad lagoons that are filling with clay and silt deposits.

Land finds better analogy with the modern Georgia coast (brought to his attention by Weimer). The Georgia coast has about 7-ft tides, and the barrier chain is separated from the mainland by a saltmarsh-estuary channel complex. The high-energy environments of sand deposition in these estuaries is believed to be similar to the postulated Fox Hills environments.

Lanham, R. E., 1980, Petrography and diagenesis of low-permeability sandstones of the lower Almond Formation, Southwestern Wyoming: M.S. Thesis, Univ. of Colorado, 113 p.

Petrographic study of the lower Almond sandstones in the Tierney Gas Field, in the Wamsutter Arch area of southwestern Wyoming; the sandstones are fine-grained sublitharenites containing chert fragments and little or no feldspar. Sandstones average 9% porosity and have very low permeabilities, averaging 0.10 mD. Compaction and quartz cementation have reduced both k and ϕ ; dissolution

of unstable minerals has created varying amounts of secondary porosity.

Quartz cement averages 15% of rock volume and has inhibited compaction, but also occluded porosity and reduced permeability. In many instances, cementation by quartz was hindered by detrital and authigenic clays. Where clay is common, quartz cement is less abundant and intergranular microporosity is widespread.

Based on thin section analyses, up to one-half of existing porosity of some sandstones is secondary, having been formed by dissolution of detrital and authigenic minerals. Much of the porosity was created by dissolution of siderite and possibly dolomite-ankerite. Some of the resulting pores were subsequently filled by authigenic quartz and kaolinite. (A complete solid solution between dolomite and ankerite appears to exist). Dissolution of chert grains also appears to have created a significant amount of secondary porosity. Chert dissolution first produces a microporous mass but with continued leaching results in grain-size voids. Leaching of biotite, and possibly feldspar, created minor amounts of secondary porosity. Formation of secondary porosity was hindered by the presence of matrix, which inhibited access of leaching fluids to potentially soluble minerals. Good photomicrographs and SEM images illustrate the text.

Law, B. E., 1984, Relationships of source-rock, thermal maturity, and overpressuring to gas generation and occurrence in low-permeability Upper Cretaceous rocks, Greater Green River Basin, Wyoming, Colorado and Utah: in J. Woodward, F. Meissner, and J. Clayton, eds, Rocky Mt. Assoc. Guidebook, Hydrocarbon Source Rocks of the Greater Rocky Mountain Region, p. 469-476.

Most of the hydrocarbon production from Upper Cretaceous and Lower Tertiary reservoirs in the Greater Green River Basin is gas. The basin covers areas of southern Wyoming, northwestern Colorado and northeastern Utah. Gas deposits are found interbedded with coal and carbonaceous rocks. Gas accumulations are associated with overpressuring. Overpressuring is caused by thermal generation of gas. Gas migrates limited distances of less than several hundred feet. Large volumes of gas in the Greater Green River Basin occur at temperatures of 190° to 200° F with a vitrinite reflectance of about 0.8.

Law, B. E., 1992, Paleofluid flow paths - Evidence from thermal maturity mapping, Greater Green River Basin, Wyoming and Utah (abst.): AAPG Ann. Convention Program, Calgary, Alberta, page unnumbered.

Thermal maturity mapping is used to reveal unusually high and low areas resulting from thermal perturbations associated with ascending and descending fluids. An area of high thermal maturity is coincident with Patrick Draw Field, Wyoming, and an area of low thermal maturity is

coincident with the Bridger Lake and Lucky Ditch oil fields near the Moxa Arch. Vitrinite reflectance values for the Almond Formation at a depth of 5,000 ft range from 0.48 to 0.68. Faults are the suggested pathways for the hot fluids. In contrast, the southern end of the Moxa Arch has a low thermal maturity and a low thermal gradient.

Law, B. E., C. W. Spencer, and N. H. Bostick, 1980, Evaluation of organic matter, subsurface temperature and pressure with regard to gas generation in low-permeability Upper Cretaceous and Lower Tertiary sandstones in Pacific Creek area, Sublette and Sweetwater counties, Wyoming: *The Mountain Geologist*, v. 17, p. 23-35.

The area for this report is 35 miles directly north of the Rock Springs Uplift. The onset of overpressuring occurs about 11,600 ft, at the base of the Upper Cretaceous Lance Formation. Generation of wet gas is apparently one of the main processes related to overpressuring. Reversal of SP curves near the top of overpressuring is related to reduction of formation water salinity. Small amounts of water produced during thermochemical decomposition or organic matter and the dehydration of clays during clay transformation may provide enough low-salinity water to effectively dilute the original formation water.

Total organic content (TOC) averages 1.38% (range 0.25 to 7.84). The top of overpressuring and beginning of important wet-gas generation occurs at vitrinite reflectance values of 0.74 to 0.86.

Lawson, D. C., and C. W. Crowson, 1961, Geology of the Arch Unit and adjacent areas, Sweetwater County, Wyoming: WGA Guidebook, 16th Ann. Field Conf., p 280-299.

The Arch Unit at Patrick Draw field is 10 miles long and 4.5 miles wide. The first oil well was drilled in early 1959. A history of the production and initial geology is presented. Patrick Draw Field is located on the crest of the Wamsutter Arch on the east flank of the Rock Springs uplift. Stratigraphic units are the early Tertiary Wasatch Formation, and Upper Cretaceous Lance, Fox Hills, Lewis Shale, and Almond formations. Oil production is from sand bodies in the Almond.

Leckie, D., and L. F. Krystinik, 1989, Is there evidence for geostrophic currents preserved in the sedimentary record of inner to middle-shelf deposits?: *J. Sed. Petrol.*, v. 59, p. 862-870.

Wave-ripple crests in the Almond trend generally N-S, parallel to regional shoreline, while other shoreline indicators and hummocky cross stratiation (HCS) beds trend E-W, normal to shoreline orientation.

Lewis, J. L., 1961, The stratigraphy and depositional history of the Almond Formation in the Great Divide

Basin, Sweetwater County, Wyoming: Wyoming Geological Assoc., Symposium of Late Cretaceous rocks Green River, Washakie, Wind River and Powder River Basins; p. 87-95.

The Almond Formation crops out on the east flank of the Rock Springs uplift, the structural divide between the Great Divide Basin to the east and the Lesser Green River Basin to the west. The Almond outcrops are characterized by cuestas with low west facing escarpments. The Almond outcrop is bordered on the west by the steep escarpment of the Ericson Sandstone and on the east by a long strike valley into the Lewis Shale. Three major environments of deposition are recognized; (1) coastal swamp in the lower shale, (2) beaches or sandbars and sandspits created by waves and currents, (3) shallow marine to non-marine deposits from lagoons and coastal swamps.

McCubbin, D. G., and M. J. Brady, 1969, Depositional environment of the Almond reservoirs, Patrick Draw Field, Wyoming: The Mountain Geologist, v. 6, no. 1, p. 3-26.

This study supports Weimer (1966) that the main reservoir sandstone is a composite shoreline deposit, at least partly replaced updip by lagoonal shales.

UA-5 at Patrick Draw consists of a western bar and a younger eastern bar that partly overlaps the western bar. The western bar and, in places, the eastern bar rest with sharp contact on a widespread coal that forms the uppermost unit of the underlying cyclic sequence. Both sandstone bodies contain transported bivalves and some forams and show burrows including rare *Ophiomorpha*. Both sand bodies show a vertical sequence of stratification types interpreted as deposition in nearshore-marine and beach environments on a seaward-prograding shoreline. Lateral changes in stratification types suggest that the seaward direction was to the east. Vertical and lateral variations in grain size of this record an initial transgression, followed by deposition in progressively more shallow environments during shoreline progradation.

The lagoonal facies that overlies the western bar and appears to be at least partly equivalent to the eastern bar consist of silty to sandy shales and some thin sandstones. Oysters are common and are a major constituent of coquina beds. The occurrence of large, whole, randomly oriented oyster valves in a shale matrix indicates that these oysters are in their original place of growth. Some of the shales contain a microfauna of arenaceous forams. Structures formed by burrowing animals are abundant in the silty or sandy shales.

McDonald, R. E., 1973, Big Piney-La Barge Producing Complex, Sublette and Lincoln Counties, Wyoming: Wyoming Geol. Assoc., 25th Field Conf., p. 57-77.

A gas producer since 1956, and major oil producer since 1960. Cumulative gas production is over 1.2 tcf, total oil produced is about 65 MMBBL. The producing complex is on and around the flanks of a Laramide anticlinal fold that was formed subjacent to a salient along the Disturbed Belt, west of Wind River Mountains, in the northern part of the Green River Basin.

Meyers, W. C., 1977, Environmental analysis of Almond Formation (Upper Cretaceous) from the Rock Springs Uplift, Wyoming: Ph.D. Dissertation, University of Tulsa, 280 p.

Micropaleontology and photos of two 5-in diameter cores drilled 1/2 mile down dip from the outcrop face exposed in the Rock Springs Uplift (T20N, R101W) were studied. There were 150 palynological species were recorded.

Mieras, B. L., 1992, Sequence stratigraphy, Frontier Formation, south-central Wyoming: eustatic and tectonic influences: Wyoming Geol. Assoc. 43rd Field Conf. Guidebook, p. 51-60.

An erosional unconformity 90 million years old forms the boundary between the Greenhorn Cycle and the Niobrara Cycle in the Western Interior Basin. The boundary is marked by sandstone poor deposits of the underlying Bell Fourche Member. The Wall Creek Member is the sand-rich upper member of the Frontier Formation. The Emigrant Gap Member lies between the Wall Creek and Belle Fourche in a discontinuous pattern. The Frontier Formation overall is a coarsening upward succession. The sequence boundary of the Greenhorn and Niobrara Cycles falls in the Upper Wall Creek Member. The transgressive phase of the Niobrara Cycle suggests local tectonic control of the late Frontier deposition.

Unconformities as observed in sequences and marine deposits vary from place to place within the geographic and stratigraphic locations of the Frontier Formation. This paper reconstructs the chronostratigraphic sequences of the Frontier Formation using textural features, lithology and maps for the correlations.

Miller, F. X., 1977, Biostratigraphic correlation of the Mesaverde Group in Southwestern Wyoming and Northwestern Colorado: Rocky Mountain Assoc. Geol., Symposium, p. 117-137.

The Mesaverde Group consists of Upper Cretaceous marine strata in eastern Wyoming and Colorado and non-marine strata in north-central Utah. Biostratigraphic units are based on paleontologic data on the marine faunas. Faunal samples are from cores and outcrop. Formation names within the Mesaverde Group are difficult to correlate and differ from basin to basin. The purpose of this paper was to place all the regional formations in proper chronostratigraphic order. Numerous maps and correlation charts are used to illustrate the stratigraphy.

Myers, R. C., 1977, Stratigraphy of the Frontier Formation (Upper Cretaceous), Kemmerer Area, Lincoln County, Wyoming: Wyoming Geol. Assoc. Guidebook, 25th Annual Field Conference, p. 271-292.

The Frontier Formation of Turonian age on the west side of the Green River Basin, Wyoming, is a nearshore sequence of marine and nonmarine bentonites, shales, siltstones, sandstones, conglomerates, and coals. These strata represent two cycles of clastic shoreline progradation along the western fringe of the Cretaceous Seaway in the western interior of the United States.

Newman, H. E., 1981, Greater Green River Basin stratigraphy as it relates to natural gas potential: SPE/DOE 9845, Presented at SPE/DOE Low Perm. Symposium, Denver, Colorado, pages unnumbered.

The 21,000 square miles of the Greater Green River Basin encompasses the Green River Basin proper, the Rock Springs Uplift, the Red Desert and the Washakie and Sand Wash Basins. Drilling for hydrocarbons reaches depths of 20,000 ft. Natural gas is found in tight sands from the Mesaverde Group, Lewis, Lance, Fort Union, and Wasatch formations.

Five lithofacies maps of the basin are presented, and a geological analysis of potential gas reservoirs is given. The Almond was deposited in transitional coastal plain and nearshore environments during a transgression; however, the barrier island sediments were deposited during stillstands or local regressions of the Lewis Sea. The Almond barrier may have advanced seaward as much as 20 miles (Jacka, 1965).

Pryor, W. A., 1961, Petrography of Mesaverde sandstones in Wyoming: Wyoming Geol. Assoc., 16th Ann. Field Conf. Guidebook, p. 34-46.

This study was based on a systematic sampling of outcrops from uppermost, middle, and lower sandstone bodies in the Mesaverde section from a number of formations including the Almond. Textural classification of the Almond as a lithic graywacke (immature chert arenite) with 25% chert: Q58F12R30. Heavy minerals comprise less than 0.8% by weight of Mesaverde sandstone samples. Much of the report dwells on species and interpretation of heavy minerals

Richers, D. M., 1990, Patrick Draw Oil Field: Unpublished review copy. Submitted to AAPG.

Discovered in 1959, the estimated reserves are 200 to 250 MMBBL oil. Patrick Draw is just one of many Cretaceous oil fields in Wyoming that produce from elongate sand bodies that were distributed along the margin of the Upper Cretaceous Sea. The field is divided into three producing units: (north to south) Patrick Draw North, Arch, Monell. Production is from Almond, although localized pay or shows in Lewis, Fox Hills, and Lance

formations (Cretaceous), as well as from the Paleocene Fort Union and Eocene Wasatch formations. Patrick Draw like, most fields in the area, is a stratigraphic trap. The Almond is felt to represent near-shore barrier bar and beach front sands. As a result, reservoirs tend to be several miles long and less than 4 miles wide.

The field is located on the eastern flank of the Laramide Rock Springs Uplift, and on the southern limb of the Wamsutter Arch. Present axis of the arch is about 10 miles north of the original axis formed at the end of the Cretaceous. Vitrinite reflectance data and thermal modeling indicate that Patrick Draw is currently in the oil window; the Lewis Shale several miles east of Patrick Draw could have entered the oil window 18-20 million years ago.

The Almond represents near-shore barrier bar and/or ancient shorelines, with some shallow tidal-flat facies. Generally, the producing sandstone bodies are less than 2 miles wide and some are up to 20 miles in length. Lateral facies changes are abrupt, resulting in extreme porosity differences over a very small distance. Updip seal for stratigraphic traps is provided by facies change into less permeable coastal plain shales and siltstones. Overlying seal is provided by the Lewis Shale. UA-6 is productive only in the northern portion of the field, about 10-ft below the UA-5. UA-5 and UA-6 are generally separated by a dark gray shale and silty shale.

Tidal flats are represented as fine-grained, laminated and rippled mudstones and sandstones. Burrows are common. Evidence for small tidal creeks includes deformed and slumped features.

Marsh environments are evidenced by dark, organic-rich very fine grained sand and mudstone. Some coal is also present.

Oil samples had API gravity of 44.4 and a density of 0.7977 g/cc at 25° C; and a GOR between 600:1 to 1554:1 for Almond production. Whole oil chromatogram shows preponderance of lighter n-paraffin components generally indicative of maturity because mature oils are generally enriched in the lighter components. Pristane to phytane ratios greater than 3.0 in high wax crude oils and condensates characterize input from terrigenous materials common to lacustrine, fluvial, and deltaic environments. This assessment fits Patrick Draw. A terrigenous source for Patrick Draw oils is strongly suggested.

Surface geochemical studies support: (1) fractures and faults are the preferred migration pathway of hydrocarbons leaking from the subsurface reservoir to the surface, (2) high surface hydrocarbon anomalies are repeatable over a period of years, (3) geobotanical anomalies exist over the gas cap in western up-dip portions of the field. A stressed sage community is located over the field.

Richers, D. M., V. T. Jones, M. D. Matthews, J. Maciolek, R. J. Pirkle, and W. C. Sidle, 1986, The 1983 Landsat soil-gas geochemical survey of

Patrick Draw area, Sweetwater County, Wyoming: AAPG Bull., v. 70, p. 869-887.

Resampling the Geosat test site at Patrick Draw indicated that the 1980 assessment was correct: that faults and fractures visible as linear features on satellite and aircraft imagery provide paths for active microseepage of hydrocarbons from depth to the near surface. This association is particularly true near the earlier described blighted sage zones, where a much wider area of anomalously high free soil-gas values and fluorescence was revealed.

Richers, D. M., R. J. Reed, K. C. Horstman, G. D. Michels, R. N. Baker, L. Lundell, and R. W. Marrs, 1982, Landsat and soil-gas geochemical study of Patrick Draw oil field, Sweetwater County, Wyoming: AAPG Bulletin, v. 66, p. 903-922.

Anomalous hydrocarbon concentrations in soil-gas samples appear in those areas near lineaments mapped from Landsat images of the Patrick Draw Field. These lineaments represent extensional faults and fractures produced during development of the Rock Springs Uplift to the west. Several of the lineaments extend to depth and are able to serve as conduits allowing preferential microseepage of hydrocarbons to the surface in the Patrick Draw area, indicating the nature of expected hydrocarbons at depth.

Ritzma, H. R., 1955, Late Cretaceous and Early Cenozoic structural pattern, southern Rock Springs Uplift, Wyoming: Wyoming Geol. Assoc. 10th Annual Field Conference Guidebook, Green River Basin, p. 135-137.

The structure of the Rock Springs Uplift exposes a succession of Late Cretaceous and Early Cenozoic formations east of Rock Springs, Wyoming. The uppermost strata are outcrops of the Green River (Eocene) and Fort Union (Paleocene) formations. The lowermost strata exposed are the Baxter Shale, Blair, and Mancos Shale formations, all Upper Cretaceous. The beds dip to the east onto the Wamsutter Arch into the Red Desert and Washakie Basins exposing the Mesaverde Group, Lewis Shale, and Lance Formation. The numerous unconformities and overlaps give an indication of the great changes brought about by structural movement.

Roehler, H. W., 1965, Summary of Pre-Laramide Late Cretaceous sedimentation in the Rock Springs Uplift area: Wyoming Geol. Assoc. 19th Field Conference Guidebook, Sedimentation of Late Cretaceous and Tertiary Outcrops, Rock Springs Uplift, p. 11-12.

Short descriptions of the late Cretaceous formations in the Rock Springs Uplift accompany a map showing depositional relationships. The section is restored to late Cretaceous view and the extent of Tertiary erosion is

shown cutting through the Lance, Fox Hill, and Lewis Shale formations to expose underlying units.

Roehler, H. W., 1977, Lagoonal origin of coals in the Almond Formation in the Rock Springs Uplift, Wyoming: 1977 Symposium on the Geology of Rocky Mountain Coal, Colorado Geol. Surv. Resources Series 1, p. 85-89.

Three units are recognized:

Upper 300 ft-coastal lagoon, mixed barrier bar, lagoon, shallow marine; saltwater deposition is indicated by shark teeth, and cephalopods.

Middle 350 ft-brackish water lagoonal environment. Brackish water deposition indicated by oysters and other mollusks.

Lower 200 ft-freshwater coastal swamps. Freshwater environment are indicated by dinosaur, crocodile, turtle, and fish fossils.

Depositional Model: marine coastline with lagoons formed behind barrier island during westward transgressions of late Cretaceous sea. Evidence for lagoonal origin of coals is: intertonguing and juxtaposition of the coal beds and barrier islands and by presence of fossil oyster beds containing coal-bearing sequences. Eighteen coal beds that range from 25 to 16 ft thick have been mapped in the Almond Formation.

Roehler, H. W., 1977, Geologic map of the Cooper Ridge NE Quadrangle, Sweetwater County, Wyoming: U. S. Geol. Surv., Map GQ-1363.

Roehler, H. W., 1978, Geologic map of the Mud Springs Ranch Quadrangle, Sweetwater County, Wyoming: U. S. Geol. Surv., Map GQ-1438.

Roehler, H. W., 1978, Correlations of coal beds in the Fort Union, Lance and Almond formations in measured sections on the east flank of the Rock Springs uplift, Sweetwater County, Wyoming: U. S. Geol. Surv., Open File Report 78-248.

Fold out stratigraphic column and measured sections of the upper Mesaverde Group formations.

Roehler, H. W., 1978, Correlations of coal beds in the Fort Union, Almond, and Rock Springs Formation in measured sections on the west flank of the Rock Springs uplift, Sweetwater County, Wyoming: U. S. Geol. Surv., Open File Report 78-395.

A fold out stratigraphic column and measured section of the upper Mesaverde Group formations in the Green River Basin.

Roehler, H. W., 1979, Geology and energy resources of the Sand Butte Rim NW Quadrangle, Sweetwater County, Wyoming: U. S. Geol. Surv. Professional Paper 1065-A, A54 p.

The Sand Butte Rim quadrangle is on the east flank of the Rock Springs Uplift in southwestern Wyoming. The underlying 20,000 ft of sedimentary deposits include 28 formations ranging in age from Cambrian to Tertiary. Upper Cretaceous and lower Tertiary rocks outcrop and dip 3 to 6 degrees southeast. Coal resources are estimated at 1 billion short tons in the Fort Union, Lance and Almond formations. Oil was first discovered in Sand Butte Rim quadrangle in 1959 at Patrick Draw Field.

Roehler, H. W., 1979, Geology and mineral resources of the Mud Springs Ranch Quadrangle, Sweetwater County, Wyoming: U. S. Geol. Surv. Professional Paper 1065-C, C35 p.

Mud Springs Ranch quadrangle is located on the southeast flank of the Rock Springs Uplift in southwestern Wyoming. Sedimentary rocks exposed are 5,400 feet thick and are gray sandstone, siltstone, and shale; gray and brown carbonaceous shale and thin beds of coal. The Blair, Rock Springs, Ericson, Almond, and Lewis formations of Cretaceous age and the Paleocene, Fort Union Formation are represented. There are three coal beds in the Fort Union Formation and 15 in the Almond Formation that can potentially be mined. Oil and gas tests have been made, but the structurally controlled stratigraphic trap prospects have not been analyzed.

Roehler, H. W., 1979, Geologic map of the Camel Rock Quadrangle, Sweetwater County, Wyoming: U. S. Geol. Surv., Map GQ-1521.

Roehler, H. W., 1979 Paleogeography and lithofacies of barrier bar G and associated rocks, Almond Formation, southwest Rock Springs Uplift, Wyoming: Rocky Mountain Sec. Soc. Economic Paleo. and Mineralogists, Field Trip, Cretaceous of the Rock Springs Uplift, Wyoming, p. 2-21.

Surface and subsurface investigations of barrier bars in the Almond Formation are discussed.

1. Barrier bars were deposited in interdeltic areas during the westward transgression of the Lewis Sea in the late Cretaceous.
2. Large brackish lagoons formed behind the barriers
3. As many as ten barriers are stacked along the east flank of the Rock Springs Uplift. The vertical sequences are cyclic:
 - a. marine erosion
 - b. lagoon and back barrier carbonaceous shale and coal
 - c. dune, washover and tidal channel sandstone
 - d. upper shoreface sandstones
 - e. middle shoreface sandstone
 - f. lower shoreface sandstone
 - g. marine shale
 - h. marine erosion

4. Lithofacies are identified by primary sedimentary structures.
5. The barriers are prograding.
6. The shape, size, and spacing of tidal channels, flood tidal deltas and ebb-tidal deltas suggest a tidal range of 5 to 6-ft.

Roehler, H. W., 1988, The Pintail Coal Bed and Barrier Bar G - A Model for coal of barrier bar-lagoon origin, Upper Cretaceous Almond Formation, Rock Springs Coal Field, Wyoming: U.S. Geological Survey Professional Paper 1398, 60 p.

The early Maastrichtian upper Almond barrier is 60 miles long and 4 miles wide. There are 18 miles of outcrops on the east flank of Rock Springs Uplift.

The study was based on outcrops around Rock Springs Uplift: 104 measured stratigraphic sections plus 14 others that describe lithofacies and primary sedimentary structures were used. Four widely spaced holes were drilled and logged (no cores were taken).

Barrier bar G: mesotidal (4.5-8 ft range); islands 5 to 7 miles long, roughly drumstick-shaped, washover fans present, but not common; numerous tidal inlets; flood-tidal deltas large (up to several miles wide); ebb-tidal deltas moderately large to small.

Divisions of Almond Formation: Upper 100-400 ft-very fine-grained to medium grained; deposited in shallow marine, barrier bar and lagoonal environments; saltwater fauna-marine mollusks, shark teeth, ammonites, numerous trace fossils. Middle 125-250 ft-brown carbonaceous shale and coal, some thin interbedded gray shale and gray, fine-grained crossbedded sandstone deposited in lagoonal environments; brackish water fauna of abundant oysters and brackish mollusks. Lower 100-600 ft-swampy, coastal plain setting: fresh water fauna of dinosaurs, turtles, crocodile, and fish bones.

The Pintail coal bed was deposited in a lagoon, landward of barrier bar G. As the barrier prograded, the back-barrier flat was progressively covered by swamp deposits that include the seaward wedgeout of the coal bed. The coal bed is massive and locally more than 6 feet thick. Splits and partings of carbonaceous shale are interpreted as tidal inlet and tidal creek deposits. The model demonstrates that the barrier and its lagoon evolved through saltwater to brackish-water to freshwater stages, with the times of maximum peat accumulation occurring in the freshwater stage.

Roehler, H. W., 1990, Stratigraphy of the Mesaverde Group in the Central and Eastern Greater Green River Basin, Wyoming, Colorado and Utah: U. S. Geological Survey Professional Paper 1508, 52 p.

The Mesaverde Group comprises 5,000 ft of deposits in the central and eastern Greater Green River Basin. The lower Mesaverde formations; Rock Springs, Blair,

Haystack Mountains, Allen Ridge and Iles were deposited in a major eastward regression of the Cretaceous Seaway. A regional uplift of the Rocky Mountains followed the deposition. The upper Mesaverde; Almond and William Fork formations were deposited during a westward transgression of the Seaway.

Environments of deposition in the Mesaverde Group include alluvial plain, floodplain, coastal-plain, barrier plain, tidal-flat, delta-plain, marine shoreline, marine shelf and slope deposits.

Lithologies, sedimentary structures, fossils, water depth and salinity, diagenetic processes and sediment sources are analyzed and illustrated.

Roehler, H. W., J. Horne, R. Levey, M. Hendricks, M. Van Horn, C. Land, and B. Weimer, 1979, Field trip Cretaceous of the Rock Springs Uplift, Wyoming: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, Sept. 21-23, 1979, 72 p.

A series of papers on the Cretaceous geology of the region of the Rock Springs Uplift. The three day field trip observed outcrops of the Almond, Blair, Rock Springs, Fox Hills and Ericson formations. Papers discuss the paleogeography, lithology, and stratigraphic relationships of the formations of the Rock Springs Uplift. The papers are well illustrated by maps, cross sections, cores, and paleogeographic reconstructions.

Ryder, R. T., M. W. Lee, W. R. Agena, and R. C. Anderson, 1990, Seismic expression of subtle stratigraphic trap in Upper Cretaceous Almond: Oil and Gas Journal, v. 88, no. 51, p. 54-57.

Patrick Draw Field produces oil and gas from a stratigraphic trap in the Upper Cretaceous Almond Formation. Table Rock Field produces from a faulted anticline structural trap from multiple Tertiary, Mesozoic, and Paleozoic reservoirs. The objective of this study was to determine if the stratigraphic trap in the Almond could be detected on a 12-fold common depth point seismic profile. Seismic data was analyzed across the entire Rock Springs Uplift.

Schatzinger, R. A., M. J. Szpakiewicz, S. R. Jackson, M. M. Chang, B. Sharma, M. K. Tham and A. M. Cheng, 1992, Integrated Geological-Engineering Model of Patrick Draw Field and Examples of Similarities and Differences Among Various Shoreline Barrier Systems: NIPER-575, U. S. Department of Energy, Bartlesville, OK, 146 p.

Shoreline barrier deposits were studied to determine problems specific to this class of reservoirs and to develop methods to characterize shoreline barriers. Prediction of residual oil saturation on interwell scales and improvement of flow patterns of injected fluids was an important goal.

Four main areas studied were: (1) development of a quantitative geological and engineering model for Patrick Draw Field, Wyoming; (2) comparison of the mesotidal barrier island system at Patrick Draw Field to the microtidal barrier island system at Bell Creek Field, Montana; (3) application of geostatistical analysis to determine interwell properties at Patrick Draw Field; (4) continued development of methodologies to characterize shoreline barrier reservoirs.

Later compartmentalization is indicated at Patrick Draw Field by: (1) anomalous production zones, (2) precipitous changes in formation water salinity, and (3) large decreases in formation pressure during primary production. Channeling and poor waterflood sweep efficiency in the Arch Unit may be caused by fractures.

The comparison and contrast between Patrick Draw Field and Bell Creek Field show that both reservoirs are compartmentalized. Initial production is influenced by the internal architecture of the reservoir. Secondary and tertiary production are more influenced by structural and diagenetic features. Faults in both fields contribute to poor sweep efficiency. Diagenetic changes were more significant at Bell Creek in the early stages of leaching, at Patrick Draw the later stages of cementation by carbonates and clays had more significant effects.

Shapurji, S. S., 1978, Depositional environments and correlation of the Mesaverde Formation, Wind River Basin, Wyoming: Wyoming Geol. Assoc. 30th Field Conf. Guidebook, p. 167-180.

The Upper Cretaceous Mesaverde Formation is widespread in the central Rocky Mountain area. In the Wind River Basin facies include marine and nonmarine sandstones, siltstones, shales and coals. The multiple transgressions and regressions caused intertonguing of marine and nonmarine deposits and confused the stratigraphy. The Wind River Basin is a structural basin bounded on the west by the Wind River Mountains, on the north by the Owl Creek and Big Horn Mountains, on the east by the Casper Arch, and on the south by the Granite Mountains. The Mesaverde Formation has extensive exposures on the flanks of the Casper Arch. A number of well logs and cores were correlated to describe and interpret the complex stratigraphy of the Mesaverde Formation in the Wind River Basin. The coal and hydrocarbon potential for the Mesaverde Formation is discussed. At the time of publication coal was of greater significance than oil or gas.

Sharma, B., 1992, A new technique to estimate vertical variability of rock properties for reservoir rock evaluation: SPE 24724, Soc. Petroleum Eng., Washington, D. C., p. 637-652.

Examples from Patrick Draw Field, Wyoming and Bell Creek Field, Montana are presented to demonstrate a new technique for description of vertical variability within a reservoir. Information on rock properties used to verify the technique includes: geological description of cores, XRD analysis, SEM and CT-scan data, porosity, air permeability, primary and waterflood oil production data.

The vertical distribution of reservoir rock properties available as a function of depth is transformed into functions of frequency (cycles per foot) by the application of standard time series analysis techniques. Estimation of vertical variability is computed by a 'power spectra' of core measured permeability, and digitized gamma ray, sonic, density and neutron logs. The 'power spectra' for a clean sandstone decayed very rapidly at higher frequencies if there was no thin bed stratification. Sandstones with variable reservoir properties showed slower decay in the 'power spectra'. Kaolinite clay filled sandstones showed very low amplitudes at higher frequencies. The study of decay spectra may provide quantitative information on variations in cement content and types and volumes of clays in reservoir rocks.

Smith, L. K., and R. C. Surdam, 1992, Cyclic CO₂ enhanced oil recovery in Wyoming Cretaceous fields: Wyoming Geol. Assoc. 43rd Field Conf. Guidebook, p. 145-166.

A number of CO₂ projects have been attempted in the Cretaceous oil reservoirs of Wyoming. Both reservoir geology and fluid geochemistry affect the success of CO₂ projects. Five case studies from Wyoming are presented and analyzed and recommendations given. The five reservoirs tested are from four Cretaceous formations in Wyoming; Dakota, Muddy, Cody and Frontier.

The major problems in the CO₂ projects have come from confinement, loss of CO₂ and scale damage or precipitation. The confinement of the CO₂ to near the well-bore is essential to maintain contact with residual oil and to move the oil. This loss of confinement is usually due to high permeability, heterogeneity of the reservoir, fractures and the spacing of nearby injection or production wells. Scale problems are not as common with cyclic CO₂ projects, but cause severe damage when they occur. Shortening the duration of CO₂ soak time will lessen scale problems. Other causes of scale damage are abundant calcite in the reservoir and large pressure drops into the wellbore.

Stearns, D. W., W. R. Sacris, and R. C. Hanson, 1975, Structural history of southwestern Wyoming as evidenced from outcrop and seismic: Rocky Mountain Assoc. Geol. Symposium, in Deep Drilling Frontiers of the Central Rocky Mountains, ed. D. W. Bolyard, p. 9-20.

The study area in southwestern Wyoming includes the Red Desert, Green River and Wind River Basins. The Western Wyoming thrust belt lies just west of the study area. The mountain ranges in the area were produced during the Laramide Orogeny. Early structural deformation began in the Precambrian rocks of the Sierra Madre, Medicine Bow, Wind River and Owl Creek mountains. The widespread Cambrian sandstones were deposited on a peneplained Precambrian surface. Later deformations occurred in the Ordovician and Devonian. During the Pennsylvanian the region was a sedimentary depocenter. Shallow marine and continental sedimentary deposits of the

Mesozoic indicate a relatively stable area. Movement was a slow continuous downwarping with 30,000 ft of Cretaceous rocks deposited. The elongate Moxa Arch formed in the Cretaceous. Seismic evidence for the Cretaceous downwarping and crustal movements in southwestern Wyoming is discussed in detail.

Stone, D. S., 1975, A Dynamic analysis of subsurface structure in northwestern Colorado: Rocky Mountain Assoc. Geol. Symposium in Deep Drilling Frontiers of the Central Rocky Mountains, ed. D. W. Bolyard, p. 33-40.

Northwestern Colorado subsurface structure is extensively folded and faulted. The fold-fault trends are consistent with regional tectonic trends which effect the central Rocky Mountains. The structural trends and anticlinal folding in northwest Colorado are very complex and confusing. They were formed by northeast-southwest compression extending from the Precambrian through the Laramide. Numerous maps and cross sections are used to illustrate the stages discussed. Northward in the Green River Basin the wrench faults of northwestern Colorado become deeply buried and die out in the Upper Cretaceous rocks (Almond and Lewis formations).

Surdam, R. C., 1992, Sandstone geometries, petrophysical characteristics, and pressure regimes, Mesaverde Group, Green River Basin, Wyoming: Wyoming Geol. Assoc. 43rd Field Conf. Guidebook, p. 167-169.

A summary of the lithology, petrophysical characteristics and pressure of the tight gas sands of the Mesaverde Group in the Green River Basin, Wyoming. The Mesaverde ranges from 2,000 to over 5,000 feet in thickness and covers 19,000 sq. miles within the Green River Basin. Hydrocarbon production is primarily from tight gas sands. The sandstone beds consist of multiple stacked wedges of deltaic deposition into the Western Interior Seaway. Two major regressions, two regional transgressions and numerous local events encompass a period of 13 million years. These sea level changes have compartmentalized the basin into shoreline, nearshore and offshore sandstones which interfinger with each other.

Szpakiewicz, M. and A. G. Collins, 1985, Hydrochemical Study of the Upper Cretaceous and Lower Tertiary Formations in the Uinta, Piceance and Greater Green River Basins; Implication for Oil and Gas Related Problems: DOE Report NIPER-95, 70 p.

Formation waters from Upper Cretaceous and Lower Tertiary strata in the Uinta, Piceance and Green River basins were analyzed for hydrogeochemical components. Oil and gas reservoirs in these basins are organic-rich, non-marine rocks of lacustrine, paludal, and alluvial origin.

Chemical analysis of the samples reveals zones within the rocks depend on proportions of meteoric, ancient marine, and diagenetic fluids. Anaerobic bacteria has caused biochemical degradation in some zones. Isolated, biologically inactive low-temperature zones are favorable

for oil survival. Formation waters may be diluted or enriched by bicarbonates, by thermal decarboxylation of organic acids, or by thermometamorphism of the carbonates.

Szpakiewicz, M. J., R. Schatzinger, S. Jackson, B. Sharma, A. Cheng, and M. Honarpour, 1991, Selection and Initial Characterization of a Second Barrier Island Reservoir System and Refining of Methodology for Characterization of Shoreline Barrier Reservoirs: DOE Report NIPER-484, 170 p.

Patrick Draw Field, Wyoming and Bell Creek Field, Montana represent a combination of end-member models of shoreline barriers developed under different hydrodynamic conditions. The hydrodynamic conditions primarily involve changes in sea level and the dominant tide and wave regime of a coastline. The Muddy Formation in Bell Creek Field consists of fine-grained littoral and neritic sandstones deposited as shoreface and foreshore facies in a shoreline barrier system. The Almond Formation in Patrick Draw Field has two units; fine- to medium-grained estuarine sandstone deposited in a tidal channel/tidal delta environment with associated migrating tidal inlets, and fine to very fine grained littoral and shallow neritic sandstones. The similarities and contrasts between the microtidal (Bell Creek) and mesotidal (Patrick Draw) types of shoreline barrier deposits is used to improve the generalized shoreline barrier model. A study of the engineering and geological data is used to correlate the heterogeneities with log signatures, pressure, injection, production characteristics, and fractural distribution.

Thomas, G. E., 1973, Evanston Lineament Green River Basin, Wyoming: Wyoming Geol. Assoc. 25th Annual Field Conference Guidebook, Symposium and Core Seminar on the Geology and Mineral Resources of the Greater Green River Basin, p. 93-95.

ERTS imagery in the Green River Basin area of southern Wyoming shows a prominent tonal alignment which is here named the Evanston lineament. The Evanston lineament is parallel to the Sweetwater River lineament defined in 1971. The outcrop pattern in the photographs shows that the lineament extends southeasterly into Colorado between the Washakie Basin and the Uinta Mountains.

Thomas, J. B., 1978, Diagenetic sequences in low-permeability argillaceous sandstones: Journal of the Geological Society of London, v. 135, p. 93-99.

Based on Cretaceous sandstones from the Rockies, a regular sequence of mineral paragenesis is observed in low permeability sands. Diagenetic sequences in the coarser sandstones do not match the order of free energies of formation. This implies that early precipitation in very fine-grained sandstones probably occurs under nearly static

conditions, whereas constant fluid throughput in coarser-grained rocks leads to a markedly different diagenetic sequence. Thus, two potential sandstone reservoirs, one coarse and one very fine, commonly will have different authigenic mineral suites even though their original pore waters were broadly identical.

The author uses examples from the Almond Formation; contrasts upper Almond (coarser, cleaner) with lower Almond (finer grained, tighter).

Tillman, R. W., 1990, Tidal channels in Almond barrier islands sandstones, Patrick Draw Field, Wyoming (abst.): in Davis, R.A. Jr., D. Nummendal, and R. W. Tillman, Conveners, Tidal Inlet and Related Sand Bodies: Modern and Ancient; SEPM Research Conference, San Juan Basin New Mexico, May 5-10, pages unnumbered.

The reservoir produces from tidal channel sandstones designated as UA-5, that consist of a western barrier island and a younger overlapping eastern barrier island. In parts of the fields, the barrier islands have been thoroughly dissected by what are interpreted as tidal inlet channels. The UA-4 and UA-5 reservoirs include tidal inlets, while the UA-6 sandstone may be predominantly tidal creeks. The western barrier, and in places the eastern barrier, rests with sharp contact on a widespread coal that forms the uppermost unit of the underlying cyclic sequence.

The tidal channel fill typically is coarsest grained and includes abundant transported oysters at the base. Oysters also are scattered throughout the lower half of the inlet fill. Current structures, including cross-lamination and asymmetrical ripples, dominate the inlet fill. *Ophiomorpha* and other burrows are scattered throughout the sandstone fill of the inlet.

Van Horn, M. D., 1979, Stratigraphy of the Almond Formation, East-Central flank of the Rock Springs Uplift, Sweetwater County, Wyoming: A mesotidal-shoreline model for the Late Cretaceous: M.S. Thesis, Colorado School of Mines, 150 p.

The Almond Formation was deposited as a mesotidal barrier island coastline on a fluvial-coastal plain, with estuarine, open-marine littoral, and shallow neritic environments. The lower Almond is fluvial deposits of small, lenticular, channel sandstones; levee, overbank, and floodplain sandstones, siltstones, mudstones; and carbonaceous shales and coals. The upper Almond is a sequence of coals deposited in fresh water coastal-marsh environments; carbonaceous shales, mudstones, siltstones, and thin sandstones deposited in salt marsh-tidal flats in an estuarine setting. A detailed analysis of the sediments, fossils, and sedimentary structures of the Almond Formation is covered. Surface and subsurface studies of Patrick Draw Field indicate that the oil is trapped by a stratigraphic trap of combined facies changes and westward

truncation. The overlying Lewis Shale provides an impermeable seal for the migration of hydrocarbons.

Van Horn, M. D., 1979, Stratigraphic relationships and depositional environments of the Almond and associated formations east-central flank of the Rock Springs Uplift: Rocky Mountain Sect. Soc. Economic Paleontologists and Mineralogists, Field Trip, Cretaceous of the Rock Springs Uplift, Wyoming, p. 50-63.

The upper Ericson, Almond and lower Lewis Formations are nonmarine to marine deposits of the final transgression of the Cretaceous Seaway. They were deposited along a mesotidal barrier-island coastline in fluvial-coastal plain, estuarine, and marine environments.

The lower Almond has fluvial-related deposits of small lenticular channel sandstones, levee, overbank, and floodplain sandstones, siltstones, mudstones carbonaceous shales and coal beds. The upper Almond unconformably overlies the lower Almond. It has two distinct units of fine to medium-grained estuarine sandstones and fine to very fine grained littoral and shallow neritic sandstones. The estuarine sandstones were deposited in migrating tidal inlets associated with a barrier-island coastline.

The large oil accumulation in the upper Almond is attributed to early placement of the Patrick Draw sandstones in a structurally high position on the incipient Wamsutter Arch by downwarping to the west.

Ver Ploeg, A. J., R. H. DeBruin, R. L. Oliver, and M. Clark, 1983, Almond and Frontier tight gas sand cross sections, Greater Green River Basin, Wyoming: Geol. Surv. Wyoming, Open File Report 83-5, 22 p.

The Almond and Frontier formations in southeast Wyoming account for most of the tight gas sand production in Wyoming. The deposits range from continental deltaic to barrier and offshore bar sands.

The Almond Formation is composed of fine to medium grained sandstones interbedded with shales, silty shales, and coal units. The environments are barrier island, marsh-mudflat, and lagoonal-bay. The upper Almond facies migrate upward stratigraphically in a westerly direction approaching the Rock Springs Uplift. The overlying Lewis Shale represents the last major marine invasion of the Upper Cretaceous sea.

Wach, P. H., 1977, The Moxa Arch, an overthrust model?: Wyoming Geol. Assoc. Guidebook, 29th Annual Field Conf., p. 651-664.

Moxa Arch is a major north-south structural feature extending from Bridger Lake, where it is over ridden by the North Uinta Thrust Fault, to at least the Big Piney-La Barge Platform, where it becomes lost in thrust faulting and attendant strike-slip faulting. The Moxa Arch may serve as a model for buried or scalped arches in the Overthrust Belt.

Wanner, J. J., D. A. Chesnut, and D. O. Cox, 1979, Gas production from tight Mesa Verde sands in Wyoming-A field case history: SPE 7934, p. 233-237.

Barrel Springs Field, Washakie Basin, Wyoming is described. Production is from Almond and Ericson sands in the Upper Mesaverde.

Weaver, C. E., 1961, Clay mineralogy of the Later Cretaceous rocks of the Washakie Basin, Wyoming: Wyoming Geol. Assoc. 16th Annual Field Trip Guidebook, Symposium of Late Cretaceous Rocks, p. 148-154.

This is one of the earliest papers dealing with the subsurface mineralogy of the Mesaverde Group. X-ray diffraction analyses of the clay size fraction of well cutting from Upper Cretaceous rocks in the Washakie Basin were used to determine that clay minerals in the Almond Formation are comprised of kaolinite, montmorillonite, chlorite, illite, and mixed-layer illite-montmorillonite. Weaver reported that montmorillonite (smectite) does not occur at depths greater than 10,000 ft because of its presumable conversion to mixed-layer illite-montmorillonite. Weaver did not attempt to distinguish authigenic from detrital clays but did mention that some of the kaolinite might be of diagenetic origin.

Weimer, R. J., 1961, Uppermost Cretaceous rocks in central and southern Wyoming and northwest Colorado: Wyoming Geological Assoc. 16th Ann Field Conf. Symposium of Late Cretaceous Rocks, Green River, Washakie, Wind River and Power River Basins, p. 17-28.

Upper Cretaceous stratigraphy is very complex and the nomenclature is often confused. Changes from marine to non-marine, as the Lewis Sea transgressed and regressed the area, are correlated across the region, not just in local basins. Maps show regional restorations of the stratigraphy from the Rock Springs Uplift east to the Denver Basin and south toward Grand Junction, Colorado. Petrographic samples from a wide area of localities in Wyoming and Colorado were analyzed and are presented in tables.

Weimer, R. J., 1966, Time-stratigraphic analysis and petroleum accumulation, Patrick Draw Field, Sweetwater County, Wyoming: AAPG Bull., v. 50, p. 2150-2175.

Patrick Draw Field was discovered in 1959. Although several sandstone reservoirs produce at Patrick Draw, the principal productive interval consists of two sandstone bars at the top of the Almond Formation. Spatial dimensions, lithologic character, and stratigraphic framework of the bars suggest that they are barrier-bar sandstone bodies deposited along the margin of the Lewis sea. The bars are linear and grade up dip into impermeable shale and sandstone that was deposited in a swamp and lagoonal environment. A second important productive interval is approximately 40-ft below

the top of the Almond Formation. The areal distribution, lithologic character, and stratigraphic framework of the sandstone in this interval suggest that it was deposited as a tidal delta in a lagoon. Each of the three major productive sand bodies have different oil-water contacts.

Weimer, R. J., and R. W. Tillman, 1982, Sandstone Reservoirs: SPE 10009, Pres. at the International Petroleum Exhibition and Technical Symposium of the SPE, Beijing, China, p. 1-5.

Patrick Draw Field was discovered in 1959. Approximately 56 MMBBL oil and 11 TFC gas have been produced (22 years). Reserves in place are estimated at 200-250 MMBBL oil. The upper 60 ft of Almond Formation consists of two sands: UA-5 (upper sandstone), UA-6 (lower sandstone).

UA-6 Sandstone: Productive in West Desert Springs Field and northern part of Patrick Draw. Gray, very fine to fine grained calcareous sandstone, ranges from 0 to 25 ft; Average thickness 12 ft. Interpreted as tidal creek channels and tidal flats west of a shoreline sand trend based on erratic distribution of production, fine grain size, close association above and below with coal beds and lagoonal shale.

UA-5 Sandstone: Main producing zone in Patrick Draw. Overlain by marine Lewis Shale, by oyster coquina layers or by 5-10 ft of carbonaceous shale and impermeable sandstone. The sandstone is quartzose, gray, fine to medium grained, calcareous and contains abundant dark gray to black chert grains and minor amounts of feldspar, quartz 64%, chert 32%, feldspar (mostly plagioclase) 4%; trace amounts of biotite, muscovite, chlorite and zircon. Cements are dominantly silica, calcite, dolomite and clay minerals (kaolinite). Thickness is 0-30 ft, lateral extent of sandbody is 20 miles long, 6 miles wide. UA-5 pinches out updip at the western margin of Patrick Draw into impermeable coal-bearing shale and siltstone.

Depositional Model: UA-5 is a shoreline sand deposit based on sedimentary structures and geometry. Unit has characteristics of prograding barrier island shoreline deposit: coarsening upward texture with burrowed sandstone near base, overlain by trough crossbeds in sets 1 to 2 ft thick with laminae of clay or carbonaceous material within the cross lamina. *Ophiomorpha* trace fossils indicate near normal marine salinity. The mesotidal range (4 to 8 ft) is based on widespread occurrence and thickness of the channel sands.

White, E. J., O. C. Baptist, and C. S. Land, 1963, Physical properties of the Almond sands in the Patrick Draw area, Wyoming: U. S. Bureau of Mines, Rept. of Invest., p. 1-19.

The Almond sandstone samples were included in part of a long term study of the relationship between the clay mineral content of reservoir rocks and water damage. The physical properties and clay content of the Almond

sandstone were analyzed in the laboratory. Samples were included from a wide area of Patrick Draw Field. Susceptibility to water damage was estimated and the injectivity to water of the Almond sandstone inferred from the samples.

Wiloth, G. J., 1961, Symposium on Late Cretaceous Rocks, Wyoming and adjacent areas: in Wiloth, G. J. ed, Wyoming Geol. Assoc. 16th Ann. Field Conf. Green River, Washakie, Wind River and Power River Basins, 347 p.

Seven regional papers and forty papers on local basins, formations, and oil and gas fields are presented. A road log of the three-day field trip is given along with numerous maps.

Winn, R. D., Jr., S. A. Stonecipher, and M. G. Bishop, 1984, Sorting and wave abrasion: Controls on composition and diagenesis in Lower Frontier sandstones, Southwestern Wyoming: AAPG Bull., v. 68, p. 268-284.

The lower Frontier Sandstone on Moxa Arch was deposited in wave-dominated, multi-river delta plain which prograded eastward into the Cretaceous Interior Seaway. Depositional hydrodynamics largely controlled diagenesis. Fluvial sandstones contain a greater percentage of rock fragments and have less quartz than equivalent marine sandstones owing to the combined effects of sorting and wave abrasion. The coarsest sands and gravels, which were trapped on the delta plain, were initially richer in rock fragments than finer-grained sands that were passed to the shoreline. These latter sands had a significant portion of unstable grains, including chert, destroyed by wave abrasion. Quartz-rich permeable marine sandstones were cemented early by silica (that preferentially formed as monocrystalline quartz), whereas primary porosity in quartz-poor fluvial sandstones was largely preserved through this stage. Fluvial sandstones were affected more by grain dissolution, calcite replacement, calcite precipitation in open pores, and by subsequent carbonate dissolution. Fluvial sandstones generally have the best porosity and permeability mostly due to creation of secondary porosity. Compaction in finer-grained sandstones destroyed permeability by squeezing clays into open spaces. Other major diagenetic processes are late-stage growth of kaolinite and continued precipitation of silica.

Wyoming Geological Association, 1973, Symposium and core seminar on the geology and mineral resources of the Greater Green River Basin: Wyoming Geol. Assoc. 25th Ann. Symposium and Core Seminar, Casper, Wyoming, 178 p.

A description of proper core handling and labeling techniques used for core is discussed in this paper. A map

of the Greater Green River Basin designates where the samples cores were collected. Sample cores from 20 localities are shown. The cores are logged and shown with accompanying photographs. Information was donated by a number of petroleum companies from wells in the Greater Green River Basin.

Wyoming Geological Association, 1979, Wyoming Oil and Gas Fields, Greater Green River Basin (2 vols): Wyoming Geol. Assoc. Symposium, 428 p.

A complete survey (through 1978) of oil fields drilled in the Greater Green River Basin, Wyoming is presented. Each field is listed alphabetically and data is given in tabular form. The discovery well is named and dates of discovery and drilling are given. Data for each field includes; range and township location; general field data on type of trap, number and type of wells; reservoir data on formation, lithology, oil statistics and cumulative production; and structure maps. A short discussion on the history or any unique features of a field is given in a summary paragraph.

Yin, P., J. Liu, and R. C. Surdam, 1992, Petrographic and petrophysical properties of the Almond Sandstone in the Washakie Basin: Wyoming Geol. Assoc. 43rd Field Conf. Guidebook, p. 191-205.

Almond Formation sandstones are sublitharenite, litharenite and lithic arkose in composition. The grains are well sorted and fine to very fine. There is a marked change in porosity, permeability and authigenic mineral content at 8,000 ft. The diagenetic changes in the sandstone suggest burial at greater depth than at present. Detailed petrographic analysis is used to reconstruct the diagenetic changes and burial history of the Almond Formation. The reservoir at 4,000 to 5,000 ft has permeabilities ranging from 20 to 80 mD. The 10,000 to 13,000 ft reservoirs have in the range of thousandths of a milliDarcy.

B. POWDER RIVER BASIN

The Powder River Basin is a large sedimentary basin in northeast Wyoming and southeast Montana. Structurally the Powder River Basin is bounded on the north and east by the Black Hills Uplift and on the west by the Wyoming Thrust Belt and the Big Horn Mountains and on the south by the Hartville Uplift. The Belle Fourche Arch is the only major structural feature within the Powder River Basin. It has a northeast trending axis resulting from tectonic movements in the Cretaceous. Hydrocarbon productive formations includes Permian aged Minnelusa Formation sediments and Cretaceous aged deposits from the Dakota, Muddy, Turner, Shannon, Sussex and Parkman formations of the Dakota Group. The uppermost Dakota Formation, the Muddy Sandstone, is overlain by Benton Group shales of the Mowry and Shell Creek formations. Hydrocarbon discoveries in the Powder River Basin are primarily stratigraphic traps.

Almon, W. R., and D. K. Davies, 1979, Regional diagenetic trends in the Lower Cretaceous Muddy Sandstone, Powder River Basin: SEPM Special Pub No. 26, p. 379-400.

Hydrocarbon reservoirs in the Powder River Basin are found in Lower Cretaceous rocks of the Muddy Formation. The environments represented are fluvial, deltaic, and shallow marine. Diagenetic clay minerals greatly affect the porosity and permeability of the Muddy sandstones. An assemblage of kaolinite-chlorite-illite-quartz with some smectite dominated the clays. A changing trend in the clay content is matched by changes in the detrital composition. Older Muddy sandstones have more feldspars, more rock fragments, and less quartz than younger sandstones. The diagenesis must be taken into account in well stimulation and completion tests. Illustrations include maps, cross-sections, and SEM photomicrographs of clays and detrital rock fragments.

Berg, R. R., and D. K. Davies, 1968, Origin of lower Cretaceous Muddy Sandstone at Bell Creek Field, Montana: AAPG Bull., v. 52, p. 1888-1898.

Geological study of the Muddy Sandstone at Bell Creek Field in Montana gives an analysis of grain size, sediment content and textures to account for the range of porosity and permeability values charted. The Muddy Sandstone is recognized as a barrier bar, and changes in bar texture and morphology are related to the environments of deposition. Isopach maps, log data, and grain analysis are used to support the conclusion of barrier bar.

Berg, R. R., G. M. Larberg, and J. T. Lin, 1980, Hydrodynamic flow in Lower Cretaceous Muddy Formation, northeast Powder River Basin, Wyoming and Montana (abst.): AAPG-SEPM-EMD Convention, Denver, CO., p. 676.

Hydrodynamic gradient in the Muddy Formation averages 25 ft/mi (5 m/km) in a downdip direction. Isolated high pressure areas are suggested by local gradients and a reduction of the oil column in some areas. The oil columns are in equilibrium with vertical and cross formational flow. Migration of oil from the Mowry Shale source rock is still continuing. Dehydration of montmorillonite in the Mowry shale occurs at

temperatures above 200° F (94° C) which results in oil flow. Oil traps in the Muddy Formation are post-Laramide in development. Earlier fluid flow in the area may have been updip and prevented oil accumulation.

Berg, R. R., G. M. Larberg, and L. D. Recker, 1985, Hydrodynamic flow in Lower Cretaceous Muddy Formation, northeast Powder River Basin, Wyoming and Montana: Wyoming Geol. Assoc. 36th Field Conf. Guidebook, p. 149-156.

An average Hydrodynamic flow gradient of 50 ft/mi (10 m/km) reaches from the Muddy outcrop westward into the Powder River Basin. The distribution pattern of the porous sandstone controls the flow direction and rates. The Mowry Shale serves as a source rock for the Muddy.

The Muddy sandstones are irregular lenses and oil collects in stratigraphic traps. Flow rates vary from field to field within the Powder River Basin. The oil column for several fields is calculated as follows; 130 ft (40 m) at Recluse Field, 208 ft (63m) at Draw Field, 429 ft (150 m) at Bell Creek Field, and 700 ft (214 m) at Kitty Field. Vertical flow results in larger oil columns, caused by the vertical pressure gradient and hydrostatic head.

Cheng, A. M. and B. Sharma, 1991, Determination of Favorable Areas for EOR From Differential Oil-in-Place Calculations in Bell Creek Field, Montana: SPE 21824, Rocky Mountain Regional Meeting, Denver, CO., 20 p.

The theory that positive differential OIP areas could indicate the presence of geological heterogeneities like high clay content, sealing faults or different types of flow barriers was tested on data from Bell Creek Field, Montana. DOIP equals volumetric oil-in-place at a given well spacing minus the material balance equation OIP. Geological and engineering data from 54 wells was analyzed. A differential OIP map indicated several areas with significantly positive and negative differential OIP anomalies.

Differential OIP is dependent on geological heterogeneities and proved an effective index for measuring the importance of such heterogeneities on oil production at Bell Creek Field. Drainage efficiency and effective drainage volume for each well was determined. Optimal well spacing and determination of the best wells for injection and production by waterflood, infill and EOR processes can be analyzed by this method.

Dalziel, M. C. and T. J. Donovan, 1980, Biogeochemical evidence for subsurface hydrocarbon occurrence, Recluse oil field, Wyoming: Preliminary results: U. S. Geological Survey Circular 837, 13 p.

The discovery that anomalous mineral ratios in plants can indicate petroleum leakage into the soils is suggested as a new biogeochemical prospecting tool. Pine needles and sage leaves from plants growing on the surface of Recluse Field in the Powder River Basin, Wyoming were tested for manganese to iron ratios. Anomalously high ratios led to study of the soils. Carbon and oxygen isotope ratios suggested that oil leakage was producing a reducing environment that allowed high absorption of iron and manganese. Plant testing can thus be used to monitor oil leakage and to suggest new areas for drilling.

Dolson, J., D. Muller, M. J. Evetts, and J. A. Stein, 1991, Regional paleotopographic trends and production, Muddy Sandstone (Lower Cretaceous), central and Northern Rocky Mountains: AAPG Bull. v. 75, no. 3, p. 409-435.

As of early 1991 more than 1.5 billion BBL of hydrocarbons have been produced from the Muddy Formation. Unconformities caused by sea level changes are the main control on production. Ten or more paleodrainage basins existed when the seas were at their lowest levels. A regional divide in southern Wyoming separated southeast and northwest flowing alluvial systems. Erosion cut into underlying Skull Creek sediments. The best reservoirs developed from coarse grained fluvial systems.

Valley fill and channel reservoirs are the main source of hydrocarbon production. Within a given field the best resources are from marine sandstones. The Skull Creek and Mowry Shale formations are considered the source for hydrocarbons and form traps in the overlying Muddy Sandstone. Numerous maps, correlations and cumulative production data are presented.

Gardner, M. H., and E. R. Gustason, 1987, Valley-fill sequences and onlap geometries, Lower Cretaceous Muddy Sandstone, Kitty Field, Powder River Basin, Wyoming (abst.): AAPG. Bull., v. 71, p. 558.

The valley-fill sequence of Muddy Sandstone at Kitty Field, Wyoming, comprises a series of depositional units which onlap the erosional surface. The main reservoirs in the sequence are channel belt sandstones at the base and barrier bar sandstones at the top.

Gustason, E. R., 1988, Depositional and tectonic history of the Lower Cretaceous Muddy Sandstone, Lazy B Field, Powder River Basin, Wyoming: Wyoming Geol. Assoc. 39th Field Conf. Guidebook, p. 129-146.

The Lazy B Field is a large producing oil field located in the center of the Powder River Basin. Production from the Lower Cretaceous Muddy Sandstone by 1988 was over 2.2 MMBBL and 4800 MMCF gas. The unconformable contact of the Muddy Sandstone over the underlying Skull

Creek Shale at Lazy B Field reveals over 40 ft of erosion into the shale.

The sandstones at Lazy B Field are chert-rich subarkoses and arkose. Sandstone reservoirs at Kitty and Recluse fields are fluvial quartz arenites. The morphology and texture of the Muddy Sandstone at Lazy B Field suggests wave dominated or storm modified marine deposition. The sandstone sequences coarsen and thicken upward in progradational strandline deposits. The northeast trend of the Lazy B sandstones is an erosional remnant of a sheet strandplain deposit preserved in this small area. The preservation was caused by tectonic movements which produced a graben. The Lazy B Field may overlie a strike-slip fault in the Precambrian basement rocks.

Gustason, E. R., T. A. Ryer, and S. K. Odland, 1988, Stratigraphy and depositional environments of the Muddy Sandstone, Northwestern Black Hills, Wyoming: Wyoming Geol. Assoc., Earth Science Bull., v. 20, p. 49-60.

The Muddy Formation at Bell Creek Field is interpreted as a topographic feature formed during prolonged subaerial erosion of a once widespread regressive sand sheet.

Honarpour, M., R. A. Schatzinger, M. J. Szpakiewicz, S. R. Jackson, L. Tomutsa, and M. M. Chang, 1990, Integrated Methodology for Constructing a Quantified Hydrodynamic Model for Clastic Shallow Marine Petroleum Reservoirs: DOE Report NIPER-439, 152 p.

A methodology for integrating geological and reservoir engineering information is presented. The methodology addresses: (1) data collection, organization, evaluation and integration; (2) hydrodynamic model construction and verification; and (3) prediction and ranking of reservoir parameters by numerical simulation. The types of data used include; petrophysical analyses, core descriptions, structural analyses, petrographic analysis, rock-fluid interaction analyses, well tests, wireline log analyses, production/injection data analyses, pressure history, drive mechanisms and analogous reservoir, outcrop and modern depositional descriptions. These factors can be combined to construct a three-dimensional hydrodynamic model for an oil reservoir. The basis for construction of this model was the shoreline barrier island system at Bell Creek, Field, Montana.

Honarpour, M., M. Szpakiewicz, B. Sharma, M. M. Chang, R. Schatzinger, S. Jackson, L. Tomutsa and N. Maerefat, 1989, Integrated Reservoir Assessment and Characterization: DOE Report NIPER-390, 336 p.

The Lower Cretaceous Muddy Formation at Bell Creek Field, Montana was the site of a multidisciplinary evaluation of barrier island and associated overlying valley fill deposits. The objective was to present an integrated reservoir model for the prediction of fluid flow and entrapment of residual oil through an understanding of reservoir heterogeneities. Knowledge of the heterogeneities

that affect the production can improve EOR project management and design.

The second objective was to develop a methodology for reservoir characterization of barrier island reservoirs. The barrier island facies at Bell Creek Field are described and their influence on production is discussed. The most productive facies at Bell Creek Field was the high energy barrier island core. Heterogeneities include: fluid related parameters, depositional features, the structural framework, diagenesis and faulting. After ten years of waterflooding the remaining oil saturation was highest in the most geologically heterogeneous part of the reservoir. The Dykstra-Parsons coefficient was used to identify these areas.

Honarpour, M. M., M. Szpakiewicz, R. A. Schatzinger, L. Tomutsa, H. B. Carroll, Jr. and R. W. Tillman, 1988, Integrated Geological/Engineering Model for Barrier Island Deposits in Bell Creek, Montana: SPE/DOE paper 17366; Sixth Symposium on Enhanced Oil Recovery, Tulsa, OK., p. 491-512.

The Lower Cretaceous Muddy Formation in Bell Creek Field produces from geological heterogeneities that control fluid flow. Production, injection, core, log and structural data were used to develop a model for Bell Creek Field.

Engineering parameters used in the model include: analysis of initial production rates; cumulative primary, secondary and tertiary production; pressure test data; electrical resistivity; tracking of injected water; oil depletion; and simulated fluid flow patterns and residual oil saturation distributions.

Geological parameters including stratigraphy, facies dimensions, valley incisions, high permeability channels, reduction in net pay caused by diagenetic clay, fault and structural features all contributed to the multigenetic heterogeneities found in Bell Creek Field.

The techniques used, and descriptions of all the engineering and geological findings are integrated into a model for barrier island deposits in general. Numerous maps; tables of rock and fluid properties, production history, core analysis and structural representations are used to illustrate the model and describe Bell Creek Field in detail.

Honarpour, M., M. Szpakiewicz, et al., 1989, Integrated Reservoir Assessment and Characterization: Dept. of Energy, Bartlesville, Oklahoma, NIPER-390, 336 p.

An integrated multidisciplinary evaluation of the barrier island and associated overlying valley fill deposits of the Lower Cretaceous Muddy Formation at Bell Creek Field, Montana. Two objectives of the study were to improve the predictability of fluid flow and entrapment of residual oil in interwell areas and to develop a generic methodology for characterization of barrier island reservoirs. Understanding fluid movement in enhanced oil recovery (EOR) requires the integration of depositional, diagenetic, structural, and fluid flow models that define heterogeneities

within the hydrocarbon reservoir. The study shows that the productive unit in Bell Creek Field is associated with a well-developed, high-energy barrier island facies with low amounts of diagenetic clay cement. Heterogeneities in the field result in large production and residual oil saturation contrasts over small distances.

Jackson, S. R., M. M. Chang, L. Tomutsa, M. Szpakiewicz, M. M. Honarpour, and R. A. Schatzinger, 1989, Application of an Integrated Methodology for Construction of Quantified Transmissivity Model--Bell Creek Field, a Barrier Island Reservoir: NIPER/DOE Second International Reservoir Characterization Technical Conference, Dallas, TX, 40 p.

The method of developing a complex geological and engineering model is discussed in this paper. Integration proceeds in steps as more and more information becomes available and different scales of heterogeneities are recognized.

The geological model is the framework on which additional quantitative and engineering information is attached. A three year study of the Lower Cretaceous Muddy Formation in Bell Creek Field, Montana provided the basis for the model. The Muddy sandstone producing unit at Bell Creek is a 30 foot thick barrier island sequence which acts as a stratigraphic trap. Valley fill unconformably overlies the channel sandstone. Where valley cutting has removed entire sections of the barrier island sandstone hydraulic barriers form. These barriers define the productive units within Bell Creek Field. Method developed for this model may be used to describe and interpret other barrier island systems.

Jackson, S. R., L. Tomutsa, M. Szpakiewicz, M. M. Chang, M. M. Honarpour, and R. A. Schatzinger, 1991, Construction of a Reservoir Model by Integrating Geological and Engineering Information—Bell Creek Field, a Barrier/Strandplain Reservoir: in L. W. Lake, H. B. Carroll, Jr., and T. C. Wesson, eds., Reservoir Characterization II, Academic Press, p. 524-556.

Bell Creek Field, Montana, was studied using a reservoir model which incorporates both geologic and engineering information. A simple, permeability layer model is based on sedimentologically defined units. This model is used to calculate reservoir volumetrics and forecast field and well primary production performance. A flow unit model uses all available geological and engineering information to provide a reservoir description. It is used to predict production performance from secondary and tertiary recovery processes.

Larberg, G. M. B., 1980, Depositional environments and sand body morphologies of the Muddy sandstones at Kitty Field, Powder River Basin, Wyoming: Wyoming Geol. Assoc. 31st Field Conf. Guidebook, p. 117-135.

Kitty Field produces from a stratigraphic trap in the Lower Cretaceous Muddy Formation in Campbell County,

Wyoming. The reservoir has an effective porosity of 17% and a maximum permeability of 442 mD. The sandstone body averages less than 15 ft thick. Electric logs have been used to define four zones in the Muddy Sandstone at Kitty Field. The upper three zones were deposited during a transgression of the Lower Cretaceous Sea. The lowest zone was fluvial in origin and deposited unconformably over the Skull Creek Shale. Lateral flood plain deposits and channel sands suggest a stream traversing a coastal swamp. The middle two zones represent strandline deposits, facies recognized include; offshore bar, beach, estuarine, lagoonal and fluvial.

Core data and isopach maps of the logs were used to interpret the environments. The strandlines in the 2nd and 3rd zones were reworked into a wide linear trend by longshore drift, wind and wave-generated bottom currents.

Lin, J. T. C., 1981, Hydrodynamic flow in Lower Cretaceous Muddy Sandstone, Gas Draw Field, Powder River Basin, Wyoming: *The Mountain Geologist*, v. 18, no. 4, p. 78-87.

The Gas Draw Field in the Powder River Basin produces from the Lower Cretaceous Muddy Sandstone. The trap is a simple stratigraphic trap formed by layers of sandstones and shales. The Muddy Sandstone at Gas Draw has six distinct units. The lowest unit (6th) is fluvial in origin. The next unit (5th) is a transgressive marine deposit grading into a fluvial to shallow marine 4th unit. The 3rd unit is fluvial overbank deposits of bay-lagoonal origin. The 2nd unit is a fluvial-deltaic environment. The upper (1st) unit is lagoon and marsh environments.

The 2nd unit of the Muddy is the major producing zone at Gas Draw Field. It has a permeability of 209 mD and porosity of 22.6%.

Drill stem tests have been used to interpret the fluid flow relationships within the Muddy units at Gas Draw. The oil column is 210 ft with a potentiometric gradient of 32 ft/mi.

Magara, K., 1975, Importance of hydrodynamic factor in formation of Lower Cretaceous combination traps, Big Muddy-South Glenrock area, Wyoming: discussion: AAPG Bull. v. 59, no. 5, p. 890-893.

The author disagrees with the methods and conclusions of Stone and Hoeger (1973) on the hydrodynamic environment of the Big Muddy-south Glenrock field area. Stone and Hoeger postulate a 500 ft/mi tilt in the Dakota Sandstone which alters the hydrodynamics of the area allowing for abnormally high oil columns. The potentiometric map interpreted by the author shows this tilt as much less sufficient. The author suggests that the heights of the oil column result from the lateral facies changes in the reservoirs. "Trapping capacity should be determined by the high-displacement-pressure layers (shales) rather than the low-displacement-pressure layers (sands or silts)."

Marrs, R. W., and G. L. Raines, 1984, Tectonic framework of Powder River Basin, Wyoming and

Montana, interpreted from Landsat Imagery: AAPG Bull., v. 68, no. 11, p. 1718-1731.

Landsat images were used to interpret linear features in the Powder River Basin of Wyoming and Montana. Several features were identified trending northwest and one prominent northeast trend. Smaller subparallel trends were interpreted as joints, fractures, folds or lithologic changes. Comparison with geological maps and structural data suggests that the prominent lineaments represent surface expression of the boundaries of crustal blocks. The authors suggest that study of lineaments may be useful in petroleum and mineral exploration.

McGregor, A. A., and C. A. Biggs, 1968, Bell Creek Field, Montana: A rich stratigraphic trap: AAPG Bull., v. 52, p. 1869-1887.

A description of the early history and production at Bell Creek Field is presented. Bell Creek is a Lower Cretaceous stratigraphic trap along the east flank of the Powder River Basin. The deposits are at the intersection of nearshore marine bars and deltaic deposits. The nearshore environments formed during a regressive phase of two major advances of the Early Cretaceous sea. The sand bodies are very porous and permeable and are overlain by the Mowry Shale. Drilling is expected to be the best method of exploration for this kind of stratigraphic trap.

Mersch, W. R., 1985, Lower Cretaceous Paleogeography, Big Muddy-South Glenrock area, southeast Powder River Basin, Wyoming: Wyoming Geol. Assoc. 36th Field Conf. Guidebook, p. 81-90.

The Big Muddy Anticline was first discovered in 1916 during early exploratory mapping in Wyoming. The first production from the Big Muddy Anticline was from the Shannon Sandstone of Cretaceous Age. More recent deeper drilling has produced from the Frontier, Muddy, Dakota and Lakota formations.

The upper Muddy sands along the eastern and southeastern flanks of the Big Muddy anticline were deposited as near-shore and off-shore bars. The lower Muddy sands were deposited as channel point-bar sands downcut into the Skull Creek Shale. The channel fill of the lower Muddy is nine miles long and averages one mile wide. Log correlations, outcrop samples and production data was used to suggest further areas of potential production.

Michael, R. C., and I. S. Merin, 1986, Tectonic framework of Powder River Basin, Wyoming and Montana, interpreted from Landsat Imagery: Discussion: AAPG Bull., v. 70, no. 4, p. 453-455.

Lineaments mapped from satellite images mark structural features. The authors disagree with Marrs and Raines (1984) that lineaments should be defined by the type of statistical approach used to analyze them. This statistical treatment obscures the individual linear features.

Specific linear features can be correlated with recognizable geological features. The Powder River Basin is used as an example to explain the authors' method of

interpreting satellite imagery. Landsat imagery shows northwest and northeast trending linear features in the Hilgert Field in the Powder River Basin. These features correlate with isopachs of thickness for the Muddy Sandstone.

Nelson, G. E., 1985, The Cretaceous Geology of Wyoming: Wyoming Geol. Assoc. 36th Field Conf. Guidebook, 184 p.

A series of papers on the geology and hydrocarbon potential of the Cretaceous rocks of Wyoming. Included are papers on structure, stratigraphy, sedimentology and hydrology on both large basins and specific oil fields. One section (several papers) is on the production from the Muddy Sandstone in the Powder River Basin.

Noll, J. H., and K. M. Doyle, eds., 1986, Rocky Mountain Oil and Gas Fields: Wyoming Geol. Assoc. Symposium, 272 p.

A series of papers on the geology and hydrocarbon exploration/production in northeast Wyoming and the Dakotas are presented. Five papers cover the Williston Basin. Three papers are on the structure of large oil fields in central Wyoming. Six papers cover topics of stratigraphy, structure and seismic exploration in the Powder River Basin. Illustrations include maps, photographs of core samples, logs and interpretative stratigraphic correlations.

Reynolds, M. W., 1976, Influence of recurrent Laramide structural growth of sedimentation and petroleum accumulation, Lost Soldier Area, Wyoming: AAPG Bull., v. 60, no 1, p. 12-33.

Uplift and anticlinal folding of sediments in the eastern Powder River Basin, Wyoming during the Laramide resulted in the structural features of the Lost Soldier Area. Very thick sandstone sequences accumulated in the Lost Soldier Area. Two periods of anticlinal folding and erosion truncated the older deposits. Folding continued at Lost Soldier through the early Oligocene and thick arkosic sediments filled the basin. Closure of the Lost Soldier anticline occurred during the Paleocene and entrapment of oil continued into the Eocene. Folds formed later than the Eocene are barren of hydrocarbons.

Schatzinger, R., M. Szpakiewicz, and B. Sharma, 1989, Applicable Correlations and Overall Characteristics of Barrier Island Depositional Systems: DOE Report NIPER 427, 39 p.

Five types of shoreline barriers are described: spits, shoals, barrier islands, barrier peninsulas, and barrier bars. These fall into three genetic groups; aggradational, progradational and transgressive. All shoreline barriers are strongly effected by wave- or tide-dominated coasts. Differences in external dimensions, internal structures, facies sequences and sand body thickness occur in all the types of shoreline barriers. Descriptions and examples of these five types of shoreline barriers are given.

In ancient barriers diagenetic processes may have strongly modified the original sand composition, texture

and petrophysical properties of the barriers. Bell Creek Field, Montana was studied as a model of a barrier island shoreline deposit. Three geological facies at Bell Creek were defined by log characteristics. These include a high productive facies (high energy barrier island), an upper sand facies of nonbarrier channel or valley fill deposits and a lower shoreface/lagoonal facies (low energy barrier island/nonbarrier). The high productive facies is the thickest and has the best reservoir quality.

Sharma, B., M. M. Honarpour, S. R. Jackson, R. Schatzinger and L. Tomutsa, 1989, Determining the Productivity of a Barrier Island Sandstone Deposit From Integrated Facies Analysis Based on Log and Core Data and Fluid Production: SPE paper 19584, 64th Tech. Conf., San Antonio, TX., p. 133-148.

Two crossplot techniques are used to distinguish barrier island sandstones. Bell Creek Field, Montana is a shoreline barrier island deposit with a high quality oil producing reservoir. The techniques are based on core-calibrated resistivity, porosity and gamma ray log interpretation. The crossplot pattern was able to distinguish the barrier and nonbarrier sandstones and separate the barrier island sandstone into two facies. Lithologic properties used to differentiate the facies include grain size, pore throat size, sorting, pore-size geometry and amount and distribution of detrital clays. The upper sandstone has a variable thickness and deep valley incisions. The lower shoreface has less variation in lithologic properties.

Results from primary, secondary and two EOR pilot projects indicate that the barrier island reservoir at Bell Creek Field is influenced by heterogeneities which strongly effect waterflood sweep efficiency, and distribution of residual oil saturation.

Sharma, B., M. M. Honarpour, M. J. Szpakiewicz, and R. Schatzinger, 1987, Critical Heterogeneities in a Barrier Island Deposit and Their Influence on Primary, Waterflood and Chemical EOR Operations: SPE 16749, 62th Tech. Conf., Dallas, TX., p. 83-98.

The Muddy Formation productive in Bell Creek, Field, Montana was used as a study area for geological heterogeneities which control fluid production. The facies relationships within the barrier island and adjacent environments are described using core and log correlations, a structural contour map and an isopach map. Faulting and valley incisions occur within the barrier island, and valley fill deposits act as barriers to fluid migration. Permeability and porosity analysis of the barrier island sandstones indicate that the best reservoir quality is in the core of the bar.

A log-derived heterogeneity index map was used with analysis of clay content and sonic and density logs, petrographic analysis and XRD data to chart the distribution of clays in the reservoir. The geological information was integrated with the production data from primary, secondary and tertiary production to identify

heterogeneities that significantly affect the capacity of the reservoir.

Sharma, B., M. M. Honarpour, M. J. Szpakiewicz, and R. Schatzinger, 1990, Critical Heterogeneities in a Barrier Island Deposit and Their Influence on Various Recovery Processes: SPE Formation Evaluation, March, p. 103-112.

Geological heterogeneities were studied at Bell Creek Field, Montana using log and core data. Literature from other field studies was examined and the information compared with the Bell Creek Field data. Correlations were made between geologic heterogeneities and fluid production from barrier island reservoirs. The integration of various geological, geophysical and engineering techniques allowed for the identification of heterogeneities that influence production.

Sharma, B., and S. Jackson, 1991, A Crossplot Technique for Discrimination of Various Sandstone Facies in Barrier Island Sandstone Deposits: in L. Lake, H. Carroll, Jr., and T. Wesson eds., Reservoir Characterization II, pp. 689-691.

Data from Bell Creek Field, Montana was used to develop a crossplot technique which discriminates between barrier and nonbarrier sandstone facies. The technique is based on interpretation of density, resistivity and gamma ray logs. The technique allows for prediction of productivity from barrier island sandstones based on the distribution of clay, porosity, permeability and oil saturation within each facies.

Slack, P. B., 1981, Paleotectonics and hydrocarbon accumulation, Powder River Basin, Wyoming: AAPG Bull., v. 65, p. 730-743.

The Belle Fourche Arch is a vertical uplift of Cretaceous Age extending from the central part of the Powder River Basin. Structural lineaments trend northeast toward the Black Hills Uplift. The topography is marked by escarpments and drainages following deep fracture zones. The deep zones of basement weakness reflect shear zones of Precambrian Age. The shear zones and stresses that formed the Belle Fourche Arch occurred repeatedly throughout the Phanerozoic.

Depositional environments and hydrocarbon accumulation was effected by movements along the lineaments. (1) The Minnelusa Formation had localized hydrocarbon production along the crest of the Arch. (2) The Dakota Formation had alluvial point-bar production along the crest. (3) The Lower Muddy Formation formed channel deposits on the downthrown sides of the lineament trends. (4) The Upper Muddy Formation formed marine bars close to the Arch demonstrating changes in lineament strike. (5) The Turner Sandstone deposits overlay the trend of the Muddy channels. (6) The Upper Cretaceous Shannon and Sussex sandstones form offshore marine-bars along the crest of the Belle Fourche Arch.

Smith, D. A., 1988, The integration of hydrodynamics and stratigraphy, Muddy Sandstone, northern Powder River

Basin, Wyoming and Montana: in Diedrich, R.P., M.A. K. Dyka and W.R. Miller, eds., Wyoming Geol. Assoc. Guidebook, 39th Field Conf., p. 179-189.

Hydrodynamic analysis of total dissolved solids (TDS) data for the Muddy Sandstone reveals regional and localized fluid flow patterns. Variations reflect the isolated and discontinuous nature of the Muddy Sandstone as observed in permeability, sandstone thickness, and anomalously high pressure areas. Bell Creek Field is in the area of low hydraulic gradient. A potentiometric surface ΔP map is used to delineate pressure systems and show barriers to oil migration. The Bell Creek Field map shows significant pressure differences updip from the producing area.

Stone, D. S., and R. L. Hoeger, 1973, Importance of hydrodynamic factor in formation of Lower Cretaceous combination traps, Big Muddy-South Glenrock area, Wyoming: AAPG Bull., v. 57, no. 9, p. 1714-1733.

The Big Muddy-South Glenrock field area in the Powder River Basin has three sandstone reservoirs. The oldest sandstone in the Dakota Formation, followed by the Lower Muddy Sandstone and the Upper Muddy Sandstone. Entrapment of oil in all three reservoirs is stratigraphic, by updip pinchout or facies changes. Shales, siltstone and non-porous, impermeable sandstones are the facies which seal hydrocarbon migration.

The Dakota Sandstone was deposited by a fluvial-deltaic system with a lateral assist by destructive marine processes. The Lower Muddy is a single continuous reservoir along the east flank of the Big Muddy anticline. It is a fluvial deposit with the classic channel pattern of deposition. The Upper Muddy has two sandstone units lying parallel, deposited as barrier bars.

Hydrocarbon production from these fields has been and continues to be high. The oil column in the Dakota oil pool is 2,800 ft, in the Lower Muddy the oil column is 3,000 ft and 1,500 ft in the Upper Muddy. These very high oil columns are the result of a "downdip hydrodynamic flow which has enhanced the oil holding capacity of the low-displacement pressure, updip barrier zones".

Stone, D. S., and R. L. Hoeger, 1975, Importance of hydrodynamic factor in formation of Lower Cretaceous combination traps, Big Muddy-South Glenrock area, Wyoming: reply: AAPG Bull., v. 59, no. 5, p. 894-899.

The authors discuss the comments made by Magara (1975) on their 1973 paper on the hydrodynamics of the Big Muddy-South Glenrock field area. They feel that Magara has rejected the principles of hydrodynamic theory. Specific points of Magara are discussed and the original explanation for the high oil columns are reiterated. The anomalous oil-water contact of the Dakota at South Glenrock is a fact and can't be disputed. Mathematical equations used by Magara are reinterpreted and used to confirm the author's original claims.

Szpakiewicz, M., K. McGee and B. Sharma, 1987, Geological Problems Related to Characterization of

Clastic Reservoirs for Enhanced Oil Recovery: SPEFE, December, p. 449-60.

Reservoir heterogeneities were grouped into four categories: depositional, diagenetic, structural and formation-fluid composition. Study areas for analysis of reservoir heterogeneities were: Big Muddy Field, Wyoming; North Burbank Field, Oklahoma; Bell Creek Field, Montana and El Dorado Field, Kansas. EOR pilot projects in each field encountered geological problems in the areas of deposition, diagenesis, structure and interstitial fluid distribution. Each of these problems were found to cause heterogeneities that effected the production from the field. The problems within each category are listed, defined and suggestions to correct the problems are given where applicable.

Szpakiewicz, M., R. A. Schatzinger, S. R. Jackson, B. Sharma, A. M. Cheng, and M. M. Honarpour, 1990, Selection of a Second Barrier Island Reservoir System for Expanding the Shoreline Barrier Reservoir Model and Refining NIPER Reservoir Characterization Methodology: DOE Report NIPER-472, 55 p.

A review of eighteen shoreline barrier reservoirs was conducted in order to select a second barrier island system for comparison with the Bell Creek Field, Montana barrier model. The criteria for selection included: (1) a reservoir with a shoreline barrier that will expand the model developed based on Bell Creek Field; (2) a prolific oil producer (OOIP greater than 100 MM STB); (3) geological and engineering data from the reservoir available for research; (4) outcrops near the reservoir of analogous age; (5) the reservoir should have had primary and secondary production and be a potential EOR candidate; (6) reservoir should be in the United States, preferably in the Rocky Mountain Region. Using these criteria the Almond Formation in Patrick Draw Field, Sweetwater County, Wyoming was selected for further study.

Szpakiewicz, M., R. Schatzinger, M. Honarpour, M. Tham, and R. Tillman, 1989, Geological and Engineering evaluation of Barrier Island and Valley-Fill Lithotypes in Muddy Formation, Bell Creek Field, Montana: in, Coalson, E.B., ed., *Petrogenesis and Petrophysics of Selected Sandstone Reservoirs of the Rocky Mountain Region*, The Rocky Mountain Association of Geologists, Denver, Colorado, p. 159-182.

The Lower Cretaceous Muddy Formation produces oil from barrier-island and overlying valley-fill deposits at Unit "A" of Bell Creek Field, Montana. A combined geological and engineering study was made of the depositional, diagenetic, and architectural aspects of the barrier-island and valley-fill deposits; the classification and scaling of geological heterogeneities that affect production; and the petrophysical and production characteristics of the Muddy reservoir rocks. Data were from both Muddy Formation cores from Unit "A" and outcrops around the Powder River Basin.

The productive interval consists of stacked, upward-shallowing barrier-island sandstones. They are confined on the basinward side by valley fills and on the landward side by nonproductive lagoon or estuarine facies. Non-barrier sediments form a large part of the valley fill, generally have low permeability, and contribute little to total oil production. An unconformity separates valley-fill and barrier-island reservoirs. Erosion removed a significant portion of the barrier-island sequence, the best reservoir sandstone.

Depositional, diagenetic, and structural heterogeneities at a variety of scales define the geometry, continuity, and transmissivity of flow units. Large scale heterogeneities include fluid properties, depositional features, and structural framework. Among medium and small scale features are diagenesis and faults. Depositional trends such as sequence of facies, rock textures, and distribution of detrital clays are the most predictable heterogeneities in the barrier-island facies. The least predictable heterogeneities are diagenetic, erosional, and fault-related features.

Tillman, R. W., 1990, Sequence stratigraphy and sedimentology of non-tidal-inlet "channels" through a barrier island, Bell Creek Field, Montana (abst.): in Davis, R.A., Jr., D. Nummedal, and R.W. Tillman, *Conveners, Tidal Inlet and Related Sand Bodies: Modern and Ancient: SEPM Research Conference San Juan Basin, New Mexico, May, 1990*, pages unnumbered.

Only a single barrier was deposited in the area designated as production Units A and B. During a post-barrier drop in sea level several narrow, possibly dendritic, valleys were cut into and locally entirely through the barrier island. These relationships are indicated by:

1. Ability to correlate barrier facies and thicknesses on either side of the valleys.
2. The fill of the valleys varies, bottom to top, from continental to shallow marine.
3. Secondary clays formed as part of an inferred soil zone below an unconformity surface that separates the barrier island sandstones and the valley fill sandstones, siltstones, and shales.
4. Dendritic valleys that cut the barrier island may be connected to a larger valley system recognized over a large portion of the northern Powder River Basin in NE Wyoming.
5. Some valleys are entirely filled with marine shales.

Two periods of post-barrier erosion and sandstone and shale valley-fill are postulated to result from two falls in relative sea level. Earlier valley incisions are broad and relatively shallow and commonly involve erosion of only the top of the barrier. Younger valley fill deposits along the northwest side of Unit A are 30 ft thick where erosion has cut completely through the barrier island and the valleys are filled with marine shale.

One unconformity, interpreted to be a sequence boundary, occurs below the Muddy Sandstone barrier island and it separates back barrier and other facies of the barrier island from the underlying Albian marine Skull Creek Shale. A second sequence boundary occurs between the valley fill and the underlying barrier. No true barrier inlet fills are recognized in the portion of the field designated as Units A and B.

Tillman, R., M. Szapkiewicz, M. Honarpour, and S. Jackson, 1988, Reservoir Description and Production History; Bell Creek Field, Muddy Sandstone, Barrier Island, and Valley Fill Deposits (abst.): AAPG Bull, v. 72, p. 254.

Barrier-island sandstone and related deposits were analyzed to improve our understanding of reservoir management. The model for Bell Creek Field was based on sedimentologic and stratigraphic interpretation. 70 wells were logged and 15 cores were used in the interpretation. The barrier island sandstone is composed of stacked shallowing-upward sequences. Facies present in the Bell Creek Field Unit A include; foreshore, upper shoreface, lower shoreface, transition, washover and perhaps backshore. There were two periods of erosion and valley fill incised into the original barrier island sediments.

Heterogeneities within the field vary from small scale diagenetic effects to large scale facies changes and faults. Twenty years of production have required several techniques to produce oil from these heterogeneities. Mapping of the waterflood history indicates significant injection anomalies which have effected production.

Weimer, R. J., J. J. Emme, C. L. Farmer, L. O. Anna, T. L. Davis, and R. I. Kidney, 1982, Tectonic influence on sedimentation, Early Cretaceous, east flank Powder River Basin, Wyoming and South Dakota: Quarterly of Colo. School of Mines, v. 77, no. 4, 62 p.

A review of the effect of structural changes on stratigraphic units in the Powder River Basin. Most oil entrapment in the basin is due to structural development following sedimentation.

Weimer, R. J., C. A. Rebne, and T. L. Davis, 1988, Geologic and seismic models, Muddy Sandstone, Lower Cretaceous, Bell Creek-Rocky Point area, Powder River Basin, Montana and Wyoming: Wyoming Geol. Assoc. 39th Field Conf. Guidebook, Eastern Powder River Basin-Black Hills, p. 161-177.

The Muddy Sandstone in the northern Powder River Basin consists of two genetic units (members) that are separated by a widespread subaerial surface of erosion. The older sandstone member, comprising the reservoir rock at Bell Creek Field, was deposited in shoreline and associated nearshore marine environments. The younger member is a valley fill deposit of fluvial, estuarine and tidal flat environments.

Deposition and distribution of these two genetic units was controlled primarily by relative sea level changes. The Bell Creek sandstone (the older unit) was deposited as a widespread regressive sandstone during a high stand of sea level. A following sea level lowstand caused valley cutting, erosion of all or portions of the Bell Creek sandstone, and paleosol development causing early diagenesis. A rising sea level resulted in valley filling (the younger unit); coastal onlap and a transgressive surface of erosion that is overlain by black marine shale.

Recurrent movement on basement-controlled fault blocks appears to have controlled distribution of the Muddy members, drainage incisement patterns, present structure and heat flow, and possibly petroleum migration.

Seismic modeling indicates that it is possible to seismically distinguish Muddy facies changes. A strong Muddy amplitude is associated with a thick valley fill facies, while a low amplitude corresponds to the Bell Creek sandstone.

Wheeler, D. M., E. R. Gustason, and M. J. Furst, 1988, The distribution of reservoir sandstone in the Lower Cretaceous Muddy Sandstone, Hilight Field, Powder River Basin, Wyoming: in Giant Oil and Gas Fields, a core workshop, SEPM Core Workshop, Houston, TX., p. 179-228.

The Lower Cretaceous Muddy Sandstone produces oil from thin fluvial and shallow marine sandstones in the Hilight Field. Sea level changes and tectonic movements governed the deposition of the units. The Muddy Sandstone was deposited during a rise in sea level. The Muddy Sandstone was deposited as valley fill in channels cut into the underlying Skull Creek Shale. Two lower members of the Muddy Sandstone are fluvial and fluvial-estuarine deposits in the valley fill. These deposits are scattered and thin and produce only minor amounts of oil. The upper members are fluvial-deltaic and barrier island deposits. The barrier island sands are thicker and good oil producers as are the delta front sands.

Three northeast-trending structural lineaments cross the Hilight Field. Tectonic movement occurred along these lineaments before and during the early Cretaceous, and developed the drainage system which the Muddy Sandstone fills. Recurrent movement allowed the barrier islands sands to become stacked. Maps, cores, and reconstructions are used to illustrate the stratigraphic and structural development of the Hilight Field.

Wyoming Geological Association, 1981, Powder River Basin Oil and Gas Fields (2 vols.): Wyoming Geol. Assoc., 472 p.

A complete survey through 1980 of the oil and gas fields drilled in the Powder River Basin of Wyoming. The fields are listed alphabetically by name. Information for each field includes: range and township location; date of discovery; general field data on number of wells, dates, and production; reservoir data on formation, lithology and oil statistics; a general discussion of the field history; and maps of the structure of the field.

C. SAN JUAN BASIN

The San Juan Basin is on the eastern part of the Colorado Plateau and covers northwest New Mexico and a portion of southwest Colorado. The Puerco Fault Zone forms the southeastern boundary of the San Juan Basin. The eastern part of the basin is bounded by the Rio-Grande Rift and the Nacimiento Uplift. The Colorado Plateau forms the boundary along the southwest, west, north and northeast (Woodward and Callender, 1977). Structural features in the San Juan Basin are the Four Corners Platform, Defiance Uplift, Zuni Uplift, and the Gallina-Archuleta Arch (Woodward and Callender, 1977).

Sedimentary deposits in the basin include Cretaceous and early Tertiary age sandstones, primarily of the Mesaverde Group. The Cliff House, Pictured Cliffs and Crevasse Canyon and Gallup formations are barrier island deposits. Exploration of these reservoirs has led to the discovery of large natural gas and oil reserves.

Arnold, E. C., J. M. Hill, K. S. Hatton, L. B. Martinez, and D. A. Donaldson, 1978, Stratigraphy and oil and gas production of northwest New Mexico: *in* Fassett, J. E., N. D. Thomaidis, M. L. Matheny, and R. A. Ullrick, eds, *Oil and Gas Fields of The Four Corners Area*, v. 1, Four Corners Geological Society, p. 46-61.

The stratigraphic history of the Four Corners area is reviewed. Oil and gas production in this area is due more to stratigraphic traps than to structural deformation.

Beaumont, E. C., 1957, The Gallup Sandstone as exposed in the western part of the San Juan Basin: Four Corners Geological Society, *Geology of SW San Juan Basin*, Second Field Conference, p. 114-120.

This paper gives a detailed stratigraphy of the Gallup Sandstone in the San Juan Basin.

Budd, H., 1957, Facies Development of the Gallup Formation: Four Corners Geological Society, *Geology of SW San Juan Basin*, Second Field Conference, p. 121-127.

Brief description of Upper Cretaceous Gallup gradation from a porous massive sandstone on the southwest flank to a black calcareous shale on the northeast side of the San Juan Basin.

Campbell, C. V., 1971, Depositional model-Upper Cretaceous Gallup beach shoreline, Shiprock area, northwestern New Mexico: *Jour. Sed. Petrology*, v. 41, p. 395-409.

Gallup regressive beach deposits are overlain unconformably by upper Gallup transgressive offshore-bar sandstones. The offshore bars formed on a shallow shelf that may be up to 100 miles wide; one documented offshore bar that is contemporaneous to the studied shoreline sandstones is 12 miles offshore, but others are at several multiples of that distance. Deposition of offshore bars was localized at a seaward steepening or break in slope of the sea floor amounting to less than 1 degree increase in slope.

Campbell, C. V., 1979, Model for beach shoreline in Gallup Sandstone (Upper Cretaceous) of northwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 164, 32 p.

This model includes a lower regressive beach sandstone overlain unconformably by an upper transgressive offshore-bar sandstone. Landward, the beach sandstones interfingers with coal-swamp deposits or is truncated and overlain by dune sandstones. Seaward, the beach sandstones grades through shoreface sandstones into a transition zone that gives way to offshore siltstone and mudstone. Offshore siltstone and mudstone overlie and, in part, grade laterally into offshore-bar sandstone that has no contiguous landward equivalents and transgresses all beach and related facies.

Cumella, S. P., 1981, Sedimentary history and diagenesis of the Pictured Cliffs Sandstone, San Juan Basin, New Mexico and Colorado: M.S. Thesis, University of Texas, Austin, 219 p.

A detailed analysis of the deposition of sediments and subsequent diagenetic changes in the Picture Cliffs Sandstone. The Picture Cliffs is a barrier island deposited in a regressive sequence. Maps and illustrations are included.

Curtis, B. F., R. K. Kirkbride, W. S. McCabe, M. D. Picard, M. D., and F. I. Pritchett, Jr., 1957, Nature of Rocky Mountain stratigraphic fields: *AAPG Bull.*, v. 41, p. 813-822.

One of the examples is Bisti Field a regressive Gallup Sandstone member of the Mesaverde Formation. Micaceous shales are interpreted as lagoonal or tidal flat deposits. Clean sandstone grades updip into tight shaley lagoonal beds, basinward into marine silty and sandy shales.

Devine, P. E., 1980, Depositional patterns in the Point Lookout Sandstone, Northwestern San Juan Basin, New Mexico: M.S. Thesis, University of Texas, Austin, 238 p.

A detailed description of the Point Lookout Sandstone is presented. The Point Lookout Sandstone is a strand-plain deposit of coarsening upward layers. The deposits represent the reworked shoreline of lagoons and estuary environments. Numerous maps, correlations and textural features are used to illustrate the depositional patterns.

Devine, P. E., 1991, Transgressive origin of channeled estuarine deposits in the Point Lookout Sandstone, northwestern New Mexico: a model for Upper Cretaceous, cyclic regressive parasequences of the U. S. Western Interior: AAPG Bull., v. 75, no. 6, p. 1039-1063.

A model for regressive and transgressive phases of the Western Seaway is based on strandline deposits in the San Juan Basin, New Mexico. Strand-plain progradation occurs during regressive phases. This produces upward-coarsening shoreline deposits. During the transgressive phase deposition occurs landward of a reworked shoreline and deposits are lagoonal-estuarine environments.

Transgressive backbarrier deposits from Point Lookout Sandstone outcrops are used as examples. The facies described include; fine grain lagoonal deposits, and upward fining cross-bedded sandstones deposited by migrating tidal channels. The estuary formed by infilling of the backbarrier lagoon during episodic transgressions. The transgressive estuarine deposits at Point Lookout are the best hydrocarbon reservoirs. Each estuarine unit is a discrete reservoir. These estuarine units have been mapped and are used to develop a predictive model for further exploration.

Devlin, F. J., and J. Q. Tomkins, 1957, The Bisti area, San Juan County, New Mexico: Four Corners Geological Society, Geology of SW San Juan Basin, Second Field Conference, p. 152-154.

A short history of Gallup and Tociito production and local stratigraphy is presented.

Donselaar, M. E., 1984, Flood tidal delta sedimentation in the Late Cretaceous Menefee Formation (Mesaverde Group), San Juan Basin, northwest New Mexico: Geologie en Mijnbouw, v. 63, p. 323-331.

The Menefee Formation of northwestern New Mexico consists largely of deltaic plain and nearshore deposits. The sediments were deposited along the west coast of the Cretaceous Seaway. The Upper Menefee is a sequence of sandstone bodies embedded in carbonaceous shales of coastal swamp and lagoonal origin. The sandstone bodies are lobate and were deposited in flood tidal deltas. Study of models based on these tidal deltas indicates the changes in sea level and the interaction of deltas and tidal inlets on the barrier coast of the Cretaceous Seaway.

Donselaar, M. E., 1989, The Cliff House Sandstone, San Juan Basin, New Mexico: Model for the stacking of "transgressive" barrier complexes: Jour. Sed. Petrol. v. 59, p. 13-27.

The Cliff House Sandstone is represented by linear sandstone bodies deposited in successive phases along the western margin of the Cretaceous Seaway. Analysis of lithofacies, spatial relationships of facies and geometry indicate a storm-dominated tidal barrier island coast for the upper unit of the Cliff House Sandstone. Four stacked

sand bodies are separated by sharp erosional bases. The deposition as barrier island occurred during a regressive phase between major transgressions. Erosion during the later transgression destroyed all but the low lying parts of the barrier, shoreface, tidal inlets, and lagoonal deposits.

Fassett, J. E., 1977, Geology of the Point Lookout, Cliff House and Pictured Cliffs Sandstones of the San Juan Basin, New Mexico and Colorado: New Mexico Geol. Soc. Guidebook, 28th Field Conf., San Juan Basin III, p. 193-197.

Point Lookout, and sequences of the Pictured Cliffs are regressive; the Cliff House is more transgressive. A table of subsurface wells used in the analysis is presented. The purpose was to discuss the subsurface geometry of the three units and compare them.

Fassett, J. E., and J. S. Hinds, 1977, Geology and Fuel Resources of the Fruitland Formation and Kirtland Shale of the San Juan Basin, New Mexico and Colorado (abst.): New Mexico Geol. Soc. Guidebook, 28th Field Conf., San Juan Basin III, p. 207.

This is the abstract from USGS Professional Paper 676, which is a companion volume to the New Mexico Geology volume. The 1971 USGS volume details the subsurface and surface stratigraphy of Pictured Cliff Sandstone, Fruitland Formation, Kirtland Shale, and Ojo Alamo Sandstone throughout the San Juan Basin.

Franklin, S. P. and T. T. Tieh, 1988, Diagenetic controls of petrophysical properties of Dakota Sandstone, West Lindrith Field, Rio Arriba County, New Mexico (abst.): AAPG Bull. v. 72, no 2, p. 186.

West Lindrith Field is on the eastern margin of the San Juan Basin. The basin consists of coarsening upward, shallow marine sandstones interstratified with marine shales of Cretaceous Age. The fine to medium grained sandstones have been extensively altered in the diagenetic process. Compaction, authigenesis and dissolution were the major agents of change. The porosity, permeability and water saturation of the rocks show a variation in the degree of alternation. At one end of the spectrum are clean sands deposited by currents that are silica cemented and have high porosity, permeability and low water saturation. Intermediate are sandstones interbedded with shales. These are carbonate cemented and have very low reservoir potential. At the opposite end of the spectrum are shaly sandstones deposited in low-energy environments. These are fine grained, bioturbated and have low porosity, very low permeability and high water saturation.

Franklin, S. P., and T. T. Tieh, 1989, Petrography, diagenesis, and reservoir properties of the Dakota Sandstone of West Lindrith Field, Rio Arriba County, New Mexico: in E. B. Coalson, et al., eds, Petrogenesis and Petrophysics of Selected Sandstone

Reservoirs of the Rocky Mountain Region, Rocky Mountain Assoc. Geol., Denver, CO., p. 117-134.

West Lindrith Field is on the eastern margin of the San Juan Basin, New Mexico. The producing zone at West Lindrith Field is the Upper Cretaceous Dakota Sandstone. The Dakota Sandstone is a series of upward coarsening shallow-marine, sandstones interbedded with shale. The sandstones are very fine to medium-grained litharenites. They have been diagenetically altered by compaction, authigenesis and dissolution.

The Dakota Sandstone at West Lindrith Field averages 180 to 260 ft of stacked sandstone layers in four recognizable units. The sandstone lenses are interbedded with shales that act as source rock and seal for hydrocarbons. The diagenetic history of the region is complex and the sandstones have undergone repeated periods of alteration. Multivariate factor analyses of petrographic data has been used to define the environments, diagenesis, and reservoir quality. Reservoir properties for the four units vary with primary lithology and the type and degree of diagenetic alteration. Log correlations, structural maps and photographs of cores are used to describe the West Lindrith reservoir.

Hook, S. C., 1983, Stratigraphy, paleontology, depositional framework, and nomenclature of marine Upper Cretaceous rocks, Socorro County, New Mexico: 34th Annual New Mexico Geol. Soc. Field Conference Guidebook, p. 165-172.

Barriers are present in the following: (1) Atarque Sandstone member of Tres Hermanos Formation is regressive coastal-barrier or shoreface complex. It was deposited along a low energy shoreline. Wave energy was not great. Tidal currents were important depositional agents. (2) The Fite Ranch Sandstone member of the Tres Hermanos Formation is a well-developed coastal barrier sandstone with an upward coarsening sequence. (3) The Gallup Sandstone consists of a series of northeast prograding coastal-barrier or delta-front sandstones that grade seaward into the Mancos Shale, and intertongue landward with nonmarine coastal deposits. This study was based on outcrops, paleontology, and field mapping.

Jacobs, J. L., 1977, Some Recent shallow Pictured Cliffs gas discoveries: New Mexico Geol. Soc. Guidebook, 28th Field Conf., San Juan Basin III, p. 247-249.

In the 1970's four small, shallow gas pools were discovered in the Pictured Cliff Sandstone near Farmington, New Mexico. These pools have thin pay zones, low bottom-hole pressures, and low recoverable reserves. The shallow depth of the small pools makes their gas recovery economical.

King, V. L., and S. A. Wengerd, 1957, The Hospah oil field. McKinley County, New Mexico: Four

Corners Geological Society, Geology of SW San Juan Basin, Second Field Conference, p. 155-168.

This is a good summary of the history of exploration, regional stratigraphy, structure, and production from the Hospah Field. Production is from Hospah Upper Gallup interval, from a combination stratigraphic-structural trap. Hydrodynamic drive is strong in this field.

Kirk, C. L., E. B. Montgomery, R. Knapp, R. Dow, J. R. Lukas, and K. A. Barrie, 1983, Bibliography of theses and dissertations on New Mexico, 1968-1982: Mountain Geologist, v. 20, no. 2, p. 63-81.

These references are listed alphabetically by author.

Kirk, A. R., and Zech, R. S., 1977, The transgressive and regressive relationships between the Upper Cretaceous Mulatto Tongue of the Mancos Shale and the Dalton Sandstone Member of the Crevasse Canyon Formation, Gallup-Pinedale area, New Mexico: New Mexico Geol. Soc. Guidebook, 28th Field Conf., San Juan Basin III, p. 185-192.

Upper and lower units of the Dalton sandstone members are regressive coastal barrier sandstones. Lower shoreface, upper shoreface, and foreshore are overlain by paludal (swamp/marsh) deposits. Description of a strand plain backed by marshes or swamps is provided. This is an outcrop study.

Mannhard, G. W., 1976, Stratigraphy, sedimentology, and paleoenvironments of the La Ventana Tongue (Cliff House Sandstone) and adjacent formations of the Mesaverde Group (Upper Cretaceous), Southeastern San Juan Basin, New Mexico: Ph.D. Dissertation, The University of New Mexico, 182 p.

The study is based on seven measured sections along an outcrop belt that is nearly parallel to depositional dip. Delatic sedimentation in this area is represented in the Menefee Formation which represents the fresh water aggradational delta plain deposits, the La Ventana Tongue the marine delta front transgressive and progradational deposits, and the Lewis Shale the offshore prodelta deposits.

Five facies recognized in the La Ventana Tongue are: (1) fining upward destructional delta front sheet sandstone, (2) thin bedded tabular sandstone deposited in the offshore area during storms, (3) thick coarsening upward progradational delta front sheet sandstones from areas of relatively high sediment input, (4) tabular cross-stratified sandstone with shale interbeds, interpreted as channel mouth bar deposits, and (5) lenticular tidal inlet channel sandstones. Virtually no mention of barriers is made in this interpretation.

La Ventana delta prograded into shallow water gently sloping shelf under conditions of relatively high wave energy relative to sediment input. The stratigraphic framework is similar to the modern Rhone delta, the

Pleistocene Surinam cusped delta, and abandoned shoal water Mississippi deltas.

Matheny, M. L., and D. M. Thomas, Jr., 1957, The Gallegos-Gallup Field, San Juan County, New Mexico: Four Corners Geological Society, Geology of SW San Juan Basin, Second Field Conference, p. 147-151.

Gallegos-Gallup Field is a stratigraphic oil field with an updip gas cap. Production is primarily from fractures in siltstones and shaley sandstones of the Gallup Formation.

McNeal, R. P., 1961, Hydrodynamic entrapment of oil and gas in Bisti Field, San Juan County, New Mexico: AAPG Bull., v. 45, no. 3, p. 315-329.

The Bisti Field produces oil and gas from the Cretaceous age Gallup Sandstone in the San Juan Basin, New Mexico. The deposit is a series of lenticular bodies up to 30 miles long. The sandstones units are shoreline barrier deposits. The entrapment is stratigraphic as shales from marine and deltaic deposits surround the sandstone units. The oil column averages 200 ft in most of Bisti Field. Hydrodynamic processes serve to entrap and move the fluids in the sandstone by capillary pressure. Pressure increases at Bisti Field with depth at a rate of 0.303 psi per foot.

Molenaar, C. M., 1973, Sedimentary facies and correlation of the Gallup Sandstone and associated formations, northwestern New Mexico: Four Corners Geological Society Memoir Book, p. 85-110.

The Upper Cretaceous Gallup Sandstone is regressive clastic wedge that prograded about halfway across the San Juan Basin from sources in southwestern Arizona. Numerous closely spaced outcrop sections were used to determine details of correlations of the complex of marine coastal barrier sandstones and associated nonmarine paludal mudstones, coal beds, and fluvial channel sandstones that comprise the formation.

There is a discussion of barrier facies: lower shoreface, upper shoreface, and foreshore. Vertical succession in their figure 3 is a classical coarsening upward barrier with root-mottled zone at top (barrier island).

Molenaar, C. M., 1977, Stratigraphy and depositional history of Upper Cretaceous rocks of the San Juan Basin area, New Mexico and Colorado, with a note on economic resources: New Mexico Geol. Soc. Guidebook, 28th Field Conf., San Juan Basin III, p. 159-166.

A correlation chart that labels marine and coastal barrier sandstones is presented. The author uses the term coastal barrier for barrier island and non-barrier island shoreline sandstones. The Semilla Sandstone member of Mancos Shale is a discontinuous offshore sandstone bar in the SE part of the basin. The Semilla is the offshore equivalent of and derived from the lower regressive coastal-barrier sandstone of the lower Gallup. Several elongate offshore

bars occur above and seaward from the regressive Gallup (lower part). These sandstones bars are oil productive and have been referred to as transgressive Gallup, Tocito, or basal Niobrara sandstones. The Dalton Sandstone is a regressive coastal-barrier sandstone that is included in the Crevasse Canyon formation, above the Gallup. The Dalton Sandstone member of the Crevasse Canyon is a typical regressive coastal-barrier sandstone. The Hosta tongue of the Point Lookout Sandstone is a fining-upward deepening water sandstone.

In the Mesaverde Group the basal Point Lookout Sandstone is a regressive coastal-barrier sandstone. The middle unit, the Menefee Formation is nonmarine-paludal to alluvial-plain landward of the Point Lookout and Cliff House shorelines. The upper unit, the Cliff House Sandstone, is a shoreline-barrier, in an overall transgressive cycle, but deposited during stillstands or regressions of the shoreline. The Pictured Cliff Sandstone is a regressive coastal barrier sandstone.

Economic resources of the Upper Cretaceous units in San Juan Basin are listed. This basin contains the nations third largest gas field, Blanco gas field, with estimated recovery of 23 TCF gas plus significant amount of condensate. The Dakota sandstone produces oil in several small structurally controlled fields on basin flanks of the Hogback, Table Mesa, and Rattlesnake fields. Most of the oil in the basin is from stratigraphic traps in transgressive Gallup or basal Niobrara sands. The estimated ultimate recovery is 40 MMBBL. The only production from the regressive Gallup Sandstone is at Hospah Field, which is structurally controlled, and has produced 11.5 MMBBL as of 1974.

Molenaar, C. M., 1983, Principal reference section and correlation of Gallup Sandstone, Northwestern New Mexico: Contributions to Mid-Cretaceous Paleontology and Stratigraphy of New Mexico Part 2: New Mexico Bur. Mines Mineral Resources Circular No. 185, p. 29-40.

An index Map shows the subsurface control throughout the basin. The principal reference section includes an interval interpreted as regressive coastal barrier overlying marine mudstones and overlain by paludal sediments. The study is based on outcrops.

Noon, P. L., 1980, Surface to subsurface stratigraphy of the Dakota Sandstone (Cretaceous) and adjacent units along the eastern flank of the San Juan Basin, New Mexico and Colorado: M.S. Thesis, Bowling Green State University.

Deposition of Dakota Sandstone was in response to regional transgression of the Western Interior Sea during Cenomanian time. Within the overall transgression, there were minor regressions which may have been brought about by local progradation related to increased local sediment supply. The Cubero, Paguate, and Twowells

sands were deposited by southward flowing paleocurrents oriented approximately parallel to the shoreline.

Twowells, Paguate, and Cubero sandstone bodies all show coarsening upward patterns on logs. Northwest trends within the Twowells may represent offshore bars derived from a northwestern source, or linear sand shoals derived from shoreface sands.

Parker, J. M., E. A. Riggs, and W. L. Fisher, 1977, Oil and gas potential of the San Juan Basin: New Mexico Geol. Soc. Guidebook, 28th Field Conf., San Juan Basin III, p. 227-234.

Mesozoic potential is limited, because much of the section has been eroded or crops out. So little of this section is preserved in the subsurface that its resource potential is negligible. In the San Juan Basin, most of the resource potential in the Mesozoic section is proven, but undeveloped. The best potential for future development is within the Middle to Upper Paleozoic carbonate section.

Peterson, F., and A. R. Kirk, 1977, Correlation of the Cretaceous rocks in the San Juan, Black Mesa, Kaiparowits, and Henry Basins, southern Colorado Plateau: New Mexico Geol. Soc. Guidebook, 28th Field. Conf., San Juan Basin III, p. 167-178.

Correlations show general depositional environments for formations including coastal barrier and nearshore marine sandstones, especially in Toreva and Dakota sandstones.

Peterson, J. A., A. J. Loleit, C. W. Spencer, and R. A. Ullrich, 1968, Sedimentary history and economic geology of San Juan Basin, New Mexico and Colorado: AAPG Mem., no. 10, p. 186-231.

A good correlation chart, structural contour map, and map of oil and gas fields of the San Juan Basin, and isopach maps by age and formation are presented. The author notes that the Gallup Sandstone is no longer considered the basal part of the Mesaverde Group, but stands alone.

Reneau, W. E., Jr., 1957, Reservoir characteristics of Cretaceous sands of the San Juan Basin: Four Corners Geological Society, Geology of SW San Juan Basin, Second Field Conference, p. 40-43.

This is a good, short summary of the Pictured Cliffs, Mesaverde Group, Gallup Formation, Tocito, and Dakota reservoirs.

Ridgley, J. L., 1977, Stratigraphy and depositional environments of Jurassic-Cretaceous sedimentary rocks in the southwest part of the Chama Basin, New Mexico: New Mexico Geol. Soc. Guidebook, 28th Field Conf., San Juan Basin III, p. 153-158.

Environments of deposition in this area include the Entrada Sandstone (eolian), Todilto Limestone (lacustrine);

and the Morrison Formation; a variety of continental fluvial and lacustrine environments. The Burro Canyon Formation is a series of high-energy braided to meandering streams. The Dakota Sandstone basal unit is dominantly fluvial. The middle unit is fluvial and shallow marine. The upper unit is a variety of near-shore littoral environments deposited as the sea transgressed toward the south-southwest.

Sabins, F. F., Jr., 1962, Stratigraphy, petrography and paleoecology of Bisti stratigraphic trap, San Juan Basin (abst.): AAPG Bull. v. 46, no 2. p. 277-278.

Bisti Field produces oil from bar sands in the Upper Cretaceous Gallup Sandstone of New Mexico. The main Gallup Sandstone facies are offshore and beach sands. The offshore sands are overlain by three units of bar sands. The bar sands are 30 miles long, up to 3 miles wide and 40 ft thick. The bars grade seaward into fine-grained fore-bar facies, and landward into back-bar facies. The lithology of the bar sands shows subrounded medium grained quartz with some feldspar, chert and rock fragments. Glauconite is abundant and dolomite is rare. The cement and matrix are clay, calcite and quartz.

The Bisti sand is a stratigraphic trap. The Mancos Shale overlies the Gallup Sandstone. It was deposited during a basin-wide period of subsidence and serves as a seal to the Gallup Sandstone.

Sabins, F. F., Jr., 1963, Anatomy of stratigraphic trap, Bisti Field, New Mexico: AAPG Bull., v. 47, p. 193-228.

The depositional history of Bisti Field began with regressive deposition interrupted by a pulse of subsidence and possibly a minor disconformity after which the low Spontaneous potential (SP) interval was deposited. Wave action winnowed the mud from this sediment and concentrated the sand as a series of bars. A restricted marine environment (lagoon) existed on the landward side of the bar complex and open marine environment on the seaward side. The abstract does not mention subaerial exposure at any time.

Sabins, F. F., Jr., 1972, Comparison of Bisti and Horseshoe Canyon Stratigraphic traps, San Juan Basin, New Mexico: AAPG Mem. no. 16, p. 610-622.

Bisti and Horseshoe Canyon Fields produce from sandstone bodies of Late Cretaceous age in the San Juan Basin of northwest New Mexico. The fields are stratigraphic traps formed in linear sandstone units enclosed in marine shales. The Bisti Formation was deposited as a marine bar sandstone. The lower Tocito reservoir in Horseshoe Canyon is a marine sandstone. The upper Tocito at Horseshoe Canyon is a barrier-bar sandstone.

The Bisti bar-sandstone and the upper Tocito producing units in the Horseshoe Canyon Field are at the same stratigraphic level. There is an unconformity below the Tocito at Horseshoe Canyon, but the Bisti Sandstone grades downward into a sandy marine shale. Comparisons

of the stratigraphy and petrography of these two nearby fields of similar age suggest different origins for the deposits.

Speer, W. R., 1957, Verde-Gallup Pool, San Juan County, New Mexico: Four Corners Geological Society, Geology of SW San Juan Basin, Second Field Conf., p. 141-146.

The Verde-Gallup pool produces oil from fractures within the final regressive phase of the Lower Gallup sandstone and shale interval.

Struna, S. M., and F. H. Poettmann, 1986, In-situ combustion in the Lower Hospah Formation, McKinley County, New Mexico: SPE 14917, SPE 5th Enhanced Oil Recovery Symposium, Tulsa, OK, p. 469-482.

In the early 1980's the South Hospah Field was selected for an in-situ combustion pilot project. Production was from the Lower Hospah Formation and the reservoir appeared to meet all criteria. Test results were poor and only minor amounts of incremental oil was recovered. A model was made to test the problems which occurred at the site. The failure of the in-situ test has been contributed to the migration of the combustion front beneath the oil zone, processing of an interval of low oil saturation and the resulting very large air-oil ratios.

Tomkins, J. Q., 1957, Bisti Oil Field, San Juan County, New Mexico: AAPG Bull., v. 41, p. 906-922.

Production is from the Gallup Sandstone Formation, Mesaverde Group of Upper Cretaceous age. Bisti Field is a stratigraphic trap. The author interprets the reservoir as an offshore sandbar.

Valasek, D. W., 1990, Compartmentalization of shoreface sequences in the Cretaceous Gallup Sandstone west of Shiprock, New Mexico: Implications for the position of tidal deposits in the rock record (abst.): in Davis, R.A., Jr., D. Nummedal, and R.W. Tillman, Conveners, Tidal Inlet and Related Sand Bodies: Modern and Ancient: SEPM Research Conference San Juan Basin, New Mexico, May, 1990, pages unnumbered.

The Cretaceous Gallup Sandstone exposed west of Shiprock, New Mexico, is a seaward-stepping progradational unit capped by a transgressive sequence. The seaward progradational event is divided into eleven, one to three km wide compartments bounded by time significant surfaces. Compartments are further divided into 0.1 to 0.5 km wide sub-compartments termed shingles. A wave to tidal dominated facies transition occurs within compartments.

The transgressive sequence (Tocito) is composed of thick clastic tidal deposits. Common sedimentary structures include double mud drapes, reactivation surfaces, dewatering structures, and sigmoidal laminations. The Tocito occupied an estuarine setting at the most seaward extension of the shoreline upon initial transgression. The tidal deposits thin and are transitionally replaced by bioturbated clastic shelf deposits landward.

Van Couvering, M., 1958, Geology of southwestern San Juan Basin, by Four Corners Geological Society San Juan (Book Review): AAPG Bull., v. 42, p. 1100-1106.

The San Juan Basin and parts of northwestern New Mexico are covered in a road log and fieldguide. Two fold out maps include the geology of northwest New Mexico and an oil and gas survey of the western San Juan Basin. Numerous short papers are on regional geology, oil and gas exploration, and stratigraphy.

Woodward, L. A., and J. F. Callender, 1977, Tectonic framework of the San Juan Basin: New Mexico Geol. Soc. Guidebook, 28th Field Conf., San Juan Basin III, p. 209-212.

The San Juan Basin on the eastern Colorado Plateau has only been moderately deformed compared to adjoining Basin and Range structures. The effect on the Cordilleran Foldbelt on the formation of the Colorado Plateau and San Juan Basin are discussed and illustrated. Details of the structure of the uplifts surrounding the San Juan Basin are described.

D. OTHER ROCKY MOUNTAIN BASINS

Other Rocky Mountain basins besides the Greater Green River, Powder River and San Juan basins have important reservoirs that may yield information to the study of barrier island reservoirs and the improved recovery of hydrocarbons. Consideration of the structure and sedimentary geology of the entire Rocky Mountain area and its basins is basic to reservoir characterization and useful to the analysis of barrier island deposits. General summary papers that discuss several basins in the Rocky Mountains are included in this section.

Baars, D. L., et al., 1988, Chapter 8. Basins of the Rocky Mountain region: *in* Sloss, L.L., ed., *Sedimentary Cover—North American Craton*; U.S.: Boulder, Colorado, Geological Society of America, *The Geology of North America*, v. D-2, p. 109-220.

Covers the following basins: Paradox, Eagle (northwestern Colorado), San Piceance Creek (Colorado/Utah), Greater Green River, basins of the Rio Grande Rift, Raton and Huerfano Park, South Park, Denver, Wind River, Bighorn, Powder River.

Bibler, C. J., and J. G. Schmitt, 1986, Barrier-Island coastline deposition and paleogeographic implications of the Upper Cretaceous Horsethief Formation, Northern Disturbed Belt, Montana: *The Mountain Geologist*, v. 23, no. 4, p. 113-127.

The Horsethief Formation was deposited along a barrier island coastline in the western margin of the Western Interior Cretaceous Seaway. In the lower part of the Horsethief the units are transgressive while those in the upper part are regressive. The sandstone units in the Upper Horsethief Formation have a high volcanic rock fragment content. Stratigraphic units are defined and illustrated and petrographic data is tabulated.

Bolyard, D. W., 1975, Deep Drilling Frontiers of the Central Rocky Mountains: Rocky Mountain Assoc. Geol. Symposium, 254 p.

A series of papers is presented dealing with exploration and drilling discoveries and difficulties in the Central Rocky Mountains. Basins and structural features are analyzed and the stratigraphy is correlated well to well within basins and to a lesser extend from basin to basin. Most of the papers deal with hydrocarbon reserves in central and southwestern Wyoming, northeastern Utah, and northeast and northwest Colorado.

Cobban, W. A., 1955, Cretaceous rocks of northwestern Montana: Billings Geological Society, 6th Annual Field Conference, p. 107-119.

General stratigraphic nomenclature is applied to Cretaceous rocks in Montana. Specific stratigraphic information is somewhat dated.

Dickinson, K. D., H. L. Berryhill, Jr., and C. W. Holmes, 1972, Criteria for recognizing ancient barrier coastlines: *in* Rigby, J.K., and W. K. Hamblin,

eds., *Recognition of Ancient Sedimentary Environments*, SEPM Spec. Pub. no. 16, p. 192-214.

This appears to be one of the best relatively early papers that describes modern barrier coastline attributes (eg. facies, geometry, physiography, fauna, and internal structure of the sand bodies) as well as the ancient barriers. Numerous examples of ancient barrier islands are cited and referenced including those from Bisti Field (Gallup Sandstone), Eagle Sandstone (Montana), Bell Creek Field (Muddy Sandstone), Bartlesville shoestring sands (Kansas), and ancient Gulf Coast barriers.

Dickinson, W. R., et al., 1988, Paleogeographic and paleotectonic setting of Laramide sedimentary basins in the central Rocky Mountain region: *Geol. Soc. America Bull.*, v. 100, p.1023-1039.

From central New Mexico to central Montana isolated sedimentary non-marine basins were formed by basement deformation during the Laramide Orogeny. These basins are found in the large Late Cretaceous foreland basin.

Twelve specific stratigraphic and sedimentological criteria have been established to study the chronology of basin formation. The Maastrichtian beginning of the Laramide deformation was synchronous throughout the western region, but its termination varied from north to south during the Eocene. Eocene erosion surfaces truncate Laramide sequences and are in turn overlain by volcanic sediments of late Eocene and Oligocene age. Isolated basins are of two types: (1) fluvial depo-centers in perimeter and axial basins, and (2) ponded basins occupied by large lakes. Structural maps and diagrams are used to illustrate the position and chronology of the basins formation. Lithostratigraphic columns from several basins are compared and aligned to demonstrate the sedimentation patterns from basin to basin across the region.

Gill, J. R. and W. A. Cobban, 1973, Stratigraphy and geologic history of the Montana Group and equivalent rocks, Montana, Wyoming, and North and South Dakota: Geological Survey Prof. Pap. 776, p. 1-37.

An epicontinental sea covered the western interior of North America from the Gulf of Mexico to the Arctic Ocean during the Late Cretaceous. The rising Rocky Mountain Cordillera separated the epicontinental sea from the Pacific Ocean. A span of 14 million years is recorded by twenty-nine distinctive ammonite zones on the margins of the epicontinental sea representing the marine strata. Strandlines mark the deposition of the Fox Hills Formation in Montana and the Mesaverde Formation in Wyoming.

In central Montana strandline movements were more rapid during periods of transgression. The Telegraph Creek and Eagle strandlines average 50 miles per million years. During the Claggett deposition movement was 95 miles per million years. The Judith River regression was 60 miles per million years and the Bearpaw advance was 70 miles per million years. These regression are plotted out on maps using detailed correlations with ammonite species. During the final retreat of the marine waters from Montana (the Fox Hills regression) movement accelerated from 35 miles per million years to 500 miles per million years.

Sedimentation rates of 50 feet per million years in North and South Dakota correspond to modern open ocean deposition. High deposition rates up to 2,500 feet per million years in western Wyoming equate to modern coastal sedimentation.

Jordan, T. E., 1981, Thrust loads and foreland basin evolution, Cretaceous, Western United States: AAPG Bull., v. 65, no 12, p. 2506-2520.

An analysis of thrust belt movements and regional isostatic compensation by flexure of sedimentary deposits is presented. The Cretaceous Rocky Mountain foreland basins are used as examples. Loading observed along the Idaho-Wyoming thrust belt is used in the development of a two-dimensional model. Downwarping and the shape and thickness of the sedimentary wedge on the Western Interior Seaway is discussed. Erosion redistributed part of the load in the Late Cretaceous and spread the subsidence over a broad area. The paleotopography of the Cretaceous foreland basins is compared to the modern foreland thrust belt and basin system of the South American Andes Mountains. Basin topography is controlled by thrust faulting, ramp zones and isotatic subsidence.

Lawson, D. E., 1962, Geology of the Grieve Field, Natrona County, Wyoming: Wyoming Geol. Assoc. 17th Field Conf. Guidebook, p. 284-303.

Grieve Field is in the extreme southeastern part of the Wind River Basin along the flanks of the Rattlesnake Mountains. Production is from the Lower Muddy Sandstone. Oil entrapment is a combination of a downdip structural barrier and the absence of sandstone below the Lower Muddy. At the time this paper was written there was a question of the stratigraphic relationship of units in this region. The producing layer was thought to be an unrelated sand termed the Grieve Sandstone. Environmentally the sandstone was recognized as a channel scour zone in the Skull Creek Shale.

McGee, H. W., H. J. Meyer, and T. R. Pringle, 1989, Shallow geothermal anomalies overlying deeper oil and gas deposits in Rocky Mountain region: AAPG Bull. v. 73, no. 5, p. 576-597.

Eight Rocky Mountain oil and gas fields have shallow geothermal hot spots at depths from 10 ft (3 m) to 500 ft (150 m). Similar shallow, low temperature geothermal anomalies were first reported by the Russians. The fields studied were: Wattenberg Field, Colorado; Bennett Field,

Colorado; Peoria Field, Colorado; South Swan Hills Field, Alberta, Canada; Antelope Field, North Dakota; Redwing Creek Field, North Dakota; Ryckman Creek and Whitney Canyon Fields, Wyoming and Lost Soldier Field, Wyoming.

Lateral and upward movement of fluids from greater depths carries higher temperatures to surface rocks. Four of the fields have positive temperature anomalies both at surface and greater depths and are not located on structural features. This tends to disprove the theory that temperature anomalies are related to structural highs.

Meyer, H. J. and H. W. McGee, 1985, Oil and gas fields accompanied by geothermal anomalies in Rocky Mountain region: AAPG Bull., v. 69, no. 6, p. 933-945.

Positive geothermal anomalies are associated with at least 15 major oil fields in the Rocky Mountain region. Lateral and upward movement of fluids through the rock into areas of entrapment causes the temperature gradient anomalies. The fluids transport considerable heat from depth. These geothermal hot spots are an effective tool in prospecting for hydrocarbon reserves.

Oil fields discussed with anomalous temperature gradients include: Madden and Frenchie Draw fields, Wind River Basin, Wyoming; Salt Creek Field, Wyoming; Bell Creek Field, Montana; Wattenberg Field, Colorado; Peoria Field, Colorado; and Redwing Creek Field, North Dakota. 289 wells in 12 additional fields in Colorado, Montana, Utah and Wyoming were tested.

Causes of geothermal anomalies include topographic and climatic factors, movement of meteoric water down into rock fractures, movement of connate and juvenile fluids upward and laterally through fractures and natural porosities, natural heat sources within a field (chemical and biological processes including radioactive decay) and variations in rock properties.

Olson, G., 1977, Catalog of Jurassic, Cretaceous and Tertiary Rock names for the Overthrust Belt and vicinity: Wyoming Geol. Assoc. Guidebook, 29th Annual Field Conf., p. 91-99.

The names in usage in 1977 are given for each group formation, member and tongue of Mesozoic and Lower Cenozoic rocks in the Overthrust Belt of Wyoming and Montana. For each a regional distribution, age, type locality, and general lithology is given. General remarks and correlations are presented along with references to more complete analysis of each unit.

Pattison, L., 1977, Catalog of Triassic, Permian and Paleozoic Rock names for the Overthrust Belt and vicinity: Wyoming Geol. Assoc. Guidebook, 29th Annual Field Conf., p. 81-90.

The names in usage in 1977 are given for each group formation, member and tongue of Upper Paleozoic and Lower Mesozoic rocks in the Overthrust Belt of Wyoming and Montana. For each a regional distribution, age, type locality, and general lithology is given. General remarks

and correlations are presented along with references to more complete analysis of each unit.

Sabins, F. F., and F. A. Petersen, 1961, Geology and petrography of Dead Horse Creek and Barber Creek fields: Wyoming Geol. Assoc. Guidebook, Symposium on Late Cretaceous Rocks Wyoming and Adjacent Areas, 16th Ann. Field Conf., p. 301-309.

Oil production is from the Ferguson and Parkman sands. The Ferguson is a stratigraphic trap due to updip pinchout into shale. The sand body is a linear bar. It is a sandstone deposited in a regressive marine environment. Contour maps show definitely elongate patterns. No further depositional information is presented.

Shelton, J. S., 1963, Measured sections of sandstones and shales: AAPG Bull., v. 47, p. 2047-2050.

Examples of graphic core and outcrop facies logs from an example in the Eagle Sandstone at Billings, Montana are presented.

Shelton, J. S., 1965, Trend and genesis of lowermost sandstone unit of Eagle Sandstone at Billings, Montana: AAPG Bull., v. 51, p. 2441-2461.

The barrier island originated as a bar in over 75 ft of water and more than 50 miles offshore. It built toward the mainland in a transgressive phase. The subaerial part of the barrier has been removed by erosion.

Stalkup, F. J., and W. J. Ebanks, Jr., 1986, Permeability variation in a sandstone Barrier Island-tidal Channel-Tidal Delta complex, Ferron Sandstone (Lower Cretaceous), Central Utah: SPE, 61th Ann. Tech. Conf. New Orleans, Louisiana, SPE 15532, p. 1-13.

Variation in permeability within outcrops of the Ferron Sandstone, a barrier island-tidal channel-tidal delta complex, is discussed. Samples from 15 outcrops were analyzed to determine lithofacies and distribution. Several scales of permeability heterogeneity exist in the Ferron sandstone. The sandstone is crossbedded, burrowed, rippled, and in places shaley. Permeability units extend 500 to 1,000 ft in a seaward direction and greater distances parallel to the shoreline and are 2 to 4 ft thick. Outcrop permeability is compared with core samples from a nearby well. The goal of the paper is to aid in answering the old question, "What's between the wells?"

Stone, D. S., 1983, The Greybull Sandstone pool (Lower Cretaceous) on the Elk Basin thrust-fold complex, Wyoming and Montana: Rocky Mountain Assoc. Geol. Foreland Basins and Uplifts Field Conf., p. 345-356.

The Elk Basin Field produces from the Lower Cretaceous Greybull Sandstone. The field is a giant trap controlled by the structural trends of a complex thrust-fold belt. The Greybull is underlain by a thrust fault zone along the Precambrian basement rocks. By 1983 over 500 million barrels of oil had been produced and the Greybull Sandstone pool became a storage reservoir for gas.

Two units of the Greybull are present at North Clark's Fork Field in Montana. At Elk Basin Field the lower unit B is the larger. The lower unit B is a fluvial channel deposit up to 150 ft thick and 2 miles wide. The upper unit A is a series of shoreline sandstone deposits oriented northeast-southeast ranging from 2 to 20 ft thick. These Greybull units form a gas pool at the crest of the Elk Basin anticline.

Taylor, A. M., 1980, Depositional environments of the Dakota Sandstone in southeastern Colorado: SEPM Field Trip Guidebook, 69 p.

The Dakota Sandstone is interpreted as a prograding barrier island composed of a beach complex with seaward shoreface, inshore, and offshore deposits and landward marsh-swamp-estuarine deposits. This Barrier Island prograded seaward toward the northeast.

Uhler, D. M., Akers, A., and C. F. Vondra, 1988, Tidal inlet sequence, Sundance Formation (Upper Jurassic), north central Wyoming: Sedimentology, v. 35, p. 739-752.

Sandstone and coquinas of the uppermost 15 to 20 m of the Sundance Formation within Bighorn Basin represent deposits of a Late Jurassic prograding, barrier coastline. Previously proposed offshore sand body models do not explain the conformable relations between Sundance and Morrison formations. The study is based on outcrops.

Ver Ploeg, A. J., and P. L. Greer, 1986, Geologic maps of Wyoming included in 1980-1985 graduate theses from The University of Wyoming: Wyoming Geol. Surv., Open File Report 86-19.

Lists the titles of the maps and indicates which are available through the Wyoming Geological Survey.

Weimer, R. J., K. W. Porter, and C. B. Land, 1985, Depositional modelling of detrital rocks with emphasis on cored sequences of petroleum reservoirs: SEPM Core Workshop No. 8, Golden, Colorado, p. 105-127.

Depositional models are based on cores from several Rocky Mountain basins, particularly the Denver Basin.

E. GULF COAST BASIN

A number of references on sedimentary deposits from the Gulf Coast Basin of the United States are included. Barrier island deposits in the Gulf Coast region are younger in age than those of the Rocky Mountains. Tertiary to modern barrier islands are less obscured by later sedimentation and deformation than Rocky Mountain barrier island systems. Barrier islands along the modern coast reveal the dynamics of formation. Data from modern barrier islands can relate processes to features and provide identifying characteristics for use in developing barrier island models.

Bernard, H. A., Major, C. F., Jr., and B. S. Parrott, 1959, The Galveston barrier island and environs: A model for predicting reservoir occurrence and trend: Transactions of the Gulf Coast Assoc. of Geol. Societies, v. IX, p. 221-224.

Geological processes that produce barrier islands and associated shoreline land bodies in Recent sediments were used to define and describe similar bodies in ancient deposits. A detailed stratigraphic analysis of the processes, framework, lithology, genesis, and sequence development of Galveston Island, Texas was used as the basis for the model. Wave heights from 2- to 4-ft with 20-ft waves during hurricanes combine with winds, surface currents, and westerly longshore currents to shape the sediment input into a barrier island complex. The sand source is from the Trinity and San Jacinto Rivers. Galveston Bay formed with the drowning of the lower Trinity River at the close of the Pleistocene. Barrier islands are greatly effected by eolian deposition as well as fluvial input and marine redeposition.

Bulling, T. P., and J. A. Bryer, 1986, Exploring for subtle traps with high-resolution paleogeographic maps: Reklaw 1 interval (Eocene), South Texas: AAPG Bull., v. 73, p. 24-39.

Results for Atkinson Field: This field produces from a sand within the Reklaw 1 interval; the sand extends for 9 miles along strike and reaches a width of 2 miles and a maximum thickness of 60 ft. Four electrofacies are recognized: blocky, bell shaped, simple spike, and tapered spike. Electrofacies must be considered in context, including sand-body geometry and orientation. Most of the logs from the central part of the sand have blocky patterns. Environmental interpretations include barrier beach, barrier bar or barrier island, tidal inlet fill, washover fan, and seaward edge of barrier all summarized in their Table 1. The shoreline-parallel sands at Atkinson Field have lobes that extend updip into shales and represent washover fan deposits, probably indicating a microtidal system. The Atkinson sand does not show upward coarsening pattern commonly associated with barrier islands. This barrier was built and subsequently drowned in place, it did not prograde.

Galloway, W. E., 1986. Depositional and structural framework of the distal Frio Formation, Texas coastal zone

and shelf: Bur. Eco. Geol., Univ. of Texas, Geol. Circular 86-8, 16 p.

The Oligocene Frio period of progradational deposition on the continental platform was limited by Miocene growth faults. Along the headlands deltas built on the continental slope and were reworked as an extensive barrier-lagoon strandplain system along the Texas Gulf Coast.

The Frio system can be divided into three depositional units. In the lower unit the continental margin prograded rapidly and large submarine canyons were cut into the flank of the South Texas Norias delta system. During the Middle and Upper Frio interval the coast stabilized. Sandy, distal delta and shoreline facies including; frontal-splay, slump and storm-deposited inner-shelf sandstones were deposited. These distal facies are thin and discontinuous.

Deposits which onlap the slope and fill the submarine erosional canyons are very productive of hydrocarbons.

Galloway, W. E., D. K. Hobday, and K. Magara, 1982, Frio Formation of the Texas Gulf Coast Basin-Depositional systems, structural framework, and hydrocarbon origin, migration, and exploration potential: Bur. Economic Geology, The University of Texas at Austin, Report of Investigations No. 122, 78 p.

The Frio Formation is one of the major Tertiary progradational wedges of the Texas Gulf Coast Basin and has yielded nearly 6 billion BBL of oil and 60 TCF gas. The Frio and its updip equivalent, the Catahoula Formation, consist of deposits of two large fluvial and associated deltaic systems centered in the Houston and Rio Grande Embayments. These two major deltaic depocenters are separated by a vertically stacked, strike-parallel barrier and strandplain system. Underlying, interbedded, and transgressive shelf, prodelta, and continental slope mudstone sequences provide principal source and sealing facies. Sparse organic geochemical data and regional thermal and compaction-history analyses show that large volumes of hydrocarbons have probably been generated within, and effectively expelled upward and landward from normally to moderately undercompacted sequences of these mudstone facies.

Two strandplain-barrier systems listed included (1) Buna, and (2) Greta/Carancahua. Within both of these systems vertical upbuilding of sands was the main depositional pattern.

Greta/Canancahua barrier-strandplain system comprises a linear sandstone belt separating marine from brackish-water shales and extends from Nueces County in the west, where

it is gradational with the Norias delta system, to the Houston delta system in the east.

Massive, blocky, stacked barrier and strandplain sandstones dominate intervals of as much as 4,000 ft. Shoreline conditions remained remarkably uniform during lower and middle Frio deposition. To the south, a wave-dominated barrier coast, probably resembling the Padre/Mustang/Matagorda complex of modern Texas islands, underwent significant aggradation. Northward, many small streams supplied sediment directly into the gulf, where sands were combined with strike-reworked sediment to form a complex assemblage of strandplain and delta-destructive facies. Large proportions of these barrier sands were preserved during ensuing transgressions because of continued subsidence. The lenticular and tongue-shaped sands along the landward margin of the Frio barrier trend are probably stacked washover-fan and flood-tidal-delta deposits.

Galloway, W. E. and E. S. S. Cheng, 1985, Reservoir Facies Architecture in a Microtidal Barrier System-- Frio Formation, Texas Gulf Coast: Bur. Eco. Geol. Univ. of Texas, Rep. Invest. 144, 36 p.

Microtidal barrier systems have large oil and gas reserves in reservoirs along the Gulf Coast. Three Frio Formations reservoirs are examples of microtidal barrier systems, these are 41-A, Glasscock and Greta in the West Ranch Field.

41-A is a progradational barrier sand body. The barrier core and the inlet fill deposits are the best hydrocarbon producing facies. The permeability and water saturation patterns reveal multiple compartments within the major facies.

The Greta reservoir is a aggradational barrier bar complex averaging 100 ft. thick. Compartments are dip oriented and include barrier core and inlet fill facies.

The Glasscock reservoir is a thin, discontinuous sand body with relatively low permeability. It represents transgressive barrier deposits of washover fan and sand flats.

Recovery efficiency from these Frio reservoirs is high and oil in place is estimated at from 39 to 56%.

ICF and BEG, 1990, An Assessment of the Reserve Growth Potential of the Frio Barrier-Strandplain Play in Texas, DOE/BC/1400-6, ICF Resources Inc. and Bur. Eco. Geol. Univ. of Texas, 128 p.

The Frio Barrier-Strandplain Play of south Texas has 44 major reservoirs. As a major source of hydrocarbon recovery in the 1970's and 1980's the Frio system is a target for advanced primary and secondary recovery techniques, particularly infill drilling.

Development of infill drilling on 10 acre spacing suggests a recoverable potential of 263 MMB of oil and 145 BCF of gas from the Frio Barrier-Strandplain play.

The control of hydrocarbon occurrence in the Frio Formation is a combination of structure and depositional facies. Depositional facies pinchout of sandstone units is important in implementing the infill drilling program.

The thick, stacked multi-reservoirs of the strandplain give a high degree of compartmentalization to the play. The barrier core averages from 50 to 100 ft thick and pinch out occurs landward into back-barrier lagoonal and mudstone facies.

Johnston, D. D., and Johnson, R. J., 1987, Depositional and diagenetic controls on reservoir quality in First Wilcox Sandstone, Livingston Field, Louisiana: AAPG Bull., v. 71, p. 1152-1161.

Marine channel and barrier island deposits dominate. The barrier island deposit is 40 to 50 ft thick, at 9,917 to 10146 ft sea depth. Reservoir quality is a direct result of diagenetic events that were strongly influenced by depositional facies. Early porosity was significantly reduced by authigenic clay, quartz, and carbonates. Dissolution of carbonates, feldspar, and labile rock fragments restored porosity to 65-75% of original values. The highest degree of secondary porosity was created in facies that had the highest primary porosity. Late stage diagenetic clays have reduced permeability by blocking or reducing pore-throat openings.

McBride, E. F., and M. O. Hayes, 1962, Dune cross-bedding on Mustang Island, Texas: AAPG Bull. v. 46, p. 546-551.

Eolian cross bedding was studied on Mustang Island, Texas, following the 1961 hurricane Carla. Waves exposed well developed Holocene cross beds along the seaward side of the island and cut into stabilized dunes. Cliffs up to 10-ft high preserved the internal structure and nature of the eolian cross bedding. The observations were documented by sketches and photographs immediately after the hurricane's retreat as the drying sand quickly collapsed the cliff walls.

Morton, R. A., and J. H. McGowen, 1980, Modern depositional environments of the Texas coast: Bureau of Eco. Geol. Guidebook 20, 167 p.

The Texas coast spans 350 miles and a broad spectrum of depositional systems; coarse-grained and fine-grained fluvial channels, bayhead and oceanic deltas, coastal lagoons, transgressive and regressive barriers, and nearshore facies. The coastal area deposits are responses to climatic gradients, low wave energy, low tidal range, and sediment input. The Texas Gulf Coast is a microtidal region dominated by storms, wind, and river flooding. The coastal zone is a dynamic area with changing physical and biological parameters. Historical interference by man has caused erosion, spit accretion, and bay silting. Vertical succession of the sand bodies is analyzed to demonstrate changes with time. Numerous illustrations and maps show the different depositional systems, their sedimentology, and process of formation.

Self, G. A., et al., 1986, Lockhart Crossing Field: New Wilcox trend in southeastern Louisiana: AAPG Bull., v. 70, p. 501-515.

The main reservoir is from a 40 to 80 ft Eocene marine sandstone. Dominant facies is a sequence of upward-coarsening very fine to fine-grained glauconitic sandstone deposited as a nearshore marine bar. Associated is a younger fining upward channel fill sequence. Oil entrapment is primarily structural.

Sneider, R. M., C. N. Tinker, and N. D. Sullivan, 1984, Sandstone reservoir models from Recent deposits Texas Gulf Coast: Geology and Geological Engineering Field Trip Guide, SPE-AIME 59th Annual Technical Conference, Houston, Texas, R.M. Sneider Exploration, Inc.

An examination of common sandbodies found in reservoirs including alluvial channels, delta distributary channels and bars, offshore coastal bars and tidal channels, and transgressive sands. The processes of sediment dispersal and distribution are reviewed. The geometries of the sandbodies as they appear in the depositional record are studied. An analysis of log responses and reservoir characteristics are applied to typical sandstone reservoirs.

Tyler, N., and W. A. Ambrose, 1985, Facies architecture and production characteristics of strandplain reservoirs in the Frio Formation, Texas: Bur. Eco. Geol., Univ. Texas, Austin, Rept. of Invest. 146, 42 p.

Shoreline depositional environments encompass strandplain and barrier-island systems. Strandplains can be subdivided into sand-rich, beach-ridge plains and mud-rich, chenier plains. The Tertiary shorelines of the Texas Gulf Coast have examples of all of these shoreline depositional environments. Three strandplain reservoirs are found in the Frio Formation, the Cayce, the Cornelius, and the Carlson in the North Markham-North Bay City Field, Matagorda County, Texas. Excellent 3-dimensional diagrams, maps, and cross-sections from the depositional environments (and their processes of formation) are provided.

Vavra, C. L., M. H. Scheihing, and J. D. Klein, 1992, Reservoir Geology of the Taylor Sandstone in the Oak Hill Field, Rusk County, Texas: Integration of petrology, sedimentology, and log analysis for delineation of reservoir quality in a tight gas sand: in R. Sneider, et al., eds., The Integration of Geology, Geophysics, and Petroleum Engineering in Reservoir Delineation, Description, and Management, Proceedings of the First Archie Conference, Houston, Texas: AAPG, p. 131-158.

The Upper Jurassic Taylor Sandstone is a tight gas reservoir. Petrologic and sedimentologic analysis of five cored wells and log analysis of 118 wells was done to study the quality of the reservoir. The Taylor is a tightly cemented, fine-grained sandstone interbedded with mudstones, siltstones, and carbonates. Porosity and permeability are low, and open fractures are extremely rare. Six major petrofacies were distinguished based on pore geometry and pore filling. Porosity models were developed using wireline log data. Petrofacies show a strong association with the environments of deposition. The Taylor sandstone is interpreted as a barrier island with back-barrier, foreshore, shoreface, and inner shelf environments. The Oak Hill Field in Rusk County, Texas contains two barrier island complexes. Study of the zones and sub-zones present in the Taylor permitted mapping and determination of the quality of the reservoir rocks in each petrofacies.

Weise, B. R., and W. A. White, 1980, Padre Island National Seashore; A guide to the geology, natural environments, and history of a Texas barrier island: Bureau of Economic Geology, University of Texas, Guidebook 17, 94 p.

Padre Island is 113 miles long, and is the longest barrier island in the United States. The dynamic environments of the barrier island change continuously, effected by winds, currents, tides and waves. Hurricanes have caused sudden and dramatic changes in Padre Island. This guidebook describes the environments of Padre Island and Laguna Madre, the lagoon separating it from mainland, Texas.

Most of Padre island is only twenty feet above sea level with a high point of fifty feet. The island is very recent geologically forming only in the past several thousand years. Sand dunes are stabilized only along the central ridge of the island. Padre Island developed along with a string of other barrier island from Louisiana to Mexico from wind and wave deposited sands. The restricted water flow into Laguna Madre causes a very high salinity content for the waters of the lagoon. Dunes, beaches, marshes, and lagoon offers homes to a variety of wildlife.

Colored maps and photographs show the past and present geologic environments of the island. Construction of buildings, roads, causeways and piers has altered both the dimensions and timing of the changes on Padre Island. Mapping and descriptions of environments can aid in monitoring the effects of present and future development and provide guidelines for environmental conservation of Padre Island.

F. OTHER UNITED STATES SHORELINE BARRIER ISLAND DEPOSITS

References in this section are included to describe barrier island systems from all over the United States. Barrier islands along the eastern and southern coasts of the United States are recent and still actively forming. Analysis of the dynamic processes within barrier islands is vital to the study of ancient barrier island systems. Several papers in this section review barrier island deposits throughout the United States.

Abrams, M. J., J. E. Conel, and H. R. Lang, 1984, The Joint NASA /GEOSAT Test Case Project: AAPG, Part 2, v. 2.

Volume 2 contains the Sensor Assessment Report for petroleum studies and the Technical Appendix. Satellite imagery remote sensing has been used to provide maps of petroleum producing areas in the United States. The numerous authors give detailed analysis of the landsat photos reproduced. They interpret the geology from these photos and present maps based on the remote sensing images. Included in the petroleum assessment are photos and maps of Patrick Draw Field, Wyoming.

Anderson, J. B., C. Wolfteich, R. Wright, and M. L. Cole, 1982, Determination of depositional environments of sand bodies using vertical grain-size progressions: Gulf Coast Assoc. Geol. Soc. Transactions, v. 32, p. 565-577.

Attempts to distinguish modern fluvial, coastal barrier, and turbidite sands using grain size on two-dimensional scatter diagrams yields poor results. Environmental subdivisions were too broad. It was possible to distinguish braided river, alluvial fan, meandering river, coastal barrier, and deep-sea fan sands using vertical progressions of grain size data. Test cases were from sandstones whose depositional setting had been previously established prior to their vertical grain size trend analysis.

Aubrey, D. G., and L. Weishar, eds., 1988, Hydrodynamics and sediment dynamics of tidal inlets: Lecture Notes on Coastal and Estuarine Studies, v. 29, Springer-Verlag, 440 p.

Twenty-three papers are included that discuss aspects of tidal inlet hydrodynamics, sediment transport and morphology of tidal inlets, and associated barrier islands.

Belknap, D. F., and J. C. Kraft, 1981, Preservation potential of transgressive coastal lithosomes on the U.S. Atlantic Shelf: Marine Geology, v. 42, p. 429-442.

Variable fractions of the transgressive sequence may be preserved, depending on pre-existing topography, depth of erosion, wave energy, sediment supply, erosion resistance, tidal range, and rate of relative sea-level change. However, their not too earth shaking conclusions are that materials at greater depth in the stratigraphic column are more likely to be preserved during transgression; there is better

preservation on the outer shelf and more reworking on the inner shelf.

Belknap, D. F., and J. C. Kraft, 1985, Influence of antecedent geology on stratigraphic preservation potential and evolution of Delaware's barrier systems: Chapter VI. Barrier Platforms; Marine Geology, v. 63, p. 235-262.

The Delaware coast is dominantly transgressive. As Holocene coastal lithosomes migrate over the Pleistocene erosional surface, they fill pre-Holocene valleys first, and then thicken. Shoreface forms, and ravinement unconformity (another erosional surface) determine the degree of preservation of the Holocene section.

Bernard, H. A., and R. J. LeBlanc, 1965, Resume of the Quaternary geology of the northwestern Gulf of Mexico province: in Wright, H.E., Jr., and D.G. Frey, eds., The Quaternary of the United States, Princeton University Press, p. 137-185.

A somewhat dated, but excellent review of the Quaternary geology of the High Plains. Changes in coast line and related sea level rise are discussed.

Cant, D. J., 1986, Diagenetic traps in sandstones: AAPG Bull., v. 70, p. 155-160.

Formation of diagenetic traps requires that parts of the sandstones react differently from one another. This can be caused by differences in (1) detrital mineralogy (depositional control), (2) early diagenetic mineralogy (largely controlled by depositional environment), (3) burial history, and (4) fluid content. Each of these factors can lead to differences in porosity and permeability of the sandstone sufficient to form reservoirs and seals.

Clifton, H. E., 1990, A wave-dominated inlet on a mesotidal coast: Willapa Bay, Washington (abst.): in Davis, R.A., Jr., D. Nummedal, and R.W. Tillman, Conveners, Tidal Inlet and Related Sand Bodies: Modern and Ancient: SEPM Research Conference San Juan Basin, New Mexico, May, 1990, pages unnumbered.

Willapa Bay is located on the coast of Washington, just north of the mouth of the Columbia River. Tidal range within the bay is 2-3 m (6.6 to 9.8 ft). The Inlet is 8-9 km (4.9 to 5.6 miles) wide and consists of broad shallow subtidal and intertidal flats dissected by two narrow channels less than one km (.62 miles) wide, which are 10 to 15 m (32.8 to 49.2 ft) and greater than 20 m (64 ft)

deep, respectively. A large ebb-tidal delta extends from the inlet into the Pacific Ocean. The flood-tidal delta is less pronounced and is truncated by the large tidal channel that forms the north-south axis of the bay.

Where the tidal channel enters the bay, the ebb and flood tidal currents dominate different parts of the channel: dunes on the shallower parts of the channel (its southern bank) are oriented in an ebb direction, whereas those in the deeper part of the channel (off its erosional northern bank) are oriented predominantly in a flood direction. Wave-related processes dominate on the outer part of the ebb tidal delta.

Three-dimensional consideration of the sand body indicates that it is an asymmetrically northward-thickening accumulation that is dominated by tidal process in its deeper parts and on its bayward side and by wave processes in its shallower parts and on its oceanward side.

Crowe, D. E., and R. A. Davis, Jr., 1984, Upward-Shoaling origin of an eastern Gulf Coast barrier island (abst.): AAPG Bull, v. 68, p. 467.

The island first became emergent in 1960. It has grown to a length of 2 km (1.2 mi) with widespread vegetation and dunes which rise about 2 m (6 ft) above mean sea level.

Good documentation of upward shoaling of North Bunces Key from a subtidal shoal area without benefit of significant storm activity.

Davies, D. K., and F. G. Etheridge, 1975, Sandstone composition and depositional environment: AAPG Bull., v. 59, p. 239-264.

Depositional environments were studied and related by changes in detrital-sedimentary composition and size of grains. Three-hundred sample sets from Holocene sedimentary sequences in Texas and the lower Mississippi River Valley were analyzed. Comparisons were made to suites of samples from the Wilcox (Eocene) fluvial and deltaic rocks, from Lower Jurassic marine rocks from England, and from the Lower Cretaceous Muddy sandstone of the Powder River Basin, Wyoming.

Petrographic data from the sequences reveal that composition of detrital sediments in both ancient and modern environments is reflected in textural changes.

Davies, D. K., F. G. Etheridge, and R. R. Berg, 1971, Recognition of barrier environments: AAPG Bull. v. 55, p. 550-565.

The vertical succession of sedimentary structures in the Galveston barrier island, Texas, is compared to identical sequences from the Lower Cretaceous (Bell Creek) of Montana and a Lower Jurassic complex in southern England. Barrier islands have in common; (1) irregular siltstone and clay laminations at the base, (2) burrowed, structureless sandstones, (3) low angle microtrough cross laminations, 4) structureless and rooted sandstones. This

sequence represents (1) lower shoreface, (2) middle shoreface, (3) upper shoreface-beach, and (4) eolian environments.

Data from cores included textural and compositional analysis and grain size studies based on thin sections. Sedimentary similarities between Galveston Island and the ancient barrier islands allowed for the development of a model for barrier sedimentation.

Davis, R. A., Jr., ed, 1985, Coastal Sedimentary Environments, Springer-Verlag, N.Y., 707 p.

Contains ten lengthy chapters with numerous illustrations.

"River Deltas," by L. D. Wright, discusses distribution and characteristics of deltas and delta formation.

"Estuaries" by M. M. Nichols and R. B. Biggs, discusses evolution, distribution, and hydrodynamic processes which effect estuaries.

"Intertidal flats and intertidal sand bodies" by G. deVries Klein, presents an overview on world wide intertidal flats and describes facies represented.

"Coastal salt marshes," by R. W. Frey and P. B. Basan, defines coastal salt marshes and environmental zones within marshes.

"Coastal Dunes," by V. Goldsmith, describes the processes of eolian sedimentation which form dunes.

"Beach and Nearshore Zone" by R. A. Davis, Jr. describes the distribution, processes and sedimentary structures of nearshore environments.

"Tidal inlets and Tidal deltas" by J. C. Boothroyd, discusses bedforms and tidal deltas formation and depositional models for tidal deltas.

"Shoreface," by A. W. Niedoroda, D. J. P. Swift, and T. S. Hopkins, discusses the dynamics of shoreface processes and formation, suggests engineering implications for changing shorefaces.

"Coastal stratigraphic sequences," by J. C. Kraft and M. J. Chrzastowski, presents an analysis of sea level changes and their effect on lagoon-barrier systems and coastal changes in time.

"Modeling Coastal Environments," by W. T. Fox, reviews various systems for modeling coastal deposits.

Demarest, J. M., II, and J. C. Kraft, 1987, Stratigraphic record of Quaternary sea levels: implications for more ancient strata: Sea-Level Fluctuation and Coastal Evolution, SEPM Special Publication No. 41, p. 223-239.

Analysis of sea level changes in the Pleistocene and Holocene. Suggests how techniques of identification of facies and depositional processes can be applied to older deposits of a similar nature.

Dolan, R., and H. Lins, 1986, The Outer Banks of North Carolina: U. S. Geological Survey Prof. Paper 1177-B, 47 p.

Nearly 300 barrier islands rim the Atlantic coast of the United States. The outer Banks of North Carolina are excellent examples of the barrier island systems. The barrier islands undergo constant changes by man-made and natural dynamic processes. Storms have the biggest and fastest effect on island formation, but human development may be more devastating in the long run. Developers assume that barrier islands are stable environments and governmental agencies have been slow to halt and control unwise development.

This study covers the history of the Outer Banks. Since the earliest settlement of North America the Outer Banks have been a hazard to shipping. The ever changing hidden shoals have sunk many ships and many more have been grounded by storm surges. The dynamic processes and geologic history as well as the social history of the Outer Banks are described and interpreted. Color photographs illustrate the environments.

Studies of delicate and complex systems like the Outer Banks are essential in understanding barrier islands and their environments. Nine of the islands have been set aside as a National Park to preserve their ecosystems.

Dolan, R., and H. Lins, 1987, Beaches and barrier islands: *Scientific American*, July, p. 68-77.

This is a general article that emphasizes the continually changing nature of barrier islands and beaches. Most of the paper is oriented toward land usage and attempts at barrier/beach stabilization.

Dolan, R., H. Lins, and J. Stewart, 1980, Geographical analysis of Fenwick Island, Maryland, a Middle Atlantic Coast barrier island: U. S. Geol. Survey Prof. Paper 1177-A, 24 p.

Barrier islands represent the terrestrial/marine interface along the Atlantic and Gulf Coasts. Barrier islands are the product of rising sea levels, ample input of sand from landward sources and waves strong enough to move the sand. Barrier islands are unstable environments and extensive development on them along the Atlantic Coast is a continuing problem. This paper studies the processes which create and destroy barrier islands using Fenwick Island, Maryland as an example. Daily tides and storm events were recorded and correlated with historical records for the island. About 12,000 years ago the Maryland shoreline was 350 ft lower and 100 miles further out to sea. Historic maps were used to chart the changes in Fenwick Island morphology since 1649 A. D.

Donselaar, M. E., 1990, Facies and geometry of fossil flood-tidal deltas (abst.): in Davis, R. A., Jr., D. Nummedal, and R. W. Tillman, Conveners, Tidal Inlet and Related Sand Bodies: Modern and Ancient: SEPM Research

Conference San Juan Basin, New Mexico, May, 1990, pages unnumbered.

Preservation potential of flood-tidal deltas in a transgressive setting is high because of the protected lagoonal environment of deposition and the low stratigraphic position in the transgressive sequence. Two examples are presented.

The first example includes laterally and vertically-stacked flood-tidal sandstone bodies with lobate geometry in the Menefee Formation. Individual sandstone lobes are 2 to 7-m (6.6 to 22.9 ft) thick and widths are 100 to 650 m (328 to 2,132.6 ft). Upper surfaces are often wave rippled and have a goethite cap. Concave scours, produced by tidal channels, locally cut the upper surfaces of the sand lobes. Channel fill is either with coaly lagoonal shale or with cross-bedded sands. Internally, the sandstones are characterized by lagoonward-inclined primary bedding planes and tabular-to-wedge-shaped, large-scale cross beds with foreset dips in the lagoonal direction. Tidal features include mud drapes on the foresets, occurrence of bundle sequences, and bimodal distribution of foreset dips with a dominant landward component.

The second example is a wedge-shaped, flood-tidal sandstone in the Pano Formation, Spain. The sandstone body had a maximum thickness of 12 m (39.4 ft). Thickness of the sand body decreases lagoonward as the flood-tidal delta interfingers with lagoonal marl. Lagoonward-inclined primary bedding characterizes the internal arrangement of the sandstone. The upper part of the sandstone shows deep erosive scours. Scours are filled with cross-bedded sandstone. Tidal criteria comprise bundle sequences, mud drapes, and bimodal foreset dips with a dominant landward component.

Elliott, T. T., 1980, Clastic Shorelines: in Reading, H. G., ed., *Sedimentary Environments and Facies*: Elsevier, New York, p. 152-169.

Chapter 7 addresses tidal inlets, tidal deltas, lagoons, transgressive barriers, and ancient beach and barrier facies. Some general comments: The extent to which tidal inlets are developed and maintained in a barrier island is related to the tidal range; and microtidal and mesotidal barriers can be distinguished on this basis. Three types of tidal inlet are recognized: overlap, symmetrical, and offset, where each type is related to longshore drift characteristics. Inlets generally range from several hundreds of meters to a few kilometers in width and may be up to 20 m (65.6 ft) deep. The updrift bank tends to be constructional and the downdrift (relative to longshore drift) bank tends to be erosional. Dunes and sandwaves that cover the subtidal part of the inlet depositional bank are overlain by a series of wave-induced recurved spits attached to the channel margin.

Inlets can become extremely important because of their tendency to migrate laterally in the direction of longshore

drift. The extent to which inlet deposits are developed depends on (1) frequency of inlets along the barrier; (2) rate and consistency of direction of inlet migration; (3) nature of barrier migration, whether transgressive, regressive, or stationary; and (4) rate of barrier migration relative to the rate of inlet migration. Rates of migration of inlets can be extremely high: on Sapelo Island inlet migration has produced a sandbody 1 km (.621 mi) long parallel to shoreline and 10 to 13 km (6.2 to 8 mi) wide normal to the shoreline in 4,000 years. The western tip of Fire Island has migrated 8 km (4.9 mi) in 115 years at an average rate of 64 m/yr (210 ft/yr).

Evans, M. W., and A. C. Hine, 1990, Distribution and infilling sequences of tidal inlet channels in the open-water lagoons of southwest Florida (abst.): *in* Davis, R. A., Jr., D. Nummedal, and R. W. Tillman, Conveners, Tidal Inlet and Related Sand Bodies: Modern and Ancient: SEPM Research Conference San Juan Basin, New Mexico, May, 1990, pages unnumbered.

The Charlotte Harbor system is low energy- 28 cm (11 in) average wave height, and mixed tides with a 62 cm (24.4 in) maximum average tidal range. Three sediment types comprise the estuarine fill: a mature, well sorted, fine quartz sand, a molluscan shell gravel, and a silt-dominated clayey mud. Cores indicate multiple fining-up sequences which are interpreted as tidal channel fill. These fills contain coarse shell layers a few cm to a meter thick at the base, and fine up to muddy sands. Thickness of fining upward sequences varies from 30 cm (11.8 in) to more than 200 cm (78.8 in).

Similar sequences have been interpreted from nearby lagoons as storm overwash deposits; however, seismic data show channel structures rather than thin, widespread reflectors. Migration and infilling of tidal channels account for 50% of the Holocene lagoon and lower estuarine accumulation and have been the most important depositional processes in those areas.

FitzGerald, D. M., 1976, Ebb-tidal delta of Prince Inlet, South Carolina: Geomorphology, physical processes, and associated inlet shoreline changes; *in* Hayes, M.O. and T.W. Kana, eds., Terrigenous Clastic Depositional Environments, Coastal Research Division, Dept. of Geology, Univ. of South Carolina, p. 143-157.

The ebb-tidal delta of Prince Inlet is a multicomponent system that continually responds to a changing wave climate and varying tidal range. The recent landward migration of sands and the changes in the delta and bar shape are documented. The history of the inlet can be traced in historic records as far back as 1661. Erosional events in the past 300 years have changed the asymmetric ebb-tidal delta. This paper gives an analysis of the processes of these changes.

FitzGerald, D. M., 1988, Shoreline erosional-depositional processes associated with tidal inlets: *in* Aubrey, D. and L. Weishar, eds., Hydrodynamics and sediment dynamics of tidal inlets, Springer-Verlag, p. 186-225.

Average barrier length is controlled by the size and number of tidal inlets. Tidal inlets, in turn, are a function of the region's tidal range and bay area. Migrating and stable inlets transfer coastal sand landward during a transgression.

Ebb-tidal deltas form a large sand reservoir comparable in volume to the adjacent barrier islands. Sediment bypassing occurs by three major methods; (1) inlet migration and spit breaching, (2) stable inlet processes, (3) ebb tidal delta breaching. Migrating tidal inlets have shallow inlet channels. Diagrams and maps demonstrate different methods of barrier island accretion and destruction.

Galloway, W. E., 1986, Reservoir facies architecture of microtidal barrier systems: AAPG Bull, v. 70, p. 787-808.

First part of paper is good summary of barrier systems, their stratigraphy, and recognition. Second part of paper is an example from West Ranch Field (Frio) in Texas.

George, D. J., and B. M. Hand, 1977, Computer simulation of barrier-island migration: Computers and Geosciences, v. 3, p. 469-473.

This is an early attempt at computer simulation of depositional processes.

Grube, J. P., 1992, Reservoir Characterization and improved oil recovery from multiple bar sandstones, Cypress Formation, Tamaroa and Tamaroa South Fields, Perry County, Illinois: Illinois State Geol. Surv., Illinois Petroleum 138, 49 p.

Tamoroa and Tamoroa South oil fields in Perry County, Illinois produce from lenticular sandstones of the upper Chesterian Cypress Formation. The depth of the producing unit is 1,150 ft. The sandstones are 2 miles long, 1/4 to 1/2 mile wide and average 10 ft in thickness. They were deposited as marine bars. The bars are en echelon and vertically stacked and separated by thin shales into discrete reservoir compartments.

Diagenetic clays (iron chlorite and kaolinite) in the Tamoroa reservoir cause formation damage. To prevent formation damage caution must be taken when drilling and using stimulation processes. Pore throats may be blocked by iron hydroxides when hydrochloric acid reacts with the iron chlorite. Permeability is further reduced by kaolinite blockage of pore throats. The process of introducing low salinity water into a reservoir containing brine (water shock) is used to dislodge the kaolinite.

Modeling of compartmentalized reservoirs may be utilized to relate the geology with processes for optimizing hydrocarbon recovery.

Hayes, M. O., 1975, Morphology of sand accumulation in estuaries: An introduction to the symposium: *in* Cronin, L.E., ed., *Estuarine Research*, v. 2, Geology and Engineering, p. 3-22.

Four processes, (1) tidal range, (2) tidal currents, (3) wave conditions, and (4) storm action are responsible for the morphology of sand deposits in estuaries. Tidal range has the greatest effect on estuary type. Estuaries are classified as (1) microtidal with tidal ranges 0-2 m (0.56-6 ft), (2) mesotidal with tidal ranges 2-4 m (6.6 to 13.1 ft), (3) macrotidal with tidal ranges greater than 4 m (13.1 ft). Examples for each type of estuary are discussed and illustrated. Galveston Bay is microtidal, estuaries of New England, South Carolina and Georgia are mesotidal; and Bristol Bay, Alaska, and the Ord River Estuary, Australia, are macrotidal.

Hayes, M. O., 1979, Morphology of sand accumulation as a function of tidal and wave regime: *in*: Leatherman, S. P., ed., *Barrier Islands from the Gulf of St. Lawrence to the Gulf of Mexico*, Academic Press, N. Y., p. 1-27.

The morphology of sandbodies is discussed as it relates to tidal and wave constructional and destructional processes. Comparisons are made between barrier islands in the Gulf of St. Lawrence and the Gulf of Mexico.

Hayes, M. O., 1989, Modern clastic depositional environments, South Carolina: 28th International Geological Congress, Field Trip Guidebook T371, 85 p.

This is basically an updated version of Hayes and Kana (1976). Includes very organized descriptions of the coastal environments along the South Carolina/Georgia Bight, including barriers and related settings.

Hayes, M. O., and T. W. Kana, eds, 1976, Terrigenous clastic depositional environments, some modern examples: A Field Course Sponsored by the American Association of Petroleum Geologists: Technical Report No 11-CRD, Coastal Research Division, Dept. Geology, U. of South Carolina, pt. 1, 135 ; pt. 2, 185 p.

Very useful lecture notes, especially part of Chapter C on Beaches and Barrier Islands. Defines and compares mesotidal and microtidal barrier island geomorphological components:

(1) microtidal: long elongated, washovers abundant, tidal inlets infrequent, large flood-tidal deltas, small to no ebb-tidal deltas.

(2) mesotidal: stunted, drumstick shape, minor washovers, frequent tidal inlets, moderate size to no flood-tidal deltas, large ebb-tidal deltas with strong wave-refraction effects.

A lot of other well organized information are also available including three separate papers on mesotidal barriers and four papers on tidal inlets.

Hayes, M. O., and W. J. Sexton, 1989, Modern clastic depositional environments, South Carolina: Field Trip Guidebook T371, 28th Intern. Geol. Congress Amer. Geophysical Union, Washington, DC, 85 p.

Details on barrier islands and beach front deposits along the Carolina coast are presented. Numerous maps and illustrations are used.

Heron, D., 1990, A summary of tidal inlet and delta stratigraphy of a microtidal wave-dominated foreland, Cape Lookout, NC (abst.): *in* Davis, R. A., Jr., D. Nummedal, and R. W. Tillman, Conveners, *Tidal Inlet and Related Sand Bodies: Modern and Ancient: SEPM Research Conference San Juan Basin, New Mexico, May, 1990*, pages unnumbered.

Cape Lookout is at the center of barrier system consisting of two limbs. The NE limb has a tidal range of only 0.47 m (1.5 ft), and the SW limb has a tide range of 0.89 m (2.9 ft). Wave energy on the NE limb is almost 3 times as high as that focused on the SW limb.

The sedimentary sequence in most tidal inlets fines up and consists of inlet floor, active inlet channel, spit platform and overwash facies. Sand dominates in all facies. The coarsest material forms the inlet floor lag and consists of coarse pebbly sands and heavy shell fragments. The active inlet channel is cross-bedded coarse sand and shell. The spit platform is finer well-sorted sand with parallel lamination of sand and shell. The top overwash unit has the typical horizontal lamination of sand and shell and is rooted with *Spartina* and other plants. The overwash unit may be topped with dune sands. The thickness of this sequence is variable depending on the size and duration of an inlet. The section at the modern migrating Beaufort Inlet is 18 m (59 ft) thick, and one relic inlet is 25 m (82 ft) thick.

Not all inlets have a simple fining-upward sequence. Detailed study of the active inlet channel facies typically shows a stacked fining upward sequence of normal graded fine- to coarse-grained sand and shell fragments. These small cycles vary in thickness, but 2 m (6.6 ft) is a common value.

Flood-tidal deltas have a similar facies sequence as tidal inlets, but they fine-up into a mud zone rather than overwash or wind-dune sands.

About 35% of the Holocene section of the barriers in the Cape Lookout foreland is inlet fill. When the associated flood-tidal delta deposits are added, the bulk of the barrier system is of tidal channel and delta origin. Since most of these sediments are deposited below wave base, or in protected areas behind the barriers, they will have the best preservation potential of the barrier system.

Heron, S. D., Jr., T. F. Moslow, W. M. Berelson, J. R. Herbert, G. A. Steele III, and K. R. Susman, 1984, Holocene sedimentation of a wave-dominated barrier-island shoreline: Cape Lookout, North Carolina: *Marine Geology*, v. 60, p. 413-434.

Cape Lookout represents a microtidal (0.9 m range) high wave energy barrier 130 km thick. Cape Lookout has a highly cusped shoreline. Holocene sedimentation was studied with extensive, closely spaced core samples. Five depositional processes are recognized in the Holocene sequence: (1) eustatic sea-level rise and barrier shoreline transgression, (2) lateral tidal inlet migration and reworking of barrier sands, (3) shoreface sedimentation with barrier progradation, (4) storm washover deposition and filling of shallow lagoons, (5) flood-tidal delta sedimentation in back-barrier environments.

Between 9000 and 4000 B. P. the barrier migrated landward with rapid high sea level rise. Since 4000 B. P. stabilization has occurred. High energy, storm deposits on the northeast part of the barrier have caused a limb which has curved and migrated landward during this period of relative stabilization.

An adjacent barrier island, Shackleford Banks, is dominated by inlet-fill sedimentation. Average barrier island sequences along this coast are 10 m thick, but inlet-fill deposits are 25 m thick.

Hoyt, J. H., 1967, Barrier island formation: *Geol. Soc. America Bull.*, v. 78, p. 1125-1136.

Empirical data fail to substantiate classical theories of barrier island formation from offshore bars. Absence of open ocean beach and neritic sediments landward of barrier islands suggests that barriers have not developed from offshore bars. Formation of barrier islands from emergent bars is also rejected, because evidence from many areas of the world does not support a sea level higher than present during the Holocene. Also unacceptable is the hypothesis of continuous barrier development through the Holocene submergence because it does not explain the original formation. Barrier islands which form from barrier spits or, in some instances, from bars are accepted, but these methods are not regarded as the general mechanism.

The hypothesis advanced in this paper maintains that barrier island is initiated by building a ridge immediately landward of the shoreline from aeolian or water-deposited sediments. Slow submergence floods the area landward of the ridge and forms a barrier and lagoon. Slow submergence, or negligible sedimentation is necessary to maintain the lagoon. Emergence in excess of lagoonal depth terminates the barrier system.

Hoyt, J. H., and V. J. Henry, Jr., 1965, Significance of inlet sedimentation in the recognition of ancient barrier islands: in R.H. DeVoto and R.K. Bitter, eds., *Sedimentation of Late Cretaceous and Tertiary*

Outcrops, Rock Springs Uplift, 19th Field Conf., Wyoming Geol. Assoc., p. 190-194.

The Gulf and Atlantic coasts of the United States demonstrate a variety of barrier island types. Burial and sedimentation and the sequences of deposition in barrier islands are studied in this paper. Barrier islands from Georgia show a variety of ancient and modern barrier systems and shorelines. The inlets along the Georgia coast are shifting southward. Rapid deposition of sediment on the landward side of the barriers offers a number of shallow neritic, island and lagoonal salt marsh environments for analysis.

Hunter, R. E., H. W. Clifton, and R. L. Phillips, 1979, Depositional processes, sedimentary structures, and predicted vertical sequences in barred nearshore systems, southern Oregon coast: *Jour. Sed. Petrol.*, v. 49, p. 711-726.

This article describes a shoreline barrier consisting of elongate nearshore (submerged) bars that extend obliquely out from shore and that migrate alongshore.

Imperato, D. P., Sexton, W. J., and M. O. Hayes, 1988, Stratigraphy and sediment characteristics of a mesotidal ebb-tidal delta, North Edisto Inlet, South Carolina: *Jour. Sed. Petrol.*, v. 58, p. 950-958.

Bedforms and surface textures at North Edisto Inlet reflect typical ebb-tidal delta circulation patterns. The main ebb channel is dominated by large ebb-oriented bedforms, and channel sediments become finer in seaward direction. At the inlet throat, the coarsest available sediment forms a lag deposit. Marginal flood channels adjacent to the barrier islands are dominated by flood-oriented bedforms composed of medium-grained sand. Channel-margin linear bars, flanked by bedforms with opposing orientations, develop where flood channels approach the main ebb channel. The extensive swash platform is dominated by wave energy, which effectively sorts swash platform sediments.

Ebb-tidal delta stratigraphy is dominated by sequences deposited by shifting tidal channels and the migration of swash bars. Proximally, the ebb-tidal delta sequence is dominated by thick tidal channel deposits which fine upward and have a sharp, disconformable base. Ebb-channel deposits up to 20 ft thick flank the channel and are composed of well-sorted, planar-bedded, fine-grained sandstone.

Adjacent to barrier islands, marginal flood-channel deposits dominate the ebb-tidal sequence. These channel sequences are composed of moderately to intensely burrowed, wavy to flaser-bedded sand and mud. Barrier island accretion in the vicinity of inlets often involves flood-channel switching; marginal flood channel deposits could comprise a significant portion of the barrier island lithosome in the vicinity of inlets.

Distally, wave-formed swash platform deposits dominate the ebb-tidal delta sequence. These are very well sorted, fine-grained sand and have planar bedded, landward-oriented crossbeds; coarse shell-hash layers; and extensively burrowed zones. Swash platform deposits interfinger with shoreface deposits laterally and at depth. Distal ebb-tidal delta deposits are relatively thin and have an overall coarsening-upward, grain-size trend.

John, C. J., 1977, Internal sedimentary structures, vertical stratigraphic sequences, and grain-size parameter variations in a transgressive coastal barrier complex: The Atlantic Coast of Delaware: Delaware Sea Grant College Program, College of Marine Studies, University of Delaware, Sea Grant Technical Report DEL-SG-10-77, 287 p.

This study provides detailed information on the internal sedimentary structures, vertical stratigraphic sequences, and grain-size variations in a transgressive coastal barrier complex. The barrier extends from Cape Henlopen in the north to Cottonpatch Hill in the south, along the Atlantic coast of Delaware. Data is from 32 transverse cross sections and one longitudinal cross section.

Four major variations of the coastal transgressive barrier were found: (1) spit-beach-dune complex, (2) barrier against marsh, (3) beach against Pleistocene highland, and (4) barrier-tidal delta-lagoon, which included a baymouth barrier and a tidal inlet section.

Littoral transport carries sediment from south to north; the sands are mostly derived by coastal erosion of the Atlantic shoreline. Washovers are the dominant mechanism for landward barrier migration. Washovers and back-barrier marshes form part of the leading edge of the Holocene marine transgression.

The greater thickness of transgressive sequence deposits in ancestral steam valleys crossing the barrier complex, compared to that at other sections of the barrier complex, gives it a better potential for preservation under a cover of marine sediments. The current barrier is about 3,750 years old.

Vertical sedimentary sequences of coarse sediments over fine sediments occur in both transgressive and regressive coastal settings. Shapes of geophysical logs may be funnel-shaped, columnar-shaped, and/or possibly bell-shaped in an overall transgressive coastal setting.

Kraft, J. C., 1971, Sedimentary facies and geologic history of a Holocene marine transgression: *Geol. Soc. America Bull.*, v. 82, p. 2131-2158.

This paper is based on a study of the Delaware coast, where the sediments are infilling a drowned topography with local relief of 70 ft and possibly up to 125 ft. Thickness and areal extent of sedimentary bodies are to a large degree, controlled by the morphology of the Pleistocene unconformity. Depositional units are thin,

highly irregular in areal extent, extremely variable in thickness, and difficult to project.

Kraft, J. C., and C. J. John, 1979, Lateral and vertical facies relations of transgressive barrier: *AAPG Bull.*, v. 63, p. 2145-2163.

This paper appears to be a condensation for AAPG of the 1977 paper by C. J. John.

Of particular interest are: (1) coarse sediments overlying fine sediments, generally believed to be characteristic of regressive barriers, also are present in this transgressive example; (2) From the abstract, "Time lines clearly diverge and cross lithologic boundaries in both transgressive and regressive barrier sedimentary units. Hence, the transgressive or regressive nature of preserved barrier sequences cannot be positively identified on the basis of characteristic shapes of geophysical logs or sedimentary sequences."

Kumar, N., and J. E. Sanders, 1974, Inlet sequence: a vertical succession of sedimentary structures and textures created by the lateral migration of tidal inlets: *Sedimentology*, v. 21, p. 491-532.

Based on Fire Island Inlet, located 56 km (34.8 mi) east of New York City, that has migrated west-southwest at mean rate of 64 m/yr (210 ft/yr) during the period 1825-1940. Deposition of sediment on the east side of the inlet has forced the tidal currents to erode the west side of the inlet, causing inlet migration. Lateral migration of the inlet along with changing hydraulic conditions that vary from channel floor to the subaerial part of the spit, produced five major units:

- 1) Spit with subenvironments: steep and gentle, seaward to landward-dipping laminae.
- 2) Spit platform: Steep, seaward-dipping planar cross-strata and small scale flood-oriented cross-laminae at top; ebb oriented cross-laminae at bottom.
- 3) Shallow channel: parallel laminae
- 4) Deep channel: Lenticular sets of ebb-oriented cross-laminae bounded by flood-oriented reactivation surfaces.
- 5) Channel floor: Lag gravel composed of large shells, pebbles, and other coarse particles.

Units 3 to 5 compose the inlet proper. Because of the great variability in rates of lateral migration inlet sediments may be preserved as elongate lenses, or as widespread blankets.

Larue, D. K., and P. A. Martinez, 1989, Use of bed-form climb models to analyze geometry and preservation potential of clastic facies and erosional surfaces: *AAPG Bull.*, v. 73, p. 40-53.

The authors propose a model that explains how erosion surfaces and vertical sequences of clastic strata are preserved; where deposition occurs in channelized or local

erosional environments—including fluvial and submarine-channels, barred beaches, and transgressive (barrier) coastlines.

Lewis, J. J. M., 1988, Outcrop-derived quantitative models of permeability heterogeneity for genetically different sand bodies: SPE paper 18153, 63rd Annual Technical Conference and Exhibition, Houston, Texas, p. 449-457.

This paper addresses the problem that accurate prediction of reservoir heterogeneity needs to be based on more than core data. Reservoirs need to be studied in two- or three-dimensional outcrops of analogous sediments. Data from outcrops can be applied to reservoir heterogeneity problems using a system of quantitative models. These models of sediment-body types are not reservoir specific and can be applied generally.

Linville, B., T. E. Burchfield, and T. C. Wesson, eds. 1993, *Reservoir Characterization III*: PennWell Books, Tulsa, OK., 1008 p.

This book contains forty-nine papers which were presented at the Third International Reservoir Characterization Technical Conference in Tulsa, Oklahoma on November 3-5, 1991. All classifications of reservoirs are included and analysis of the geology and techniques and problems of enhanced production are discussed.

Session 1 included seven papers on problems of heterogeneities and anisotropies. Session 2 covers field studies and data collection in five papers. Session 3 has seven papers dealing with reservoir modeling and simulation. Six papers on the optimization of reservoir management are presented in Session 4. Session 5 has twenty-four poster presentations which are described and illustrated.

McBride, R. A., and T. F. Moslow, 1990, Distribution of tidal inlets and shoreface sand ridges along wave-dominated barriers, Atlantic Inner shelf, USA (abst.): *in* Davis, R. A., Jr., D. Nummedal, and R. W. Tillman, Conveners, Tidal Inlet and Related Sand Bodies: Modern and Ancient: SEPM Research Conference San Juan Basin, New Mexico, May, 1990, pages unnumbered.

Ebb-tidal deposits associated with migrating tidal inlets provide the initial sand body for development of shoreface-attached sand ridges. The oblique orientation and linear form of shoreface-attached sand ridges are a function of shoreline transgression, lateral inlet migration, and wave reworking of ebb-tidal delta deposits along an ebb-tidal delta retreat path. Shelf processes are important in the evolution of sand ridges after their initial deposition.

McCubbin, D. G., 1982, Barrier-Island and strand-plain facies: *in* Scholle, P.A., and D. Spearing, eds., *Sandstone Depositional Environments*: AAPG, p. 247-279.

Barriers and strand-plains are supplied by and molded entirely by marine processes. Barriers are defined as sandy

islands or peninsulas elongate parallel with the shore and separated from the mainland by lagoons or marshes. Chenier plains are a type of strand-plain consisting of sandy ridges separated by coastal mudflats. The major environments of barriers and strand-plains are (1) beach and shoreface on the seaward side of the barrier, (2) inlet channels and tidal deltas, (3) washover fans on the landward or lagoonal side of the barrier.

Examples illustrated and examined in modern and ancient sediments: Galveston Island, Texas; Nayarit Strand Plain, Mexico; Plum Island, Massachusetts; Sapelo Island, Georgia; Norderney, Germany; Ventura-Oxnard coast, California; Gallup Sandstone, New Mexico; Parkman Sandstone, Wyoming; Patrick Draw, Wyoming.

Miall, A. D., and N. Tyler, 1992, The three-dimensional facies architecture of terrigenous clastic sediments and its implications for hydrocarbon discovery and recovery: SEPM, *Concepts in Sedimentology and Paleontology*, v. 3, 309 p.

Papers are presented on a variety of terrigenous clastic rock deposits and hydrocarbon reservoirs. Four introductory papers discuss architectural controls on sandstone reservoirs, facies heterogeneity, and production techniques. Two papers discuss eolian environments; ten papers are devoted to fluvial environments, five to deltaic environments, three to shelf environments, and two to deep-water environments.

The examples are from deposits all over the world. The illustrations, maps, cross-sections, and tables are large, numerous and of excellent quantity.

Morton, R. A., and Donaldson, A. C., 1973, Sediment distribution and evolution of tidal deltas along a tide-dominated shoreline, Wachapreague, Virginia: *Sed. Geol.*, v. 10, p. 285-299.

Borings and cores from a barrier island/lagoon on the Virginia coast demonstrated an unconformity between the Pleistocene barrier island and offshore marine sediments and the Holocene tidal delta and barrier island sediments. Sediment color, composition, grain size changes in vertical sequence, and faunal debris were used to define flood-tidal delta, marsh, tidal flat, and mouth bar portions of the barrier island system. Tidal inlets in the Holocene have become stabilized around drowned Pleistocene stream valleys. Tidal delta development began with accretion of fan-shaped inlet mouth bars. Tidal channels stabilized the bar crests and marshes formed. A landward progradation across the lagoon of sand rich sediments goes from inlet into tidal flat-bay and marsh environments. Flood tidal deltas are building progressively southward.

Moslow, T. F., 1980, Stratigraphy of mesotidal barrier islands: Ph.D. Dissertation, Dept. of Geology, University of South Carolina, 187 p.

Kiawah Island, South Carolina was the site of extensive field studies to study the formation and structure of a barrier island. Kiawah has been prograding since 4,000 B. P. Cores and grain-size analysis of the unconsolidated sands from each environment on the island were used to analyze the facies relationships. Facies described are beach ridge-backshore, foreshore-upper shoreface, middle lower shoreface, barrier sands, marsh, lagoon, and estuarine-tidal flats. Numerous tables of data, photographs of textures and environments, and maps are used to illustrate the findings and conclusions.

Moslow, T. F., 1984, Depositional models of shelf and shoreline sandstones: AAPG Cont. Educ. Course Note Ser. 27, 102 p.

A study of the development of depositional and exploration models for sandstone reservoirs associated with shelf and shoreline environments. Well logs, cores, and outcrop data; seismic, isopach, and structure maps are used to define and illustrate the sedimentologic and stratigraphic character of the sand-bodies. Subsurface data are used in developing a three-dimensional framework for sedimentary environments.

The major depositional systems reviewed are barrier island, tidal inlet, shoreface and inner continental shelf sand-bodies. These differ in deltaic and non-deltaic settings.

Moslow, T. F., and R. S. Tye, 1985, Recognition and characterization of Holocene tidal inlet sequences: Chapter IV. Barrier inlets and inlet deltas: *Marine Geology*, 63, p. 129-151.

Eighty vibracore and auger core samples were collected from Holocene sediments on the coasts of North and South Carolina. The sedimentary sequences for wave and tide dominated inlets contrast sharply. Wave height and tidal range are the controlling factors. Hydrographic regime, topography, sediment supply, and lateral facies changes are important in tidal inlet sequences. Inlet deposits have a higher potential for preservation than other barrier island deposits. Fining-upward sand and/or mud-rich inlet sequences dominate ancient clastic shorelines. The most seaward wave-dominated inlet sequences are overlain by laminated overwash and cross-bedded eolian dune sands. Further landward sequences are interbedded fine-grained flood-tidal delta sands overlain by salt marsh deposits. Inlet deposits become concentrated by ebb delta bar-bypassing in the updrift portions of barrier islands resulting in vertical stacking of abandoned inlet channels.

Neese, K. J., 1984, Stratigraphy of a transgressive barrier island arc (abst.): AAPG Bull., v. 68, p. 511.

Isles Derrieres is a Holocene transgressive barrier island arc off the Louisiana Gulf Coast. Spit accretion by longshore currents has formed small islands 10 to 13 ft

thick. Marsh and tidal flat deposits constitute the fluvial-deltaic central part of the island arc. The western part of the arc is well preserved due to subsidence, and lack of shoreface erosion.

Nummedal, D., and D. J. P. Swift, 1987, Transgressive stratigraphy at sequence-bounding unconformities: Some principles derived from Holocene and Cretaceous examples: *in* Nummedal, D., O.H. Pilkey, and J.D. Howard, eds., *Sea-Level Fluctuations and Coastal Evolution*, SEPM Special Publication No. 41, p. 241-259.

This paper aids in identifying key stratigraphic boundaries by emphasizing the sedimentology and different patterns of systems stacking above the sequence boundaries.

Key stratigraphic surfaces encountered in shallow marine sedimentary sequences are: (1) subaerial unconformities, erosion by episodes of sea-level fall representing a significant hiatal break; and (2) diastem surfaces represent relatively short interruptions in sedimentation. Most diastems in shallow marine and coastal settings are associated with transgressions. Diastems include the ravinement diastem, which is formed by transgressive shoreface retreat, channel-base diastems, and various marine erosion diastems.

Oertel, G. F., 1985, The Barrier Island System: Chapter I. Introduction: *Marine Geology*, v. 63, p. 1-18.

Barrier islands are composed of six sedimentary environments; (1) mainland, (2) backbarrier lagoon, (3) inlet and inlet deltas, (4) barrier island, (5) barrier platform, (6) shoreface. The total relationships among the environments forms the barrier island system.

Oertel, G. F., 1988, Processes of sediment exchange between tidal inlets, ebb deltas, and barrier islands: *in* Aubrey, D., and L. Weishar, eds., *Hydrodynamics and sediment dynamics of tidal inlets*, Springer-Verlag, p. 297-318.

Tidal inlets are considered sediment sinks and barrier islands are the sediment source. In tide-dominated inlets scouring of the inlet may provide a sediment source for delta growth and by-passing.

The magnitude of sediment by-passing is a factor in deciding if barrier islands or deltas become sediment sources or sinks. Most migrating inlets are poor by-passers. Sediment accumulates on spits on the updrift barriers (sinks) and erodes from ridges on downdrift barriers (sources). Stable inlets that are poor by-passers have deep inlet gorges (sources) and large tidal deltas (sinks). Sediment in deltas may return to the barrier islands by way of the adjacent shoreface.

Penland, S., R. Boyd, and J. R. Suter, 1988, Transgressive depositional systems of the Mississippi delta plain: a model for barrier shoreline and shelf sand development: *Jour. Sed. Petrol.* v. 58, p. 932-949.

This paper outlines the following three transgressive stages of evolution; (1) erosional headland and flanking barriers, as transgression continues an intradeltaic lagoon forms and the stage one sandbody is separated from the shoreline. (2) a transgressive barrier island arc: landward-migrating barrier island is unable to keep pace with relative sea level rise and retreating mainland shoreline; (3) the resulting inner shelf shoal: as the barrier island arc continues to be reworked into an inner shelf marine sandbody.

Penland, S., J. R. Suter, and R. Boyd, 1985, Barrier island arcs along abandoned Mississippi River Deltas: *Marine Geology*, v. 63, p. 197-233.

The transgressive barrier island arcs along the Mississippi River Delta are discussed. The barrier shoreline is controlled by (1) shore translation, (2) age of transgression, and (3) the thickness of the sediments in the barrier island. Shorefaces retreat at rates from 5 to 15 m/yr (16.4 to 49.2 ft/yr). Isles Dernieres is a young barrier island with thin sands and has limited landward retreat of the shoreface. The Chandeleur Islands are older, thicker and have significant landward movement of the shoreface. Ravinement causes truncation of sediment sequences. A thin sheet sand usually marks the path of retreat.

High resolution seismic profiles have been used to identify transgressive stratigraphic sequences from sheet sands to truncated barrier islands to sand-filled tidal inlets. Isles Dernieres is a recently detached barrier island in early stages of transgression. The Chandeleur Island Arc gives examples of long term shoreface retreat.

Rampino, M. R., and J. E. Sanders, 1981, Evolution of the barrier islands of southern Long Island, New York: *Sedimentology*, v. 28, p. 37-47.

More than 400 cores have been used to reconstruct the Holocene sequence of barrier islands on Long Island. The Holocene transgressive sequence is behind the modern barrier islands. The retreat of the shoreline barriers has been by shoreface erosion and by drowning the barriers during sea level rise. The present sea level is 24 m (78.7 ft) above the level of 9,000 years ago. Ancient barriers were 7 km (4.3 miles) offshore of the present barriers. The rapid sea-level rise and diminished sediment supply is a common feature of submerged coastlines in the eastern United States.

Reinson, G. E., 1984, Barrier-island and associated strand-plain systems: in Walker, R.G., ed., *Facies Models*, Second Edition, Geoscience Canada, Reprint Series 1, p. 119-140.

Barrier islands form in areas of wave-dominated shorelines in interdeltaic and non-deltaic regions. Strand-plain and barriers can vary from attached beach, beach-ridge strand plain, barrier islands partially or completely separated by lagoon, estuary or marsh. Strand plains and barrier islands may have single or multiple sand ridges. This paper reviews all the types of barrier and strand-plain shoreline development. The genetic relationship of prograding sand bodies, and how they differ into a variety of forms, is illustrated and discussed.

Three geomorphic elements in the barrier island system are (1) the sandy barrier island chain; (2) lagoon or estuary; and (3) tidal inlet or channels that cut through the barrier. Depositional environments include: (1) subtidal to subaerial barrier-beach complex, (2) back-barrier region or subtidal-intertidal lagoon, and (3) subtidal-intertidal delta and inlet channel complex. Basic models for study of barrier islands and strand-plains are presented.

Richardson, J. G., J. B. Sangree, and R. M. Sneider, 1988, Coastal barrier reservoirs: *Jour. of Petroleum Tech.*, v. 40, p. 1127-1128

A short definition and description of barrier islands and their hydrocarbon reservoirs is given. The processes of barrier island formation are discussed and illustrated. Examples are Galveston Island, Texas (Holocene), Gulf of California (Holocene), and Elk City Field, Oklahoma (Pennsylvanian).

Siever, R., 1983, Burial history and diagenetic reaction kinetics: *AAPG Bull.*, v. 67, no. 4, p. 684-691.

This paper investigates the relations among burial histories deduced from stratigraphy, thermal regimes imposed by tectonic and sedimentation diagrams, plots of burial with respect to the sediment-water or sediment-air interface as a function of time since deposition. Paleogeotherms are estimated based on assumptions about heat flow, thermal conductivities, compaction, and cementation effects on porosity and convecting formation waters. From these, one can deduce the temperature history of a sediment as a function of postdepositional time. This parameter (temperature as a function of time) is the relevant parameter for reaction kinetics. Deductions about when a sediment would have had sufficient time and temperature to accomplish a given reaction can then be compared with petrologic information on the time of origin of the given diagenetic phase.

Sneider, R. M., F. H. Richardson, D. D. Paynter, R. E. Eddy, and I. A. Wyant, 1977, Predicting reservoir rock geometry and continuity in Pennsylvanian reservoirs, Elk City Field, Oklahoma: *Jour. of Petroleum Technology*, v. 29, pt. 2, p. 851-866.

The Elk City Field in the Anadarko Basin of Oklahoma produces from a Pennsylvanian Age barrier island complex.

The reservoir rock characteristics of the sand body, its geometry, fluid flow characteristics, and previous production history are presented. The sandstones are interbedded with siltstones, shales, carbonates, and conglomerate units. Data from 310 wells in the field was used to map and interpret the geology

Swift, D. J. P., 1975, Barrier-island genesis: Evidence from the Central Atlantic Shelf, Eastern U.S.A.: *Sedimentary Geology*, v. 14, p. 1-43.

Most barrier systems today appear to have retreated into their present positions from out on the continental shelf. The relative roles of coastwise spit progradation and mainland-beach detachment depend on coastal relief and slope, with steep, ragged coasts favoring spit progradation at the expense of mainland-beach detachment. Since most major barrier systems form on flat coastal plains, it would appear that mainland-beach detachment is the more important mode of barrier formation. During stillstands, or periods of reduced rate of sea-level rise, coasts can more nearly approach their climax configurations with straight coasts and well developed shoreface.

Swift, D. J. P., A. W. Niederoda, C. E. Vincent, and T. S. Hopkins, 1985, Barrier Island evolution, Middle Atlantic Shelf, U.S.A. Part I: Shoreface Dynamics: *Marine Geology*, v. 63, p. 331-361.

The fluid velocity of near-bottom sediments of the shoreface of Long Island is analyzed. The dynamics of erosional shoreface retreat are discussed and illustrated.

Waves tend to drive sediments shoreward onto Long Island. Waves in water up to 10 m (32.8 ft) deep (upper shoreface) have a shoreward component; in deeper water the shoreward movement of sediment drops rapidly. On the lower shoreface and inner shelf floor, wave-current action causes nearly symmetrical fluid velocity with a landward creep of sediments.

Fluid-shear stress on the sediments is reinforced during the shoreward stroke of the waves and partially cancelled during the seaward stroke.

Sediment transport increases during storms with a wind-driven current component. Storm-intensified currents may reach jet flow proportions. During this period, sediment is swept down from the shoreface to the inner shelf in rapid erosion. Fair-weather landward transport may not be able to maintain stability over the effect of seaward transport during storms.

Wilson, M. D., and E. D. Pittman, 1977, Authigenic clays in sandstones: Recognition and influence on reservoir properties and paleoenvironmental analysis: *Jour. Sed. Petrol.*, v. 47, p. 3-31.

Authigenic clays occur as pore linings, pore fillings, pseudomorphous replacements, and fracture fillings. Sandstones also contain detrital clays and clay clasts and grains. Authigenic origin can be established on the basis of clay composition, structure, morphology and distribution, and sandstone textural properties. No individual criterion is an infallible indicator of authigenic origin. The most reliable criteria include: (1) delicacy of clay morphology, (2) clay as pore linings, absent only at grain contacts, (3) composition radically different than associated detrital clay. Distinction between authigenic and detrital clays is difficult if the clays are recrystallized or deformed by burial and tectonism.

Each of the major clay groups has distinctive morphologies: Smectite occurs as highly wrinkled or honeycomb-like pore linings, with individual flakes not resolvable. Illite forms pore lining overlapping flakes whose edges tend to curl away from the grain surface and form highly elongated lath-like projections. Mixed layer smectite/illite morphologies resemble both smectite and illite. Chlorite occurs primarily as pore-lining pseudo-hexagonal flakes with a cardhouse, honeycomb, or rosette arrangement. Kaolinite and dickite have stacks of pseudo-hexagonal flakes. Analysis of the clay diagenesis is useful in studying barrier island preservation.

G. FOREIGN SHORELINE BARRIER ISLAND DEPOSITS

This brief survey of barrier island systems from all over the world is important to demonstrate the variability of barrier island formation and preservation. Examples of microtidal, mesotidal and macrotidal barrier island systems are included. Research on barrier island formation and related hydrocarbon recovery has been very active in recent years in northern Europe, particularly in countries bordering the Baltic Sea.

Amajor, L. C., 1984, Lower Cretaceous Viking Barrier Island, Southwestern Alberta Canada (abst.): AAPG Bull., v. 69, p. 448.

The Viking trend is more than 120 km (75 mi) long and has a maximum thickness of over 30 m (100 ft). It prograded to the northeast as much as 24 km (15 mi).

The presence of an ebb-tidal delta and marine shelf shales beneath and above the middle shoreface facies, respectively, lead the author to compare the Viking barrier more closely with Recent barriers of the South Carolina coast than with Galveston Island, Texas, or the Muddy barrier, Montana.

Bagnoli, E., 1990, The Mossoro Sandstone, Canto Do Amaro oil field, Late Cretaceous of the Potiguar Basin, Brazil: An example of a tidal inlet-channel reservoir (abst.): in Davis, R.A., Jr., D. Nummedal, and R.W. Tillman, Conference, Tidal Inlet and Related Sand Bodies: Modern and Ancient: SEPM Research Conference San Juan Basin, New Mexico, May, 1990, pages unnumbered.

Eight lithofacies are associated in inlet channel and flood-tidal delta associations within this field. The vertical sequence of lithofacies suggests that the deposition of the Mossoro Sandstone took place in a tide-dominated transgressive setting. The main reservoir sandstones comprise inlet channel deposits whose characteristics change across the field, suggesting decreased depositional energy from ENE to WSW.

Although diagenesis has significantly modified the amount and geometry of the pore spaces, it is the depositional environment that controls the porosity and permeability. The coarser lithofacies deposited by high-energy processes are more porous and permeable than fine-grained lithofacies deposited by lower-energy processes.

Boyd, R., and S. Penland, 1984, Shoreface translation and the Holocene stratigraphic record: Examples from Nova Scotia, the Mississippi delta and eastern Australia: Marine Geology, v. 60, p. 391-412.

Three examples of barrier bar sedimentation are described: New South Wales, Australia; Mississippi delta, Louisiana; and Nova Scotia, Canada. These barriers are characterized by low to moderate rates of sea level rise and wave energy.

The central coast of New South Wales had a rapid sea level rise followed by a stillstand since 6500 B. P. The

barrier has a thick sequence of basal marine transgressive sands with overlying beach and dune facies.

The barriers of the Mississippi delta are underlain by compacted deltaic muds and were influenced by a very rapid relative sea level rise. The barriers are supplied by deltaic headland erosion and are affected by low wave energy and dramatic storm deposits.

Glacially deposited drumlins are the sediment source for the barriers on the eastern coast of Nova Scotia. The sea level rise is moderate, but continual along this coast.

These three barrier sequences suggest that models based on Texas and U. S. Atlantic coastal barriers represent regional examples. A generalized coastal model controls vertical and horizontal parameters and their relationships to formation processes, distribution and geometry of facies.

Cant, D. J., 1984, Development of shoreline-shelf sand bodies in a Cretaceous epeiric sea deposit: Jour. Sed. Petrol. v. 54, p. 541-556.

The Spirit River Formation (Lower Cretaceous) of west-central Alberta consists of eight major transgressive-regressive sequences. Cores indicate sequences 30 to 50 m (98 to 164 ft) thick of fine-grained, well-sorted sandstone with low angle laminations and some burrows. Conglomerate units up to 10 m thick, and carbonaceous mudstones and coal beds also occur. The deposits are interpreted as shoreface-beach, overlain by backswamp-lagoon sediments. The coarsening upward sandstone sequences are bordered by marine shales. The slope formed by the seaward accreting sandbodies was controlled by shallow water depths, a stable tectonic setting, rapid sediment input and high wave energy.

Czapowski, G., 1984, Upper Miocene barrier sediments in southern margin of the Holy Cross Mountains (in Polish): Przegląd Geologiczny, no. 4, p. 185-194.

Regressive barrier island and associated facies are identified: open marine, barrier zone, main barrier body, barrier flat and inlet, and lagoon/embayment.

Dalrymple, R. W., R. J. Knight, B. A. Zaitlin, and G. V. Middleton, 1990, Dynamics and facies model of a macrotidal sand-bar complex, Cobequid Bay-Salmon River Estuary (Bay of Fundy): Sedimentology, v. 37, p. 577-612.

The Cobequid Bay-Salmon River Estuary is 40 km long and has a maximum tidal range of 16.3 m. The axial belts of sands deposited by the river are prograding seaward. The axial sands are divided into three facies zones: (1) elongate, tidal sand bars, (2) sand flats with a braided channel pattern, (3) the inner, single channel of tidal-fluvial transition. Tidal speeds are maximum in zone 2. Grain size decreases to fine and very fine sands in zones 2 and 3.

The prograding bar is a 20 m thick fining upward succession with cross-bedded medium to coarse sand at the bottom. The ebb-dominated portion of the bar has trough cross-bedding and megaripples. The fine grained deposits of zones 2 and 3 are parallel laminations. The bar is capped by 4 m thick unit of mudflat and salt marsh sediments. The macrotidal range of the estuary is 10 m.

Davidson-Arnott, R. G. D., and B. Greenwood, 1976, Facies Relationships on a barred coast, Kouchibouguac Bay, New Brunswick, Canada: in Davis, R.A. Jr., and R.L. Ethington, eds., *Beach and Nearshore Sedimentation*, SEPM Spec. Pap. 24, p. 149-168.

Modern nearshore environments formed by wave action are used as an analogue for bedforms and sedimentary structures in ancient sediments. A basic model for a barred nearshore environment is presented. The flow regime is related to bedform development. The dimensions of barrier islands in New Brunswick are studied from box cores taken in the nearshore zone. Four subfacies are identified and described for barrier shorelines: (1) a seaward slope with small-scale oscillation ripples, (2) bar crest with medium-scale cross-beds and lunate megaripples, (3) landward slope with oscillation ripple cross-lamination and landward dipping beds, and (4) trough facies with poorly preserved oscillation and current ripples. Nearshore flow conditions are divided into three distinct regimes: (1) symmetric oscillatory flow, (2) asymmetric oscillatory flow, and (3) unidirectional flow controlled by longshore currents.

FitzGerald, D. M., S. Penland, and D. Nummedal, 1984, Control of barrier island shape by inlet sediment bypassing: East Frisian Islands, West Germany: *Marine Geology*, v. 60, p. 355-376.

The East Frisian Islands are barrier islands formed by inlet sediment bypassing. High wave energy and a high tidal range shoreline with abundant sediment supply and a strong eastward current, characterize the buildup of these islands. The islands have extended eastward more by inlet narrowing then by inlet migration. Easterly longshore currents deposit $2.7 \times 10^5 \text{ m}^3$ sand annually bypassing the inlets to form large, migrating swash bars. The swash bars attachment to the beach is influenced by the position of the ebb-tidal deltas. Pleistocene and Holocene development of the barrier islands has formed humpbacked, bulbous updrift and downdrift shapes. Illustrations

demonstrate differences in development of high and mixed energy coasts.

Holmes, I. G., and Y. A. Rivard, 1976, A marine barrier island bar, Jenner Field, Southeastern Alberta: *The Sedimentology of Selected Clastic Oil and Gas Reservoirs in Alberta*: Canadian Soc. of Petroleum Geologists, p. 44-61.

No reasons are given in this paper to support barrier island development rather than strandplain with attached shoreface for this field in Alberta.

Percival, C. J., 1992. The Harthope Ganister—A Transgressive barrier island to shallow-marine sand-ridge from the Namurian of Northern England: *Jour. Sed. Pet.*, v. 62, no. 3, p. 442-454.

The Harthope Ganister is a quartz arenite sand body which outcrops in the northern Pennines, England. It formed during the Namurian age in the late Carboniferous. The Namurian is a succession of stacked progradational shallow-water deltaic clastic sequences separated by transgressive marine deposits. The barrier island is 4.5 km (2.8 mi) long, 2.5 km (1.6 mi) wide, and up to 9 km (5.6 mi) thick. The barrier island sequence was deposited during a transgression. The barrier island formed from reworked deltaic sands and migrated northward towards the shore by washover deposition. The backbarrier was bioturbated and ripples and megaripples developed due to wind driven currents. The barrier was submerged as transgression gradually outpaced migration. Continued migration of spits formed large scale cross-bedding up to 6 m (19.7 ft) high. The barrier island was preserved by encasement in pro-delta muds as the adjacent deltas prograded into shallow water.

Ping, S. L., 1990, Sedimentological studies of the ebb-tidal deltas along the West Frisian Islands, the Netherlands: *Geologica Ultraiectina*, v. 64, 159 p.

The Frisian or Wadden Islands of the North Sea include 17 large barrier islands and several smaller ones with 40 tidal inlets. Numerous illustrations of sedimentological features and barrier growth and destruction are given.

Priisholm, A., B.L. Nielson, and O. Haslund, 1987, Fines migration, blocking, and clay swelling of potential geothermal sandstone reservoirs, Denmark: *SPE Formation Evaluation*, v. 2, p. 168-178.

The West Frisian Islands are composed of barrier islands in which ebb-tidal deposits are a major component. The deposits are modified by marine processes including longshore currents and tidal currents.

Geothermal exploration in Denmark has resulted in the study of clays from sandstone reservoirs of Triassic and Jurassic age. Core analyses included porosity, air permeability and grain density. The sandstones were

fluvio-deltaic in origin. Brine flow caused kaolinite and quartz fines to be produced from compacted sandstones. Kaolinite, illite, and detrital fines were produced from uncompacted sandstones. Reservoir damage occurred when formation brine was replaced by KCl brine. Changes in flow direction caused blocking by fines. An inverse relationship between porosity and the amount of fines produced was found.

Reineck, H. E., and I. B. Singh, 1975, *Depositional Sedimentary Environments*, with reference to terrigenous clastics: Springer-Verlag, 439 p.

Very complete text on depositional forms and processes of terrigenous clastic environments world wide. Several chapters cover barrier islands, strand plains, and shoreline deposits including channels and shoals. Contributions by a number of authors gives a broad scope to this work. Maps, illustrations, and references are extensive and excellent.

Roy, P. S., B. G. Thom, and L. D. Wright, 1980, *Holocene sequences on an embayed high-energy coast: an evolutionary model: Sedimentary Geology*, v. 26, p. 1-19.

Based on research in Southeastern Australia. Three primary Holocene embayments fills (valley fills are described): (1) open ocean, (2) barrier estuary, (3) drowned river valley .

Silseth, J. K., A. C. MacDonald, J. Alvestad, A. T. Buller, and S. B. Torp, 1993, *SPE Reservoir Engineering*, February 1993, p. 27-33.

A simulated waterflood performance test was done on a synthetic model of a heterogeneous barrier-bar sand body. A simplified flow-unit representation of reservoir heterogeneity was used to contour petrophysical zonal averages. Comparative simulation were made. "The contour models did not generate consistently optimistic predictions of reservoir performance". Well behavior varied individually based on the model type.

This simulation was designed to more realistically analyze reservoir simulation studies. Past studies in the North Sea mature fields have had a tendency to give overly optimistic predictions of water breakthrough and ultimate recovery. The architecture of the model was based on a regressive, barrier-bar sand body complex. It was bounded above and below with marine mudstones. It was designed with the reservoirs of the Norwegian Continental shelf in mind.

Swift, D. J. P., 1968, *Coastal erosion and transgressive stratigraphy: Jour. of Geology*, v. 76, p. 444-456.

Study of ravinements in the Bay of Fundy shows that they are caused mainly by surf action along a narrow zone at the foot of the shoreface.

Appendix A

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