sediments comprise the Tyler and Minnelusa-Amsden formations.

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Pennsylvanian Gas in Four Corners Region

Pennsylvanian accumulations of gas and casing-head gas in the Four Corners region (junction of Utah, Colorado, New Mexico, and Arizona) occur in carbonates of Desmoinesian age (Middle Pennsylvanian) in four lithologic zones of the Paradox member of the Hermosa formation. These zones, from oldest to youngest, have been named Barker Creek, Akah, Desert Creek, and Ismay. They are shelf counterparts of basinal evaporitic sequences.

Reservoir beds are calcirudite, calcarenite, and sparsely to moderately fossiliferous carbonate, which is nearly in place and was deposited in biostromal and biohermal complexes. Dolomitization and other diagenetic changes have affected these units. Vuggy and intercrystalline porosity are predominant; fracturing is important in some places.

Only in a few instances can the type of trap, with fair assurance, be defined from present subsurface control. Structurally, all of the gas fields are found on surface or subsurface highs of varying relief and areal extent. Sedimentary compaction has contributed to this relief in some places, and late Pennsylvanian-Permian warping has occurred. Most of the present structural relief of these structures is due to folding during the Laramide orogeny. Stratigraphic variations, from porous reservoir beds to nonporous units, are a contributing factor in most accumulations, and the major controlling factor in some.

Eleven gas and five casing-head gas fields have been found to date, but these are still largely undeveloped. The cumulative gas production to July 1, 1959, in the Aneth Complex was 9,682,004 MCF. To September 1, 1959, the cumulative production from four zones was 179,825,593 MCF at the Barker Creek field which represents slightly over one-half of the calculated original recoverable reserves of 315 billion cubic feet. Gas from the Barker Creek field, and from the Aneth Complex, is transmitted to Kirtland, New Mexico, and from there to Topock, Arizona. Buyers at Topock distribute to customers in California and southern Nevada.

These Pennsylvanian gas accumulations are believed to be essentially *in situ* occurrences. Migration was predominantly local, not exceeding a few miles; and entrapment occurred in laterally adjacent areas of bioclastics and sparsely to moderately fossiliferous carbonates. After initial entrapment, some later re-migration is believed to have occurred.

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Bar-X, San Arroyo, Westwater Creek Gas Fields, Colorado

The Bar-X, San Arroyo, and Westwater Creek natural gas fields are located on anticlinal structures having the same names, in townships: T. 16 & 17 S., R. 24, 25 & 26 E., Grand County, Colorado. The first gas in the region was discovered on the Bar-X anticline in 1948 by Stanolind Oil and Gas Company. However, further drilling was not accomplished until 1954. Development of the fields has been slow due to the lack of a market for the gas, inadequacy of the present pipeline gathering system, and to controversial estimates of the natural gas reserves.

To date, 35 wells have been drilled on the three structures with 28 of the wells completed as gas producers from one or more sands in the Dakota, Cedar Mountain, Morrison and Entrada formations. The initial production of the gas wells in the three fields has ranged from 250 MCF to over 20,000 MCF of gas per day. The B.T.U. of the gas varies from 550 to 1,150 with the lower values being confined to the gas from the Entrada formation.

The subject area is located in and near the Book Cliffs which bound the southern end of the Uinta Basin. Much of the area is extremely rugged, being dissected by deeply incised canyons and prominent cliffs. Development is largely confined to the canyons in the Book Cliffs and to the rolling terrain at their base.

The pay zones in the Dakota, Cedar Mountain and Morrison formations are largely discontinuous sandstone lenses. The lithology of these formations is extremely erratic and virtually no two adjacent wells are completed in the same sandstone bed. The Dakota sands in the San Arroyo field are the most continuous. The natural gas found in the Dakota, Cedar Mountain, and Morrison formations is primarily accumulated in stratigraphic traps. Structural control may be secondary. The over-all general region might be considered as a potential reservoir with the sandstone lenses providing concentrated accumulations within the larger reservoir. Perhaps artificial stimulation at the proper interval might result in obtaining commercial gas production, even though a porous sandstone lens was not penetrated by the well bore. A lower salt water contact has not been established in the area for these formations. Natural gas production has been obtained in the Dakota formation all the way from 3,000 feet above sea level down to sea level. An upper water contact at an elevation of 3,200 feet has been fairly well established. This may infer that some peculiarities due to pressure variations caused by hydrodynamic and saline anomalies are present.

The gas in the Entrada formation is probably controlled by structure since the Entrada sand is a fairly continuous body.

Faulting in the region apparently has not affected the migration and accumulation of the gas, but has quite definitely affected the porosity of the sands adjacent to the faults.

The natural gas reserves estimated in the three fields vary considerably. Based on volumetric calculations using the porosity, pressure, sand thickness, and similar data, estimated reserves of natural gas in place vary from 2.5 billion to 8 billion cubic feet per section from the Dakota, Cedar Mountain, and (or) Morrison formations. The reserves, based on volumetric calculations, in the Entrada vary from 8 to 15 billion cubic feet per section.

The Bar-X field is the only field in the group which has a production history, having produced for approximately three years. Pressure-decline curves on the wells in this field for the Dakota and Morrison formations indicate minimum reserves of 1.5 to 5 billion cubic feet per section.

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Thickness and Distribution of Devonian Formations in Relation to Buried Pre-Madison Structural Features in Williston Basin

Rocks of Devonian age underlie all but the south-central part of a 200,000 square mile area that includes the southern Williston basin in North Dakota, South Dakota, and eastern Montana and adjacent parts of central Montana and northern Wyoming. They crop out in the Bighorn, Pryor, Absaroka, Beartooth, Big Snowy, and Little Rocky Mountains.

These Devonian rocks consist predominantly of marine carbonates, evaporites and shales, and attain a maximum thickness of about 2,000 feet in northwestern North Dakota. Lower Devonian rocks assigned to the Beartooth Butte formation, an estuarine channel-fill deposit as thick as 150 feet, crop out at many isolated localities in north-central Wyoming and south-central Montana. Middle Devonian rocks underlie the central Williston basin but are not present at the surface. They reach a maximum thickness of about 870 feet in north-central North Dakota. The Middle Devonian series is divided into the Winnipegosis and Prairie formations of the Elk Point group and the overlying Dawson Bay formation. Upper Devonian rocks underlie most of the area studied and make up most of the outcrops. They attain a maximum thickness of about 1,250 feet in northern Montana. The Upper Devonian series is divided, in ascending order, into the Souris River formation; the Jefferson group, consisting of the Duperow and Birdbear formations; and the Three Forks formation.

Several major anticlines and a large reverse fault have been interpreted from the isopach maps of the Devonian formations. These structural features were formed during Middle and Late Devonian and earliest Mississippian time and then buried beneath thick deposits of the Madison group (Mississippian). They controlled Devonian sedimentation and probably trapped large quantities of oil and gas in Devonian and older strata. Minor oil production has already been established from reservoir rocks in every Middle and Upper Devonian formation except the Prairie. Most of the Devonian oil fields are located on the trends of the pre-Madison features which diverge slightly from the trends of related Laramide features.

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Photogeomorphology and Oil Exploration in Rocky Mountain Region

Structure and stratigraphy at or near the earth's surface can be identified and defined by photogeomorphic mapping methods. Processes necessary to proper photogeomorphic mapping are somewhat similar to geologic mapping processes.

Some geomorphic features that contribute information with respect to structure and stratigraphy include trellis drainage, annular drainage, radial or centrifugal drainage, centripetal or interior drainage, drainage deflection, arcuate drainage, linear stream segments, barbed tributaries, channel pattern variation, antecedent and super-imposed drainage, entrenched meanders, oblate tonal variations, tone halos, fracture traces, geomorphic lineaments, curved tonal features, drainage divides, glacial land forms and landslide debris. With proper symbolization and application of these symbols to geomorphic data, structure and stratigraphy can be mapped in a manner that produces data pertinent to oil exploration programming.

When photogeomorphic criteria are delineated in areas of good or poor outcrop expression and density, the resulting map presents both areas of anticlinal folding and (or) associated fault relationships as well as stratigraphic delineation. Use of photogeomorphic interpretation in areas where surface geologic mapping is difficult is a pertinent application of this tool for exploration.

Photogeomorphic features exist at the earth's surface due to the influence of surface rocks, climate, and vegetative growth. Tectonic adjustment so subtle as to be overlooked by normal geologic mapping techniques may be apparent through the use of definitive photogeomorphic mapping. A detailed familiarity with known structure and stratigraphy within the area of study is imperative. In the Cenozoic, emphasis should be directed toward physiographic development for proper application of geomorphic data. The photogeomorphologist must be adequately prepared to discern misleading information and to concentrate on those data that are indicative of favorable conditions for oil or gas entrapment. A method of compilation for photogeomorphic analysis is suggested as well as a tentative programming for analysis of the criteria.

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Facies and Porosity Relationship in Some Mississippian Carbonate Cycles of Western Canada Basin

Case histories of textural and reservoir analyses of selected Mississippian carbonate cycles of the Western Canada Basin are presented to illustrate the relationship that exists between the occurrence and petrographic nature of an effective carbonate reservoir rock and the framework of carbonate sedimentation. Various types of carbonate rock pores are described and evaluated with respect to effective porosity.

Large stratigraphic oil pools have been discovered, at or near the Paleozoic subcrop of the Mississippian "Midale" carbonate cycle, in southeastern Saskatchewan. Apart from scattered, vuggy, algal-encrusted strand line deposits, most of the carbonates of the "Midale" producing zone consist of skeletal and oolitic limestones which have a finely comminuted, frequently dolomitized, limestone matrix with intergranular and chalky porosity. Effective reservoir porosity is controlled by the relative distribution and grain size of this matrix.

Major hydrocarbon (oil and gas) reserves have been found in the Mississippian "Elkton" carbonate cycle, both in the Foothills Belt and along the subcrop, in southwestern Alberta. Effective reservoir material of this cycle was found to consist mainly of the dolomitized equivalent of an originally coarse skeletal limestone, with a variable amount of generally porous, finely comminuted (granular) skeletal matrix. Primary porosity was very important in the control of dolomitization which probably began with the replacement of this matrix by euhedral rhombohedrons and finally affected the coarse skeletal material (now generally indicated by leached fossil cast outlines). These porous dolomites grade laterally in a predictable way into tight, relatively undolomitized, well sorted, coarse skeletal limestones with original high interfragmental porosity now completely infilled with clear crystalline calcite. This lithification by cementation took place early in the history of carbonate sedimentation of this area and before secondary dolomitization processes took effect.

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Coyote Creek Field, Wyoming, Its Character and Significance

Coyote Creek is the largest stratigraphically trapped Dakota oil field discovered on the eastern flank of the Powder River basin. The trap is formed by an updip change from clean sand to impermeable sand, siltstone and shale in a pinch-out zone which is only a few hundred yards wide. The trap occurs in an area of homo-