INTRODUCTION

The Jicarilla Apache Indian Reservation covers approximately one million acres in north-central New Mexico on the eastern edge of the San Juan Basin, comprising parts of townships 22 to 32 north and ranges 1 east to 5 west (Figures J-1 and J-2). The San Juan Basin contains the second largest natural gas field in the coterminous United States and has produced more oil from fractured Mancos shale than any other basin in the Rocky Mountain province. The Jicarilla Apache Tribe is the single largest mineral owner in the basin, excluding the United States government. During more than 35 years of gas and oil activity within the Reservation, over 2,700 wells were drilled, predominantly on the southern half. The 1993 production from 2,300 active wells was nearly 900,000 barrels of oil (BBO) and 30 billion cubic feet of gas (BCF).

Two recent discoveries highlight the new potential in this mature basin. Fruitland coal seam gas has more than doubled the basin's gas production. Additionally, a 1992 horizontal Mancos oil well has tapped an estimated 5-10 million barrel of oil (MMBO) reservoir on the relatively unexplored northern half of the Reservation.

The Jicarilla Apache Indian Tribe has successfully financed, drilled, produced and marketed oil and gas resources from Tribal properties for more than 15 years. The Tribe plans to continue to expand its own operations and participation as a working interest owner. For entities interested in working with the Tribe, Tribal oil and gas exploration and development agreements are negotiated and structured individually to address the needs of the outside parties and the Tribe and the specific concerns relative to the reservoir. Agreements will follow basic industry standards as applicable and are governed by federal laws protecting all parties.

The basin contains a complete infrastructure of gas gathering and delivery systems, oil pipelines, and refineries to process, market and deliver oil and gas. Gas transportation systems such as the Williams Company, El Paso Natural Gas, West Gas and The Gas Company of New Mexico provide competitive markets in almost all directions.

RESERVATION PRODUCTION OVERVIEW

Figures J-2 and J-3 shows the outline of the Jicarilla Apache Reservation, on the eastern side of the San Juan Basin, and the general distribution of the primary producing fields. A stratigraphic chart of the eastern part of the San Juan Basin is shown in Figure J-4. In general, the producing formations are Cretaceous-age fluvial, deltaic, and nearshore sandstones, offshore shales and shales and coal deposit ed during numerous transgressive and regressive cycles. Typically, land was to the west and southwest sheding sediment toward the sea, and open to the east and northeast.

Most of the gas in the sandstones are stratigraphically trapped against shales in a structural setting of regional west dip. However, localized structures may enhance trapping and productivity. Oil producing sandstones such as the Dakota may require more structural closure. The Mancos Shale occurs in fractures along the steeply dip

Figure J-1. Regional index map of the the Four Corners area showing major uplifts and basins with superimposed minor features (after Peterson, 1965, p. 278).

Figure J-2. Index map of the San Juan Basin with major tectonic features. Position of cross section A-A’ (see Figure 5) is shown (after Peterson, 1965, p. 2079).
REGIONAL GEOLOGY

Dakota Formation

The Dakota Sandstone is a transgressive marine unit formed as the Late Cretaceous sea moved from east to west across the land. It contains coastal marine sandstones and continental fluvial sandstone units. It is a dominantly stratigraphic gas play in the basin and a structural and stratigraphic oil and gas play along the basin's flanks. The rocks represent a wide variety of depositional environments, ranging from braided and meandering stream complexes to nearshore deposits. Lithologies vary considerably, as do reservoir quality and trapping mechanisms.

The first Dakota discoveries were made in the early 1920s on the northwestern flank of the basin and a central basin discovery well was drilled in 1947 south of Bloomfield, New Mexico in the Angel Peak area. A few additional discoveries were made in the 1950s. In 1961 several fields were combined to form the Basin Dakota field, which by the end of 1976 contained 2,400 producing wells that had produced over 2.7 trillion cubic feet (TCF) of gas with an estimated total production of over 5 TCF. The field produces from a combination of hydrodynamic and stratigraphic traps. Dakota fields range in size from 40 to 10,000 acres with most production from fields of 100 to 2,000 acres (Huffman, 1987). Production of oil ranges from field totals of 1-7 MMBO. Over 14 BCF of associated gas has been produced.

Potential still exists for future discoveries in the Dakota interval and the limits of the Basin Dakota field have not yet been defined. Exploration in the Dakota is challenging and demands an understanding of basin structure and complex Dakota depositional patterns. New production techniques for tight gas sandstones and new interpretive tools such as 3-D seismic and the application of sequence stratigraphy will be critical in the development of future Dakota reserves.

Mancos Formation

The monocline flexure surrounding the east, north and west flank of the San Juan Basin concentrates most of the Mancos oil production in fractured dolomitic siltstones sandwiched by marine shale. The Jicarilla Apache Indian Reservation lies along the east rim of the basin and the southeastern part of the central basin.
Tectonic activity associated with the Laramide Orogeny in late Cretaceous to early Tertiary time resulted in the subsidence of the central basin, uplifts of the surrounding rim and associated fracturing of brittle beds (Fassett, 1985 and 1991; Baltz, 1967). Figure J-5 is an east-west section through the San Juan Basin showing the central basin and marginal steeply dipping strata.

Mancos oil production in the San Juan Basin is nearly 30 MMBO. Seventy five per cent of the total or 23.3 MMBO comes from the four Mancos fields that lie within and just outside the Reservation boundary. Mancos oil production on the Reservation has been 5.1 MMBO. The unexplored northern part of the Reservation lies on the same geologic and structural trend of this prolific Mancos production. Hence the potential is quite high for additional Mancos discoveries in the area.

Figure J-5: East-west cross section through the San Juan Basin (see Figure J-2 for line of section) showing lithologies and structure. The Jicarilla Apache Indian Reservation is located on the steeply dipping eastern flank, west of the Nacimiento uplift (after Peterson, 1965, p. 2088).
The three primary oil bearing reservoirs of the Mancos occur in fractured dolomitic siltstone beds (London, 1972) within a 300 foot interval of the Niobrara called the “A”, “B” and “C” zones. The more brittle rocks, such as the calcareous siltstones of the Niobrara A, B and C zones, fractured more easily when bent or folded than the more plastic encasing shales. The zones are 20-60 feet thick with individual siltstone beds within the zones 5-20 feet thick. The A and B zones are the main productive intervals near the study area, as found in East Puerto Chiquito field and the northern part of West Puerto Chiquito field. The C zone produces the most oil in the southern part of West Puerto Chiquito field. Increased resistivity in the Niobrara zones may be due to the tightly cemented dolomitic siltstone and/or oil in the fractures.

The abrupt bending of the rocks along the monoclinal rim resulted in many north-south trending faults and fractures. Eizenhoffer (1989) showed a prevailing north to south fracture orientation in the greater Puerto Chiquito/Gavilan area based on wireline dip meter fracture logs (Figure 2.4). This trend extends into the Jicarilla Apache Reservation. Remote sensing data such as satellite, radar and photo images and surface mapping also show similar linear and fracture orientations in the eastern Rio Grande Basin. The larger features appear to be reactivated basement fault zones that control reservoirs, uplift, fracturing and folding throughout geologic time (Dart, 1992).

Five structural settings of fracture intensity and associated oil production have been recognized in the central Jicarilla Apache Indian Reservation area. These include: monoclinal flexure, basal monocline flexure, antitonic fracture, synclinal trough and central basin structure. The central basin structures contain low relief anticlins and synclines but are west of the monocline. The common structural traits of these five settings are maximum curvature of the clines and synclines but are west of the monocline. The character of the sandstones appears to be the primary controlling factor in the distribution of oil and gas deposits. Since the development of the Mesaverde and Mancos groups in the central area, oil has been discovered in the Orobe Quarry, Ebro, Estancia, and the East Puerto Chiquito field. These are the most productive areas of the Jicarilla Apache Reservation (after Emmendorfer, 1989, p. 66).

The Mesaverde Group is the largest producer of natural gas (excluding coal bed gas) of all geologic units in the San Juan Basin, followed by the Dakota Sandstone and the Pictured Cliffs Sandstone. The Mesaverde has furnished energy to North America in the region for several hundreds of years, beginning with oil and gas fields in the San Juan Basin, in a well drilled for water in the Chaco Slope, on the southwestern side of the Pictured Cliffs Sandstone. The Mesaverde has furnished energy to North America in the region for several hundreds of years, beginning with oil and gas fields in the San Juan Basin, in a well drilled for water in the Chaco Slope, on the southwestern side of the Pictured Cliffs Sandstone. The Mesaverde has furnished energy to North America in the region for several hundreds of years, beginning with oil and gas fields in the San Juan Basin, in a well drilled for water in the Chaco Slope, on the southwestern side of the Pictured Cliffs Sandstone. 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NEW MEXICO

JICARILLA APACHE INDIAN RESERVATION

**Pictorial Cliffs**

- Hydrocarbon production in the Pictorial Cliffs has been primarily by gas trapped in sandstone beds which are enclosed in shales or coals at the top of the unit. The Pictorial Cliffs Sandstone is similar to the Cliff House Sandstone in that it is a regressive marine sandstone deposited in low-energy nearshore or barrier environments.

- The Fruitland is the shallowest of the San Juan Basin reservoirs. Therefore, recompleting wells in the coals can provide limited gas potential on the Jicarilla Apache Reservation.

**GEOLOGIC HISTORY**

- The Jicarilla Apache Reservation is located on the east side of the San Juan Basin in northwest New Mexico (Fig. J-3), comprising parts of Townships 22 to 32 N and Ranges 1 to 5 W (Fig. 1-2). The outcrop of the Cretaceous Fruitland formation is generally accepted as the outer limit of the geologic San Juan Basin and the outcrop trends generally north to south along the east side of the Reservation (Figure J-7). The east edge of the basin marks the approximate eastern edge of the Colorado Plateau physiographic province.

- Formations present in the eastern part of the San Juan Basin and under the Reservation range in age from Mississippian to recent as shown in Figure J-4.

**Sedimentary History**

- The eastern part of the San Juan Basin was an area of erosion or non-deposition until Mississippian time. Even then, sediments deposited during the Mississippian and Pennsylvanian range from 0 to a few hundred feet thick under the Jicarilla Apache Indian Reservation. The first formation that appears to be present under all parts of the Reservation is the Perminian Catlin. From Catlin level upward there can be units that reach zero thickness, such as the Cretaceous Pictorial Cliffs Sandstone, but it is more likely that the pinchouts represent true depositional edges rather than erosional truncation.

- Thickness variations and pinch-outs in the pre-Pennsylvanian section seem to be a result of the San Juan Basin depositional area being on the northwest flank of the early Paleozoic Transcontinental Arch (Peterson, 1965, p. 208).

- Cambrian and older

- A very thin section of Ignacio Quartzite is present in the north west part of the San Juan Basin. It rests nonconformably on Precambrian rocks equivalent in age to the Belt Supergroup and is overlain discontinuously by Devonian rocks (Loeblach-Buh, 1972, p. 68).

- Devonian

- Up to 300 feet of lower Devonian Elbert Formation carbonates are present in the Four Corners area and these thin eastward into the San Juan Basin where they disconformably overlie both the Cambrian Ignacio Quartzite and Precambrian rocks. According to Baars (1972, p. 96) the overlying McCracken sandstone is areally restricted to the Four Corners Platform although one field in the San Juan Basin is productive (Peterson, 1965, p. 103). Mississippian rocks overlie an erosional surface developed on Devonian, Cambrian and Precambrian rocks. All of the present day San Juan Basin was emergent at the end of Mississippian time (Peterson, 1965, p. 297).

- Uplift of the Ancestral Rockies led to deposition of thin arkose and sandstone sequences adjacent to local structures. During this time, the San Juan Basin was bounded on the east north by the Uncompahgre Uplift and on the south west by the Zuni-De-fiance Uplift and formed a shallow seaway that accumulated mostly limy shale and shaly carbonates. From the base of the section upward, the three main Pennsylvanian units in the Basin are the Molus Shale, Hermosa Formation and Rino Formation. Pennsylvanian rocks lie disconformably on the Mississippian section (Childs, et. al., 1988). The section in the San Juan Basin reaches about 2,500 feet in thickness in the far northwest (Malloy, 1972, p. 115).

- Permian

- There are over 2,000 feet of Permian-age rocks in the deepest part of the San Juan Basin.

- **Figure J-7** Outline of the San Juan Basin as defined by the outcrop of the Cretaceous Fruitland formation. Position of the Jicarilla Apache Indian Reservation is shown (after Fassett, 1986, p. 24).

- **Figure J-8** Probable configuration of the North American Epeiric Sea in the time for Upper Cretaceous rocks of the San Juan Basin accumulated (after Fassett, 1988, p. 36).

**San Juan Basin**


- By this time, the Zuni-De-fiance Uplift was of minor importance and a majority of the sediments came from the north and northeast of the Uncompahgre Uplift, Archuleta Uplift and Navajo Uplift. The influx of clastics from the Navajo Uplift to the east caused almost total regression of marine depositional systems (Peterson, 1965, p. 202). On the northeast, Catlin arkoses are the predominant lithology and these are overlain southwestward by the Coconino and De Chelly Sandstones. There is an erosional hiatus at the top of the Permian section (Childs, et. al., 1988).

- Triassic

- During the Lower Triassic, parts of the future San Juan Basin became elevated as seen in thinning of the section from about 1,500 feet on the southwest to less than 750 feet on the northeast (Peterson, 1965, p. 209). In Middle Triassic the Basin was high and became a source area, experiencing active erosion. By the Late Triassic time, the area was low and was accumulating shales and sandy shales we now call the Chinle and Dolores Formations. There appear to be about 1,500 to 2,000 feet of Triassic rocks in the present San Juan Basin (Macachlan, 1972, p. 169), thickening to the southwest. A proto San Juan Basin south of the Central Colorado Uplift was the northwestern one into the Utah-Idaho trough and was the site of deposition of about 1,250 feet of Jurassic sediments (Peterson, 1972, p. 130) thinning to about 1,000 feet on the north and south (Peterson, 1965, p. 210). From the base of the Jurassic section upward, these offshore Formations are the Entrada Sandstone, Tollo Formation and Morrison Formation. The Entrada is a produdcum reservoir in parts of the Basin where it is overlain by the Eocene of the Tooldo.

- **Cretaceous**

- The present San Juan Basin was on the west edge of the Western Interior Cretaceous Sea (Figure J-3) and received a thick section of Eastes Sea. Triassic rocks related to transgression and final regression of the west end of the sea. Most of the section is Upper Cretaceous in age, but up to 200 feet of Lower Cretaceous Burro Canyon Forma tion were deposited within and adjacent approximately with the older Jurassic depositional trend (McGinley, 1972, p. 197). These are represented from the Jurassic section by an erosional hiatus (Childs, et. al., 1988).
Upper Cretaceous rocks are more than 6,000 feet thick and comprise all the rocks shown in Figure J-9. The vast majority of petroleum in the San Juan Basin is from rocks of upper Cretaceous age. The present San Juan Basin did not form until the Laramide orogeny. However, a pre-Laramide low aligned approximately north-south allowed accumulation and preservation of the Cretaceous sediments (McGookey, 1972, p. 207). It is north and northwest of the San Juan Basin starting in late Eocene time, peaking during the Oligocene and tapering off in the Miocene. Surficial deposits derived from this activity are present in much of the basin.

**Structural Geology**

Structurally, the Jicarilla Apache Reservation extends over a large portion of the San Juan Basin. The entire area was emergent in late Mississippian time (Peterson, 1965, p. 2067). For most of the period between the end of the Mississippian and beginning of the Tertiary, the area was a low adjacent to a series of uplifts to the north, northwest, southwest and east and received most of its fill during this time.

Figure J-9. Stratigraphic cross section showing upper Cretaceous rocks across the San Juan Basin, New Mexico and Colorado (after Nummedal and Minnich, 1995, p. 279).

Figure J-10. Structure contour map on the Huerfanito Bentonite in the San Juan Basin. Contour intervals are in feet (after...
The San Juan Basin as we know it today is a Laramide age feature that resulted as the North American plate drifted westward and impinged on an eastward dipping subduction zone (Woodward and Callender, 1977, p. 209). Because of the bend in the Cordilleran fold belt in southern California, the predominant stress direction was to the northeast, creating the dominant northwest trending folds and northeast trending normal faults we see today. Several northwest-plunging, en echelon, open folds and northeast-trending, high-angle faults of small displacement occur along the eastern margin of the San Juan Basin. Erdey (1997, p. 2) suggests that later activity along the Sevier thrust belt imposed a northwest-southeast compression on the basin. Evidence for this is found on the north side of the basin near Durango where northwest-southeast dikes swarms show extension, not compression. Condon (1997, p.85) thinks that clockwise rotation during the main Laramide event may have been responsible for the observed extension.

The Jicarilla Apache Indian Reservation is on the east side of the San Juan Basin and according to Woodward and Callender (1977, p. 210): The eastern boundary of the San Juan Basin is marked by a monocline along the west side of the Galina-Archuleta Arch and by range-margin upthrust and reverse faults on the west side of the Nacimiento Uplift. A sharp synclinal bend that is locally overturned occurs west of the upthrust and reverse faults. There is at least 10,000 feet of structural relief between the highest part of the Nacimiento Uplift and the adjacent part of the San Juan Basin. Structural relief between the Basin and the Galina-Archuleta Arch is at least 13,000 feet.

Verbeek and Grout (1997, p. 7) indicate that post-Laramide uplift and regional extension associated with basin and range faulting have created a significant joint network that is locally more important than those resulting from Laramide movements. Significance of these most likely northwest-southeast trending extensional fractures to subsurface fluid migration is not known, although they may have an influence on coal cleat orientation and subsequent effect on coal bed methane recovery.
### Summary of Play Types

<table>
<thead>
<tr>
<th>Play Type</th>
<th>Description</th>
<th>Oil or Gas</th>
<th>Known Accumulations</th>
<th>Undiscovered Resource (MMBOE)</th>
<th>Play Probability (%)</th>
<th>Drilling depths</th>
<th>Favorable factors</th>
<th>Unfavorable factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 Entrada Sandstone</strong></td>
<td>Associated with relict Entrada topography, created by anhydrite in overlying Tusas reservoir</td>
<td>Oil</td>
<td>4.060 MMBO (1994)</td>
<td>37.9 MMBO (mean)</td>
<td>1.0</td>
<td>2204-6,000 ft.</td>
<td>1) productive seal of Entrada 2) excellent porosity and permeability 3) Entrada topography, sealed by anhydrite 4) trend in southeast part of the basin 5) no known oil production on the reservation at present</td>
<td>1) must lie within depositional area of overlying Todilto limestone 2) sand rapidly loses permeability below 9,000 feet 3) requires favorable paleo-structurally topographic relief 4) must lie within depositional area of overlying Todilto limestone 5) relatively shallow on east 6) confusion in use of &quot;Gallop&quot; and &quot;Mesaverde&quot; sandstone lentils 7) broad sand/reservoir distribution 8) little to no secondary recovery</td>
</tr>
<tr>
<td><strong>2 Basin Margin Dakota Oil</strong></td>
<td>Marine transgressive sand and relict channel sand structural and stratigraphic play, becoming more marine to the southeast.</td>
<td>Both</td>
<td>22.9 MMBO 63.1 BCFG</td>
<td>62.9 BCFG non-associated (mean)</td>
<td>1.0</td>
<td>1,000-3,000 ft.</td>
<td>1) multiple plays 2) natural features enhance fault permeability 3) relatively shallow drilling to basin margin oil play 4) close market</td>
<td>1) stratigraphic traps 2) low matrix permeability 3) need fracture enhancement 4) long wells 5) no secondary recovery</td>
</tr>
<tr>
<td><strong>3 Tocito Gallup Sandstone Oil</strong></td>
<td>Oil and associated gas play in lenticular sandstone bodies of the Upper Cretaceous Gallup sandstone and fault/fracture controlled associated gas in overlying Todilto limestone.</td>
<td>Both</td>
<td>200 BCFG 93.1 BCFG</td>
<td>93.1 BCFG non-associated (mean)</td>
<td>1.0</td>
<td>1,100-6,800 ft.</td>
<td>1) possible multiple plays 2) high gas BTU's (1275) 3) relatively shallow on east 4) oil and gas from discontinuous, lenticular channel sands 5) thick pay sections 6) stratigraphic/hydrodynamic traps 7) possible multiple plays 8) high oil gravities small</td>
<td>1) stratigraphic traps 2) low matrix permeability 3) need fracture enhancement 4) long wells 5) no secondary recovery</td>
</tr>
<tr>
<td><strong>4 Basin Margin Mesaverde Oil</strong></td>
<td>Confirmed stratigraphic oil play, adjacent margins of San Juan Basin.</td>
<td>Oil</td>
<td>Unknown</td>
<td>7.9 MMBO 7.8 BCFG associated</td>
<td>0.80</td>
<td>1,000-3,000 ft.</td>
<td>1) possible multiple plays 2) high oil gravities 3) high gas BTU's 4) high oil recovery 5) thick pay sections 6) no secondary recovery 7) future discoveries likely to be small</td>
<td>1) stratigraphic/hydrodynamic traps 2) low recovery potential 3) thin gas zones 4) oil from discontinuous, lenticular channel sands.</td>
</tr>
<tr>
<td><strong>5 Fruitland-Kirkland Fluvial Sandstone Gas</strong></td>
<td>The play occurs in the central part of the San Juan Basin.</td>
<td>Gas</td>
<td>1.9 TCFG</td>
<td>2210.1 TCFG associated</td>
<td>1.0</td>
<td>1,500-2,700 ft.</td>
<td>1) wide fault distribution in San Juan Basin 2) productive fault gas sands 3) high porosity 4) productive overthrust fans from San Juan Basin 5) large fields already found 6) requires favorable paleo-structurally topographic relief 7) produces from discontinuous, lenticular shale sandstone</td>
<td>1) tight gas sands 2) requires favorable paleo-structurally topographic relief 3) produces from discontinuous, lenticular shale sandstone</td>
</tr>
</tbody>
</table>

Table 1. Play summary chart.
## Summary of Play Types

**JICARILLA APACHE INDIAN RESERVATION, NEW MEXICO**

### Total Production

- **San Juan Basin Cumulative Totals**
  - **Oil:** >240,000,000 BO
  - **Gas:** >18,000,000,000 CFG
  - **NGL:** Included

(FIGURES FROM NMOGA, 1997 & FCDS, 1983)

### Undiscovered resources and numbers of fields are for Province-wide plays. No attempt has been made to estimate number of undiscovered fields within the Jicarilla Apache Indian Basin

<table>
<thead>
<tr>
<th>Play Type</th>
<th>USGS Designation</th>
<th>Description of Play</th>
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<th>Undiscovered Resource (MMBOE)</th>
<th>Play Probability (Field Size)</th>
<th>Favorable factors</th>
<th>Unfavorable factors</th>
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</thead>
</table>
| **6** | Dakota Central Basin Gas | Stratigraphic trap with coastal marine barrier bars and non-marine fluvial sands. | Gas | Unknown | 6.1 TCFG (mean) | 1.0 | 6,000-7,500 ft. | 1) multiple play | 1) shallow drilling depth 
2) natural fractures enhance low permeability |
| **7** | Mancos Fractured Shale | Structural, transgressive, non-marine, fractured shale play on San Juan margin. | Oil | 16 MMBO total for basin | 22.5 MMBO on reservation | 1.0 | 1,400-7,500 ft. | 1) shallow drilling depth 
2) fracture-enhanced permeability 
3) nearby market 
4) gravity drainage | 1) future discoveries likely to be shallower 
2) continuously drilled with natural fracture systems 
3) drill graphitic/kerogen traps 
4) low oil recoveries |
| **8** | Central Basin Mancos Gas | Comprises the Point Lookout and Cliffhouse members of the Mesaverde Formation in non-marine lacustrine sandstones and thin fluvial sands. | Gas | 9.8 TCFG (mean) | 1.0 | 4,000-6,200 ft. | 1) multiple play 
2) high oil gravities 
3) ready market 
4) thin pay sands | 1) source rock quality variable 
2) requires pressure main-stem maintenance 
3) small volume of gas produced is reinjected 
4) must locate suitable fracture system |
| **9** | Pictured Cliffs Gas | Gas production is from stratigraphic traps in shale or coal at the top of the Upper Cretaceous Pictured Cliffs sandstone and is controlled by the central part of the basin. | Gas | 5 fields average 11 BCFG | 3.3 TCFG (mean) | 1.0 | 1,000-3,000 ft. | 1) good porosities and permeabilities 
2) strong market 
3) high oil gravities 
4) higher than average BTU content (1175) | 1) field production rate forecasts in deeper areas 
2) high graphic traps 
3) non-associated gas contains little condensate 
4) must locate suitable fracture system |

Table 2. Play summary chart (continued).
SUMMARY OF PLAY TYPES

The United States Geological Survey identifies several petroleum plays in the San Juan Basin Province and classifies them as Conventional and Unconventional. The discussions that follow are limited to those with direct significance for petroleum development in the Jicarilla Apache Indian Reservation. Much of the following is extracted from USGS CD-ROM DDS-30, Release 2 (Gautier, et al.,1995). Table 1 is a summary of USGS plays in the San Juan Basin.

DEFINITION OF A CONVENTIONAL PLAY

Discrete deposits, usually bounded by a downlap water contact, from which oil, gas, or NGL can be extracted using traditional development practices, including production at the surface from a well as a consequence of natural pressure in the subsurface reservoir, artificial lifting of oil from the reservoir to the surface where applicable, or the maintenance of reservoir pressure by means of water or gas injection.

ENTRADA PLAY

The Entrada sandstone produces south and west of the Jicarilla Apache Indian Reservation. This discussion is included here because of the possibility that Entrada production may develop on the Reservation in the future. The Entrada play is associated with relict dune topography on top of the coiled Middle Jurassic Entrada Sandstone in the southeastern part of the San Juan Basin and is based on the presence of organic-rich limestone source rocks and anhydrite in the overlying Todilto Limestone Member of the Wankak Formation. North of the present producing area, in the deeper, northeastern part of the San Juan Basin, porosity in the Entrada decreases rapidly (Vincelette and Chittum, 1981). Compaction and silica cement make the Entrada very tight below a depth of 9,000 ft. No eolian sandstone buildups have been found south and west of the producing area.

Reservoirs: Some of the relict dunes are as thick as 100 ft but have flanks that dip only 2 degrees. Dune reservoirs are composed of fine-grained, well-sorted sandstone, massive or horizontally bedded, with steeply dipping crossbedding in the lower part. Porosity (23 percent average) and permeability (370 millidarcies average) are very good throughout. Average net pay in developed fields is 23 ft.

Source rocks: Limestone in the Todilto Limestone Member has been identified as the source of Entrada oil (Ross, 1980). There is a reported correlation between the presence of organic material in the Todilto Limestone and the presence of the overlying Todilto anhydrite (Vincelette and Chittum, 1981). This association limits the source rock potential of the Todilto to the deeper parts of the depositional basin in the eastern San Juan Basin. Elsewhere in the basin, the limestone was oxygenated during deposition and much of the organic material destroyed.

Timing and migration: Maximum depth of burial throughout most of the San Juan Basin occurred at this time. In the eastern part of the basin the Todilto entered the oil generation window during the Oligocene. Migration into Entrada reservoirs either locally or updip to the south probably occurred almost immediately; however, in some fields, remigration of the original accumulations has occurred subsequent to original emplacement.

Traps: All traps so far discovered in the Entrada Sandstone are stratigraphic and are sealed by the Todilto limestone and anhydrite. Local faulting and draping over deep-seated faults has enhanced, modified, or destroyed the potential closures of the Entrada sandstone ridges. Hydrodynamic tilting of oil-water contacts and for "base of movable oil" interfaces has had a destructive influence on the oil accumulations because the direction of tilt typically has an updip component. All fields developed to date have been at depths of 5,000-6,000 ft. Because of increase in cementation with depth, the maximum depth at which suitable reservoir quality can be found is approximately 9,000 ft.

Exploration status and resource potential: The initial Entrada discovery, the Media field (Figs. J-13, J-14, J-15), was made in 1953. Development was inhibited by problems of high water cut and high pour point of the oil, problems common to all subsequent Entradafield development. Between 1972 and 1977, seven fields similar to Media were discovered, primarily using seismic techniques. Areal sizes of fields range from 100 to 400 acres, and total estimated production of each varies from 150,000 BO to 2 MMBO. A number of areas of anomalously thick Entrada in the southeastern part of the San Juan Basin have yet to be tested, and there is a good probability that at least a few of these areas have adequate trapping conditions for undiscovered oil accumulations, but with similar development problems as the present fields. Limiting factors to the moderate future oil potential of the play include the presence of sufficient paleo hydrodynamics, source-rock and oil migration history, and local porosity and permeability variations.

Analog Field SOUTHWEST MEDIA ENTRADA

Location: T19N, R3W, south of Reservation
Formation: Entrada
Lithology: Sandstone
Average Depth: 5,360 ft
Porosity: 23.8%
Permeability: 230 md
Oil/Gas Column: 30 feet
Average Net Pay Thickness: 30 feet
Estimated Ultimate Recovery: 1,800,000 BO
Other Information: Oil gravity 33.5 degrees API, asphaltic base with high pour point. Reservoir is in structurally enhanced stratigraphic trap.

Figure J-13. Southwest Media Entrada Field section along A-A' - see Figure J-14 (after Reese, 1978).

Figure J-14. Southwest Media Entrada Field: Structure contours on top of Entrada Sandstone. Figure J-13 is section along A-A' (from Reese, 1978).

Figure J-15. Southwest Media Entrada Field example electric log (from Reese, 1978).

Figure J-16. Southwest Media Entrada Field: Composite resistivity section.
The Basin Margin Dakota Oil Play is both a structural and stratigraphic play on the northern, southern, and western sides of the central San Juan Basin. Because of the variability of depositional environments in the transgressive Dakota Sandstone, it is difficult to characterize a typical reservoir geology. Most production has been from the upper marine part of the interval, but significant amounts of both oil and gas have also been produced from the nonmarine section.

Reservoirs: The Late Cretaceous Dakota Sandstone varies from predominantly nonmarine channel deposits and interbedded coal and conglomerate in the northwest to predominantly shallow marine, commonly burrowed deposits in the southeast. Net pay thicknesses range from 10 to 100 ft; porosities are as high as 20 percent and permeabilities as high as 400 millidarcies.

Source rocks: Along the southern margin of the play, the Cretaceous marine Mancos Shale was the source of the Dakota oil. API gravities range from 44 degrees to 59 degrees. On the Four Corners platform to the west, nonmarine source rocks of the Menefee Formation were identified as the source (Ross, 1980). The stratigraphically higher Menefee is brought into close proximity with the Dakota across the Hogback Monocline.

Timing and oil migration: Depending on location, the Dakota Sandstone and lower Mancos Shale entered the oil window during the Oligocene to Miocene. In the southern part of the area, migration was still taking place in the late Miocene or even more recently.

Traps: Fields range in size from 40 to 18,000 acres and most production is from fields of 100 - 2,000 acres. Stratigraphic traps are typically formed by updip pinchouts of porous sandstone into shale or coal. Structural traps on faulted anticlines sealed by shale form some of the larger fields in the play. Oil production ranges in depth from 1,000 to 3,000 ft.

Exploration status and resource potential: The first discoveries in the Dakota play were made in the early 1920's on small anticlinal structures on the Four Corners platform. Approximately 30 percent of the oil fields have an estimated total production exceeding 1 MMBO, and the largest field (Price Gramps) has production of 7 MMBO. Future Dakota oil discoveries are likely as basin structure and Dakota depositional patterns are more fully understood.

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Exploration status and resource potential: The first discoveries in the Dakota play were made in the early 1920's on small anticlinal structures on the Four Corners platform. Approximately 30 percent of the oil fields have an estimated total production exceeding 1 MMBO, and the largest field (Price Gramps) has production of 7 MMBO. Future Dakota oil discoveries are likely as basin structure and Dakota depositional patterns are more fully understood.
The Tocito-Gallup Sandstone Oil Play is an oil and associated gas play in lenticular sandstone bodies of the Upper Cretaceous Gallup Sandstone and Tocito Sandstone Lentil associated with Mancos Shale source rocks lying immediately above an unconformity. Almost all production has been from the Tocito Sandstone Lentil associated with Mancos Shale. The Mancos contains 1-3 weight percent or 12% OIP or 1,680,000 BPO increased by secondary recovery to 40% OIP or 5,600,000 BO.

Source rocks: The Tocito Sandstone Lentil of Mancos Shale and the Torrivio Member of the Gallup Sandstone. Reservoirs: The Tocito Sandstone Lentil of the Mancos Shale is the major producing reservoir in the San Juan Basin. The name is applied to a number of lenticular sandstone bodies, commonly less than 50 ft thick, that are organized into an unconformity and are of undetermined origin. Reservoir porosities in producing fields range from 4 to 20 percent and average about 15 percent. Permeabilities range from 0.5 to 150 md and are typically 5-100 md. The only significant production from the regressive Gallup Sandstone is from the Torrivio Member, a lenticular fluvial channel sandstone lying above and in some places scouring into the top of the main marine Gallup Sandstone.

Timing and migration: The upper Mancos Shale of the central part of the San Juan Basin entered the thermal zone of oil generation in the late Eocene and gas generation in the Oligocene. Migration updip to reservoirs in the Tocito Sandstone Lentil and regressive Gallup Sandstone followed pathways similar to those determined by present structure because basin configuration has changed little since that time. Traps: Almost all Gallup production is from stratigraphic traps at depths between 1,500 and 5,500 ft. Hospah and Hospah South, the largest fields in the regressive Gallup Sandstone, are combination stratigraphic and structural traps. The Tocito sandstone stratigraphic traps are sealed by, encased in, and intertongue with the marine Mancos Shale. Similarly, the fluvial channel Torrivio Member of the Gallup is encased in and intertongues with finer grained, organic-rich coastal plain shales.

Exploration status and resource potential: Initial Gallup field discoveries were made in the mid 1920s; however, the major discoveries were not made until the late 1950’s and early 1960’s. These were in the deeper Tocito fields, the largest of which, Bisti, covers 57,500 acres and has estimated ultimate recovery of 51 MMBO. Gallup producing fields are typically 1,000 to 10,000 acres in area and have 15 to 30 b of pay. About one-third of these fields have an estimated cumulative production exceeding 1 MMBO and 1 BCF of associated gas. All of the larger fields produce from the Tocito Sandstone Lentil of the Mancos Shale and are stratigraphically controlled. South of the zone of sandstone buildups of the Tocito, the regressive Gallup Sandstone produces primarily from the fluvial channel sandstone of the Torrivio Member. The only large fields producing from the Torrivio are the Hospah and Hospah South fields, which have combination traps. Similar, undiscovered traps of small size may be present in the southern half of the basin. The future potential for oil and gas is low to moderate.
The Basin Margin Mesaverde Oil Play is a confirmed oil play around the margins of the central San Juan Basin. Except for the Red Mesa field on the Four Corners platform, field sizes are very small. The play depends on intertonguing of porous marine sandstone at the base of the Upper Cretaceous Point Lookout Sandstone with the organic-rich Upper Mancos Shale.

**Reservoirs:** Porous and permeable marine sandstone beds of the basal Point Lookout Sandstone provide the principal reservoirs. The thickness of this interval and of the beds themselves may be controlled to some extent by underlying structures oriented in a northwest direction.

**Source rocks:** The upper Mancos Shale intertongues with the basal Point Lookout Sandstone and has been positively correlated with oil produced from this interval (Ross, 1980). API gravity of Mesaverde oil ranges from 37 degrees to 50 degrees.

**Timing:** Around the margin of the San Juan Basin the upper Mancos Shale entered the thermal zone of oil generation during the Oligocene.

**Traps:** Structural or combination traps account for most of the oil production from the Mesaverde. Seals are typically provided by marine shale, but paludal sediments or even coal of the Menefee Formation may also act as the seal.

**Exploration status and resource potential:** The first oil-producing area in the State of New Mexico, the Seven Lakes Field was discovered by accident in 1911 when a well being drilled for water. It produced oil from the Menefee Formation at a depth of approximately 350 ft. The only significant Mesaverde oil field, Red Mesa, was discovered in 1924. Future discoveries are likely to be small.

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**Figure J-20.** Otero Gallup Field structure map and example electric log (from Brown, 1978, p. 444).

**Analog Field: OTERO GALLUP**

| Location: | T24S-25N, R4-6W, on Reservation |
| Formation: | Gallup |
| Lithology: | Sandstone |
| Average Depth: | 6500 feet |
| Porosity: | 6%, fracture enhanced |
| Permeability: | Unknown |
| Oil/Gas Column: | 10 feet per bench |
| Average Net Pay Thickness: | 8 feet one bench, 14 feet two benches |
| Other Information: | Oil is 40.7 degrees API, Reservoir has gas drive. |

**Analog Field: PARLAY MESAVERDE**

| Location: | T22N, R3W, on Reservation |
| Formation: | Mesaverde, Point Lookout member |
| Lithology: | Sandstone |
| Average Depth: | 4,250 feet |
| Porosity: | 19% |
| Permeability: | 6.45 mD |
| Oil/Gas Column: | 30 feet |
| Average Net Pay Thickness: | 15 feet |
| Other Information: | Oil gravity is 44.2 degrees API, high paraffin, Estimated ultimate recovery is 18% of OOIP or 121,200 BO for the field. Associated gas yields 1,279 Btu with no sulfur. |

**Figure J-21.** Parlay Mesaverde Field, structure map and example electric log (after Gray, 1978, p. 453).
On the Jicarilla Apache Indian Reservation, the uppermost Cretaceous Fruitland Formation produces coal gas methane. West of the Reservation, the gas source is the associated Kirtland shale. This discussion is included here because of the possibility of finding concomitant Fruitland gas accumulations on the far west side of the Reservation. Please see the discussion on Pecos Cliffs coal gas, USGS Play 2211, in the Unconventional Play section that follows.

The Fruitland-Kirtland Fluvial Sandstone Gas Play covers the central part of the basin and is characterized by gas production from stratigraphic traps in lenticular fluvial sandstone bodies enclosed in shale source rocks and (or) coal. Production of coalbed methane from the lower part of the Fruitland has been known since the 1950’s. The Upper Cretaceous Fruitland Formation and Kirtland Shale are continental deposits and have a maximum combined thickness of more than 2,000 ft. The Fruitland is composed of interbedded sandstone, siltstone, carbonaceous shale and coal. Sandstone is primarily in northeasterly trending channel deposits in the lower part of the unit. The lower part of the overlying Kirtland Shale is dominantly siltstone and shale, and differs from the upper Fruitland mainly in its lack of carbonaceous shale and coal. The upper two-thirds or more of the Farmington Sandstone Member of the Kirtland Shale is composed of interbedded sandstone lenses and shales.

Reservoirs: Reservoirs are predominantly lenticular fluvial channel sandstone bodies, most of which are considered tight gas sandstones. They are commonly cemented with calcite and have an average porosity of 10-18 percent and low permeability (0.1 - 1.0 millidarcy). Pay thickness ranges from 15 to 50 ft. The Farmington Sandstone Member is typically fine grained and has a porosity of from 3 to 20 percent and permeability of from 0.6 to 9 millidarcies. Pay thicknesses are generally 10 feet or less.

Source rocks: The Fruitland-Kirtland interval produces non-asssociated gas and very little condensate. Its bulk composition (C1/C7:5) ranges from 0.39 to 0.87 and its iso-topic (D1/C5) compositions range from 43.5 to 38.5 per mil (Rice, 1983). Source rocks are thought to be primarily organic-rich non-marine shales enclosing sandstone beds.

Timing and migration: In the northern part of the basin, the Fruitland Formation and Kirtland Shale entered the thermal zone of oil generation during the latest Eocene and the zone of wet gas generation probably during the Oligocene. Migration of hydrocarbons through fluvial channel sandstone is suggested by gas production from immature reservoirs and by the areal distribution of production from the Fruitland.

Traps: The discontinuous lenticular channel sandstone bodies that form the reservoirs are both the Fruitland Formation and Kirtland Shale intertongue with overbank sandstone and shale and paludal coals and carbonaceous shale in the lower part of the Fruitland. Although some producing fields are on structures, the actual traps are predominantly stratigraphic and are at updip pinchouts of sandstone into the fine-grained sediments that form the seals. Most production is from depths of 1,900-2,700 ft. Production from the Farmington Sandstone Member is from depths of 1,100-2,300 ft. Exploration status and resource potential: The first commercially produced gas in New Mexico was discovered in 1921 in the Farmington Sandstone Member at a depth of 900 ft in what later became part of the Artesia field. Acre field sizes range from 160 to 32,000 acres, and almost 50 percent of the fields are 1,000-3,000 acres in size. The almost linear northeasterly alignment of fields along the western side of the basin suggests a paleofluvial channel system of northeasterly flowing streams.

Similar channel systems may be present in other parts of the basin and are likely to contain similar amounts of hydrocarbons. Future potential for gas is good, and undiscovered fields will probably be in the 25 sq mi size range at depths between 1,000 and 1,300 ft. Because most of the large structures have probably been tested, future gas resources probably will be found in updip stratigraphic pinchout traps of channel sandstone bodies in shale or coal in traps of moderate size.
Unconventional Plays -- Definition

A broad class of hydrocarbon deposits of a type (such as gas in "tight" sandstones, gas shales, and coal-bed gas) that historically has not been produced using traditional development practices. Such accumulations include most continuous-type deposits.

DAKOTA CENTRAL BASIN GAS PLAY

The Jicarilla Apache Indian Reservation is on the east flank of the San Juan Basin but extends sufficiently westward that there is a possibility of finding unconventional Dakota formation gas reservoirs. The preceding discussion on the conventional Basin Margin Dakota Play, USGS Play 2206, characterizes existing Reservation Dakota production on the Reservation. The Dakota Central Basin unconventional continuous-type play is contained in coastal marine barrier-bar sandstone and continental fluvial sandstone units, primarily within the transgressive Dakota Sandstone.

Reservoirs: Reservoir quality is highly variable. Most of the marine sandstone reservoirs within the Basin field are considered tight, although there are indications of much higher permeability in fluvial sandstone units, primarily within the transgressive Dakota Sandstone. Most marine reservoirs within the Basin field are considered tight, with porosities from 5 to 15 percent and permeabilities from 0.1 to 0.25 millidarcies. Fracturing, both natural and induced, is necessary for effective field development.

Source rocks: Quality of source beds for oil and gas is also variable. Non-associated gas in the Dakota pool of the Basin field was generated during late Cretaceous and Eocene time (Huffman, 1987). It is not known at what point hydrodynamic forces entered the thermal zone of oil generation during the late Mioocene (Huffman, 1987). It is not known at what point hydrodynamic forces reached sufficient strength to act as a trapping mechanism, but these forces are still active today. crop. Hydrodynamic forces, acting in a basinward direction, have been suggested as the trapping mechanism, but these forces are still poorly understood. The seal is commonly provided by either marine shale or paludal carbonaceous shale and coal. Production is primarily at depths ranging from 6,500 to 7,500 ft.

Exploration status and resource potential: The Dakota discovery well in the central basin was drilled in 1947 southeast of Farmington, New Mexico, and the Basin field, containing the Dakota gas pool, was formed February 1, 1961 by combining several existing fields. By the end of 1993 it had produced over 4.0 TCFG and 38.1 BOPD. Non-associated gas in the Dakota pool of the Basin field is 5 TCFG, 20% of which is at depths ranging from 6,500 to 7,500 ft.

I. P. = 7.8 MMCFGD

Location: T23-32N, R3-14W, partly on Reservation

Formation: Dakota

Lithology: Sandstone

Average Depth: 6,500 feet

Porosity: 5 to 15%

Permeability: 0.1 to 0.25 md, fracture enhanced

Oil/Gas Column: 250 feet

Average Net Pay Thickness: 50 to 70 feet

Other Information: Gas yields 1.100 Btu per CF and contains 3 to 5% carbon dioxide. Estimated ultimate recovery for the Basin Dakota Gas Field is 5 TCFG.

ANALOG FIELD: BASIN DAKOTA

Figure J-23. Basin Dakota Field, example electric log (after Hoppa, 1978, p. 205).

Figure J-24. Basin Dakota Field, area and marine sandstone isopach map (from Hoppa, 1978, p. 204).

UNCONVENTIONAL PLAY: Dakota Central Basin Gas Play

NEW MEXICO

JICARILLA APACHE INDIAN RESERVATION
The Mancos Fractured Shale Play is a confirmed, unconventional, continuous-type play. It is dependent on extensive fracturing in the organic-rich marine Mancos Shale. Most developed fields in the play are associated with anticlinal and monoclinal structures around the eastern, northern, and western margins of the San Juan Basin.

**Reservoirs:** Reservoirs are comprised of fractured shale and interbedded coarser clastic intervals at approximately the Tocito Lentil level.

**Source rocks:** The Mancos Shale contains 1-3 weight percent organic carbon and produces a sweet, low-sulfur, paraffin-base oil that ranges from 33 degrees to 43 degrees API gravity.

**Timing:** The upper Mancos Shale of the central part of the San Juan Basin entered the thermal zone of oil generation in the late Eocene, and of gas generation in the Oligocene.

**Traps:** Combination traps predominate; traps formed by fracturing of shale and by interbedded coarser clastics on structures are common.

**Exploration status and resource potential:** Most of the larger discoveries such as Verde and Puerto Chiquito were made prior to 1970, but directional drilling along the flanks of some of the poorly explored structures could result in renewed interest in this play.

### Analog Field

**PUERTO CHIQUITO MANCOS, WEST**

(Figure J-25)

- **Location:** T25-27N, R1E and R1W, partly on Reservation
- **Formation:** Mancos, Niobrara equivalent section
- **Lithology:** Shale
- **Average Depth:** 5,400 feet
- **Porosity:** Indefinite, fracture porosity
- **Permeability:** Unknown, transmissibility up to 6 darcy-feet
- **Oil/Gas Column:** 250 feet
- **Average Net Pay Thickness:** Unknown, less than 50 feet
- **Other Information:** The Canada Ojitos Unit lies totally within the Puerto Chiquito West Field. Originally a gravity drainage field, final stages of development will include expansion gas drive and reinjection of produced gas. Oil gravity is 39 to 40 degrees API.

### Structure Contour Map

Contoured on top of Zone “A”

Benson - Montin - Greer Drilling Corp.

December, 1977

Well Converted To Gas Injection

East & West Puerto Chiquito Mancos Fields

Rio Arriba County, New Mexico

**Figure J-25:** Puerto Chiquito Mancos East and West Fields with structure map and example electric log contoured on top of “A” zone (from Greer, 1978, p. 468).

**CANADA OJITOS UNIT #B-18**

nw ne 18-25N-1E

JICARILLA APACHE INDIAN RESERVATION

NEW MEXICO

UNCONVENTIONAL PLAY: Mancos Fractured Shale Play
The unconventional continuous-type Central Basin Mesaverde Gas Play is in sandstone buildups associated with stratigraphic rises in the Upper Cretaceous Point Lookout and Cliff House Sandstones. The major gas-producing interval in the San Juan Basin, the Upper Cretaceous Mesaverde Group, is comprised of the regressive marine Point Lookout Sandstone, the nonmarine Menefee Formation, and the transgressive marine Cliff House Sandstone. Total thickness of the interval ranges from about 500 to 2,500 ft, of which 20 - 50 percent is sandstone. The Mesaverde interval is enclosed by marine shale: the Mancos Shale is beneath the interval and the Lewis Shale above.

**Reservoirs:** Principal gas reservoirs productive in the Mesaverde interval are the Point Lookout and Cliff House marine sandstones. Smaller amounts of dry, nonassociated gas are produced from thin, lenticular channel sandstone reservoirs and thin coal beds of the Menefee. Much of this play is designated as tight, and reservoir quality depends mostly on the degree of fracturing. Together, the Blanco Mesaverde and Ignacio Blanco fields account for almost half of the total nonassociated gas and condensate production from the San Juan Basin. Within these two fields porosity averages about 10 percent and permeability less than 2 mD; total pay thickness is 20 - 200 ft. Smaller Mesaverde fields have porosities ranging from 14 to 28 percent and permeabilities from 2 to 400 Md, with 6 - 25 ft of pay thickness.

**Source rocks:** The carbon composition (CI/Cl-5) of 0.99-0.79 and isotopic carbon (dl3Cl) range of -33.4 to -46.7 per mil of the nonassociated gas suggest a mixture of source rocks including coal and carbonaceous shale in the Menefee Formation (Rice, 1983).

**Timing and migration:** In the central part of the basin, the Mancos Shale entered the thermal zone of oil generation in the Eocene and gas generation in the Oligocene. The Menefee Formation also entered the gas generation zone in the Oligocene. Because basin configuration was similar to that of today, updip migration would have been toward the south. Migration was impeded by hydrodynamic pressures directed toward the central basin, as well as by deposition of authigenic swelling clays due to dewatering of Menefee coals.

**Traps:** Trapping mechanisms for the largest fields in the central part of the San Juan Basin are not well understood. In both the Blanco Mesaverde and Ignacio Blanco fields, hydrodynamic forces are believed to contain gas in structurally lower parts of the basin, but other factors such as cementation and swelling clays may also play a role. Production depths are most commonly from 4,000 to 5,300 ft. Updip pinchouts of marine sandstone into finer grained paludal or marine sediments account for almost all of the stratigraphic traps with a shale or coal seal.

**Exploration status and resource potential:** The Blanco Mesaverde field discovery well was completed in 1927, and the Ignacio Blanco Mesaverde field discovery well was completed in 1952. Archaically, these two closely adjacent fields cover more than 1,000,000 acres, encompass much of the central part of the San Juan Basin, and have produced almost 7,000 BCFG and more than 30 MMB of condensate, approximately half of their estimated total recovery. Most of the recent gas discoveries range in areal size from 2,000 to 10,000 acres and have estimated total recoveries of 10 to 35 BCFG.
PICTURED CLIFFS GAS PLAY - USGS 2211

The Pictured Cliffs unconventional continuous-type play is developed primarily by gas production from stratigraphic traps in sandstone reservoirs enclosed in shale or coal at the top of the Upper Cretaceous Pictured Cliffs Sandstone and is confined to the central part of the basin. Thicker shoreline sandstones produced by stillstands, or brief reversals in the regression of the Cretaceous sea to the northeast have been the most productive. The Pictured Cliffs is the uppermost regressive marine sandstone in the San Juan Basin. It ranges in thickness from 0 to 400 ft and in conformable with both the underlying marine Lewis Shale and the overlying nonmarine Fruitland Formation.

Reservoirs: Reservoir quality is determined to a large extent by the abundance of authigenic clay. Cementing material averages 60 percent calcite, 30 percent clay, and 10 percent silica. Average porosity is about 15 percent and permeability averages 5.5 millidarcies, although many field reservoirs have permeabilities of less than 1 millidarcy. Pay thicknesses range from 5 to 150 ft but typically are less than 40 ft. Reservoir quality improves south of the deepest parts of the basin due to secondary diagenetic effects.

Source rocks: The source of gas was probably marine shale of the underlying Lewis Shale and nonmarine shale of the Fruitland Formation. The gas is non-associated and contains very little condensate. The gas is non-associated and contains very little condensate. The gas is non-associated and contains very little condensate.

Timing and migration: Gas generation was probably at a maximum during the late Oligocene and the Miocene. Udpip gas migration was predominantly toward the southwest because the basin configuration is limited production.

Traps: Stratigraphic traps resulting from landward pinchout of near shore and foreshore marine sandstone bodies into finer grained, silty, and shaley facies of the Fruitland Formation (especially in the areas of stratigraphic rises) contain most of the gas remaining in the basin. The Pictured Cliffs Sandstone is sealed off from any connection with other underlying upper Cretaceous reservoirs by the Lewis Shale. The Pictured Cliffs crops out around the perimeter of the central part of the San Juan Basin and is present at depths of as much as 4,300 ft. Most production has been from depths of 1,000-3,000 ft.

Exploration status and resource potential: Gas was discovered in the play in 1927 at the Blanco and Fulcher fields of northwest New Mexico. Most Pictured Cliffs fields were discovered before 1954, and only nine relatively small fields have come into production since then. Discoveries since 1954 average about 11 BCFG estimated ultimate recovery. A large quantity of gas is held in tight sandstone reservoirs north of the currently producing areas. Stratigraphic traps and excellent source rocks are present in the deeper parts of the basin, but low permeabilities due to authigenic illite-smectite clay have thus far limited production.