# PARADOX BASIN PROVINCE (021)

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## INTRODUCTION

The Paradox Basin Province is in southeastern and south-central Utah and southwestern Colorado and encompasses much of the area from latitude 37û to 40û N. and from longitude 108û to 114û W. It includes almost all of the Paradox Basin, the Uncompahgre and San Juan uplifts, the San Rafael, Circle Cliffs, and Monument uplifts, the Kaiparowits and Henry Mountains basins, and the Wasatch and Pausaugunt Plateaus. Maximum dimensions of the province area are approximately 280 mi long and 200 mi wide. It covers an area of about 33,000 sq mi. The maximum thickness of Phanerozoic sedimentary rocks ranges from 5,000-8,000 ft in the central part of the province to more than 15,000 ft in the Paradox Basin, Kaiparowits basin, and Wasatch Plateau.

Most of the production in the province has been from porous carbonate buildups (mainly algal mounds) around the southwestern shelf margin of the Paradox evaporite basin. The giant Aneth field, with more than 1 BBO in place accounts for as much as two-thirds of the proven resources in the province, and other fields in this primarily stratigraphic play (Porous Carbonate Buildup Play, 2102) account for much of the rest. Most of the other plays have a strong structural component, particularly the Buried Fault Blocks, Older Paleozoic (2101), Fractured Interbed (2103), and Salt Anticline Flank (2105) Plays. The Permian–Pennsylvanian Marginal Clastics Play (2104), Permo-Triassic Unconformity Play (2106), and Cretaceous Sandstone Play (2107), as well as the hypothetical Lower Paleozoic/Proterozoic Play (2403) which is described in Northern Arizona Province (024), are combinations of both structure and stratigraphy. The Fractured Interbed Play (2103) is an unconventional, continuous-type play.

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# CONVENTIONAL PLAYS

## 2101. BURIED FAULT BLOCKS, OLDER PALEOZOIC PLAY

The play is based on the occurrence of oil accumulations in fault blocks involving pre-Pennsylvanian rocks, mainly in the salt anticline area of the Paradox Basin, and it covers an area of approximately 7,500 sq mi. Most of the structures are associated with the salt anticlines themselves and were growing at the same time that the salt was moving.

**Reservoirs:** Reservoirs are in porous dolomite or dolomitic limestone beds of the Mississippian Leadville Limestone and the Upper Devonian McCracken Sandstone Member of the Elbert Formation. Reservoirs are as thick as 200 ft, and porosity varies from 5 to as high as 25 percent in local cases. Permeability is generally low but is as much as several hundred millidarcies in places.

**Source rocks:** Probable source rocks are the organic-rich black dolomitic shales of the Pennsylvanian Paradox Formation. Migration into Leadville or McCracken reservoirs occurred where fault blocks are in structural and (or) depositional contact with the black shale, which is commonly highly fractured.

**Timing and migration:** Hydrocarbon generation began as early as Permian time and has continued to the present in some cases. Migration into pre-salt reservoirs was probably contemporaneous with the growth of salt structures. Migration pathways were enhanced by severe fracturing of interbedded organic-rich shale during salt movement.

**Traps:** Known traps are on uplifted fault blocks adjacent to salt anticlines or swells. Seals are Paradox Formation evaporite beds, that overlie or are in fault contact with Mississippian or Devonian reservoirs. Drilling depths range from 7,000–8,000 ft at the Lisbon field to greater than 10,000 ft in other areas.

**Exploration status and resource potential:** Six oil and gas accumulations produce from pre-salt structural blocks; the largest of these is the Lisbon field, which is approximately 43 MMBO and 250 BCFG in size. The remainder of the fields are noncommercial or marginally commercial. The play is only moderately explored with respect to smaller structures. Future potential is low to moderate, and based on previous production history, undiscovered fields are estimated to be small to medium in size and have minimal oil columns.

## 2102. POROUS CARBONATE BUILDUP PLAY

This is primarily an oil play in the Paradox Basin Province and is characterized by oil and gas accumulations in mounds of algal (Ivanovia) limestone associated with organic-rich black dolomitic shale and mudstone rimming the evaporite sequences of the Paradox Formation of the Hermosa Group. Most of the developed fields within the play produce from stratigraphic or combination traps. The largest oil field in the province, Aneth, is developed in this play. Many smaller "satellite" mounds in the vicinity of the Aneth field also produce oil from the play as do other fields with more of a structural component.

**Reservoirs:** Almost all hydrocarbon production has been from vuggy limestone and dolomite reservoirs in five informal zones of the Hermosa Group, in ascending order, the Alkali Gulch, Barker Creek, Akah, Desert Creek, and Ismay. The largest producers are the upper two zones, and they are the producing intervals at Aneth. Net pay thicknesses generally vary from 10 to 50 ft but may be as great as 100 ft; porosities are 5-20 percent.

**Source rocks:** Source beds for Pennsylvanian oil and gas are the interbedded organic-rich dolomitic shale and mudstone and laterally equivalent carbonate rock within the Paradox Formation. They commonly range from 1 to 5 percent TOC. Oil is typically 40û to 43û API gravity. Correlation of black dolomitic shale units of the Paradox Formation with prodelta facies in clastic cycles, which are present in the marginal clastics and fan delta complex on the northeastern edge of the Paradox evaporite basin, helps to account for the high percentage of kerogen from terrestrial plant material in the source rocks.

**Timing and migration:** Along the northeastern margin of the Paradox Basin, Pennsylvanian sediments entered the thermal zone of oil generation during the Late Cretaceous to Paleocene, and the zone of gas generation during the Eocene to Oligocene. It is probable that Pennsylvanian source rocks entered the oil generation zone during the Oligocene throughout most of the Four Corners platform and Blanding Basin area, including the Aneth area. Updip migration and local migration from laterally equivalent carbonate rocks and shale in areas of favorable reservoir beds predominate; remigration possibly occurred in areas of faulting and fracturing.

**Traps:** Stratigraphic traps are dominant among Pennsylvanian fields of the Paradox Basin, although structures of Pennsylvanian age may have played a critical role in the

deposition of bioclastic limestone reservoir rocks. Seals are provided by a variety of mechanisms including porosity differences in the reservoir rock, overlying evaporites, and interbedded shale. Most production ranges in depth from 4,000 to 6, 000 ft.

**Exploration status: and resource potential:** Field sizes in the play vary considerably; most oil discoveries are in the 100 to 1 MMBO size range but also include the 1 BBO giant Aneth field. The greater Aneth field, comprising four production units, occupies an area of approximately 47,000 acres and was discovered in 1956. Recently, high-resolution seismic surveys have been successful in targeting many similar mounds in the vicinity of the Aneth field, but, although most are charged with oil, field sizes are in the 1-3 MMBO range.

### 2104. PERMIAN–PENNSYLVANIAN MARGINAL CLASTICS GAS PLAY (HYPOTHETICAL)

This hypothetical play, formerly known as the Silverton Delta Play (Peterson, 1989), has been renamed to more accurately reflect the geometry and depositional environment of the reservoir rocks. The Silverton fan delta is limited to an area near the Colorado-Utah State line, but marginal clastic rocks extend the length of the ancestral Uncompahgre uplift. These clastics were deposited as coalesced outwash fans that intertongue with the cyclic marine deposits of the Pennsylvanian Hermosa Group.

**Reservoirs:** Gas shows have been encountered in porous and permeable sandstone intervals within the generally arkosic Permian Cutler Formation in the vicinity of the ancestral Uncompahgre uplift. Such potential reservoir rock is present where feldspar and clay was winnowed out by wave action or fluvial stream flow. For most of the area, the lower part of the Pennsylvanian interval is more likely to contain these beds than the upper part because of the lower original feldspar content of the lower part. In the upper part of the Pennsylvanian interval, the southeastern Paradox Basin province is more likely to contain such beds because of the presence of a large fan delta complex that provided the necessary depositional environments to clean the sandstone.

**Source rocks:** This play is dependent on the presence of Desmoinesian organic-rich dolomitic shale and mudstone in contact or close proximity to reservoir lithologies. Because this juxtaposition is necessarily close to the ancestral Uncompahgre uplift, the play is gas prone due to the preponderance of type III kerogen from the uplift as well as the depth of burial in the deep trough along the basin margin.

**Traps:** Trap types are expected to be dominantly combinations of updip pinchouts of permeable sandstone lenses localized on folded and faulted structures. Seals are provided by shale beds as well as by reduced permeability due to clay.

**Exploration status and resource potential:** Little exploration has taken place within this play and no production to date, but shows have been reported from Permian Cutler sandstone bodies, and the presence of excellent source rocks and structures are strong factors in its favor.

### 2105. SALT ANTICLINE FLANK PLAY

This play is characterized by association of gas- and oil-productive Permian-Pennsylvanian reservoirs along the flanks of northwest-trending salt anticlines in the axial part of the Paradox salt basin. The play area is approximately 7,500 sq mi. Salt anticlines consist of long northwest-trending diapirs or pillows of Paradox Formation salt over which younger rocks are arched in anticlinal form. The central, or salt-bearing, cores of the anticlines range in thickness from 2,500 to more than 14,000 ft; the anticlines are flanked by deep synclines (sites of salt withdrawal) that are filled with 10,000 ft or more of chiefly arkosic clastic rocks of the Permian Cutler Formation and a mixed sequence of clastics and carbonate rocks of the Pennsylvanian Hermosa Group.

**Reservoirs:** The main reservoirs in the play are pelletal and oolitic limestone and sandstone in the upper part of the Hermosa Group and arkosic sandstone in the Cutler Formation. Sandstone reservoirs are as thick as 200 ft. No data are available on reservoir quality; however, it is estimated that permeabilities may be as high as 1,000 millidarcies locally. Vertical communication between these reservoirs is common because of (1) well-developed fracture systems resulting from strong subsidence in the flank syncline, and (2) related salt movement and flowage into the adjacent salt anticlines.

**Source rocks:** Several potential sources for hydrocarbons are present in the play. Organic-rich black dolomitic shale of the Hermosa Group is commonly in contact with reservoir rocks along the margins of salt structures and may also be sufficiently connected by fracture or fault systems to allow vertical migration under the synclines. Some coaly carbonaceous shale is locally present at the Cutler-Hermosa contact and may be the source for some of the gas accumulations.

**Timing and migration:** No data are available on maturity of these source rocks. Source rocks buried to depths of from 4,000 to more than 10,000 ft in the synclines are mature

to post mature. Hydrocarbon generation in the deeper parts of the basin probably began by Permian time. Migration was coincident with salt movement and anticlinal growth.

**Traps:** Stratigraphic and stratigraphic-structural traps are present in conjunction with the reservoirs as the result of both thinning and permeability pinchouts and are sealed along the steeply dipping flanks of the salt anticlines. Some traps may be the result of updip termination against salt diapirs. Drilling depths range from 5,000 to greater than 15,000 ft.

**Exploration status and resource potential:** The play is lightly explored; four gas fields of undetermined size have been discovered, only one of which, Andys Mesa, has had any significant production. Cumulative production from this field to the end of 1993 was 18 BCFG and 11,000 barrels of condensate. The other three fields are small, one-well fields. Future potential for oil is low and fair to good for gas.

### 2106. PERMO-TRIASSIC UNCONFORMITY PLAY

This play is a downdip extension of the tar sand deposits of south-central Utah. It is based on the assumption that oil migrated generally eastward to form the giant pools that were subsequently biodegraded into the tar sand deposits near the outcrop and heavy oil accumulations in the subsurface to the west. It is named the Permo-Triassic Unconformity Play because all of the known accumulations, shows, and oil staining are associated with this unconformity, either above or below. The play occupies a large area primarily because the source rocks and, hence, migration paths are unknown.

**Reservoirs:** The tar sand and heavy oil accumulations are in the Permian White Rim Sandstone. Downdip production has been recorded from the Timpoweap Member of the Triassic Moenkopi Formation and from the Permian Kaibab Limestone and Coconino Sandstone (laterally equivalent to the White Rim and DeChelly Sandstones of the Paradox Basin). All of the sandstones are eolian deposits that have excellent porosity and permeability. Thicknesses range from a pinchout edge to several hundred feet.

**Source rocks:** A wide variety of source rocks have been proposed for the tar sand deposits and, hence, the downdip accumulations. Among the most prominently mentioned are the Mississippian Chainman Shale, Pennsylvanian Paradox Formation, Permian Kaibab Limestone and Phosphoria Formation, and Triassic Moenkopi

Formation. A recent addition to this list is the Precambrian Chuar Group. Organic geochemical analyses have not yet been able to isolate a single source.

**Timing and migration:** Neither the time of generation nor migration is known, although most work suggests that final migration into the Tar Sand Triangle deposits of south-central Utah occurred after the Laramide orogeny.

**Traps:** Both structural and combination traps predominate even though the largest deposit, the Tar Sand Triangle deposit, is predominantly a stratigraphic trap. As the hydrocarbons migrated eastward, existing structures would have been charged, or filled with hydrocarbons, producing fields such as Upper Valley and Virgin. Depths range from less than 1,000 to almost 3,000 ft and seals are provided by shale beds as well as by reduction in permeability due to cementation and clay content.

**Exploration status and resource potential:** This play is very lightly explored, and until the source rock and timing questions are answered there is a low probability of any significant exploration effort.

### 2107. CRETACEOUS SANDSTONE PLAY

This is an extension of play 2003, Upper Cretaceous Conventional in the Uinta-Piceance Province, and a complete description is given there. In the Paradox Basin Province, the major producer has been the Ferron Sandstone Member of the Mancos Shale on the Wasatch Plateau.

**Reservoirs:** The Ferron Sandstone Member is part of two coalescing, westerly derived delta complexes. Permeable zones are present both in the delta front and in distributary sandstone bodies. In addition to the Ferron, marine and deltaic sandstones of the Mesaverde Group, Mancos Shale, and Dakota Sandstone are also potential reservoirs.

**Source rocks:** Mancos Shale beds are potential source rocks for this play; however, because only gas has been produced from the Ferron Sandstone Member, it is likely that the coals and carbonaceous shale that intertongue with the sandstone bodies are the source of gas. Data are not available on maturity of these rocks, but because the coal-bearing units of the Mesaverde Group are ranked as sub-bituminous, the source rocks probably are mature or overmature (Peterson, 1989).

**Traps:** Entrapment of gas in this play is related to structural closure on simple anticlinal folds and complexly faulted anticlines. Updip pre-faulting migration toward the depositional edge of the Ferron may also have influenced accumulation.

Discontinuous sandstone bodies in the deltaic complex also offer the possibility of stratigraphic trap accumulations. Depths range from less than 1,000 to more than 7,000 ft.

**Exploration status and resource potential:** This play can probably be considered as moderately explored on the Wasatch Plateau and lightly explored to the south. Most of the larger traps on the Plateau have been drilled, but many small structures are untested.

## UNCONVENTIONAL PLAY

### *Continuous-Type*

#### *2103. FRACTURED INTERBED PLAY (HYPOTHETICAL)*

This unconventional continuous-type oil and gas play is oil prone throughout most of the Paradox Basin but is more gas prone to the east close to the ancestral Uncompahgre uplift; the reasons for this change in character are increased depth of burial and percentage of terrestrial organics to the east.

**Reservoirs:** The play depends on extensive fracturing in the organic-rich dolomitic shale and mudstone in the interbeds between evaporites of the Pennsylvanian Paradox Formation or carbonate and clastic rocks of the related cycles on the shelf of the Paradox evaporite basin. These shales and mudstones may be as thick as 130 ft but are more commonly less than 20 ft thick.

**Source rocks:** These organic-rich black dolomitic shales and mudstones are the source rocks for most, if not all, of the oil and gas in the Paradox Basin. Total organic carbon commonly ranges from 1 to 5 percent but may be as high as 20 percent. Oil produced by these source rocks typically has 40û–43û API gravity and low sulfur content.

**Timing and migration:** The thermal history of these rich source rocks is determined mostly by depth of burial and to a lesser degree by the added effect of the Oligocene volcanic activity. Pennsylvanian, Permian, Late Cretaceous, and early Tertiary sediments thicken significantly to the east so that the Pennsylvanian section entered the thermal zone of oil and gas generation at different times depending on location. Close to the Uncompahgre uplift, Pennsylvanian rocks may have generated oil as early as the Permian; elsewhere these rocks may have entered the oil generation zone in the Late Cretaceous and the dry gas zone as late as the Oligocene.

**Traps:** Fracturing of the shale on structures is a necessary attribute of this play, but the actual trapping and sealing mechanisms may be stratigraphic as well as structural because the fractures die out into unfractured shale. Only certain intervals within the total shale thickness may be of sufficient richness or sufficiently fractured for significant oil production. Depths to potential targets vary greatly from more than 15,000 ft near the eastern basin margin to less than 5,000 ft on the Four Corners platform.

**Exploration status and resource potential:** Until recently, the only significant production from this play was from the Cane Creek Shale in the Lone Canyon field

discovered in 1962. Recently, nearby Bartlett Flat field has been developed by directional drilling in the Cane Creek Shale at a depth of approximately 9,000 ft. The Cane Creek, Chimney Rock, Gothic, and Hovenweep Shales have the most potential due to both organic content and thickness.

# REFERENCES

Peterson, J.A., 1989, Geology and petroleum resources, Paradox Basin Province: U.S. Geological Survey Open-File Report 88-450U, 69 p.