Oil and gas potential of the Pluto anticline, and surface anticlines of the fold and thrust belt play, eastern Nevada

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Nevada exploration plays

The fold and thrust belt play extends through eastern Nevada and western Utah and given its enormous area remains underexplored (Fig. 1). Specifically, this article discusses the potential of a subset of the fold and thrust belt play, surface anticlines of eastern Nevada, the results of the PXP Pluto 27-1 well that was drilled on a surface anticline, and information from the well that positively impacts future fold and thrust belt play exploration in eastern Nevada. For the purposes of this discussion all hydrocarbon traps developed in the Cordilleran orogen,[1] and during the period from late Devonian to early Tertiary belong to the fold and thrust belt play. These events include the late Devonian- to early Mississippian Antler orogeny,[2] [3] an unnamed orogenic event of middle Mississippian to late Permian age,[4] Triassic- to mid-Cretaceous structures of the central Nevada thrust belt,[5] middle Jurassic Elko orogeny,[6] and late Jurassic- to early Tertiary Sevier fold and thrust belt.[7] The Permian- to early Triassic Sonoma orogeny[3] is generally confined to western Nevada although coeval structures are recorded in eastern Nevada.[4] [8] Discovery of the 20 MMBO Covenant oil field in 2004, followed by the 2008 discovery of the smaller Providence oil field along the eastern edge of the belt in central Utah[9] [10] initiated intense exploration effort in that area, but this activity has not extended to the broad interior of the belt, much of which lies in eastern Nevada and is the focus area of this paper.

The fold and thrust belt play and graben play in Nevada have an oil and gas exploration history going back to at least the 1940s. In 1954 Shell Oil Company discovered Eagle Springs oil field in Railroad Valley that became the first significant commercial oil find in Nevada.[11] At Railroad Valley and nearby valleys it was shown that oil was sourced from early Tertiary lacustrine beds buried deep in Basin and Range grabens. Oil was generated from Miocene to present, trapped by fault blocks and unconformities developed during Basin and Range extension, and stored in Tertiary volcanic and sedimentary rocks.[12] In the early 1980's the graben play had expanded through eastern Nevada with the realization that the organic-rich beds of the Mississippian Chainman Shale are an excellent source rock and the dolomitic beds of the Devonian Guilmette Formation and Simonson Dolomite can be excellent reservoir units. By 1984 a dolomitic reservoir at the Grant Canyon oil field in Railroad Valley was flowing at ~5,000 to ~6,500 BOPD and mostly from two wells.[13][14] Knowledge from the graben play is key to future exploration, but show the fault-block trap type of play are small in closure and recoverable oil (generally < 300 AC and <25 MMBO), and despite a fair level of graben play exploration, only one other small producing area was discovered, Pine Valley (~5.5 MMBO).

A third play is now developing in Nevada, a shale play that has aspects of both a resource play and a conventional fractured-shale play, and is directed at organic-rich shale of either Mississippian or early Tertiary age, or both.[15] It is unclear at this time if the conventional aspects of this play involves fold and thrust belt structures.

Petroleum system, fold and thrust belt play, and its surface anticlines

Eastern Nevada lies within the scope of the USGS's Paleozoic-Tertiary Composite Total Petroleum System (PTPS) that provides a framework for prospect evaluation and indicates traps have oil and gas potential if they lie within the favorable Chainman Shale source-rock trend,[16] pre-date hydrocarbon generation, lie within the favorable Devonian carbonate reservoir trends of the Guilmette Formation and Simonson Dolomite,[17] and have reservoir seal.[18] Deeper source rock potential may exist in the Mississippian Joana Limestone and late Devonian Pilot Shale.[18] Secondary reservoir targets are fractured and vuggy limestone beds of the Joana Limestone, and clastic beds of the Scotty Wash Sandstone Member of the Chainman Shale and Diamond Peak Formation.[19] The PXP Pluto 27-1 well, to be discussed, showed that the fine-grained beds of the Chainman Shale can be an effective seal for hydrocarbons. Basin modeling studies show the Chainman Shale had hydrocarbon generation from late Paleozoic to middle Jurassic, and more localized generation from Miocene to present due to Basin and Range extension and burial within associated grabens.[16 18 20 21] This younger phase of burial and generation, from Mississippian and early Tertiary source rocks, supplied the accumulations of oil trapped at Railroad and Pine Valleys.[16 18] It is probable that many of the numerous traps associated with the older fold and thrust belt events (late Devonian- through middle Jurassic) were well positioned to receive the older phase of hydrocarbon generation that was widespread. However, many of these traps no longer exist due to deep erosion, numerous phases of faulting and folding with Basin and Range extension the youngest, and in places, metamorphism. Alternatively structures of the younger fold and thrust belt events (late Jurassic- through early Tertiary) postdate the older hydrocarbon generation phase and therefore have an increased exploration risk due to trap formation postdating hydrocarbon migration, or require charge from the younger phase of oil generation that is more spatially constrained.

In eastern Nevada there are extensive areas of the fold and thrust belt that are exposed between the Basin and Range grabens, where only upper Paleozoic rocks are exposed at the surface and folded into large anticlines.[8 22] Fig. 2 is a Google Earth image of one such anticline at the north end of Spruce Mountain in Elko County. One of the authors (Davis) has field surveyed numerous large surface anticlines in northeast Nevada, and located several that are suitable for test wells using constraints imposed by the previously mentioned USGS's PTPS plus the following trap specific requirements: anticline has four-way closure, be free of complex faulting, has sufficient sealing capabilities above the reservoir targets (Chainman Shale not exposed on crest), and closure at the reservoir target is large enough to make the prospect commercially viable (> 1,000 acres). Surface anticlines that meet the above criteria and are of late Paleozoic to middle Jurassic age are more favorably located in time to trap early generated oil and gas. However, these older structures are difficult to determine due to eastern Nevada's wide-spread stratigraphic hiatus between upper Paleozoic strata and mid-Tertiary volcanic rocks.

PXP 27-1 well and prospect potential of the Pluto anticline

In 2007, PXP, on a farmout from Gasco Energy, drilled the Pluto 27-1 well on a surface anticline along Hwy 50 just west of Ely, Nevada (Fig. 1). The 27-1 well was not commercial, did not reach the reservoir targets, and PXP left the play in 2008. The anticline, informally called Pluto, is not visible from the air or roadside as the surface geology is masked by vegetation and the surface rocks do not make prominent outcrops. Davis' surface mapping shows the anticline has the Permian Arcturus Formation along the axis (Fig. 3), an asymmetric profile with a steep- to- vertical east limb (Fig. 4), and is four-way closed. The anticline was known before Davis' mapping but was never drilled before the 27-1 well.[23] The 27-1 test was made on the basis of surface mapping, cross sections, and subsurface mapping between cross-section lines. The decision to drill without benefit of seismic reflection data was made because usable seismic images are difficult to obtain where Paleozoic rocks are at the surface[24] and there were other questions about the petroleum system that only drilling could address. The youngest strata folded in the anticline belong to the Permian Park City Group and the anticline is unconformably overlain by unfolded volcanic beds of Oligocene age[25] indicating the anticline developed during the span from late Permian to early Tertiary time.

The 27-1 well spudded in the Arcturus Formation, entered the Chainman Shale at 4200 ft, and at 4460 ft, and upon entering a 60 ft thick, quartz-rich sand, took a significant gas kick that recorded 377,000 ppm methane. An upright flare was installed that would jet to 10-15 ft high, and continued to flare through drilling of the well. Spotty, light- to dark-brown oil-staining and yellow-gold fluorescence were observed in about 50% of the Chainman cuttings that consisted of thinly bedded, fine-grained sandstone and black shale. It is noteworthy that the 27-1 well shows that less than 200 ft of uppermost Chainman Shale provides an effective seal for retaining gas and oil.

Dip meter results matched the surface dips, and showed the well had drilled the moderately-dipping west limb of the anticline to about 4300 ft, the crestal area from 4300 to 6700 ft, but deeper no dip meter recordings were obtained due to hole problems. Below 4460 ft the mixed sand and shale lithology is characteristic of the Scotty Wash Member of the Chainman Shale and the well remained in similar lithology to total depth (9643 ft). Chainman Shale thickness in this area is known to range from

1600-2400 ft,[19] yet the 27-1 well drilled over 5,300 ft of Chainman Shale. The simplest interpretation of the 2-3X normal thickness of Chainman Shale is that at about 6700 ft the well entered the steep limb of the anticline that is documented in the surface geology and remained in the steep limb until total depth.

What are the possible sources and timing of entrapment of oil and gas at the Pluto anticline? Miocene to present generation and migration from the Chainman Shale buried in a Basin and Range graben to the Pluto anticline does not seem likely as it would require long-range migration across large, graben-margin normal faults. Deeply buried Chainman Shale local to the 27-1 well is a more likely source and analysis of 14 Chainman samples from the well[26] show a fairly typical, organic-rich Chainman Shale section was drilled. Total organic carbon (TOC) from the samples ranged from 0.90% to 2.43% with an average of 1.37%, and the highest TOCs are from the top of the Chainman where the best oil and gas shows occurred. Samples have an equal abundance of Type II and III kerogen, and original TOCs are estimated to average 1.72 % and to be 3.5% near top of Chainman. Maturity samples from the 27-1 well are within the oil generation window (Fig. 5) and show an unusually low increase in maturity with depth that is the result of drilling a steep fold limb (0.53 to 0.85 Ro, a ~0.3% Ro increase over a ~5,000 ft depth interval). The Pluto anticline cross section (Fig. 4) shows ~16,000 ft of burial on basal Chainman in the syncline east of the Pluto anticline, however, uncertainty in the local thickness of the Permian Park City Group (Pa) and uppermost Arcturus Formation constrain the maximum burial of the base of the Chainman from ~9000 to ~16000 ft. Regardless, comparison of overburden thickness with published geohistory models[18] suggests the Pluto location entered the oil window at the end of the Permian. Hydrocarbons trapped at the Pluto anticline are most likely due to folding beginning during the Permian and hydrocarbon entrapment from that time until the middle Jurassic. A local unconformity between the Arcturus and Park City Group confirms folding during the Permian (Fig. 3), and could be the result of convergence from the unnamed middle Mississippian to late Permian event described by Cashman, et al. [4]

Summary

The 27-1 well shows there is exploration potential to the surface anticlines of eastern Nevada, and broadens the plays in the USGS's PTPS in eastern Nevada, and possibly western Utah.[18] Despite the failure of the 27-1 well to find commercial hydrocarbons the Pluto anticline remains a viable prospect for a side-track as the reservoir target was not reached, Chainman Shale was shown to be an effective seal for hydrocarbons, the anticline traps hydrocarbons in the shallower secondary reservoir targets, and the anticline predates both episodes of oil generation. Hydrocarbon-bearing fold belts are never fully evaluated until a number of the large, un-breached surface anticlines are tested through the known reservoir targets, and remarkably given "the lower 48" location of the fold and thrust belt in eastern Nevada, this has not been done.

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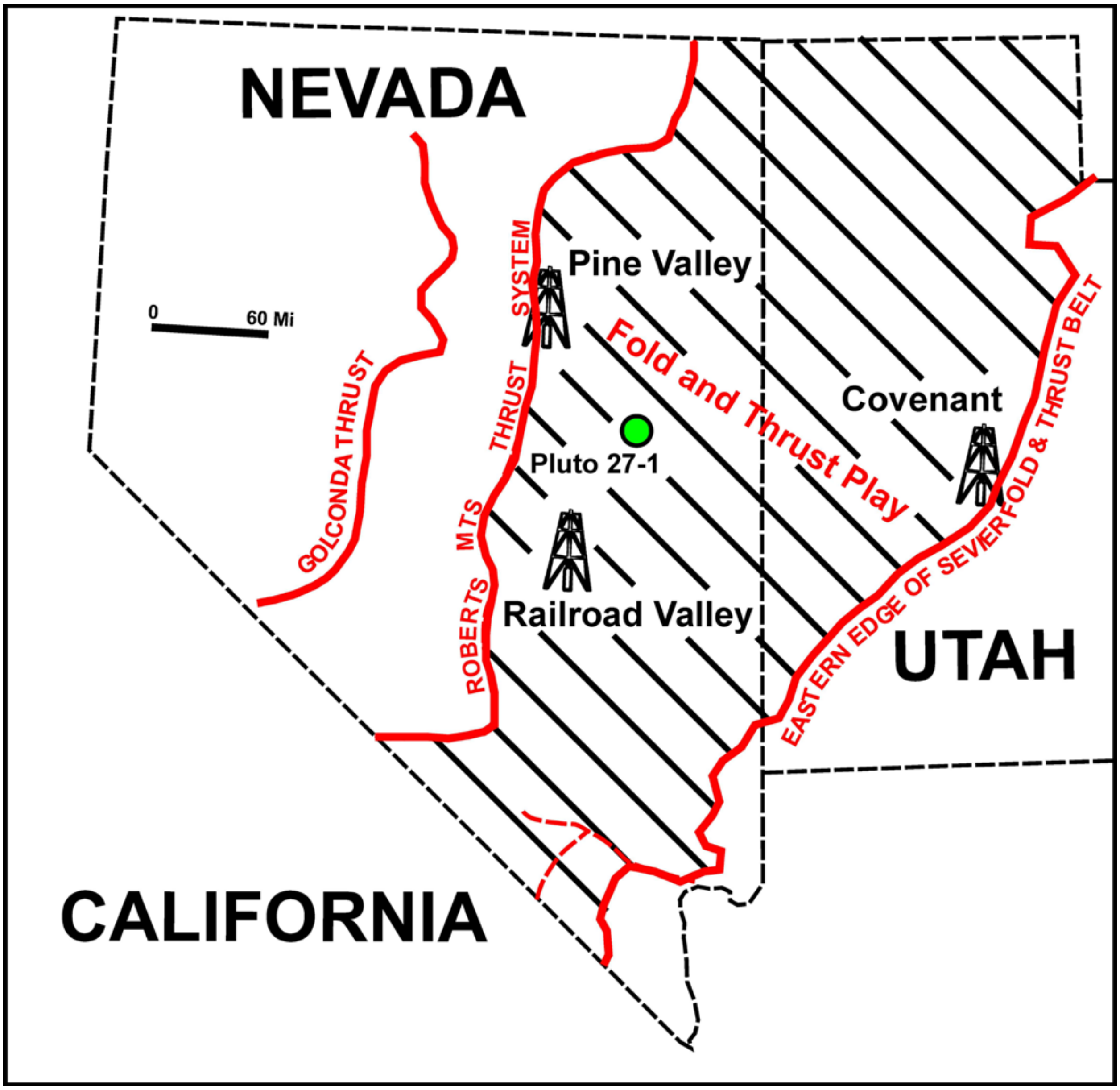

Fig. 1. Map showing extent of fold and thrust belt play in eastern Nevada and western Utah (cross-hatch), location of three oil producing areas within play, and location of Pluto 27-1 well. Distribution of primary source rock that is mostly Chainman Shale coincides,[16] more or less, with structures of the fold and thrust belt play. [1]

Fig. 2 Large, untested surface anticline of the fold and thrust belt play. Oldest strata exposed along the anticlinal axis is Permian-age Pequop Formation. Location is Spruce Mountain, Elko County, Nevada.

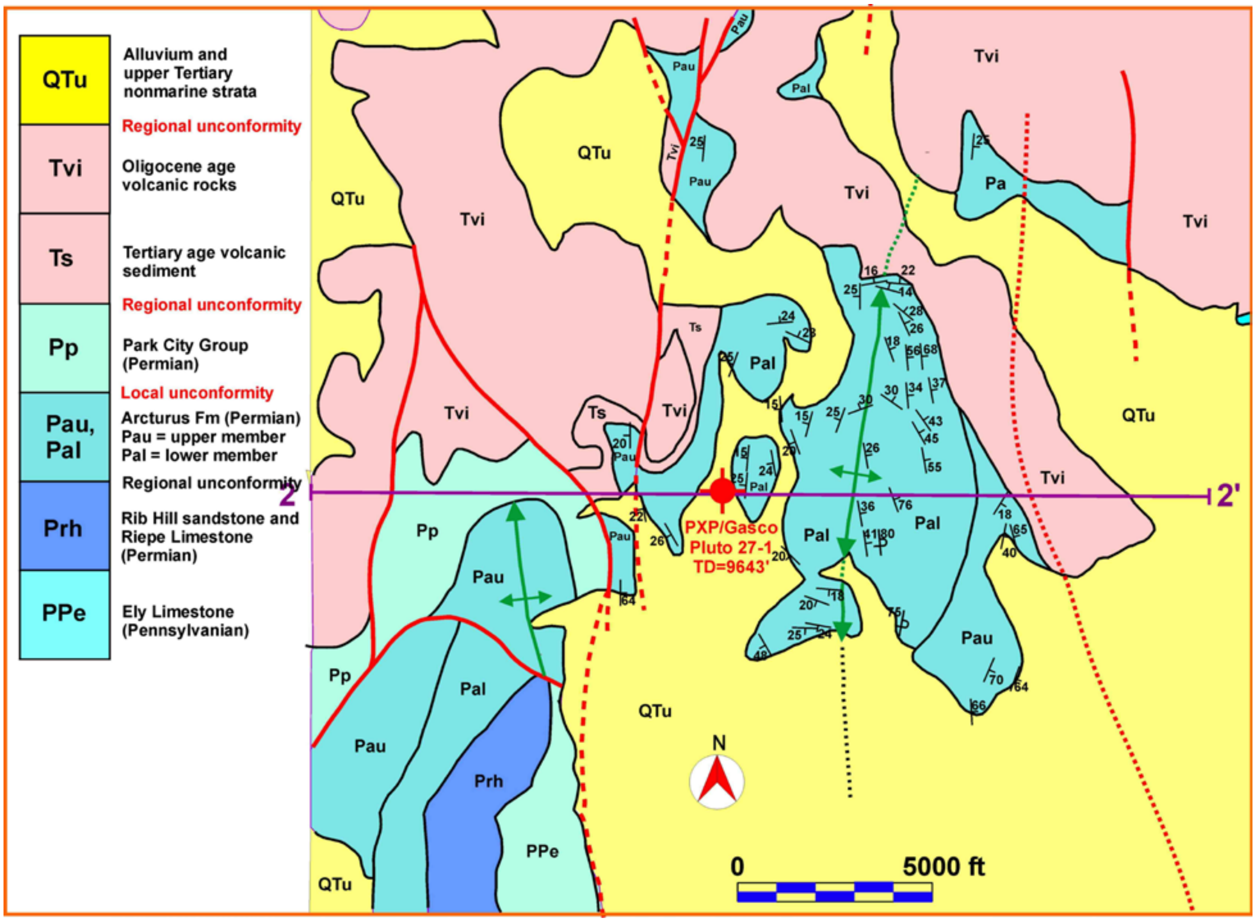

Fig. 3 Davis' surface geologic of the Pluto anticline showing locations of the PXP Pluto 27-1 well and cross section shown in Figure 4. Note unconformity between units Pp and Pau.

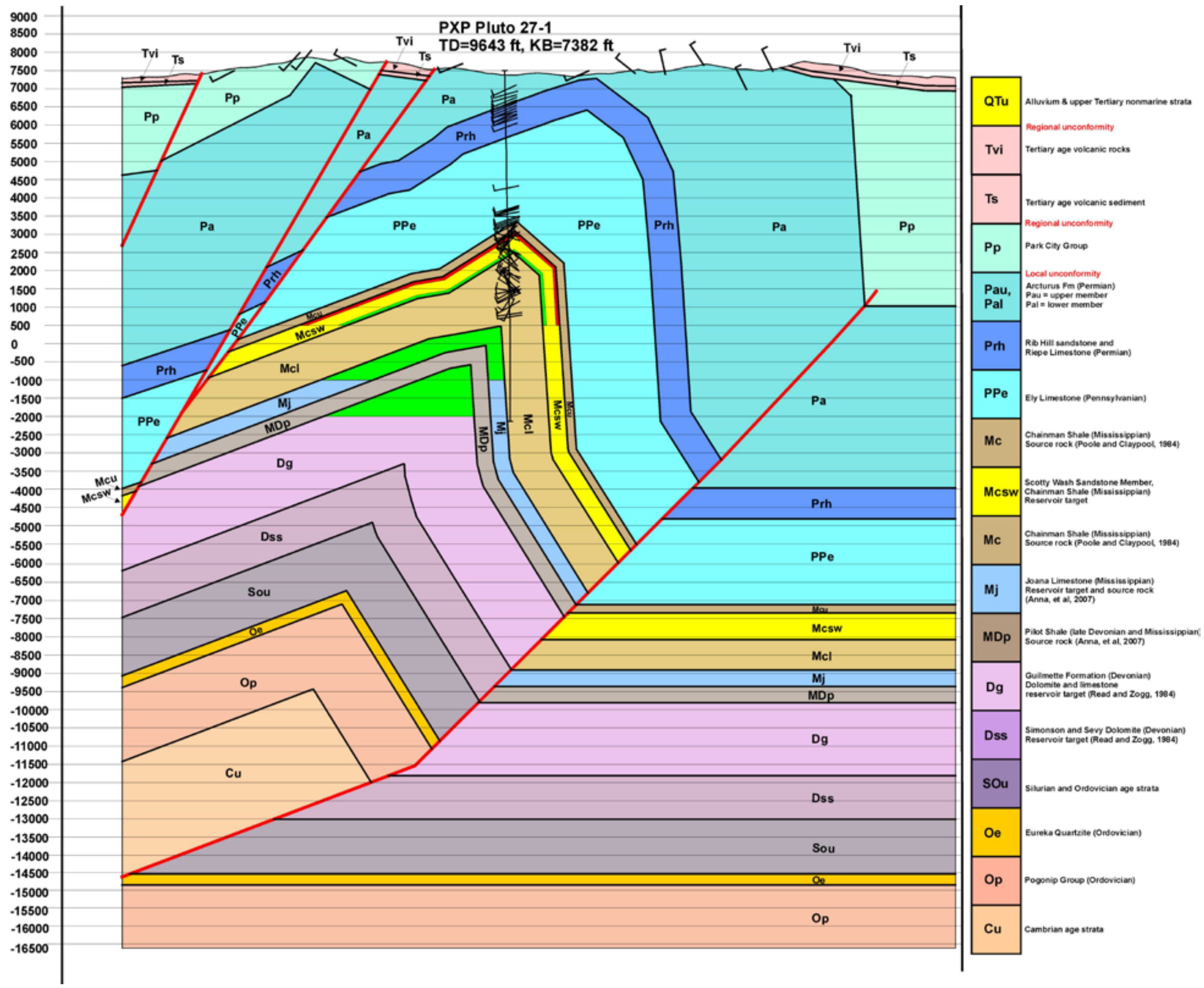

Fig. 4 Cross secton 2-2' across the Pluto anticline showing PXP Pluto 27-1 well, and untested Pluto prospect (green fills in Dg and Mj units).

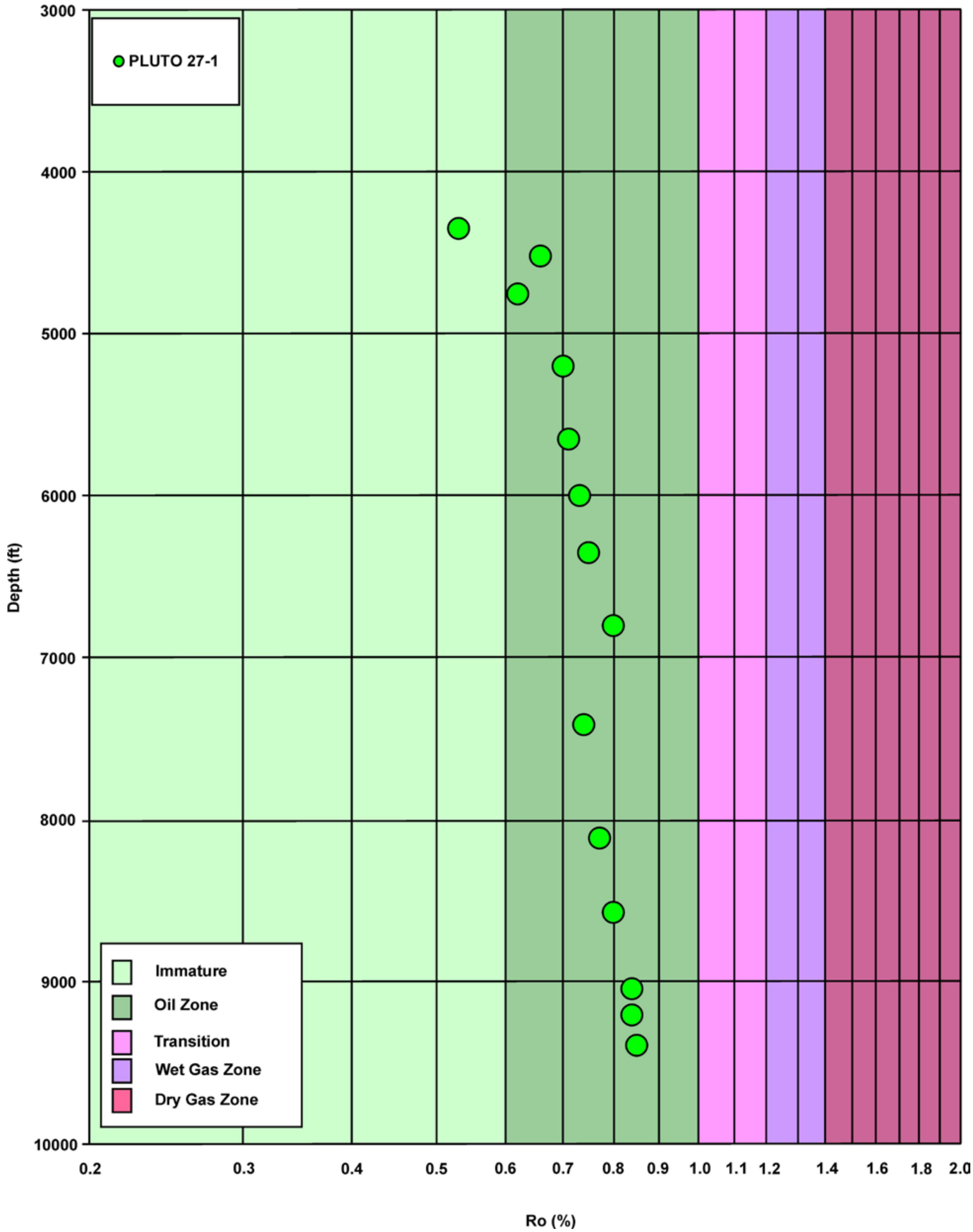

Fig. 5 Maturity and depth profile for Chainman Shale samples from the PXP Pluto 27-1 well. The increase in Ro with depth profile of 27-1 is unusually steep indicating borehole drilled the steep limb of the Pluto anticline.