Reservoirs in the Abo Formation, Southeastern NM: A Fractured Play within the Perturbed Stress Field at the Termination of Wrench Faults

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Abstract

Production of natural gas from the low-permeability arkoses and sandstones of the Permian Abo Formation, southeastern New Mexico exceeds matrix deliverability capacity, suggesting that the reservoirs are fractured. This suggestion is corroborated by the fact that the Abo Formation is highly fractured in the relatively undeformed outcrops, far distant from the reservoirs but indicating that the strata are susceptible to fracturing. Natural fractures are also present in the few available cores, thus the presence of significant fracturing is inferred in the subsurface.

Although the Abo Formation was deposited over much of southeastern New Mexico, Abo sandstones are most productive where the strata are associated with a series of sub-parallel, northeast-trending, deep-seated, right-lateral wrench faults called the Pecos Buckles. The surface strata along these buckles consist of poorly exposed evaporite and carbonate facies, complicating structural interpretations. However, well-exposed sandstones along similar wrench faults in the central Sahara have numerous irregular fractures that are commonly formed in the vicinity of such wrench faults. Strata are fractured due to volume constraints at irregularities during lateral offset along the faults. By analogy, reservoirs in the Abo Formation were fractured during lateral offset along the Pecos Buckles. Most of the Abo reservoirs are located near the northeastern termination of these wrench faults, therefore fracturing may also have been a response to stresses associated with offsets along fault splays at the ends of the Pecos Buckles.

Introduction

Natural gas occurs in fluvial-deltaic sandstones of the Permian-age Abo Formation, on the northern edge of the Delaware Basin in southeastern New Mexico (Figure 1). The play covers approximately 20 townships near the town of Roswell. The Abo sandstones are low-permeability reservoirs, and have an average in situ permeability of 6-7 microdarcys, an average porosity of 12-14%, and high irreducible water content, (Broadhead, 1984; 1993).

Only a few measurements have been made of the in situ stress orientations in southeastern New Mexico and West Texas (Figure 1). Hurley (personal communication, 2000) reports that the current maximum horizontal compressive stress trends approximately east-west in the deep Ellenberger reservoirs of the State Line oil field just east of Hobbs, NM. Approximately 75 miles to the south, near the southeastern corner of New Mexico, Major and Holtz (1997) measured wellbore breakouts in shallower (San Andres) strata in the Keystone field that indicate a northeast-southwest trending maximum horizontal compressive stress.

The Pecos Buckles are a prominent structural feature in southeastern New Mexico. They are northeast-southwest trending, parallel linear features up to 80 miles long. The buckles are defined by low but definitive linear hills in the eroded, evaporitic surface strata. They are locally multi-stranded and hard to trace, and some are only documented in the subsurface. Kelley (1971) was among the first to interpret these as wrench faults. These structures were activated within the regional east-west to northeast-southwest Laramide compressive stress field, and form very localized, linear zones of structural deformation and intense fracturing. The characteristics of the Pecos wrench faults are strikingly similar to the better studied wrench-fault systems of Mongolia in central Asia and the Hoggar massif in central North Africa (e.g., Cunningham, et al., 1997).

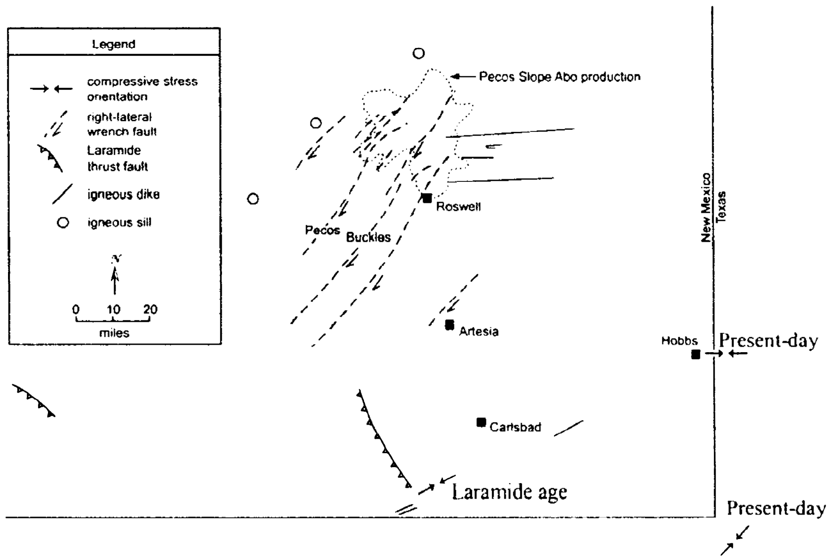

Figure 1: The present-day maximum horizontal compressive stress, and reconstructions of the Laramide age maximum horizontal compressive stress, both trend between E-W and NE-SW.

In North Africa, continental-scale, north-south striking, right-lateral wrench faults transect the central Saharan platform (Figure 2). Strata adjacent to the wrench faults consist of well sorted, well cemented, lower Paleozoic sandstones, and are highly fractured. Strata within a few hundreds of yards of the faults are abruptly upturned and locally overturned, and the sense of vertical offset (east side or west side of the fault downthrown) changes along strike. Fracturing and structural deformation increase where the faults change strike due to volume constraints at these asperities. Sharply upturned bedding immediately adjacent to the faults and a sense of vertical offset that reverses frequently along strike are characteristics of volume-constraint problems and impingement along bends in wrench faults during lateral offset (see articles in Holdsworth et al., 1998). Local re-orientation of displacement vectors and intensification of fracturing would be expected along the faults due to the strain partitioning that is common in strike-slip, transpressive zones (e.g., Teyssier and Tikoff, 1998). This area of well-exposed and highly fractured Paleozoic strata provides an analog for fractures in strata along a wrench fault, one that is applicable to fractured reservoirs in the Pecos Slope field of southeastern New Mexico.

Natural Fractures in the Abo Formation

The Abo Formation crops out approximately 100 miles to the west and northwest of the Pecos Slope field, in road cuts along route US 60 west of the Mountainair, NM, and in the faulted terrain east of Socorro, NM. All outcrops are extensively fractured and fracture spacing varies from considerably less than a meter in the thinner beds to a few meters in thicker beds. Wider and more irregular fracture spacings are typical of poorly to moderately sorted, lenticular fluvial channels that are several meters thick. Plane-parallel bedded sandstone units that are 5-10 cm thick are quarried locally for flagstone. These Abo Formation sandstones display more closely-spaced fractures and a preferential weakness direction, breaking easily along planes parallel to nearby, larger-scale fractures.

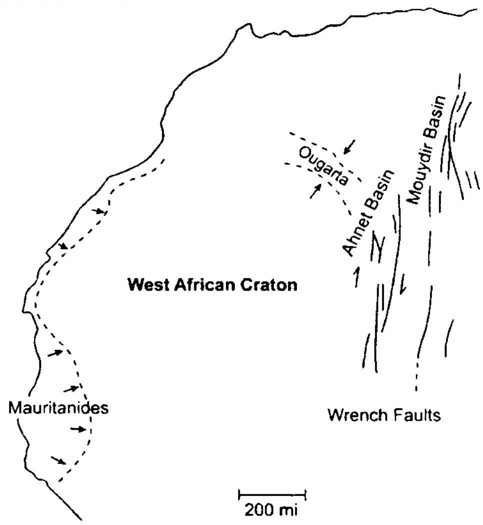

Figure 2: N-S striking, right-lateral wrench faults within central Sahara. The proposed reconstructions of Hercynian tectonics suggest that these transpressive faults were reactivated in response to E-W to NE-SW compressive stresses related to continental collision and thrust faulting in the Mauritanides mountain chain.

Forty-four linear ft of slabs from 4-inch diameter Abo core, from the Yates Petroleum J.R. State Com #1, located in section 14 of T. 9 S., R. 26 E., and 101 linear ft, both slabs and butts, of 4-inch diameter Abo core from the Yates Petroleum Thorpe MI Federal 2, located in section 3 of T. 7 S., R. 25 E. are stored in Socorro, NM, at the New Mexico Institute of Mining and Technology core repository. Both wells are from the eastern half of the Pecos Slope field, but the J.R. State well is outside of the area generally considered to be productive. The Thorpe well is approximately two miles east of the mapped location of the Six-Mile wrench fault, whereas the J.R. State well is at least 7 miles from the nearest mapped wrench fault (the Y-O fault).

Despite the small sample size of slabbed, 4-inch diameter core relative to reservoir volume, and despite the relatively low probability of intersecting vertical fractures with vertical core, nearly every sandstone and siltstone bed cored in both wells contained some sort of natural fracture. Observed fracture patterns are consistent with the model of local, irregular, wrench-fault related fracturing superimposed onto a more widely spaced, regional vertical extension fracture pattern.

Most of the fractures in the core appear to be extension fractures (plumes, no apparent offset), but some display evidence for minor shear offset (stepped surfaces, asperities indicating mm-scale offsets; Figure 3). Some fractures are hairline fractures with minimal aperture, but mineralized fractures up to a few millimeters wide are also present. Where the top and base of a vertical fracture can be determined, they are typically located at the contacts with the bounding shales and the fracture extends the full thickness of the sandstone or siltstone bed.

Numerous vertical, sub-vertical, and low-angle thrust fractures are present in the two cores. The fracture patterns are consistent with both a high intensity of fracturing and with multiple fracture orientations in the subsurface. Rare examples of juxtaposed natural and induced fractures suggest that there is not a simple relationship between the in situ stresses and fracture geometries.

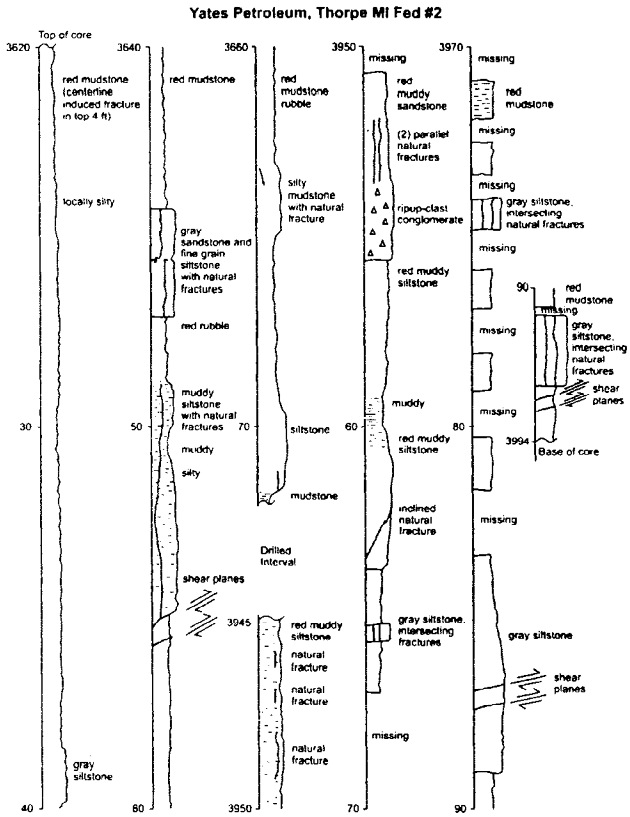

Figure 3: Yates Petroleum Thorpe MI Federal 2 core log. Approximately 18 ft of cumulative natural fracture height is present in the 101 ft of Thorpe core. More importantly, this 18 ft of fracture height occurs within approximately 42 ft of sandstone and siltstone core, thus there is approximately one ft of natural fracture height for every 2.3 ft of potential reservoir lithology, a relatively high ratio supporting the inferred high fracture density related to a wrench fault system.

Conclusions

The Abo Formation is universally fractured in outcrop, and is expected to be extensively fractured in reservoirs of the Pecos Slope field. Fracturing is similar to that seen in the Paleozoic sandstones of the central Sahara, where fractures formed during Hercynian reactivation of continental-scale, north-south wrench faults that cut the region. During this time regional compression produced sub-kilometer scale offsets and local binding along the sinuous faults. Similarly, right-lateral wrench faulting along the Pecos Buckles superimposed local stresses, additional fractures, and a higher fracture intensity onto the regional pattern within the Abo reservoirs. Local fracture orientations are difficult to predict, but enhanced fracturing is expected both where the wrench faults change strike, and where they terminate.

The Pecos Buckles acted as an accommodation zone between northeastward lateral translation with associated deformation of the crust to the northwest of the buckles, and the relatively undeformed crust to the south (Seager, 1983). They behaved in a manner similar to the Lewis and Clark lineament in Montana, which accommodated differential translation between the block-faulted Laramide foreland in the US and thin-skinned thrusting in Canada (Lorenz, 1984), and to the wrench fault system that transects the central part of North Africa. More important to production, wrench motion along the Pecos Buckles created local domains of intense fracturing (breccia in extreme cases), which, in the absence of core, are documented in the subsurface by locally enhanced gas productivity.

Acknowledgements

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