Taconic Tectonics and the Trenton/Black River Carbonate Gas Play in the Northern Appalachian Basin of New York State: Evidence from Seismic Data and the First Oriented Horizontal Core in the Appalachian Basin T/BR

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Summary

The Trenton/Black River gas play in the Finger Lakes region of New York State, northern Appalachian Basin, is the most prolific fracture-related gas play in the history of the northern Appalachian Basin. In fact the largest gas wells in onshore USA were drilled in this play in 2005 and 2006. This presentation integrates 2-D seismic reflection data with surface mapping, conodont alteration indices, and the first oriented horizontal core from the Black River Formation in NYS in order to construct a tectonic history of the faults controlling the play and their relation to the T/BR gas play in NYS. Data from the core (which is on display at this meeting) includes geochemistry of

the veins (isotopes, trace element and REE abundances, fluid inclusion data), kinematic indicators and vein/stylolite cross-cutting features. These data confirm the general tectonic model of fault slip responding to stress fields set up during attempted subduction of the Laurentian plate during the Taconic Orogeny; later generations of veins and stylolites are consistent with younger orgenies such as the Alleghanian.

Introduction

The present Trenton/Black River gas play in New York State is localized along E, ENE and WNW-trending grabens that developed during the Ordovician Taconic Orogeny. The grabens are related to reactivated fault systems. Fluid migration along the developing fault systems during the Taconic Orogeny promoted dissolution of the carbonate and resultant vuggy porosity, followed by dolomitization. The first oriented horizontal core was retrieved from one of the T/BR grabens in the Finger Lakes; the carbonate in this core generally has low porosity (on the order of $<2\%$), and an FMI log suggests that gas shows in the region of the core occurred at significant fracture/fault locations.

An important part of understanding the T/BR puzzle is thus understanding the faulting/fracturing for both the initial development of the reservoir and the gas delivery system to the well. The graben-related fault systems, as well as other fault systems in NYS, have different slip histories, controlled in part by their orientation. Tectonic models of the Taconic Orogeny predict that fault slip reversed (for all the major fault systems) during the progression of the Taconic Orogeny. Integration of seismic reflection data with surface mapping in the Mohawk Valley and the Finger Lakes, conodont alteration indices, and the first oriented horizontal core from the Black River Formation confirm the tectonic model with complex fault motion histories; this integration allows us to determine the timing and kinematic relationship among faults, fluid flow and the developing T/BR reservoir in NYS.

Model and Evidence

The tectonic model predicts that northerly-trending faults were extensional in the early phases of the Taconic Orogeny as the Laurentian plate flexed over the peripheral bulge and into the trench of the east-dipping subduction zone. (These faults were originally Grenvillian suture-related faults that were later reactivated during Iapetan opening). During this same time period, Iapetan rift faults with an arcuate trend (in map view) that form the Appalachian Basin portion of the Pennsylvania Salient should have experienced strike-slip to oblique-slip motion, given an approximately E-W directed S_h and a N-S directed S_H (maximum principal horizontal compressive stress). The arcuate ENE-trending faults would have been left-lateral. As the collision progressed, and the continent jammed the subduction zone, S_H would have reoriented to an EW direction. This orientation of S_H would result in the northerly-striking faults now relatively “tight” and reactivated as high angle reverse faults, whereas easterly-striking faults would now be extensional. The arcuate trending faults (and the NW-trending faults) would reverse shear sense from the earlier times. Riedal shears and rhombochasms would be common along the arcuate fault trends and the WNW- to NW-trending faults (those that were not parallel or orthogonal to S_H). Later orogenies, the Salinic, Acadian, and Alleghanian, would also affect these same faults. For example, the Acadian faulting should follow a similar path as the Taconic, but the later phase of the Alleghanian should have a radially-directed S_H, which would be northerly to northwesterly-directed in the Finger Lakes region.

Seismic reflection data across the northerly-striking Clarendon-Linden Fault System in western NYS demonstrate that the faults were extensional during Trenton/Black River and earlier Taconic times, and were reverse faults in Utica (late Taconic) time, as the model predicts. In the Mohawk Valley region in eastern NYS, outcrop data shows that the northerly trending faults were also extensional during Trenton/Dolgeville/early Utica time. 2-D seismic reflection data in the Finger Lakes display flower structures in the arcuate fault systems (ENE- trending) that guided the development of several of the T/BR fields. The flower structures suggest strike slip motion, as the tectonic model suggests. Finally, the relatively late timing in the tectonic model of extension along E-striking structures (and consequent graben development) is confirmed by a 2-D seismic across the E-striking graben of the Muck Farm field, which shows that this graben developed primarily during Utica (late Taconic) time.

Veins and stylolites in the horizontal core support this complicated fault motion scenario, including multiple orogenies. Geochemistry, kinematics and intersection relationships suggest that the Black River limestones were fractured very early in their history along ENE-faults, evidenced by an ENE-trending vein cut by a horizontal stylolite. Sr isotopes are consistent with a Taconic time of vein growth. Kinematic indicators in the form of rhombochasms in ENE-trending and WNW-trending veins are consistent with relatively early motion when S_h was oriented EW (ENE-trending veins are left lateral and WNW-trending veins are right lateral). Later right-lateral motion on ENE-trending veins can also be inferred from the core. Thus, fluid migration, limestone dissolution, and precipitation of dolomite were all ongoing during the early and later phases of the Taconic Orogeny. The thick accumulations of anthraxolite in horizontal stylolites and as the first rim in vugs suggest that hydrocarbons were also migrating at this time. A horizontal vein, indicative of vertical unloading, postdates the horizontal stylolites, and may denote the close of the Taconic Orogeny. ENE and WNW-trending veins postdate the horizontal vein. These veins are in turn cut by north-easterly-trending vertical stylolites, which may be Alleghanian, based on their orientation. Still later veins postdate these stylolites. This proposed multiphase evolution of fluid migration and resultant veins is consistent with fluid inclusion salinity and temperature data and multiphase vug fills. Based on fluid inclusion data and vug fills, hydrocarbon migration began in Taconic times, although the more usual model of an Alleghanian gas charge is also probable.

Conclusions

The faults and associated fractures that promoted the development of the Ordovician Black River reservoir in central New York State have a complex history that can be determined from seismic data, as well as geochemistry, kinematic indicators, and crosscutting relationships of veins and stylolites in an oriented horizontal core. These data confirm the general tectonic model that suggests the Laurentian plate flexed across the peripheral bulge before entering the subduction zone in Taconic times. During this phase of the Taconic Orogeny, northerly trending faults would be extensional, whereas ENE-striking faults would be left lateral. During final collision, the northerly trending faults would become reverse faults, and the ENE-striking faults would sustain right lateral shear. East-striking faults would now be extensional (and open). These fault systems guided the fluid migration that resulted in vuggy porosity and dolomitization; the fault systems also controlled the development of the T/BR grabens along their trends.