Exploration for Gravity Fault Controlled Structural Traps, North-Central Montana

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Summary

The Bearpaw Uplift of north-central Montana hosts a world-class example of gravity-induced faulting within Upper Cretaceous marine sedimentary rocks and their overlying Tertiary volcanic and sedimentary cover. Seismic exploration, mostly for shallow (less than 640 m, 2100 ft depth) Upper Cretaceous biogenic gas reservoirs, has yielded high quality 2D and 3D datasets spanning a large area of Hill and Blaine Counties. Mapping utilizing this seismic data reveals a complex pattern of faulting hidden beneath a glacial veneer north of the Bearpaw Mountains and into Canada (Fig. 3). This fault pattern is very similar in geometry and origin to that mapped at the surface south of the Bearpaws.

Historically, the primary exploration objective around the Bearpaw Uplift has been the Upper Cretaceous (Campanian) Eagle Sandstone. High quality marine shoreface reservoirs of the Eagle Sandstone have produced over 400 Bcfg from a wide variety of structural traps, all fundamentally related to gravity-induced movement down the flanks of the Laramide Bearpaw uplift. Recent exploration has led to the discovery of shallow gas reserves in the underlying Upper Cretaceous Niobrara (Medicine Hat) Sandstones. The Niobrara Sandstones (Santonian) are lower in reservoir quality than the Eagle Sandstone and were deposited in a more distal marine lower shoreface environment. Klabzuba's St. Joe Road field, discovered in 2001, covers 40 sq. mi. and has produced over 11 Bcfg from 74 wells in the Niobrara Sandstone. Current daily production for the field is over 10 million cfgpd.

Introduction

Detailed surface geologic mapping and interpretation of the geology of the Bearpaw Mountains by Reeves (1946) and Hearn (1976) resulted in a good understanding of the geologic history and gravity tectonics of the area. Laramide basement- involved uplift of the Bearpaw Arch was accompanied by extensive outpouring of surface flows and volcaniclastics and the emplacement of a wide variety of intrusive bodies. Thrust sheets loaded with thick volcanic and sedimentary cover moved off the flanks of the Bearpaw Arch along over-pressured organic-rich shale decollements. Rocks beneath the decollements are mostly undeformed with dips of roughly 3 degrees away from the arch. The head ward or updip portion of the thrust sheets is dominated by extensional structures in a chaotic fault array of normal faults and grabens, while the basinward downdip portion is characterized by compressional thrust-faulted structures. The southern master normal fault trends roughly N70°E and is located in townships T29N to T30N while major thrust faults have been mapped into Canada, over 50 miles (80 km) north. In a general sense the zone of demarcation between extensional and compressional structures is located at roughly the course of the Milk River, between townships T32N and T33N.

Study Area, Data and Methods

The detailed study area extends from the Milk River north into southernmost Saskatchewan (Fig. 3). Since 1995, seismic exploration, mostly for thrusted structural targets, has yielded high quality 2D and 3D datasets that cover the study area. Seismic time and isochron mapping of selected reflectors spanning the basal Judith River through Greenhorn (2WS) stratigraphic section (Fig.2) allows for accurate fault maps and structural interpretations. These interpretations are improved by integration of subsurface control from over 200 wells including core data, digital open-hole logs and accurate pressure and production data. Seismic amplitude analysis reveals startling gas-induced seismic anomalies in the Judith River, Eagle and Niobrara. The validity of these interpretations has been tested repeatedly by the drill bit, with success measured in part by gas reserves added.

Deformation History and Structural Traps

Two principal decollements carry massive thrust sheets downdip off the flanks of the Laramide Bearpaw Uplift. These faults trap biogenic gas in a variety of structural traps well imaged with 2D and 3D seismic. Within the study area, the older, upper 1WS decollement is rooted in an organic-rich shale within the uppermost Colorado Shale (First White Specks). Regional gentle NE structural dip on this thrust sheet is punctuated by regularly spaced fault-bounded horsts or “pop-up” structures that are up to 5 miles (8 km) long. Much of the Eagle gas in the study area is trapped in comparatively small, fault bounded blocks of 20-200 acres. Many one well Eagle fields have produced between 1 and 2 Bcfg from very high quality (30% porosity, 500-1000 md perm) marine shoreface reservoirs. Structural gas traps found in the area include north vergent fault-bend fold traps, backthrusts (south vergent thrusts), pop-up blocks, fault-gouge traps, blind thrusts, and footwall cutoffs.

Two distinct episodes of gravity faulting are apparent in the study area. The “pop-up” structures formed above the 1WS decollement were then carried piggyback by faulting associated with the lower, younger 2WS decollement located in organic rich shale just above the Greenhorn (Second White Specks). Several long strike-slip faults offset earlier formed pop-ups with roughly 5000 feet (1500 m) right-lateral displacement as measured by piercing points at mapped fault intersections Klabzuba’s St. Joe Road field, discovered in 2001, covers 40 sq mi (103 sq km) and has produced over 11 Bcfg from 74 wells in the Niobrara Sandstone. Current daily production for the field is over 10 million cfgpd. The updip limit for St. Joe Road Field is formed by a fault gouge seal developed along a through going strike-slip fault.

Acknowledgements

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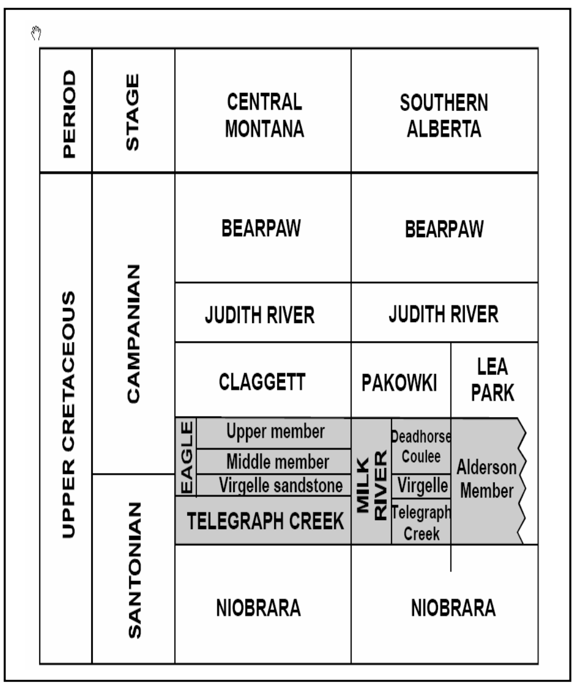

Figure 1: Stratigraphy of the study area.
From Payenberg (2002)

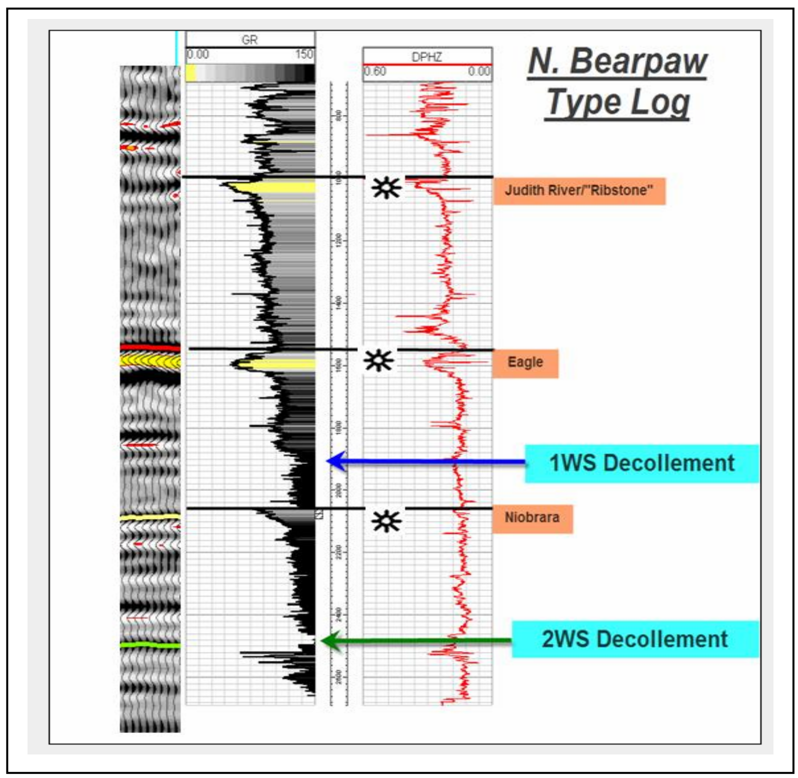

Figure 2: Type log for study area showing main gas reservoirs. Corresponding seismic section on left. Older 1WS decollement and younger 2WS decollement located in organic-rich shale.

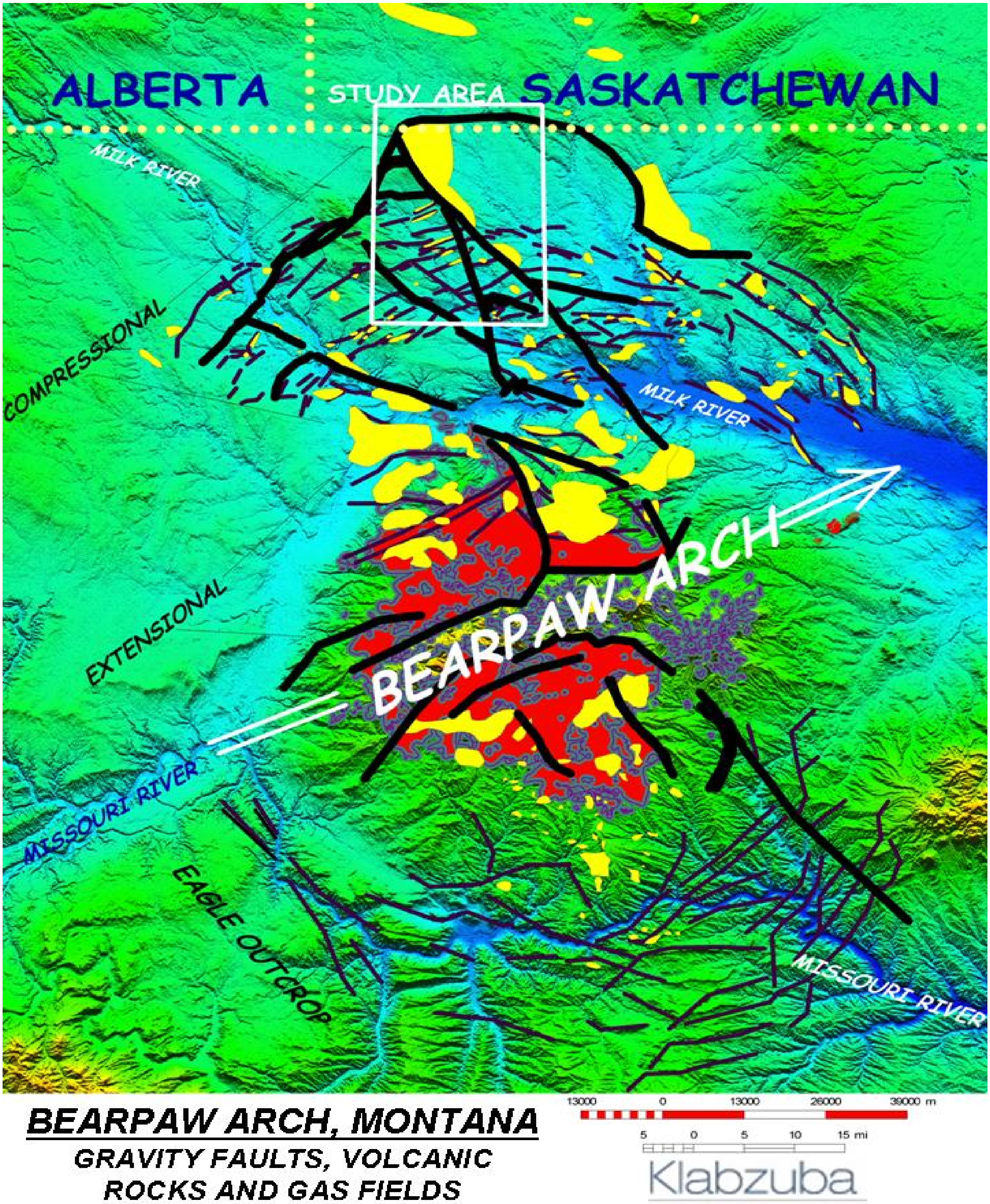

Figure 3: Bearpaw region DEM with gravity fault pattern in black. Faults south of the Bearpaws are exposed at the surface. Faults north of the Bearpaws are hidden beneath glacial veneer and have been mapped using seismic and well control. Eocene extrusive volcanics in red, intrusives in grey, and gas fields in yellow.