Shallow-Burial Fractures in Steep-rimmed Carbonate Platforms: Outcrops in Canning Basin, NW Australia, as Analog for Tengiz Reservoir, Kazakhstan*

Wayne Narr[1], and Eric Flodin[2]

Search and Discovery Article #120081 (2013)
Posted January 29, 2013

*Adapted from extended abstract prepared in conjunction with poster presentation at AAPG Hedberg Conference, Fundamental Controls on Flow in Carbonates, July 8-13, 2012, Saint-Cyr Sur Mer, Provence, France, AAPG©2012

[1]Chevron Energy Technology Company, San Ramon, CA (wnarr@chevron.com)
[2]Tengizchevroil, Atyrau, Kazakhstan

Abstract

Natural fractures have a strong impact on productivity in Tengiz field, which is one of several giant light-oil accumulations trapped in isolated, mid to late Paleozoic carbonate platforms in the Pricaspian Basin of Kazakhstan. Outcrop analogs are particularly important for understanding reservoir fracture systems because many aspects of fracture character (height, length, connectivity, etc.) are impossible to measure with subsurface data.

The Devonian margin of the Canning Basin in NW Australia presents a well-exposed outcrop analog for steep carbonate margin and slope deposits of Tengiz field. Fracture data gathered from Tengiz core and image logs suggest affinity to fractures in the Canning outcrops in terms of origin, orientation, and range of density (surface area/volume). Inclusion of additional information – gained through outcrop study – into reservoir fracture descriptions leads to improved understanding of stratigraphic influence on their occurrence and character, and thus improved ability to predict fracture occurrence.

Shallow-burial (SB) fractures – those formed in carbonate strata prior to significant burial, including neptunian fractures (i.e. fractures open to the sea-floor) – have the greatest impact on reservoir productivity at Tengiz field. The characteristics and formation mechanisms of SB fractures are generally less well established in the literature than deep-burial or “tectonic” fractures. In contrast to tectonic fractures that generally form in the presence of a strong guiding tectonic force, SB fractures form in the near-surface environment under the dominant influence of gravitational forces, and thus tend to align with respect to local topography and express less-planar traces. Furthermore, the host rock mechanical properties may differ substantially from the present state, and the fractures have enjoyed the full diagenetic history experienced by the host. Thus, SB fractures are distinguished based on their orientations, diagenetic character, and fill.

Both at Tengiz and the Canning Basin SB fractures dip steeply and strike dominantly parallel and/or normal to the local orientation of the depositional margin, which indicates the importance of depositional morphology on their development. The highest fracture density is in

boundstone-dominant facies of the platform-margin to upper slope environment, which were lithified and able to sustain fracture penecontemporaneous with deposition. Dissolution by corrosive fluids following burial led to enlargement of fracture apertures, which range from small to cavernous. In Tengiz field, cavernous fractures pose high lost-circulation risk as well as the reward of highly productive wells.

Fracture density, which is measured routinely in the Tengiz reservoir, was measured at various Canning outcrop locations along horizontal pseudowells (i.e. scanline traverses). Most of our work focused on Windjana Gorge, which is a deep, river-incised canyon that crosscuts the carbonate shelf. We limited our fracture dataset to those that are >2 m tall and show visible open aperture someplace along their exposed extent, which includes a substantial majority of the fractures in this size range. Fracture density varies as a function of facies along the Canning scanlines, consistent with the variation in the Tengiz reservoir (Figure 1). Variability of fracture density between each 75 m-long bin interval is high, and variability within matching intervals compared across the river on twinned traverses is high. This suggests the representative elemental volume for fracture density in these strata is greater than this bin size.

Fracture size adds a critical dimension to the understanding of the character of SB fractures. The height of each fracture encountered along the scanlines was estimated from cliff base to the top of the outcrop. Measurement of length was not possible; for modeling we assume a fracture length:height ratio of 5:1. Fractures in mid to upper slope facies and reef core are typically not limited by mechanical stratal layering. Hence, these fractures are much taller than fractures in the reef flat and outer platform areas. Strata in the mid to upper slope at Windjana Gorge show approximate depositional dip averaging 40° SW yet the fractures in this same sequence show consistently steep dip (Figure 2a). Fractures are not strongly limited by bedding surfaces. Despite diversity of carbonate lithology in the mid to upper slope, the mechanical fabric with respect to the SB fractures is nearly massive (mechanically homogeneous). The cumulative height distribution of fractures generally shows an exponential distribution, and in the mid to upper slope facies there is sufficient data to compare both dominant fracture sets. Both margin parallel and normal fracture sets show nearly identical size distributions (Figure 2b). The deviation in curve fit at the tall end of this distribution is an artifact introduced by censoring imposed by the limited height of outcrop.

Fracture size is integrated with density to compute surface area of intersected fractures along scanlines. The subtle fracture density variations between facies are thereby magnified. This parameter is likely a good estimator of fracture connectivity in facies, and emphasizes that the reef core and mid to upper slope should exhibit much higher fracture communication – hence better fracture productivity in the reservoir – than reef flat or outer platform facies. This result is consistent with the relative variability of fracture-controlled productivity in similar facies at Tengiz field.

Fracture spacing by set, considered separately for each facies but measured along our lines of traverse (thus not confined to specific beds), show approximately log-normal distributions. Mechanical layering is commonly cited as exercising control on tectonic fracture spacing (e.g. Bai and Pollard, 2000) as well as fracture height. However, in the mid to upper slope facies, where mechanical bedding apparently does not exercise significant control on fracture height, we found that in both fracture sets the average spacing varies linearly as a function of fracture height up to the gorge-wall height of 70 m. Thus a spacing-height correlation is present here although no spacing-thickness correlation exists.

The fracture sizes and relationships discussed here have been used to guide input for flow-simulation models of sectors of Tengiz field. Thus analog outcrop-based data can add substantially to our understanding of key fracture system characteristics that are unavailable from well data alone.

References Cited

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Bai, T., and D.D. Pollard, 2000, Fracture spacing in layered rocks; a new explanation based on the stress transition: Journal of Structural Geology, v. 22/1, p. 43-57.

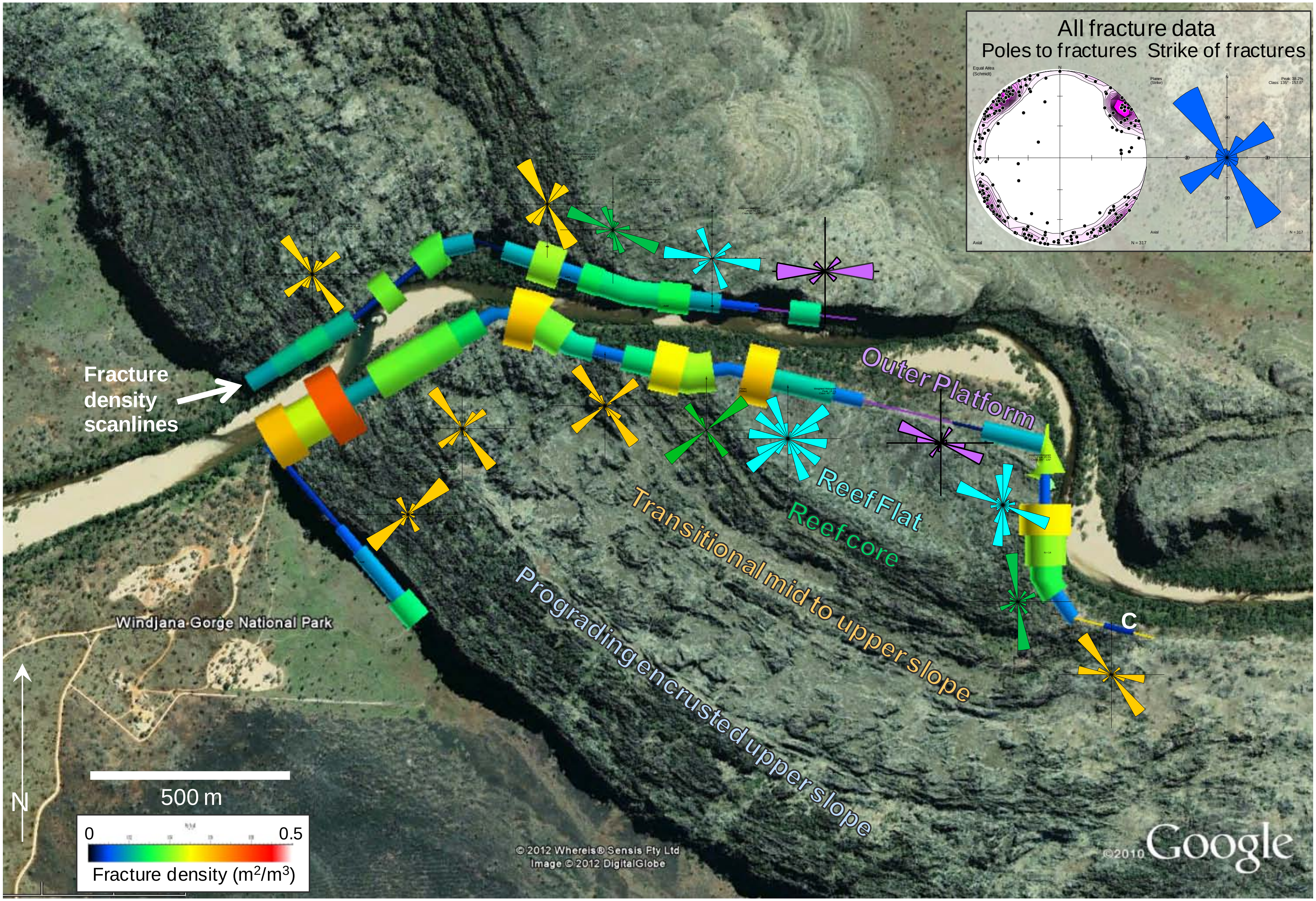

Figure 1. True-color satellite image of Windjana Gorge study site. Rose diagrams show fracture strike measured along portions of traverses, separated into facies (colors) or traverse segments. Spindles show fracture density logs along traverses; size and color of spindle correlate with fracture density.

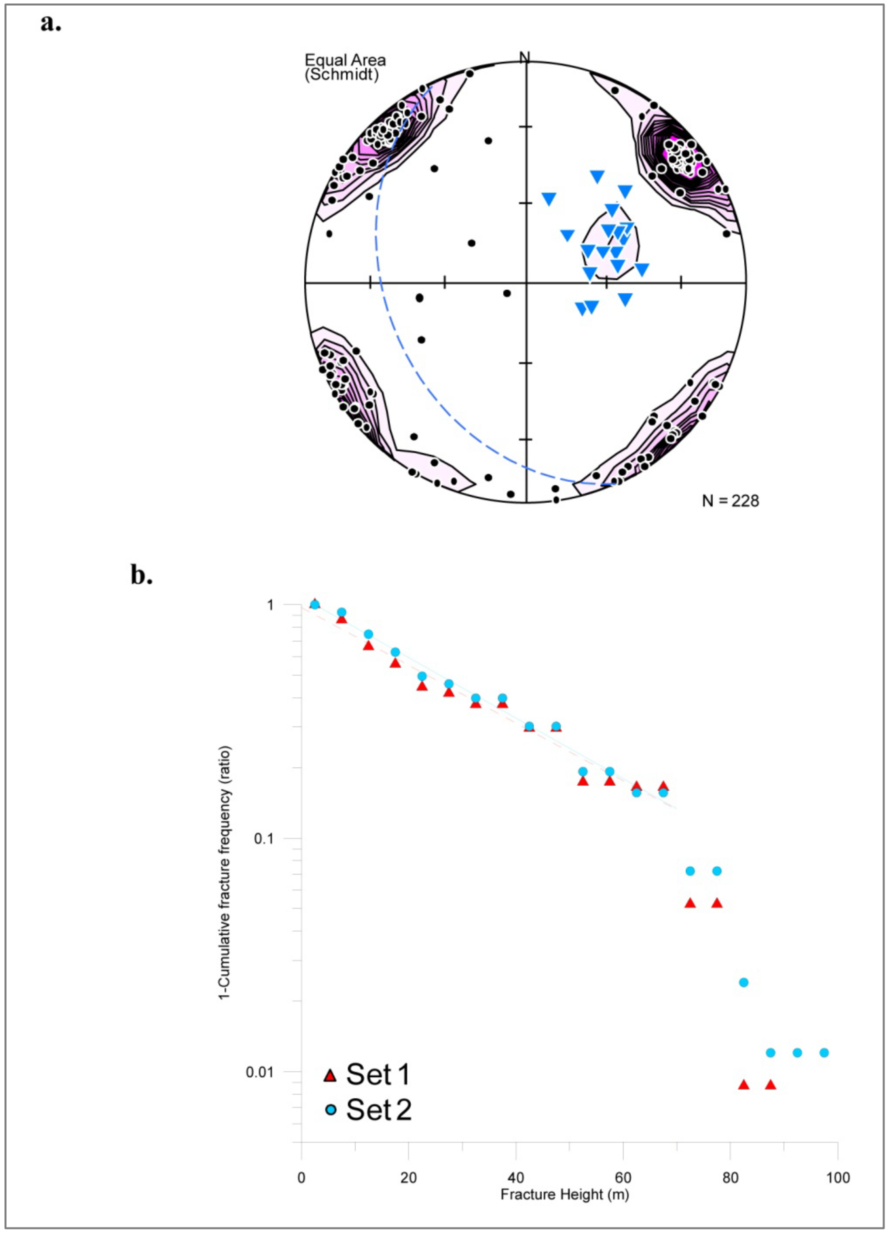

Figure 2. a. Lower hemisphere equal-area plot of poles to fractures (black circles) and bedding (blue triangles) from slope facies in western portion of Windjana Gorge. Dashed great circle is normal to center of concentration of bedding poles. Fractures show no consistent dip angle relative to bedding dip. b. Fracture height cumulative frequency distribution of Set 1 (NW-striking) and Set 2 (NE-striking) fractures in the mid to upper slope facies at Windjana Gorge.