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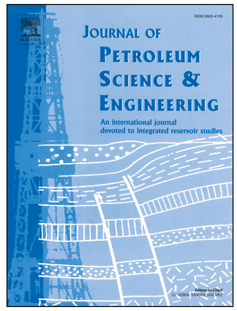

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An Application of Outcrop Analogues to Understanding the Origin and Abundance of Natural Fractures in the Woodford Shale

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Abstract

Subsurface natural fractures in shales are vital for fluid transport pre- and post-hydraulic fracturing in naturally fractured reservoirs such as the Woodford Shale. However, the dominant fracture sets that control the fluid flow in the subsurface are mostly unseen, and their intensity variation is unknown due to non-availability of image logs in most wells. In this paper, we have assessed the possibility of the existence of subsurface natural fractures in the Woodford Shale by understanding their generation history from outcrop and thin section studies. Additionally, we have addressed their relative abundance based on the bed thickness and composition.

Out of the several fracture sets identified in the Woodford Shale, two joint sets (E-W and NE-SW) were interpreted as the oldest sets based on crosscutting and fill. These sets date back to before the Mid-Virgilian Arbuckle Orogeny and likely have different generation timings. The relatively quartz and carbonate-rich beds primarily contain the E-W fractures and the relatively clay-rich beds mainly contain the NE-SW fractures. The E-W and NE-SW sets (origin both not related to structural bending) are likely more numerous in the flat subsurface compared to fractures sets whose origins are related to structural bending. These two fracture sets probably also control the fluid flow in the subsurface. Newer fracture sets show more influence of local folding and are overrepresented in the outcrops with tilted beds. Therefore, they do not likely control subsurface fluid flow. Although some fractures (fold or non-fold related) only have one type of cement or bitumen fill, others have two types of fills, i.e., bitumen along with another cement, or two types of cement (non-bitumen) indicating that these fractures underwent more than one stage of opening. Also, a negative correlation between fracture intensity and bed thickness, and a positive relationship between fracture intensity and quartz/carbonate content exist in the studied location.

1. Introduction

The standard and necessary stimulation method in shales is hydraulic fracturing which improves oil and gas recovery (Ben et al., 2012; Ghosh et al., 2014). Natural fractures are critical in controlling the fluid flow in the subsurface and connectivity to an artificial hydraulic fracture (Ferrill et al., 2014; Busetti et al., 2014; Smart et al., 2014). Outcrops are useful in measuring some of the basic natural fracture parameters such as relative fracture intensities among facies, fracture cementation, and fracture timing through crosscutting relations over laterally extensive areas. Also, due to limited visibility of fractures in core and image logs, outcrops studies are useful (Katz et al., 2006; Lacombe et al., 2011; Travé et al., 2000; Wennberg et al., 2006).

Studies related to the natural fracture generation timings have been conducted by several researchers using outcrop observations in their respective areas (e.g., Cosgrove 2001; Cruden, 2011; Pireh et al., 2015; Pommer et al., 2013; Tan et al., 2014). They have attributed diverse mechanisms such as folding and overpressure to the natural fracture generation. Also, Einstein and Dershowitz (1990) mentioned that a single stress regime is capable of producing multiple fracture sets. On the other hand, multiple stress regimes are also capable of producing multiple fracture sets. Given the fact that single or multiple stress regimes, i.e., nonunique stress regimes, are capable of producing the same fracture sets, one of the main aims of this study is interpreting the origin timings and related paleostress regimes using observations from outcrops. The