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# Brittleness index estimation in a tight shaly sandstone reservoir using well logs

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ABSTRACT

Premise evaluation of the ability of fracture network forming using hydraulic fracturing is crucial for the development of tight shaly sandstone reservoirs. X-ray diffraction, petrographic analysis integrated with petrophysical well logs was used to provide insights to the brittleness of Chang 7 shaly sandstone in the Ordos basin. The mineralogical composition of this unit is quartz, clay, carbonates and feldspar with minor quantities of pyrite. Quartz and carbonate are the critical brittle minerals. The brittleness index defined in terms of mineralogy and geomechanical properties was investigated respectively. The geomechanical brittleness derived from dipole acoustic logs has a wide range from 0.98% to 93.21%, averaging 58.07%. In contrast, the mineralogical brittleness index from X-ray diffraction results is in the range of 28.26–78.85%, averaging 59.31%. The geomechanical brittleness index could be easily calculated using the dipole acoustic and bulk density logs. For wells without dipole acoustic logs, predicting the brittleness index using conventional well log suits is of great importance. The mineralogical brittleness index was then correlated with their well-log signatures. Statistical regression analysis was carried out to find the relations between brittleness index and conventional well logs, and it is found that the ratio of gamma ray to photoelectric absorption cross section index (GR/Pe) shows a good correlation with brittleness index. Therefore, the brittleness index could be estimated using conventional logs (GR/Pe). The geomechanical brittleness index and the test oil results confirm the reliability of the brittleness index estimation model. Favorable layers for hydraulic fracturing are mainly associated with the intervals with high values of brittleness index. This work is valuable for the evaluation of hydraulic fracturing effects in unconventional oil and gas reservoirs in the future.



## 1. Introduction

Brittleness is one of the important mechanical properties of rocks (Kahramana and Altindag, 2004; Yagiz, 2009; Altindag, 2010; Meng et al., 2014). A general law with regard to brittleness is that a more brittle rock breaks at very little deformation (Yagiz, 2009). In the past several decades, the unconventional oil and gas reservoirs have become economically viable targets due to the successful application of horizontal well drilling and hydraulic fracturing (Sena et al., 2011; Fic and Pedersen, 2013; Yang et al., 2015; Boruah and Ganapathi, 2015). Hydraulic fracturing evaluation considering rock brittleness is the first choice technique to achieve economic development of these unconventional reservoirs, since the natural system matrix permeability is very low (Guo et al., 2015; Smart et al., 2014). As a key factor affecting hydraulic fracturing, the brittleness evaluation has always been the focus of research. Characterizing the brittleness index of reservoir rocks will provide insight for the future horizontal drilling programs.

The objectives of this study are to establish the prediction models of brittleness index using conventional logs. Mineralogical analyses of core samples and geochemical properties evaluation are integrated to assess the brittleness index of the Chang 7 (Mmber 7 of Upper Triassic Yanchang Formation) tight shaly sandstones. X-ray Diffraction (XRD) analysis was performed to obtain brittle mineral content. Then the brittleness index in terms of mineral

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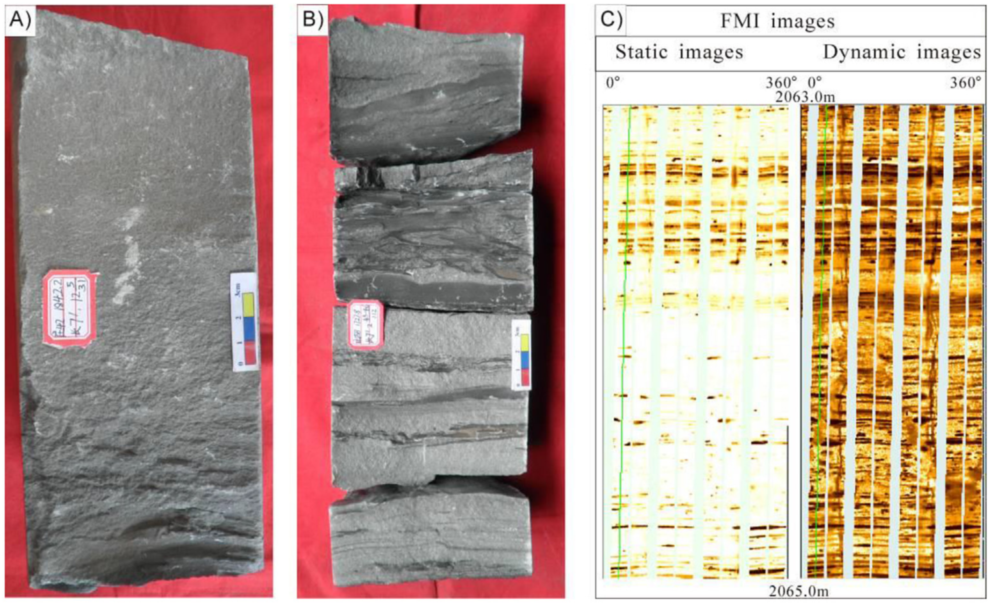


A. Dark-gray fine-grained sandstone, Zhuang 42, 1842.2m;

B. Dark massive mudstones inter-bedded with gray siltstone, Zhuang 42, 1727.7m;

C. FMI images showing the characteristics of shales, Ch96, 2063m.

**Fig. 1.** Core photos and borehole FMI images showing the lithology characteristics of Chang 7 tight shaly sandstones in Ordos basin.

composition and the geomechanical brittleness index derived from the dipole acoustic logs are calculated respectively. Statistical regression analysis was then carried out to establish the models for brittleness index estimation from conventional log suites. A blind test was applied to two wells with dipole acoustic logs in order to evaluate the accuracy of the predictive model of brittleness index, and then the reliability of the brittleness index estimation using conventional log suits is testified by incorporating well test results. The established prediction model may be applied to similar tight shaly sandstone reservoirs in basins around the world and provide access to large untapped oil and gas reservoirs.

## 2. Materials and methods

### *2.1. Overview on the methods of calculating rock brittleness index*

In the last decades, the concept and measurement method of rock brittleness have long been discussed and is not yet made precise (Goktan and Yilmaz, 2005). There is no standardized concept or a measurement method exactly defining or measuring the rock brittleness up to now (Altindag, 2010). Due to the lack of standard definitions and measurement methods (Meng et al., 2014), different experts express and use rock brittleness differently for their respective practical use (Altindag, 2010; Meng et al., 2014). The most acceptable definition of rock brittleness is that rock terminates by fracture at or only slightly beyond the yield stress (Meng et al., 2014). Generally, rock brittleness is used in two different ways by various researchers: one is that a physical measure of rock mechanical strength, and the other is a measure of energy consumption in the process of rock cutting or drilling (Goktan and Yilmaz, 2005).

The brittleness is usually evaluated by brittleness index (Rickman et al., 2008; Sondergeld et al., 2010; Wang et al., 2015a). It is strongly emphasized that the concept of brittleness index adopted in this article is from the point of view of petroleum reservoir rock drilling, with the aim to evaluate whether reservoirs can effectively produce complex fractures during hydraulic fracturing. Brittleness index can be commonly calculated from the XRD mineralogical composition or rock mechanical parameters (Rickman et al., 2008; Sondergeld et al., 2010; Wang et al., 2015a). Young's modulus ($E$) and Poisson's ratio ($\nu$) determine rock brittleness and, therefore, the rock's response to hydraulic fracturing (Rickman et al., 2008; Harris et al., 2011). Rickman et al. (2008) firstly used the Young's modulus and Poisson's ratio to compute the rock brittleness index. A lower Poisson ratio corresponds to a higher Young's modulus and a more brittle rock in which it is easy to generate complex fracture (Wang et al., 2015a). In contrast those with low Young's modulus and high Poisson's ratio are more ductile (Harris et al., 2011). Sondergeld et al. (2010) developed a mineralogical method to calculate the rock brittleness index. In shale reservoirs, the brittle mineralogical composition is key to stimulation whereby a fracture network is created, providing linkage between the wellbore and the microporosity (Jarvie et al., 2007). There is no uniform criterion for brittle minerals (Guo et al., 2015). The quartz, feldspar and carbonate are often treated as brittle components in tight shaly sandstone (Chen and Xiao, 2013; Wang et al., 2015a; Yuan et al., 2015). However, some researchers point out that the quartz and carbonate contents are critical and the relatively high content of brittle minerals is not only favorable for the formation of natural fractures, but also beneficial for well fracturing in production (Wang et al., 2015b). The feldspar minerals are relatively not brittle like quartz and carbonate. Generally, the most brittle rock has the most quartz and carbonate content but least clay content (Wang et al., 2015a). The higher the magnitude of brittleness index, the more brittle is the rock (Goktan and Yilmaz, 2005).

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