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# Brittleness analysis study of shale by analyzing rock properties

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## ABSTRACT

Brittleness of shale gas reservoir rocks is required to be well constrained in terms of fracture initiation and propagation, as well as fracture re-opening. Shale frackability could be evaluated based on geomechanical and mineralogical evaluation for optimal stimulation design. Laboratory characterization of shale properties from Gyeongsang Basin, South Korea and Green River Basin, United States, is conducted to obtain elastic and failure properties such as Young's modulus, Poisson's ratio, tensile strength, and unconfined compressive strength. Furthermore, mineralogical assessments based on brittleness prediction from Rock-Eval and XRD analysis are conducted for geologic factors such as the rock composition, origin and habit of mineral rock components. The brittleness analyses of shale are crucial to design reliable and robust stimulation strategy for shale gas reservoir.

## 1. INTRODUCTION

Brittleness is defined as how well a material breaks when it is deformed by stresses. Brittleness analysis is significant on hydraulic fracturing of shale gas reservoir in order to reduce production cost and improve efficiency of fracture initiation and propagation. Brittleness could be analyzed by geomechanical and mineralogical properties analysis. However, various definitions on brittleness, suggested by researchers, couldn't be applied to all materials in a same way. When it comes to geomechanics, brittleness is not an inherent characteristic, but a behavior of rocks and it means that brittleness could be relative depending on its conditions such as a kind and shape of material and loading (Hetenyi 1966; Cheon et al. 2006). Therefore, it is important to control these conditions constantly when brittleness evaluation is conducted through geomechanical properties.

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There are various methods of analyzing brittleness with rock mechanical and mineralogical properties. One is quantifying it with brittleness index equations, and the other is using correlation between rock properties.

In this study, methodologies of brittleness evaluation are introduced by rock properties and brittleness of shale in Gyeongsang Basin, South Korea and Green River Basin, United States is analyzed and compared by various brittleness analysis methods. Also the correlation between the indices is demonstrated and brittleness is characterized depending on the regions.

## 2. BRITTLENESS ANALYSIS METHODS

### *2.1 Brittleness Analysis by Rock Mechanical properties*

Many researchers including Hucka and Das (1974), Altindag (2003), Rickman et al.(2008) and Holt et al. (2011) suggested several brittleness index(BI) equations and a few of them, broadly used, are introduced in this study.

Eq. (1) is a ratio of uniaxial compressive strength to tensile strength. The difference between two strengths is increased, the rock has brittle behaviors (Hucka and Das 1974).

$$BI_1 = \frac{C_0 - T_0}{C_0 + T_0} \tag{1}$$

Where, $C_0$ is unconfined compressive strength and $T_0$ is tensile strength.

Also, brittleness index could be defined by dynamic Young's modulus and Poisson's ratio from sonic wave velocity data (Rickman et al. 2008). This empirical equation is based on the definition that the rock shows brittle when Young's modulus is high and Poisson's ratio is low (Eq. (2)).

$$BI_2 = \frac{1}{2}\left(\frac{E_{dyn} - 1}{8 - 1} + \frac{\nu_{dyn} - 0.4}{0.15 - 0.4}\right) \tag{2}$$

Where, $E_{dyn}$ is dynamic Young's modulus and $\nu_{dyn}$ is dynamic Poisson's ratio.

Li et al. (2013) demonstrated the relationship between Young's modulus and Poisson's ratio of Barnett shale (Fig. 1). Young's modulus is inversely proportional to Poisson's ratio in this figure, and it corresponds to the fact that brittle rock has high Young's modulus and low Poisson's ratio. The high relationship between dynamic and static Young's modulus also indicates brittleness of rocks (Fig. 2). This study was based on the relationship between dynamic and static modulus of clastic rocks which Yale and Jamieson (1994) and Lacy (1997) studied. Britt and Schoeffler (2009) compared the prospective shales with clastic rocks which is brittle and demonstrated that dynamic Young's modulus of both rocks is directly proportional to static Young's modulus.

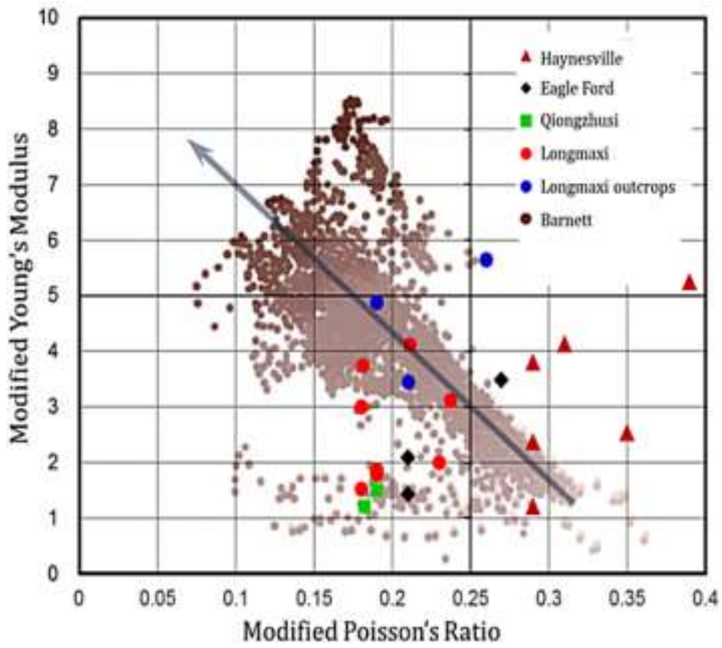


Fig. 1 Relationship between Young's modulus and Poisson's ratio (Li et al. 2013)

*2.2 Brittleness Index Analysis by Mineral rock components*

There is another brittleness index equation by mineral contents of rock. Jarvie et al. (2007) analyzed mineralogy of shale in clay, quartz and calcite and a high portion of quartz, which is stiff mineral, indicates high brittleness. And Wang and Gale (2009) developed the relation by including Total Organic Carbon (TOC) and dolomite (Eq. (3)). It is noted that clay mineral and TOC have a negative effect on brittleness index.

$$BI_m = \frac{Q + Dol + Cc}{Q + Dol + Cc + Cl + TOC} \tag{3}$$

Where, Q is quartz content, Dol is dolomite content, Cc is calcite content, Cl is clay content, and TOC is total organic carbon.

There is another simple way to determine brittleness by only clay mineral content (Fig. 2). If clay mineral component of shale is higher than 35~40%, it shows ductile behavior and it is economically infeasible in shale gas reservoir (Britt and Schoeffler 2009).

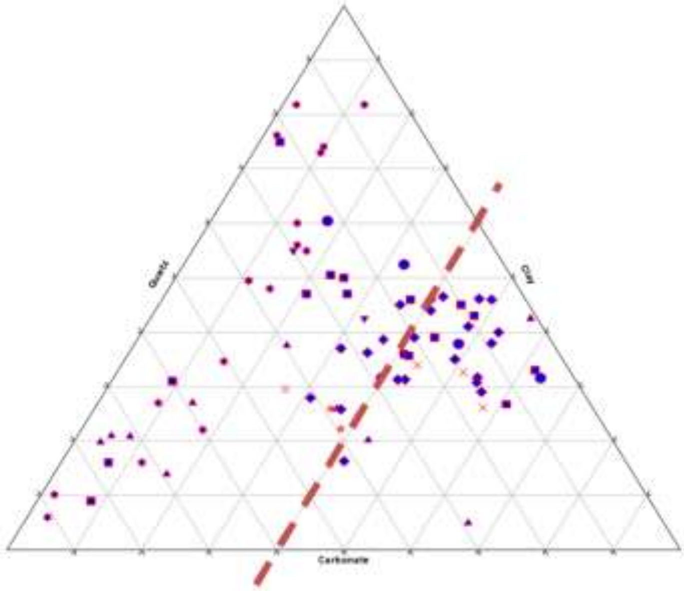

Fig. 2 Ternary diagram of mineralogy of shale in North America (Britt and Schoeffler 2009)

In this study, shale samples are collected from Gyeongsang Basin, South Korea and Green River Basin, United States. And uniaxial compressive test and Brazilian test are conducted to obtain unconfined compressive strength, tensile strength, static Young's modulus and Poisson's ratio. Sonic velocity also measured to obtain dynamic Young's modulus and Poisson's ratio. And mineralogy of those samples is analyzed by Rock-Eval and XRD analysis. With those rock properties, brittleness of the shale in Gyeongsang Basin and Green River Basin is analyzed by brittleness indices and correlation analysis between rock mechanical properties.

## 3. BRITTLENESS ANALYSIS RESULTS

Table 1 is summary of results of brittleness analysis of two different areas. When comparing results of Spot 1 with Spot 3 in Gyeongsang Basin, brittleness indices, $BI_1$ and $BI_2$, by rock mechanical properties are in a similar range and means the shale in two spots have similar mechanical properties. Also, $BI_2$ of shale samples in Spot 1 and Spot 2 are quite different, even though Spot 1 is located next to Spot 2. However, $BI_m$ by mineral components of shale of Spot 1 is comparatively higher than Spot 3. $BI_m$ of Wyoming shale in Green River Basin, United States is much higher than that in Gyeonsang Basin when comparing brittleness index by regions. The shale of Green River Basin looks much brittle than that of Gyeongsang Basin, though the comparable samples are not enough.

If we synthesize the results by brittleness indices, each of them has different indices, even though all samples are located in a same basin and brittleness could not be simply characterized by only one index. For example, Spot 3 is more brittle than Spot 1 by $BI_1$, on the other hand, Spot 1 is more brittle than Spot 3 as mineralogical brittleness index, $BI_m$. It indicates various analyses are required by different rock properties when evaluating brittleness of rocks. Also, the criterion of brittleness index which determines the brittleness of samples isn't established yet due to its diverse definitions. The shale, of which $BI_2$ is below 0.22, in Gyeongsang Basin is not adequate for hydraulic fracturing in the phrase of Rickman et al. (2008).

Table 1. Brittleness index analysis of shale in Gyeongsang Basin and Green River Basin

| Brittleness Index | Gyeongsang Basin, South Korea | | | Green River Basin, United States |
|---|---|---|---|---|
| | Spot 1 | Spot 2 | Spot 3 | |
| $BI_1$ | 0.81 | - | 0.84 | - |
| $BI_2$ | 0.25 | 0.14 | 0.21 | - |
| $BI_m$ | 0.77 | - | 0.51 | 0.93 |

Fig. 3 is illustrated brittleness analyses by the relationships between elastic moduli. As previously explained, high Young's modulus and low Poisson's ratio designate shale brittleness. In case of the shale samples in Gyeongsang Basin, Young's modulus of all spots is inversely proportional to Poisson's ratio. It isn't brittle, however, when determining brittleness of Gyeongsang Basin with all samples in three spots, even though each spots of shale shows brittle. In this case, more samples are required in order to confirm the brittleness of shale.

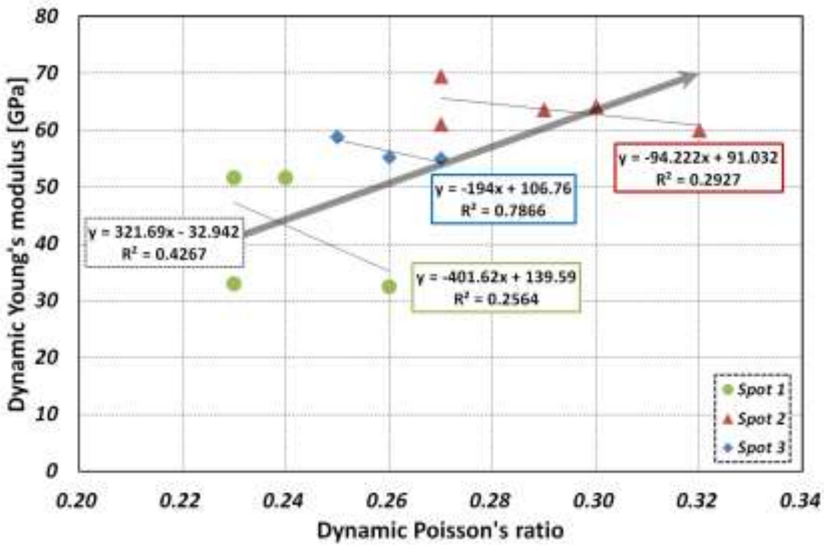


Fig. 3 Correlation between Dynamic Young's modulus and Poisson's ratio of shale in Gyeongsang Basin

This is the result of relationship between dynamic and static Young's modulus (Fig. 4). The shale in Spot 1 doesn't show brittle because there is no positive correlation between dynamic and static Young's modulus. In case of Spot 3, it is covered by the scope of prospective shale (Britt and Schoeffler 2009) and it looks like having a certain relationship. However, it is also not brittle, when it comes to the shale, in Gyeongsang basin because dynamic and static Young's modulus of two spots is inversely proportional to each other.

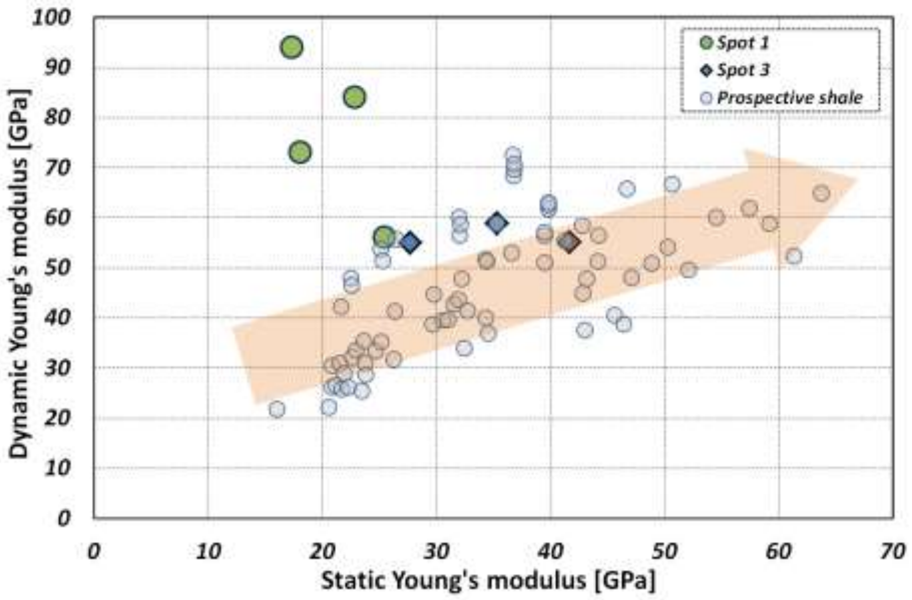


Fig. 4 Correlation between dynamic Young's modulus and static Young's modulus of shale in Gyeongsang Basin and comparison with the shale of Britt and Schoeffler (2009)

## 4. CONCLUSIONS

In this study, brittleness analyses of shale from Gyeongsang Basin, South Korea and Green River Basin, United States are performed by various brittleness analysis methods. By integrating brittleness indices, the shale of three spots in Gyeongsang Basin has similar index each other, which is comparably lower than the shale in Green River Basin, United States. Also, it does not show brittle behavior with the analysis method by correlation between elastic moduli. Hydraulic fracturing simulation by considering these geomechanical and mineralogical properties would be performed in order to simulate the fracture efficiency and verify brittleness we have analyzed.

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