Energy based normalized brittleness index and its relationship with mineralogical composition of shale rock

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The study is focused on mechanical properties of shale rocks involved into hydrocarbon development and interrelations between these properties and rocks’ mineralogical composition. Rocks’ brittleness, which is one of the key factors for problems of hydrocarbon development, is the main focus of the research.

There are many different ways to introduce brittleness index as a factor determining whether a rock is ductile or brittle in terms of its mechanical behavior while being subjected to high external stresses. In the current study we consider an energy-based brittleness index. This index is mostly based on energy balance law. According to this law, the changes in total energy of a rock sample are related to changes in elastic energy, plastic energy, and (for post-peak) rupture energy. Whenever changes in microstructure of the rock appear, it may result into ductile deformation of grains or emergence and development of microcracks. As both processes may be clearly related to changes in mechanical energy, one is capable to distinguish them after analyzing enough data.

In the current study we carried out a series of triaxial loading test on shale rock samples extracted from a particular oil field. We carefully studied the obtained stress-strain curves in terms of energy-based brittleness-index. In order to compare different samples we modified the existing brittleness index definition by introducing its normalization. We proposed two concepts of “ideally ductile rock” and “ideally brittle rock” as examples of hypothetical rocks distinguished by their inelastic behavior. The introduced “ideally brittle rock” is a rock which shows perfectly elastic behavior similar to behavior of the considered sample until the stresses achieve a certain maximum when one major fracture emerges leading to brittle failure of the sample. On the contrary, “ideally ductile rock” is characterized by infinite plastic deformation without any fractures emergence. These concepts were used to establish a mathematical definition for mechanical behavior of rock samples subjected to triaxial loading in terms of brittleness. As a result, brittleness index was strictly normalized so that brittleness index of zero was related to “ideally ductile rock” and brittleness index of one was related to “ideally brittle rock”.

Such normalization made it possible to compare the studied samples. Approximately thirty samples extracted from a particular wellbore from a depth interval of fifty meters were analyzed in terms of brittleness. At the same time, borehole and core data regarding mineral composition were studied. All the samples were divided into three groups characterized by low, average and high brittleness. According to obtained results, ductile behavior is positively connected with clay minerals content and presence of kerogen. The most brittle rocks have small amount of clay and organic material, and high values of quartz-feldspar-mica and carbonate minerals. It was also clear just from the sight of the samples, that higher value of brittleness reveal more fractures after failure. Samples with low brittleness have smaller and discrete fractures.
We believe that the obtained results on shale rock samples alongside with the approach to normalize brittleness index following the basic laws of solid mechanics will make it possible to deepen the understanding of relationship between rock mechanical properties and mineralogical composition. It

should also be noted that precise information about brittleness profile along the wellbore will significantly increase the efficiency of multi-stage hydraulic fracturing in unconventional shale reservoirs, especially in horizontal wells.

Keywords: Brittleness index, Shale formation, Mineralogy