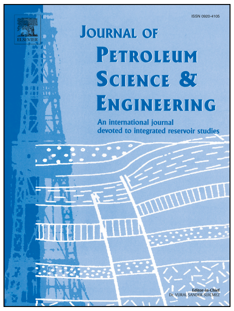

Shale brittleness evaluation based on energy balance analysis of stress-strain curves

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Abstract

Brittleness is a key mechanical characteristic of rock and critical to various engineering practices particularly to design efficient fracturing stimulation of unconventional shale gas reservoirs. Variety of brittleness definitions and evaluation criteria have been proposed to describe rock failure behavior; however, their suitability and reliability have yet to be verified. In this paper, the existing brittleness indices were reviewed in detail and their applicability to reflect rock brittle characteristics were then investigated. The analysis indicated that most of expressions cannot describe brittle failure characteristics of rock efficiently and either partially or thoroughly fail to correctly address the impact of stress state on rock brittleness. Therefore, a new brittleness evaluation method was proposed based on promising energy transformation analysis of the complete stress-strain behavior of rock under compression. The new criterion is capable of dealing with the plastic energy dissipation mechanisms in the pre-peak region and the extent and rate to which rock strength degrades during macroscopic fracturing in the post-peak stage. Besides, the proposed brittleness index describes the entire transition of rock failure behavior of class I, from completely plastic to absolutely brittle states, in a continuous scale corresponding to 0 to 1. The applicability and outperformance of the proposed brittleness index were then verified against uniaxial and triaxial compression test results of some carbonaceous lithofacies from the Garau shale gas play within the Lurestan Basin, Iran. Samples under compression revealed various deformation and failure characteristics transitioned from brittle to semi-brittle behaviors with increasing confining pressure. Application of the brittleness indices to the tested rock specimens clearly demonstrated that the developed energy-based expression is able to rigorously capture the relative brittleness sequences of lithofacies and evolution trends under application of confinement, whereas further proved lack of either sufficient physical basis or appropriate formulation strategy in the existing indices. Accordingly, the new evaluation method seems to