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Zonation of shale reservoir stimulation modes: a conceptual model based on hydraulic fracturing data from the Baltic Basin (Poland).

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Depending on the pressure distribution within Stimulated Reservoir Volume (SRV), a different modes of hydraulic fracturing or tectonic fracture reactivation are active. Hydraulic pressure-driven shortening or expansion of reservoir produces changes in stress field that results in decrease of differential stress either by increasing of horizontal stress minimum (Shmin) or/and by decreasing of horizontal stress maximum (SHmax). For further considerations we assume initial strike-slip stress regime which prevails in the Polish part of the Lower Paleozoic Baltic Basin (BB), as well as in majority of the USA shale basins. The data come from vertical and horizontal shale gas exploration wells drilled from one pad located in the middle of the BB. Structural survey of a long core interval combined with stress analysis based on microfrac tests and fracturing tests allow to reconstruct the initial structural and geomechanical state of reservoir. Further geomechanical evolution of the SRV depends on the hydraulic pressure bubble growth, which is in general unknown. However, the state of pressure can be determined close to the injection borehole and in the front of the SRV migrating in time.

In our case, we are able to distinguish four stimulation zones characterized by increasingly diverse stimulation modes and successively closer to the borehole injection zone: (1) shear on preexisting fractures generates microseismic events that produce open fractures propped by their natural asperities being impenetrable for proppant grains; (2) above + initial hydraulic opening of natural fractures that are preferentially oriented to the Shmin, which favors microseismic events triggered by secondary shear on bedding planes and produces open spaces supported by natural fracture asperities and fine-grained proppant; (3) above + failure of primary hydraulic fractures, which increases extensional component of the microseismic events and opens space for coarse-grained proppant; (4) above + opening of horizontal bedding fractures, that do not prevail any microseismic mechanism, stabilizes the stresses at the level close to the thrust fault regime and opens space for large amount of proppant. This stimulation mode is undesirable because horizontal bedding fractures do not drain shale matrix efficiently due to low vertical permeability of shale and sealing of bedding planes by high clay content that enhances embedment effect on proppant.

The number and order of stimulation zones is site- or basin-specific and may not apply directly to other locations. In the case of strong mechanical layering the stimulation mode can also vary among formations. Large number of preferentially oriented natural fractures (like in majority of boreholes in the BB), may cause the technological hydraulic fractures to play a subordinate role. Because in the BB tectonic fractures are filled with calcite, it may negatively influence gas drainage to stimulated fractures. In our scenario, also the primary shear failure mode is not achieved due to low differential stress in respect to compressive strength of shale. The shape of stimulation zones might not be regular but adjusted to the pattern of stimulated fractures creating principal pathways for hydraulic pressure propagation into reservoir. Bearing in mind the sequence of stimulation mode zones we are able to better understand the pattern of microseismic events and predict, to some extend, the proppant distribution within SRV.