# Smooth velocity models for monitoring of hydraulic fracturing experiments

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**ABSTRACT**

In oil and gas production, hydraulic fracturing is often used to increase the productivity of hydrocarbon reservoirs. Hydraulic fracturing involves pumping various types of fluids under pressure down a treatment well into the reservoir. The pressurized fluid enters the reservoir and fractures the reservoir rock. These fractures increase permeability and conductivity, and ultimately production. Creation of fractures and opening of pre-existing fractures generates microseismic events observed by geophones located in a monitoring borehole. The fracture geometry is then determined from locations of these events.

For the location of the microseismic events, a velocity model is one of the key inputs. All available data such as sonic logs, VSP traveltimes, crosswell or refraction measurements should be used to create the velocity model. The velocity model should not be too complicated to avoid multipathing, as we are usually unable to identify multiple arrivals for individual microseismic events and to include the multiple arrivals into the location procedure.

Layered 1-D velocity models composed of a set of homogeneous layers are broadly used in the geophysical community. If we use ray tracing as a forward modeling tool of our location procedure, layered models are a source of possible complications. The interfaces between the layers cause reflections and conversions of calculated seismic waves, and we thus need to specify precisely all the elementary waves which should be calculated. The layered models thus provide us with multivalued arrivals. Moreover, the thicknesses of the layers are usually comparable with the wavelengths of the calculated seismic waves, and the layered models are thus behind the limits of the validity of the ray method.

Homogeneous models are the simplest option. They provide single arrival, and there are no problems with the validity of the ray method. As the fractured rocks are usually sedimentary formations, homogeneous models are usually acceptable approximation of the horizontal properties of the structure, and they provide good estimation of the horizontal positions of the located microseismic events. For the vertical positioning of the events, the homogeneous models are usually insufficient.

Smooth velocity models appear to be optimal for the microseismic locations. If we apply the proper smoothing procedure, the models are suitable for ray tracing and provide singlevalued ray field. The velocity model should be obtained by simultaneous inversion of all available data, e.g., of sonic logs and VSP, crosswell, or refraction measurements, and the inversion should be restricted by minimizing simultaneously the Sobolev norm composed of the second velocity derivatives in the model. The resulting locations of the events using the smooth velocity model are better positioned in the depth compared to the locations in the homogeneous model.

**Key words:** ray method, velocity models, microseismic locations, induced seismicity, hydraulic fracturing

## PRESENTER'S BIOGRAPHY

Petr Bulant was born December 7, 1970, in Prague, Czech Republic. He obtained his master degree from Charles University in Prague, 1994, in Geophysics, with diploma thesis on Two-point Ray Tracing in 3-D. He then obtained his PhD degree from Charles University in Prague, 1997, in Geophysics, with PhD thesis on Calculation of Multivalued Ray Theory Travel Times in 3-D Structures. Since 1997 he works as Research geophysicist at the Department of Geophysics, Faculty of Mathematics and Physics, Charles University in Prague. Areas of his research interests are: seismic wave propagation, computational seismology and theoretical geophysics, numerical modeling of seismic wavefields and their properties, especially construction of velocity models suitable for ray tracing, two-point ray tracing and travel time calculation, wavefront tracing, weak anisotropy.