The triggering of the tectonic earthquakes by underground and open pit mining

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The phenomenological model of the earthquakes (M > 3) triggering by mining operations have been formulated. The basic items of this model can be formulated as follows:

1. The main reasons for triggering of dynamic fault slips by mining operations are:

- a quasi-static alteration of the stress pattern as a result of excavation and displacement of rock mass,
- a change of the effective stiffness of the enclosing rock massif as a result of tunnelling,
- a change of hydrogeological regime of the fault zones,
- accumulation of small deformations localized at discontinuities in stressed fault zones.

2. The following geomechanical criteria should be satisfied for a fault dynamic slip to occur:

(i) Shear stresses in a local fault segment should reach a level close to the current value of strength (it is true for active faults in most cases).

(ii) The conditions of velocity weakening when sliding along the fault must be realized.

(iii) A certain ratio of the rock stiffness to the fault stiffness should be satisfied.

3. For a triggering of the earthquake of a certain magnitude it is necessary to change the stress level or the material properties in the fault segment, at least several times bigger than the area of nucleation zone of the future earthquake. If the stress-strain conditions change at a relatively big area as a result of mining, then a positive variation of the Coulombś function by a value of some tenth of MPa may turn to be enough for triggering an earthquake.

4. The underground development of mineral deposits can change the effective elastic properties of the intact rock massif in the vicinity of an active fault. So, a rather big earthquake can take place even in a previously aseismic region.

5. Open pit mining in most cases has no effect neither on the mechanical properties of the massif at the hypocenter depth, nor on fault stiffness. Excavation and displacement of rock in open mining in aseismic or weakly seismic regions cannot be the reason of large tectonic earthquakes.

In seismically active regions development of large quarries can essentially advance the time of the earthquake.

6. The anthropogenic effect can in principle both trigger seismic events and lower the level of seismic hazard. The magnitudes of events sensitive to the anthropogenic effect are limited and, according to expert judgment can hardly exceed the magnitudes of M $\sim$ 6-6.5.

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