Common features in the manifestation of natural and induced geodynamic events in the eastern regions of Russia and China

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Abstract. The study of geodynamic processes observed in the Earth's crust at densely populated and commercially developed areas in the east of Russia and China is of great importance for their sustainable development. The research results available show that not only natural, but also man-made geodynamic events associated with mining operations reflect the global geodynamic processes. Geodynamic events that occurred while mining in impact-hazardous areas allowed to identify some common features in the manifestation of natural and man-made geodynamic events in the eastern regions of Russia and China. Thus, both natural and disastrous technogenic geodynamic events (tectonic rock bursts, induced earthquakes, cracking on the earth's surface) have positional connection with the linear zones of earth's crust modern destruction (block boundaries and faults). Existing tectonic faults get re-activated during major geodynamic events, i.e. they get displaced in response to the mining operations. Areas hazardous for manifestation of geodynamic phenomena can be defined by geodynamic zoning method which can be used to draft the development programs for the eastern regions of Russia and China

Keywords: geodynamic event, rock burst, earthquake, induced earthquake, crust fractures, blocks of the earth's crust, stress condition, fault reactivation

1. Introduction
Due to the intensive development of mineral resources and territories in the Far East and Sakhalin Island in Russia as well as in the east of China, the problem of both natural and induced seismicity is becoming increasingly relevant and attract the attention of earth science experts [1-14]. Scientists revealed that not only natural, but also technology-related geodynamic events observed on this territory reflect the global geodynamic process proceeding throughout this vast region, including the territories of Russia, Japan and China [11-16]. Accordingly, studying technogenic geodynamic events at Chinese and Russian mine fields can be useful in identifying common features of their manifestation and for drafting plans of risk free development of these regions.
2. Geodynamic zoning method

Strong rock bursts and spontaneous outbursts are known to occur at hazardous sites not everywhere, but only in certain areas, which often constitute about a third of the entire area under development. For early detection of such burst-prone areas geodynamic zoning method was developed in Russia [13]. Geodynamic zoning studies at rock burst-prone mine fields include identifying the block structure of the earth's crust, accounting for the hierarchy of blocks and their dynamic interaction, assessing the stress condition of the rock and identifying geodynamically unsafe zones. It has been established that rock bursts and tectonic rock bursts often occur at the boundaries of the earth's crust blocks. From this point of view the latter represent one of the types of geodynamically hazardous zones. Tectonic rock bursts and induced earthquakes are viewed upon as part of the tectonic process going on in the earth's crust [14]. The idea that global and local geodynamic processes are interrelated, whereupon the geodynamic zoning method is based, is finding convincing evidence and the acknowledgement of this fact is recognized as one of the major scientific achievements of the late 20th century [15]. Various dangers during the development of the subsoil may be associated with geodynamic state of the massif [16-21]. Below are some of the findings of the studies on geodynamic zoning at rock burst-prone coal deposits and the description of common characteristics in the manifestation of natural and induced geodynamic events recorded in the eastern regions of Russia and China.

3. Geodynamic events associated with mining

3.1 Geodynamic events at Huafen mine

The Huafen mine is located in Shandong province in eastern China. This mine is one of the deepest and most rock burst hazardous mines in China. In the process of mining strong rock bursts and abnormal changes on the earth's surface were observed here. 6.0m thick coal seam No. 4 of Permian age dipping northeast at 32° was mined at a depth of about 1,200m. The deeper mining operations advanced, the stronger was the adverse effect of mining on the environment. It was manifested in the formation of sinkholes and extended cracks on the earth's surface, recurrent seismic events brought about by forceful rock bursts. Thus, up to 1m wide and up to 700m long crack appeared on the surface between May and December 2010, that was crossing agricultural land, settlements, engineering structures and water courses. There are several major rock bursts every month with seismic energy up to M = 1-2, that are manifested on the surface as earthquakes with an intensity of up to 5 on the MSK-64 scale. Whereas the rock burst manifestation build up might be explained by increase in the depth of mining, the appearance of ever larger surface cracks looks abnormal. Indeed, with increasing depth of mining deformations of the earth's surface get usually less intensive, not vice versa, as is the case at this mine [24].

3.1.1 Global and regional geodynamic position of the Huafen mine field. Figure 1 shows the 2nd rank block structure of the territory of China (as per terminology from [13]). As can be seen in figure 1 the Huafen mine field is located in the zone affected by two global faults: the Tan-Lou fault and the Kunlun fault. Moreover, this mine is in the area influenced by the 35th north latitude parallel, which is considered critical because it is associated with a change in the linear velocity of the Earth's rotation.

The Tan-Lou fault is part of the system of abyssal fractures, its width varies between tens and up to 200 km, it stretches for over 2,400 km in China and strikes at 10-200. At present, the Tang-Lou fault has a horizontal sliding speed of about 2.3 mm/year. It is traced in the eastern part of China passing through Heilongjiang Province towards Russia; it is the largest seismically active sinistral dislocation fault at the eastern rim of Asia. This fault zone has also been studied in Russia and is referred to geodynamically active faults [3]. According to both historical and modern data 17 strong earthquakes with a magnitude M 6 to 8.5 has been recorded within the 200-kilometer zone around the Tan-Lou fault axis since the year 1400 AD. Xu Jiawei studied the Tan-Lou fault and supposes that its amplitude is up to 740km. In his opinion this fault may stretch further towards the south of China [22].
Figure 1. China's geodynamic zoning map (according to I.M. Batugina) [10]: 1 - 1st rank block borders; 2 - Tan-Lou fault; 3 - Kunlun fault; 4 - the Huafen mine.

The geodynamic zoning results show that the Tan-Lou fault exceeds by far the size estimated according to geological data; it continues further to the south of China (fragment BC in figure 1).

The Kunlun fault zone is traced from the southern foot of the Kunlun Range; it is the active fault zone of the northern part of the Tibet block [23]. More than 16 earthquakes with magnitude higher than 6, some events had magnitude about 8, were recorded in this area over the past 100 years. This zone consists of several reverse-shear faults and has an azimuth strike of 280^0-300^0 and stretches for over 2,000km (figure 1). According to geological data, this fault has a sinistral-shift displacement. On the map of rank I geodynamic zoning the Kunlun fault is confined by the boundaries of similarly oriented blocks. The Huafen mine site is close to ending of this fault.

The Kunlun fault coincides with the area influenced by the critical 35th north latitude parallel. According to the model of the internal structure of the Earth, its individual layers from the core to the upper mantle and the crust have different densities. The angular velocity of Earth rotation remains constant whereas the linear velocity is different, its maximum value is at the equator. The shearing forces of the polar part of the Earth relative to its central part appear in places where the density graph exhibit maximum curvature. Such maximum curvature corresponds to approximately the 35th parallel. According to G.N. Katterfeld and M.V. Stovas, this latitude corresponds to turning points and disorientation of air currents. The highest seismicity and impact hazard of the deposits is also confined to this maximum curvature (I.M. Batugina). Tangential stress arise due to uneven density of the rotating masses in the Earth's crust and such stress can reveal itself in the form of large-scale faults on the continents.

The Tan-Lou global fault zone passes through the central part of Shandong Province and divides it into two parts (blocks), known as Ludong and Lucie. In the relatively elevated Lucie block, normal faults are developed. They have a north-west strike at 290^0 to 330^0 and between 60^0 and 80^0 dip. One of
these faults, the Mengshan Fault, is traced along the southern foot of the Menshansky Range, its length and width being 170 km and 40 km respectively.

The Xingwen deposit is located in the Wenmen surface depressions in the central part of the elevated Lucie block. The Xingwen coal basin is divided by the Mengshan fault and the Yanlu fault into three parts. The Huafen mine is located in the western edge of the field and its location is limited by three faults: the Mengshan fault, the Nangguchen fault and the Qiao fault.

In the east, the mine site adjoins the Nangguchen sinistral-shear fault that pushed the coal strata to the north by approximately 1,500m. The vertical amplitude of the Nangguchen fault is over 500m.

3.1.2 The nature of the abnormal behaviour of geodynamic processes at the mine. The Huafen mine field is located at the critical 35° latitude in the area where the Tan-Lou fault and the Kunlun fault intersect. We interpret this as the key affecting global factor. Under the influence of this global factor some areas of the Earth's crust can become critically stressed which creates the conditions for the development of adverse geodynamic processes [10].

Figure 2 shows the block structure of the mine area. As is evident, the mine field is located in one of the 2nd rank blocks. The border of blocks 1-1, with 300° to 310° strike azimuth runs in the north of the mine field. This boundary is traced in the relief towards the southeast off the mine field and it joins the Mengshan Fault. The tectonic sketch map of the field shows this fault as conclusively established to the south-east of the mine field, whereas further to the north-west, towards the mine site, it is shown as a probable feature.

The field study has led us to conclusion that the border of blocks 1-1 (figure 2) is made of a system of steeply dipping fractures. As mining operations approached the border of blocks 1-1, the size of those fissures increased: one of the fissures that appeared in 2006, had a total length of about 100m while in 2008 it was already 300m long, in 2010 – 700m and in 2011 – its length was over 1km.

3.2. Geodynamic events at Beipiao deposit

From the data published it is known that the mine field of the Tai Di mine at the Beipiao deposit is located on the border of the 1st rank blocks, which in fact is a sinistral-shift displacement. In the event of tectonic rock bursts, tectonic displacements got reactivated. Sinistral-shift displacements occurred during strong rock bursts along the faults that are parallel to the border of the 1st rank blocks, whereas dextral-shift displacements occurred along the skewed faults. It is concluded that the movements of the wings of disturbances in strong rock bursts are controlled by a regional stress field [14, 24].

3.3. Technogenic seismicity in the Kemerovo region

The Tashtagol deposit, one of the most rock burst hazardous in Russia, is being developed in the Kemerovo region. It was here that experiments were carried out to measure stresses in the rock massif for the first time in Russia and it was established that horizontal forces exceed vertical ones [25]. It was established according to the geodynamic zoning data that the deposit is located between two fragments of the emerging North-Tashtagol fault, which explains its high rock burst hazard. One of the strong rock bursts here was the event of 1986 when there was a shift along reactivated tectonic fault causing rails
disconnection. The authors’ conclusion [13] was that the fault orientation and the direction of displacement was affected by the boundary of the Eurasian and Indian lithospheric plates.

In the last decade, technogenic seismicity has also been observed at the coal deposits in the Kemerovo region [25, 26]. The Bachatsky event (M=6.1) is considered to be the most disastrous induced earthquake which occurred beneath the Bachatsky open pit with a hypocenter depth of about 4 to 10km. The tectonic structure of the area, the results of geodynamic zoning of Kuzbass, data on stress fields allow us to conclude that a large tectonic fault located in the area of the coal pit [24] got reactivated in that earthquake.

4. Discussion
Seismologic studies conducted in the Far East in the vicinity of Sakhalin Island show the connection between seismically active areas and active faults of the earth's crust [28]. Both large faults, such as the Tan-Lou fault, and relatively small ones are considered unsafe. For example, the Upper-Piltun fault that is categorised as a minor regional fault connecting Hokkaido-Sakhalin and Mid-Sakhalin major faults, got reactivated in severe Neftegorsky earthquake on Sakhalin Island.

Reactivation of faults is also a characteristic feature of geodynamic phenomena occurring during mining operations. The activisation of the process of cracks formation on the earth's surface at the Huafeng mine is connected, in our opinion, with the motion of mining operations to the border of blocks 1-1, figure 2. Under the influence of mining operations, the border of blocks 1-1 is involved in the process of subsidence and along it moves the blocks earth's crust [10, 29]. It can be said that geodynamic processes at this mine proceed more intensively at the boundaries of the blocks of the earth's crust. The same can be seen in the examples of the Beipiao field and the fields of the Kemerovo region. The rock burst hazard at the Tashtagol, Beipiao, Bachat deposits, on base of geodynamic-zoning investigation, is due to their locations to the border of large blocks of the earth's crust. Here walls of the faults get displaced during strong rock burst and man-made earthquakes by the action of the regional stress field. Apparently, the interaction of global and local geodynamic processes can trigger the onset of geodynamic events the hierarchical level of which exceeds the degree of anthropogenic intervention.

5. Conclusions
There are evidently some common features in the manifestation of natural and induced geodynamic events in this region:

Both natural and strong technogenic geodynamic events (tectonic rock bursts, induced earthquakes, cracking on the earth's surface) have positional connection with linear zones of current earth's crust destruction (block boundaries and faults).

The existing tectonic faults get reactivated during major geodynamic events, i.e. they get displaced by the action of the regional stress field.

Hazardous areas, i.e. zones prone to geodynamic events can be detected by geodynamic zoning method, which can be used to justify measures aimed at the development of the eastern regions of Russia and China.

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