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Geotribometamorphism in seismic zones of the Earth’s crust

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Геотрибометаморфизъм в сеизмичните зони на Земната кора

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Abstract. Geotribometamorphism means a process of destructive-constructive changes of the rocks in the seismotectonic zones in the Earth’s crust. Due to the friction between rock blocks and layers, kinetic energy is generated, which deforms and destroys the rocks until mylonitization and melting in an environment of high temperature and pressure. Subsequently, the disintegrated material recrystallized into new high-pressure rocks such as eclogites, garnet lherzolites, phengite and kyanite schists and calciphyres. These rocks mark paleoseismic zones and events that occurred during the Precambrian and Phanerozoic.

Keywords: geotribometamorphism, seismotectonic zones, friction, eclogitization.

Introduction

The earthquakes are constant events in the past and present geologic life of the planet. About 500 000 seismological events occur annually. Each seismic event represents friction between rock blocks or layers, causing a generation of energy in the friction zone and propagation of seismic waves. The destructions of the relief and anthropogenic constructions on the surface are only an energetic echo of the processes in the hypocenter of earthquakes, where the rocks undergo various deformation and substance changes, denoted as geotribometamorphism. They depend on the strength of the energy impulse and of the rock`s rheological properties. However, they remain unknown, until millions of years later, thanks to uplift and erosion, paleoseismic zones are outcropped on the surface. The old Precambrian metamorphic complexes provide an opportunity to establish and study rock changes in the hypocenter of the paleoseismic events.

Geotribometamorphic zones

The geotribological or tectonoseismic zones in the Earth`s crust are zones of friction, which in their formation and development follow the principles of tribology. Friction manifests itself in three main forms: a) sliding; b) rotation and rolling; c) impact and pressing; d) subduction zone.

a) Sliding occurs when two bodies moving relative to a common contact surface and the driving forces are parallel. The contact surfaces of the bodies are rough in all dimensions, due to numerous unevenly distributed protrusions and depressions called asperities. Therefore, the bodies touch only in some protrusions. The occurrence and location of geotribological zones depend on the stresses in some part of the crust and on the deformation reaction of the rocks. According to this, block and interlayer geotribozones are distinguished. The block fault structures are normal fault, reverse fault, oblique fault or strike-slip fault, transform fault, horst, graben. Interlayer

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geotribozones are formed along lithological contacts between different rock layers that usually occupy flanks of fold structures: anticlins and synclins or the sliding surfaces of the thrusts.

b) Rotation and rolling structures have diverse configuration. The contact can be a point, line or circular surface and the driving forces are parallel or perpendicular to the contact surface.

c) Impact and pressing differ in the duration of the contact – instantaneous in the impact and long-term in the pressing, but the forces are perpendicular to the contact surface. Here are meteorite- and suture-structures.

d) Subduction zone. The subduction zone is a megageotribological and tectonoseismic structure, often of a planetary nature. It is formed at convergent contacts between tectonic plates, sliding in oncoming motion and the heavier one collides and sinks under the other. Three types are distinguished: i. oceanic–oceanic; ii. continental-continental and iii. oceanic– continental subduction.

Movement in the geotribological zone

The movement is a major factor in the creation and development of a geotribological zone. The geotribological zone exists only during periods of movement of the bodies – in rest it is a simple tectonic zone. When the movement begins, friction between them generates energy, produces seismic waves and the tectonic zone becomes a seismic or geotribological one.

The initial drive moment is a stage of a *preliminary displacement*. This is the period after application of a tangential force and before beginning of the macroscopic (visible) movement of a body. During this period, the frictional contact undergoes various changes: micromovements take place, the asperities are broken, and energy is accumulated and compacted, which is reflected in an increase in the coefficient of friction (COF). When the accumulated energy grows sufficiently and the magnitude of the tangential force exceeds that of the static force, the actual sliding of the body begins suddenly “with a jump”. This is a strong energy pulse of a sudden release of the accumulated energy, causing severe deformation damage of the geotribological system, which is especially clearly illustrated in earthquakes. The onset of body motion as an important aspect of friction has been the subject of special studies (e.g. Rubinstein et al., 2004) which are a starting point towards a deeper understanding of the processes preceding earthquakes (Tullis, 2015).

The *stick-slip phenomenon* is a physical characteristic that expresses the discontinuity of motion. The modern physical studies of the bodies motion establish that it is always discontinuous, even though it apparently in macro terms appears smooth and constant (Byerlee, 1970). The stick-slip phenomenon is the spontaneous jerking motion that can occur while two objects are sliding over each other. Each stick-slip pulse includes the stage of preliminary displacement and the moment of motion initiation.

Deformation and contact geometry. Distribution of forces and energy

The deformation of bodies is the visualized energy of the motion, which causes a contact interaction. The friction energy changes the thermodynamic situation and performs work. The type and intensity of deformation depend on the intensity of the energy impact, rheological characteristics of the bodies and environmental conditions. The deformations can be considered as external and internal.

- *External deformations* are expressed in changes in the shape and volume of the body following Hooke’s law and Young’s modulus. Bodies react to energy impact in three ways: a. elastic – there is no visible change in the appearance of the body or there is a quick recovery of its shape in case of a possible short-term one; b. plastic – the body changes its volume and shape but retains its integrity; c. destructive – the body disintegrates into fragments, sand, mylonite or melt.
- *Internal deformations* are manifested in damage to the crystal structure of minerals. Under the energy impact, the particles begin to vibrate more intensively, increasing their amplitude and at critical values to break crystal chemical bonds and become migrating atoms. Crystal lattice defects such as vacancies, dislocations and bulk voids appear. External deformations are caused by internal changes in the crystal lattice.

Rheological properties of the rocks in the geotribological zone affect deformation. Harder and stronger rock or mineral pieces scratch, gouge and press the softer ones, contributing to their deformation and disintegration. Also of essential importance is the contact geometry of the bodies, which affects the distribution of forces in the area (Assenova, Kozhoukharova, 2022).

During impact and pressing friction, the reaction forces have opposite directions and the damage of the bodies is much more pronounced than in sliding bodies of the same mass. A typical example of a mega-scale impact is the fall of a meteor on the Earth’s surface, forming a huge crater surrounded by concentric circles of hills, resembling frozen waves. The energy of the impact penetrates deep below the surface, the rocks undergo complete disintegration leading to melting and vaporization, spherical body waves change the relief.

Pressure friction and interaction are similar to impact. The two rock bodies are in opposite motion and the driving forces are mutually perpendicular, but the contact of the bodies is long-term, and usually covers a wide area. The touch of the bodies is continuous, and the contact spot is extensive and corresponds to the surface of the bodies. Convergent contact, with uneven pressure between the plates, sometimes forms a deformation arc. A clear one is well expressed on the geographical maps between the Pacific Nazca Plate subducting under the Chilean Andes. Similar deformation arcs expressed on the relief are observed in several regions along the Alpo-Himalayan system.

Thermodynamic development of the geotribological zone

The Earth's crust is in continuous movement, change and renewal. Individual sections of it, for some time interval can be in tectonic rest. Then the substance processes are controlled by the geothermal gradient and the confine pressure, as for the metamorphic complexes, Escola's facies scheme is valid. This is the thermodynamic system of the environment where physicochemical equilibrium is achieved. The occurrence of a seismic event forms a zone of friction, in which a new thermodynamic system is established. The seismic energy causes rapid, even instantaneous, extreme increase in temperature and pressure, disintegration and melt of the rocks. The secondary thermodynamic system is short-lived, closed in the space of the geotribological zone. It is submerged in the great environmental system and is not in equilibrium with it.

The geotribometamorphism in the friction zones

Three stages of development of processes are distinguished along the geotribozones: destruction, culmination of activity and crystallization (Kozhoukharova, 2016).

The first stage of destruction starts with elastic and plastic deformation followed by brecciation, cataclasis and mylonitization. Point, linear and planar defects emerge in the mineral lattice. The inner dislocations and translation of the crystal structure lead to fracture and fragmentation of minerals. In an advanced stage of deformation, the crystal chemical bonds are torn to complete decomposition of minerals, reaching to molecular and atomic level up to exoemission of ions and electrons and melt formation.

At the second stage of maximal activity of geotriboprocesses, specific thermodynamic conditions in the tribozone are established. The kinetic energy, delivered from tectonic movements, transforms to thermal one. The internal energy, entropy and enthalpy increase. Due to all tribochemical processes the temperature, pressure and chemical activity of components increase considerably. It is possible for a brief moment to get to temperature "explosion" of more than 1000° C.

At the third stage the melts crystallize in a new HTP mineral assemblage, sometimes containing microdiamonds and coesite. In the shallow levels of the Earth's crust, due to rapid cooling of the melts, glassy pseudotachylites may occur but in deeper levels the new rocks would show a granoblastic structure. The velocity of growth is much lower than that of melting. Temperature and pressure begin to decrease with a speed dependent on the depth level of the tribozone, although in any case much slower than the rapid flash increase during the first stage. Seismic waves near the friction zone can have a destructive effect on minerals with weak bonds such as antigorite.

Geotribometamorphism and eclogitization

Understanding geotribometamorphism enables us to find a more convincing solution to the genesis of eclogitization, an important problem of metamorphic petrology. Eclogitization in sensu lato is a process of recrystallization of minerals at high temperature and pressure, a typical product of which are eclogites. The eclogitization can develop in various petrographic rocks that have fallen into a geotribological zone. Geotribometamorphic products are also garnet lherzolites formed on serpentinites, phengite-bearing and kyanite schists, calciferous skarns. They are heterofacial to these of the country rocks.

Conclusion

Geotribometamorphism develops in the seismic zones of the Earth's crust. At the hypocenter of the event, the generated kinetic energy destroys and melts the rocks. The disintegrated material subsequently recrystallizes into eclogite rocks, which mark paleoseismic zones.

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