Structural forms, paragenesis and tectonopagation of exozone

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Abstract. Based on a field study of structural forms, formational, comparative geological, morphotectonic, and structural paragenetic analyzes and generalization of materials available in publications, a systematic analysis was made of the structural features of material complexes for the upper section of the unshared crust exozone. The results obtained made it possible to distinguish typomorphic structural paragenesis, which are exozonal. In the accepted genetic systematics, three groups of structural forms are distinguished: exogenous, endogenous, and cosmogenic, which are divided into nine subgroups. The forms of exogenous or non-tectonic origin, which to a large extent are formed as a result of the activity of underground and surface waters, or in connection with the economic activities of humans, are predominantly developed. Structural forms of endogenous and cosmogenic origin are observed in a subordinate amount within the exozone.

1. Introduction

At the end of XX – beginning of XXI century widely developed studies with the use of tectonofacial analysis, which is based on the main principles of formational and structural-paragenetic study the internal structure of the folded complexes of Phanerozoic Kazakhstan [1], and later of the Altai, the Urals, Yakutia, Mongolia and some other areas [2].

When developing the method of E I Patalakha [1] preceded from the basic provisions of the existence of a vertical cut in the earth's crust three zones – epizone, mesozone and catazone which are characterized by various thermodynamic parameters. This approach provided an improvement of the traditional structural-paragenetic analysis technique by considering specific parageneses in connection with the conditions of their formation.

Practical use of a method of the tektonofatsialny analysis, in particular when studying geology of a number of areas of the Baikal region allowed [3] to establish a significant difference between the structural forms of the upper part of the episodes from its typomorphic structures described in E I Patalakhi [1] works and then and V A Viginsky and V I Gromin [4] which detailed a technique of the tektonofatsialny analysis for an epizone. The obtained new data allowed allocating the top part of an epizone in independent division of a vertical section of continental crust – to an ekzozon [3].

The structural forms and parageneses of the basic tectonofacial zones are sufficiently fully characterized in a number of works (E I Patalakha, A V Smirnov, A I Polyakov, T V Giorgobiani, etc.), whereas structural forms of an ekzozona are described as us [3], and other researchers [2, 4] is only fragmentary, and their generalized characteristic is still absent.
In this regard the purpose of this work is systematization of structural features of material complexes of an ekzozona and allocation her typomorphic structural parageneses.

2. Research methods

The technique of a research provides a complex of methods of field studying, the formational, comparative and geological, morphotectonic and structural paragenetic analyzes on the basis of generalization material available in publications on structural forms that are exozonal.

Geological prerequisites for the allocation of each of the thermodynamic zones is the change in the vertical section of the earth's crust structural paragenesis, reflecting the thermodynamic conditions and determined by them the features of the main geological processes (sedimentation, nature of metamorphism, tectonic movements, magmatism, deformation of rocks) at different deep levels [1-3, 5].

Thermodynamic conditions that exist in each of the selected zones determine many parameters such as: conditions of deformation of rocks and the rheological state of matter, the type of folded, discontinuous and injective structural forms. Diagnostics of thermodynamic zones is carried out [1-3] both by morphological and genetic features of folded forms, the nature of discontinuous disturbances, paragenesis of small structural forms of the disjunctive and injective groups and fold deformations.

At the same time, it is possible to use not only the study of structural real complexes, but also the data of geophysical (seismic) studies, in which many boundaries are well reflected [6, 7, 8, 9, 10, 11], including different rheological state of the studied sections.

3. Research Results

The exozone in our understanding covers the highest level of the earth's crust, thus, its upper boundary is the earth's surface, and the position of the lower boundary, which in General can be defined as the level or front of the lithification of precipitation, is not strictly recorded at any hypsometric level, and is determined by several factors:

– of a thickness of friable not hardpan rainfall in oceanic, seas and lakes basins (border – the front of lithification of rainfall);
– the width of the zones of weathering on land;
– capacity of the zone of the activities of groundwater and cryolithic zone (permafrost in loose and lithified sedimentary rocks).

By the combination of these factors, the power of the exozone can be estimated from several meters in mountain areas to 2-3 km in flat conditions of sushi and up to 15-20 km in sea pool.

Exogenous geological processes have the main influence in the exozone: weathering, denudation and accumulation of sediments in depressions under water and air conditions under the in strong interaction of the stratosphere, hydrosphere, atmosphere and biosphere. This is the area where sediments accumulate and go through the initial stages of diagenesis – dehydration and compaction of the primary sedimentary material. As a rule, the level of precipitation metamorphism in the exozone is zero.

In rainfall of this zone have their characteristic deformation mechanisms, which determine the specificity of structural forms, their paragenesis, and as a result, ensemble of tektonofations of an ekzozona.

In this regard, the exozone developed mainly structural forms of exogenous or non-tectonic origin, which are largely formed as a result of the activities of groundwater and surface water, or in connection with human activities. These processes often lead to local disturbance of occurrence of rocks located at shallow depth. Non-tectonic dislocations are manifested in the displacement of rock layers, in violation of primary and secondary exogenous and endogenous structures, in low-amplitude displacements along the tectonic faults from a few centimeters to the first meters.

To a lesser extent, structural forms of endogenous and cosmogenic origin are observed within the exozone. In the development of the textbook for the course "Structural Geology" we ball started to develop the systematics of all structural forms. At this stage, in accordance with the adopted scheme of genetic systematics of structural forms, we have attempted to generalize in the same plan and structural forms of the exozone (table).
Table 1. Systematization of the main types of structural forms of exozone.

| Genetic groups (and subgroups) | Morphogenetic types and subtypes |
|-------------------------------|---------------------------------|
| Exogenous                     | Geomorphological                |
| Denudational                  | Plicative (folded)              |
| Sedimentary and contemporaneous | Accumulative (layered)         |
| Dislocation by a glacier       | Plicative (folded)              |
| Cryoturbation                 | Geomorphological                |
| Hydrogenic                    | Plicative (folded)              |
| Technogenic (anthropogenic)    | Geomorphological                |
| Endogenous                    | Neotectonics faults             |
| Tectonogenic                  | Seismogenic (seismic dislocations) |
| Magmagene                     | Plicative (folded)              |
| Cosmogenic                    | Impact-meteoric structures      |
|                               | Geomorphological                |

As can be seen from the table within the exozone there are structural forms of different origin, among which, depending on the type of generating geological process, three groups, several subgroups, morphogenetic types and different types of structural forms are distinguished.

In group of exogenous are included structural forms of denudation, of sedimentation and contemporaneous, dislocation by a glacier, cryoturbation. Also are carried to this group structural forms deformation processes of hydrogenic and of technogenic (anthropogenic).

Denudation structural forms can be divided into morphotectonic or geomorphological, fold dislocations and disjunctive (dislocation with a break in continuity).

Peneplains and denudation steps belong to geomorphological or morphotectonic structural forms. Peneplains are the surfaces of alignment which are formed as a result of the long destruction of a mountainous terrain and often in an upper have aeration bark. Denudation steps it is the intermediate surfaces of alignment which are formed at different stages due to change of level of basis of an erosion.

Fold dislocations of this subgroup are bends of layers on slopes under the influence of gravity and slipping of slide-rocks, land and landslide folds of a current and drag folds. Disjunctive (discontinuous) structures are cracks of weathering and cracks of side resistance.
Sedimentary and contemporaneous structural forms are divided into accumulative (layered), fold dislocations, disjunctive and injective. Sedimentary (layered) structural forms of this subgroup are the stratigraphic unconformities and different types of layers (turbidites, olistostrome, etc.). At formation of rainfall in the conditions of seasonal permafrost under the influence of a solifluction there is also their deformation.

Structural of fold dislocations forms are presented by dislocations, the bound to diagenesis of rainfall (with consolidation, swelling, dehydration). Each of these processes leads to change of primary form of bedding of rocks with formation of local folded bends. Also folds, the bound to loading of overlying breeds, dislocations in the turbidity flow (a current fold) and the folds which are formed because of primary roughnesses of the bottom of an oceanic, sea or lake basin belong to this subgroup.

Figure 1. Dislocation of exozone related to the activities of ice: a–b – dislocation by a glacier in sandy-argillaceous lake and glacial deposits of the Frolikhinsk late pleistocene glacier (near the Bay "Frolikha", east coast of the Lake Baikal): a – anticlinal fold with dip-slip fault (normal) in northwest in a wing and dip-slip fault (reverse) in a southeast wing; b – folded of dislocation by a glacier in tape clays; c – dislocations of cryoturbation in clay and loamy deposits in the Muysko-Kuandinsk hollow (in a pit section); d – fragment of the drawing «c» with disharmonious folds.

The faults forms of this subgroup are shrinkage cracks, diagenetic cracks at consolidation of rainfall and cracks of gravitational sliding (sliding, collapses). Injective structural forms are presented by sedimentary dykes in exogenetic cracks.
Example of such forms is the dislocation by a glacier studied near the Bay Frolikha on east coast of the Lake Baikal (figure 1). Here, in the pack of tape clays presented by alternation of shallow loamy and sand and clay layer folded and fault structural forms are at the same time observed. In the upper part of the section the rocks have subhorizontal practically undisturbed (in situ) occurrence.

In the middle part of the section (figure 1, a-b) strata are deformed, broken in some places with the formation of small-amplitude discontinuities of the type dip-slip fault (normal) or reverse faults, there are traces of slipping of rocks. Under the deformed layers of rocks lie the not clear deposits presented by fine-grained sand.

**Crypturbation** include geomorphological, fold dislocations and faults and injective structural forms.

Geomorphological structural forms of this subgroup are presented by craters and lake hollows in situ of the disappeared hydrolaccolith.

Fold dislocations of subgroup are difficult disharmonious micro folds (figure 1, c-d) which are formed as a result of deformation of rainfall by the movement of the formed ice.

The faults forms of this subgroup are submitted by cracks of frost. Injective structural forms of this subgroup are hydrolaccoliths and "bulgunyakhki" — positive self-contained forms of a cryogenic relief which result as a result of uneven injection introduction of ice in rocks (diapiric type), glacial wedges and sedimentary dykes in the in cavities of cracks of frost.

The subgroup **hydrogenic** structural forms include geomorphological forms, fold dislocations and faults. Geomorphological structural forms are karst funnels. Structural forms of fold dislocations of subgroup are folds of collapse (bends of layers in connection with karst collapses). Disjunctive structural forms are cracks in rocks which are formed in connection with karst collapses.

**Technogenic (anthropogenic)** structures include geomorphological, fold dislocations and disjunctive forms.

Geomorphological structural forms result from human activity — it is waste heaps, pits, excavations. Fold dislocations of this subgroup include folds over underground excavations. The faults are technogenic cracks and structures of collapse in excavations.

**The group of endogenous structural forms** includes two subgroups: tectonogenic structures (seismic dislocations) and magmagene structures. Tectonogenic structural forms are presented by the s seismic dislocations and neotectonic structures which are formed immediately in the conditions of an ekzozona in connection with seisogene and neotectonic movements.

Neotectonic structural forms of an ekzozona are young faults of type dip-slip fault (normal) and dip-slip fault (reverse), or strike-slip fault and thrust fault which are reconstructed in the geomorphological analysis of the modern forms of relief and of rivers network by selection of the tectonic slopes (steep linearly extended, sustained on long distance), breaks (straight sections of the river valleys) the lifted and lowered blocks (which have different hypsometric marks of relics of surfaces of alignment and denudation steps).

Seismic dislocations are divided into fold dislocations, faults and injective varieties. These include gaps, funnels, and subsidence, structures of fluidifying in Quaternary sediments of various compositions [9, 11-19].

Their manifestations are often interconnected and the leading role in this is played by rupture, which under seismic action precedes the formation of failed funnels and injection dikes.

Over places of emissions of the diluted material can sags of a soil with formation of fault structural forms in the form of seisogene cracks of mainly type mikro normal fault are formed or than mikro reverse fault [13-15, 20-24].

The injective structural forms of this subgroup are represented by dike-like bodies of seismites — due to the injection of liquefied soil arising from earthquakes by the mechanism of clastic dikes.

**Magmagene** formations that form at the exozone level can be represented by fold dislocations, faults and, and injective structural forms.

The fold dislocations reflect the primary slope of the volcanic rocks (when the lava moves down the slope of an uneven terrain).
The faults are individual prototectonic cracks (during lava solidification), circular and radial faults, exogenous cracks, and volcanic-tectonic structures.

The injective structural forms of this subgroup include flows and covers of volcanic rocks, sub-volcanic small intrusions (stocks, dikes, veins, etc.).

**The group of cosmogenic formations** includes *impact meteorite structures* manifested geomorphological in the form of meteorite craters and ring structures.

4. Discussion

*The folded forms* of the exozone, thus, can be absolutely identical endogenous in morphology. In this case, to assess the degree of deformation of the rocks by the method of tectonofacial analysis, you can use the main features, such as the angle of incidence of the wings of the folds, the degree of compression, etc. [1].

It should be noted a wide range of late-folded forms, which according to the degree of deformation – on the scale of diagnostic signs E I Patalakha, they can be attributed to both simple and medium forms of I-VII tectonofacies, and to complex forms VIII-X, or even to XI tectonofacies (overturned folds) [3].

An exception is the folds associated with cryodeformation, since during their formation the leading mechanism of deformation is permafrost swelling. In this case, folds are found both in the form of isolated structures and in whole connected groups. Anticlines are articulated with each other through synclinals with a "keel" type lock, or through concentric and similar synclinals.

Sometimes folds form multistoried packages of the difficult morphology in which folds have a different vergence and different orientation of axial surfaces (figure 1, a, c-d, figure 2, a, c).

In the majority of folds intensity of compression of wings and a slope angle of wings increases from below up, but also concentric structures meet.

A characteristic feature of folded structures is their conjugation with low-amplitude normal fault or reverse fault, which serve as constraints of folded packets and obviously develop simultaneously with them.

Often the morphology of folds of a cryolithic zone resembles diapiric structures more (figure 2, d) or structures of autochthonic granito-gneissic domes (figure 1, a) with zones between domes which are intensively deformed in folds

*The fault dislocations* are in most cases presented by normal faults (figure 2, b, f), is more rare reverse faults (figure 2, b). And often their combinations form step step-like faults or even micro grabens (figure 2, f).

Almost nothing is known about the shears at the exozone level, but this circumstance is obviously due to the fact that almost all the studied sections have a vertical or close position [6, 9, 11-14, 20-26]. To detect shears, it is necessary to study the sedimentary complexes laterally with their layer-by-layer opening from the surface.

In sources known to us, information about structures of the "thrust fault" type is also practically absent. However, according to Professor R.M. Lobatskaya (an oral report at one of the scientific conferences of the Irkutsk National Research Technical University) there are facts of the formation of boudins from soils in zone of flat thrust fault near the city of Krasnoyarsk.

So, apparently, thrusts can also form at the exozone level, as well as other morphogenetic types of fault dislocations.
Figure 2. Examples of structures of an ekzozona: a–c – seismites in quaternary deposits of southeast Altai according to E V Deyev, I D Zolnikov, S A Guskov [22]: a – the structural forms as clouds formed by introduction of fine-grained sedimentary material in coarse-grained material (the Ust-Chuysk section); b – two systems of counter micro cracks in the high layer of silts and sands of the Ust-Chuysk section; c – deformations of silts and sands in the Kyzyl-Chinsk section with formation of disharmonious folds; d–e – frost dislocations: d – the frost squeezing shown in vertical orientation of rubbles in a section of a terrace of the southern part of the bay "Mirror" in East seaside (by data A M Korotky, T A Grebennikov, L P Karaulova, L M Mokhova [25]); e–f – according to A S Gladkov, O V Lunina [14]: e – the structure of a frost wedge imposed on a sandy dike the river observed on the right coast Irkut at the settlement Pearl; f – the micro graben formed by cracks in sandy deposits (observed on the 9th km of Tunk Road – Badara).
**Injective dislocations** in the Quaternary formations are represented by clastic dykes that penetrate into the cavity of discontinuities. They are composed of material from the higher sediments – washed sand of different grains, which are very different from the sand and clay rocks that enclose them.

Often, they are found in the subsoil horizon of deluvium of loose sediments, which seem to clog these dyke-like formations. The layering in dykes is vertical or steep; the edges of dykes are usually angularly ragged (Figure 2, e).

In connection with the intensive study of soil liquefaction processes in the formation of seismic dislocations [18], it is possible to substantiate a different mechanism for the formation of dike-like structures in the exozone. This is when due to the existence of a water-resistant horizon at the time of a seismic event of considerable intensity, the material of the underlying layers of loose rocks can penetrate into seismogenic cracks and fill them, forming dykes of seismites.

According to N N Yakhimovich with co-authors [27] and A V Tevelev with co-authors [23-25] sometimes there is another morphological variety of dikes, referred to as “nails”, which are elongated structures with a small head or without it. The dikes with a long tail, and with almost parallel walls, one of which, as a rule, is quite smooth, and the second has a wedge-stepped, angular shape.

Also quite often in loose formations there are blind dykes, usually small in size, which do not have a visible exit to the surface [19, 26].

The morphology of structural forms of seismites is very diverse. Both in domestic and foreign literature in the sedimentary non-lithified complexes there are spherical structures or structures in the form of flames, simple and complex gyrus structures and structures of plate’s type and many others [11, 20]. At the same time, according to E V Deev and other authors [22, 26], the problem of reliable identification of the Genesis of such a variety of deformation textures still exists. Along with the formation of deformations in any one group or subgroup, it is likely the mechanism of the mixed Genesis, under the influence of one or more processes, such as solifluction and dislocations under the influence of ice.

5. Summary and Conclusion

Relicts of structural forms exozone can be stored in the consolidated folded complexes of epizone and even of mesozone, and possibly of catazone. This can lead to incorrect interpretation of tectogenesis conditions. In addition, in surface conditions often occur a variety of processes of structure formation, which do not belong to any of these groups.

In the works of N A Florensov and other researchers [9, 25, 28, 29] described the formation of thrust fault, strike-slip fault which were formed in surface conditions. At the same time, sedimentary rock complexes, which have already been formed earlier and have passed the stage of lithification, are moved. Apparently, such structures should be attributed to the group of forms of unclear Genesis (“other mechanism” and they need further study.

To carry out research on the method of tectonofacial analysis it is necessary to develop a system of a special approach to the study of the structures of the exozone. In one case, use the existing tectonofacial scales in another, it is necessary to assess the degree of deformation not in a separate structural form, but in the aggregate over the entire set of structural paragenesis of a group.

At the exozone level, all types of alluvial deposits, weathering crusts, and deposits of more complex (polygenic) origin are formed, such as, for example, the Kuronakh gold deposits (Aldan shield, Russia). During their formation, various processes interacted: the formation of weathering crusts, the formation of karst in the host rocks and subsequent hypergenic changes. In this regard, the study of structural parageneses and the development of methods for assessing the degree of deformation of rocks with the release of the corresponding tectonofaphations can be of great importance in assessing the industrial significance of such deposits.

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