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THE ANTHROPOGENIC CHANGES IN THE GEOLOGICAL ENVIRONMENT IN THE SOUTH OF EAST SIBERIA

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Abstract

The investigation results of the geological environment's condition in an areas marked by high anthropogenic load are described in this paper. In the southern East Siberia the strategy of key sites monitoring is used for this purpose. The selection of key sites is determined by the specific character of geological environment, as well as by the intensity and relationships of developing geological processes. In the studied territory the great variety of exogenic processes can be observed, the majority of them being activated by technogenic factors. To the inherited processes the gravitation, cryogenic and those induced by surface and subsurface water activity belong. In order to estimate the actual condition of the territories and to ensure the undisturbed exploitation of engineering structures, the specific features of lithosphere, the development of exogenic geological processes and the evolution of the anthropogenesis should be taken under consideration.

Key words: *geodynamical territory conditions, engineering structure influence area, inherited exogenic geological processes, karst landslide deformation, abrasion-accumulation process, processes interaction*

1. Introduction

Over the last 100-year period the role of human activity in the detrimental influence on the environment substantially increased, that is expressed as transformation of the natural conditions. The development and use of new technologies and engineering structures presents the definite intrusion into the laws of nature. The complicated relationships between the technical objects and the natural conditions manifest themselves in the form of radical changes in the geological environment, influencing the character of development of exogenic geological processes.

The southern area of East Siberia has experienced a series of growing anthropogenic activities during the history of the economic development of the region. Growing population, big cities with diverse infrastructure, exploitation of the Angara cascade hydro-electric stations with large artificial water reservoirs are the considerable contributors to activation of and origination of additional processes in the territory. The inherited geological processes are processes which were engendered in different geological environment and currently are labilized in connection with change of conditions (including anthropogenesis) (Trzhtsinsky et al., 1999).

Big industrial cities of the region such as Irkutsk, Angarsk, Bratsk, Ust-Ilimsk and Usolie-Sibirskoye are located primarily in the south of the territory (Fig. 1). The biggest part of population (~88%) ag-

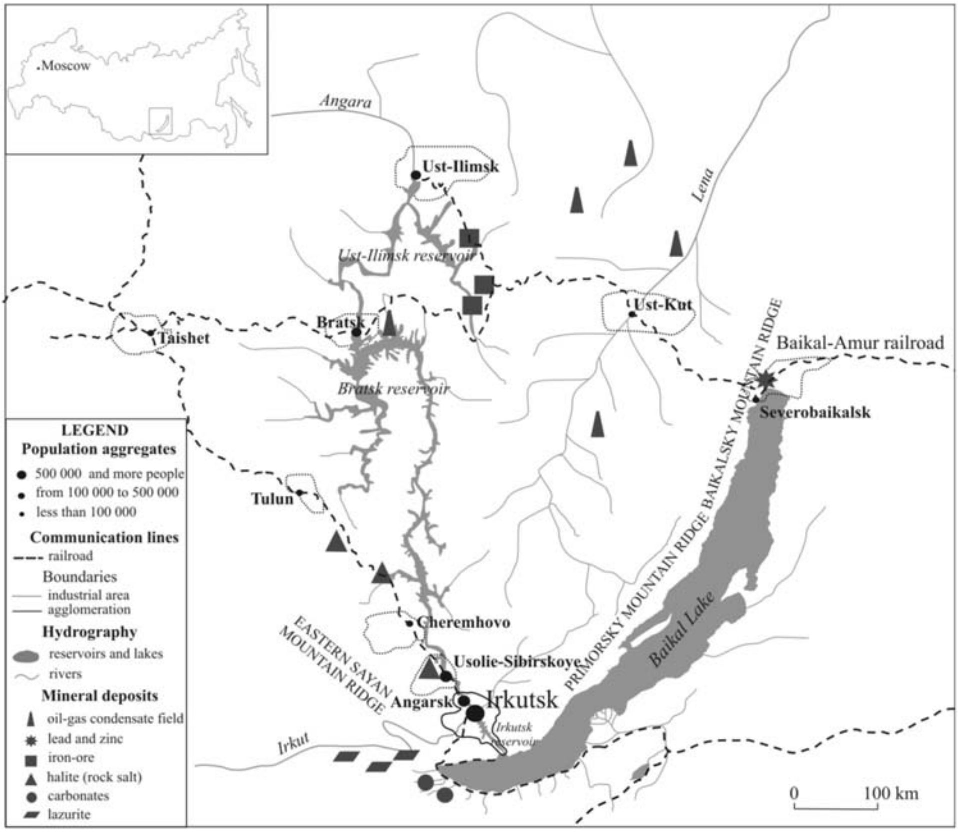

Fig. 1: Location of the study area, showing the basic elements of anthropogenic load.

glomerates in this area, with the residents numbering about 0.6 mln. in Irkutsk, 0.25 mln. in Angarsk, 0.25 mln. in Bratsk, 0.1 mln in Ust-Ilimsk and 0.1 mln. in Usolie-Sibirskoye; according to the census conducted in January 1, 2005. The industrial development of cities tends to concentrate near the transport ways such as the Trans-Siberian railway and the western part of the Baikal-Amur railway which bind the described region with the European territory of Russia (The general characteristic…, 2005).

In the territory of East Siberia the mining industry (coal, native gold, iron, salt, building materials etc.) develops over the long time; its detrimental effect on the geological environment manifests itself primarily in the form of damage to the morphometric characteristics of the land surface and the tension of soil.

The construction and exploitation of hydro-electric power plants (HPP) on the Angara-river such as the Irkutsk HPP (since 1962), Bratsk HPP (1967) and Ust-Ilimsk HPP (1977) with their water storage reservoirs have radically changed the geological environment of southern East Siberia. The changes occurred in the form of activation of inherited exogenic geological processes, and the origination of a new phenomenon (formerly not typical of the area), i.e. the change of shores. Abrasion of reservoir shores accompanied by other genetic group of processes benefits to the formation of various shore types (Kozyreva et al., 2004).

2. Brief historical view of the southern East Siberia; the geological setting of the territory

The evolution of the anthropogenic load on the environment of Siberia is to a large extent associated with the history of its colonization by Russian people. The troops of Russian Cossacks fought their way to Siberia, being often attacked by Siberian nomadic tribes. After the defeat of the Siberian Khanate (the Tatar Principality that existed in West Siberia in 16^{th} century), the territory of Siberia became a part of Russia. Within the history of Siberia, the territory of southern East Siberia belongs to the regions of large economical and administrative importance. In 1620, the first settlement of Irkutsk was founded on the left shore of the Irkut-river. The period of 1625-1650 was marked by the intensive economic development and the population of the territory was stimulated by the search for minerals (silver, gold etc.). In the course of time, the temporary Siberian settlements became the large towns. Irkutsk was built at first as a stockaded town (1652), since 1661 Irkutsk has the statute of the city. The growing population, intensive commercial development of mineral deposits benefited to increasing of the importance of Irkutsk and other Siberian towns (Brief Siberian chronicle, 2003).

The southern area of East Siberia occupies the considerable part of Siberian platform and the Baikal rift zone. The region is marked by continental climate, composite geological structure, specific geomorphologic features, permafrost and high seismicity (up to M9); all these features attribute to specific engineering-geological conditions of the region. The Siberian platform's base has the two-stage structure, the lower stage being presented by metamorphic and igneous rocks of Archean and Early Proterozoic. The sedimentary cover of the platform is marked by three structural stages of sedimentation: 1) Lower Middle –Paleozoic, 2) Upper Paleozoic-Mesozoic, and 3) Cenozoic. During Perm and Triassic periods, the active volcanic and magmatic processes stimulated the development of extensive trappean formations in the platform area (Trzhtsinsky et al., 2007). The south-eastern area of Siberian platform abut on the Lake Baikal is marked by high seismicity, whose age ranges from Archean to Quartenary, with dominating occurrence of granitoides.

3. Methods

The estimation of geodynamical condition of the territory is based on both the qualitative and quantitative analysis of the dynamics of most typical exogenic geological processes. The quantitative characteristics (such as degree of land damage by exogenic processes, depth of effects and intensity of processes etc.), identify the changes that occur within the rock massif and the ecological-geodynamical trends in the development of investigated territory. Our investigations revealed the most important factors that influence the dynamics of exogenic geological processes with the purpose to determine the access to their monitoring.

The strategy of comprehensive survey and standard computer programs were used for the first time for investigation of shore areas of artificial reservoirs; currently this strategy is used also in other key sites of investigations in East Siberia.

The methodology of investigation comprises 3 procedures: 1) selection of the key site for investigation using the data on the general trends of development and activation of geological processes in the areas of influence of engineering structures in different periods of time; the analysis of conditions and factors responsible for development of sub-systems prior and after the construction of engineering structures, and the interpretation of airphotos; 2) monitoring and topographic survey in the observation sites; 3) the analysis of investigation data and construction of 3-dimensional cartographic models to define the qualitative and quantitative relationships within the geo-system.

The comparative analysis of models provides the estimation of the character of processes, comparison of their dynamics in the context with the natural and anthropogenic factors, and the definition of relationships between the system elements and influence of the factors upon the development of the whole system and each particular element.

Currently, the GPS-technology of survey is used in kinematic regime in key sites of shore areas of reservoirs. This provides the efficient processing of field data for the estimation of quantitative characteristics of exogenic geological processes. In the laboratory, the digital 3-dimensional cartographic models of particular sites, the composite index maps and the maps of engineering-geological zoning of the territory are prepared.

4. Exogenic geological processes as the indication of development of the territory

In the territory of southern East Siberia, a great variety of exogenic processes can be observed; the majority of them are labilized naturally, or have the anthropogenic analogs. To the inherited processes belong the gravitational, cryogenic and those induced by the action of surface and subsurface waters.

The areas of developing exogenic processes are marked by different potentials of geodynamical hazard and social-economical risk. This is determined primarily by quantitative and qualitative characteristics of process development, as well as by the extents of economical development and population of the territory. This paper deals with the processes of wide occurrence, and particularly those marked by grave consequences.

In the course of construction of the Baikal-Amur railroad, the friable frozen rocks such as component moraines were stripped on a number of hillsides due to the slope undercutting and construction of embankments. Deposition of warm soil during the construction of the railroad embankment initiated the defrosting and degradation of frozen layer, which entailed the origination of landslide distortions ranging from typical solifluction to fluid soil creep and formation of rotational slides.

The degradation of permafrost is accompanied by formation of the water bearing stratum confined to permafrost, which drains in the area of embankment base as numerous springs scattered over the slope area. In some slopes with steep benches, the inundation of the friable sandy-argillaceous rock formations underlying the water-bearing stratum, initiates the fluid soil creep, in places together with shrub and small trees, resulting in formation of typical hummocky land with sliding forest.

The occurrence of permafrost is the determining factor of the peculiar character of the territory. In the context of economical development of the region, the varying conditions of heat exchange on the land surface stimulated the degradation of permafrost and activation of cryogenic processes (such as icing, thermokarst, thermoerosion, solifluction, frost heave etc.). Besides, the presence of hydrophilic argillaceous rocks within the terrigene deposits benefited to the origination of landslide. The cutting of slopes or deep steep-sided excavation present the real cause of considerable technogenic deformations. As the case, the Kazankan landslide area can be cited, where a definite part of the railroad was laid on the sand and sandy-loam moraine deposits at the south-eastward slope (12-17°), of the North-Muya ridge; in the case of inundation the deposits assume the features of plasticity and thixotropy (Geology and seismicity of Baikal-Amur railroad zone, 1985). At the 15-20% moisture, the slopes creep even at a small load or shake (Fig. 2).

In the territories of negative relief the construction and exploitation of the railroad bridges induced the intensive development of deformations that entailed the displacement of the roadbed towards the valley of the Muyakan-river. To improve the situation, the whole bridge structure was shifted for 15-

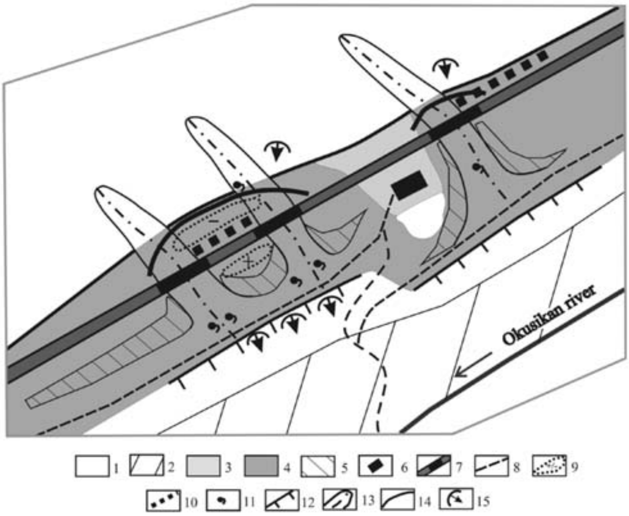

Fig. 2: Diagrammatic plan of Kazankan site: 1 – natural slope; 2 – accumulative terrace of Okusikan river; 3 – outlier of moraine; 4 – zone of railroad construction; 5 – steep slopes; 6 – station; 7 – railroad bed with bridges; 8 – roads; 9 – zone with positive (negative) amplitudes of horizontal deformations; 10 – culvert; 11 – spring; 12 – steep benches; 13 – ravines with steep thalwegs; 14 – rotational slides; 15 – small landslide body.

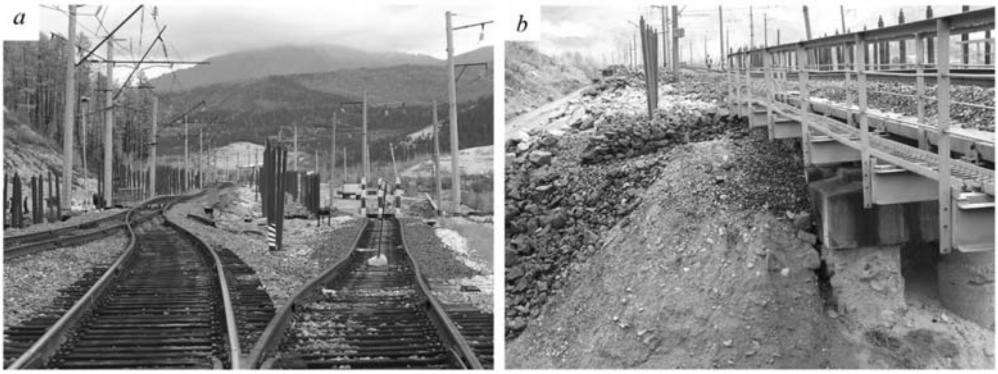

Fig. 3: (a): The railroad section displaced along the lines of the river valley, as a result of the slope deformations; (b): The open fissure in the abutment of the bridge.

20 meters towards the mountain slope (Fig. 3a). This measure, however, did not solve the problem as the displacement of the bridge structure proceeded. This was evidenced by the manifestation of fractures 15-18 m in length, up to 6 cm in width and with up to 20 cm visible depth in the mountain slope along the roadbed. Besides, the open fissures appeared in the abutment of the middle and the eastern bridges; in the base of abutment of the middle bridge the cavities appeared as the consequence of soil subsidence (Fig. 3b).

The thickness of sliding body is determined by the thickness of the defrosted zone. The upper border of the permafrost layer lying in a depth of 6-8 m, serves as the impermeable bed of the aquifer, confined to sandy-loam intercalations whose inundation benefits to formation of the slide zones.

In the case described, the relationships between two engineering-geological phenomena are discussed: 1) the degradation of frozen rocks, and 2) the landslide dislocations. The permafrost degradation was concerned as the primary phenomenon, and the landslide dislocation as the secondary. At present, however, the main hazard of the roadbed deformation and shifting of bridges is menaced by landslide, i.e. there is a direct evidence of the synergetic effect of both phenomena.

The karst process in the described territory is due to the occurrence of carbonate and sulphate deposits in ~40% of its area. Development of karst occurs both in the sedimentary deposits of carbonate and gypsiferous rocks of Cambrian and Ordovician, and in the deeply metamorphosed carbonate layers of Archean and Proterozoic. According to the lithologic features of karsting rocks, the occurrence of carbonate, sulphate and sulphate-carbonate karst is recorded, with domination of carbonate karst bound up with limestones and dolomites of Cambrian and Ordovician. However, the largest technogenic effects are attributed to the activation of sulphate karst process which is typical of the Angara-Lena region and is bound up with gypsum anhydrite rocks of Middle-Lower Cambrian and the lows of Verkholensk Suite of Upper Cambrian.

The anthropogenic changes in the character of process development manifest in larger extent within the influence zone of southern area of Bratsk reservoir, where the sulphate-carbonate deposits occur at absolute elevation marks of 380-400 m. For example, these changes occur in the zones of variable water saturation, and in the top area of the zone of complete water saturation, which provides the high rate leaching and karst activation in the reservoir's backing zone. Below the 10 m-thick layer of Quaternary deposits, the presence of karst forms was plotted. With the aid of symmetrical electro-profiling (SEP) the occurrence of inherited karst was revealed. By drilling, the karst cavities of different depth (up to 63 m) filled with wet loose material of high capacity were found.

The comparison of karsting gypsa and dolomites in laboratory and in situ revealed that the annual rate of gypsum bleaching in the studied region is 0.02-0.08 mm, which is by 2-3 orders of magnitude higher than that of dolomite (Filippov, 1988). So, the sulphate rocks are most susceptible to variations of hydrodynamical conditions, typical of the backing zone of Bratsk reservoir, whose amplitude of water level fluctuation is 10 m, as recorded during the 40-year period of reservoir exploitation.

In the course of exploitation of the reservoirs, the rates of karst development rose by one order of magnitude. So, the territories defined as formerly stable and low-stable (marked by formation of 0.01-0.1 karst hole/km^2 annually) are actually defined as unstable (with annual caving 0.1-1.0 karst hole/km^2) and greatly unstable (with annual caving of 1.0-10.0 karst hole/km^2). The zone of eventual activation of the gypsum karst incremented up to 6 km width; the territory covered by karst forms also increased (Fig. 4). Due to the deformation of land surface within the Khadakhan-Melkhitui karst massif more than 550 hectares of the territory of agricultural land use were lost, and a number of buildings were damaged (Trzhtsinsky et al., 2005).

The activation of karst landslide deformation in the shore area is evidenced by the origination of additional caverns, suffosional karst funnels, as well as the well-defined landslide elements, such as cracks, joints, trenches, etc. In the zones of variable water level, the horizontal solution caverns filled with friable material (dolomite meal) develop at the base of shore slopes. The laboratory analysis of this material (dolomite meal) has shown its low mechanical strength: under the inundation conditions it acquires the plasticity and fluidity features. The slackened state of filling material is the cause of the plastic deformation, stimulating the displacement of overlying rock layers towards the erosional channels. The dynamics of development of karst landslide areas depends upon the leaching rates of carbonate rocks in the slope base. One of the sites in the cape area of the Shaloty bay of the Bratsk reservoir can be considered as the typical case of intensive development of the karst landslide deformation. Within this area, the evident karst and landslide relationships regulated by the reservoir's water regime can be observed. In this area, the shore slopes are affected by two rotational slides; actually this is the technogenic landslide of blockglide type. The interpretation of aerial photos made in 1953 shows, that this was formerly a stable area located on the steep slope over the Angara-river's water level, and separated from the river channel by the low terrace with faint relief. The aerial photos made after the reservoir impounding show the well-defined landslide forms close to the brink. The systematic yearly investigation of the deformation-affected slopes and the analysis of field materials revealed the occurrence of landslide trenches and the starting formation of additional fissure zone aslope; this demonstrates the high dynamics of landslide process ascertained by the annual land surface grading. The washout of deluvial deposits at higher water level in the reservoir (recorded during the period of 2003–2004) leads to the 3 m-deep retreat of the slope base. Within fissure zones the subsidence of land surface (15 cm/year) occurs. The mechanism of this block-type landslide is the slow depth creep of slope. The permanent high rate of karst development exists within the massif, and the intense landslide deformation in the influence zone of the reservoir occurs.

The origination and intense development of the abrasion-accumulative processes (which are new for the discussed territory) were induced principally by anthropogenic factors. The construction of reser-

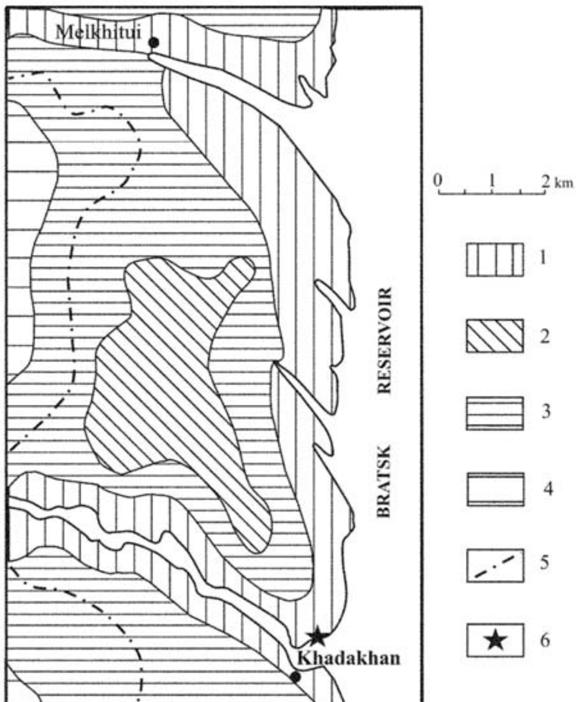

Fig. 4: Zoning of the area of Bratsk reservoir (Khadakhan-Melkhitui karst massif) by the stability against karst processes; areas: 1 – greatly unstable (1 to 10 karst holes/km^2 annually); 2 – unstable (0.1 to 1 karst hole/km^2 annually); 3 – low-stable (0.01 to 0.1 karst hole/km^2 annually); 4 – stable (< 0.01 karst hole/km^2 annually); 5 – the zone of prognostic activation of the karst; 6 – the site of intensive development of the karst landslide deformation in the cape area of the Shaloty bay.

voirs of the Angara cascade hydroelectric stations entailed the radical change in the environment of the territory, particularly the morphometric conditions of the slopes and interfluve areas. In the course of exploitation of reservoirs, many river terraces got entirely submerged; the changed water table caused the extensive decrease of stability of steep slopes. The abrasion process spread over the large area of shore zone: ~3000 km in length and 200 m in width (Ovchinnikov et al., 1999).

One of the basic factors that influence the dynamics of abrasion-accumulation processes is the water level regime, whose instability and large-amplitude variations determine the active stage of the shore slope failure, the initial stage of formation of shoals and along-shore banks. The actual regimes of reservoir exploitation benefits to formation of accumulative and abrasion-accumulative banks that serve as wave dampers and impede the shore abrasion, particularly in the Bratsk reservoir.

The original character of shore zones of artificial reservoirs is attributed to close interaction of definite processes within shore slopes. In the Rassvet-site of the Bratsk reservoir's shore area, the erosion process intensely develops aslope from the shore edge. The rate of erosion development is currently (after the 40-year exploitation of the reservoir) is 8 m/year at maximum water level. High intensity of erosion development is evidenced by increasing number of erosion cuts and the total volume of gully forms. At present, development of 36 erosion forms with the total volume of 1959 m^3 within the 2 km-long shore area is recorded. The current observations reveal that the gullies have increased in number (by 20 gully forms) and volume (by 916 m^3) against the data of 2004.

The current development of gully forms is attributed to the influence of recurrent water level fluctuations in the reservoir, as well as the abrasion process. These are the basic factors of the modern gully activity. The shore cliff undercutting at high water level entails its upslope displacement and the destruction of major gentle mouth parts of gully forms that decreases their length and impedes the formation of longitudinal profile of equilibrium (Fig. 5a). Lowering of the water level stimulates the vertical erosion in gully bottoms and the activation of backward erosion (Fig. 5b,c). Destruction of gully mouth parts at higher water level, and intensification of the vertical and backward erosion at low water level induce the formation of the stepped profile of gully thalwegs (Mazaeva et al., 2006).

This is the consequence of recurrent prevalence of the high rate shore abrasion over the vertical erosion. The seasonal variations of the reservoir water level also influence the cyclic changing of the ground moisture irrespective of the climate conditions. It should be noted that the lithological variability of deposits presented by the underconsolidated loess-like sandy loams, overlying the sand layers, as well as their properties (such as dusty condition, sulphate salinization of sandy loams and sands) make the grounds erosion-pliable. In the condition of high humidity the ground acquires the characteristics of fast water soaking, instability and shrinkage-strain (Khak et al., 2008).

The gully forms of complex genesis developing currently in shore areas of the Bratsk reservoir, display the diverse relationships between the natural environment and the human activity (construction of reservoirs and the manner of their exploitation). The formation of longitudinal profile of equilibrium for the above mentioned forms is impossible at the actual regime of exploitation of the Bratsk reservoir and the incessant process of shore abrasion.

5. Conclusion

Development of exogenic geological processes in the territory of East Siberia is determined by the general historical factors, the inherited condition of the region and a group of external factors, particularly by human made actions. In the context of current engineering-geological investigations, the

Fig. 5: Dynamics of gully form conditional by activation of the vertical erosion; (a): The data of July 2, 2007; (b, c): The data of July 7, 2007.

principal trends in the development of different genetic groups of exogenic processes, and the invariable mechanisms and forms of their occurrence have been determined. The variations concern the dynamics of processes, the extents of damage to the territory, and the activity and intensity of developing processes. In connection with increasing anthropogenic load some territories of East Siberia achieve status of bad social-economical risk area.

For estimation of the present-day conditions in the described territory, and ensuring of the undisturbed exploitation of engineering structures, the natural peculiarities of lithosphere, development of exogenic geological processes and the evolution of anthropogenesis should be taken into consideration.

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