A map of ancient erosion channels for the study and assessment of karst hazard in Moscow

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Abstract: The Moscow area of Russia has a complex geological structure. Carboniferous terrigenous-carbonate rocks, which are karstified and fractured, occur at a depth of 10-100 m overlain by a heterogeneous terrigenous sandy clayey massif. Three generations of river valleys of different age are distinguished. The erosional activity of these valleys controls the form of both ancient and present-day relief, plus the composition and thickness of the terrigenous massif overlying the karstified bedrock. It has been found that surface collapses and subsidence are confined to the areas of ancient erosion channels.

The ancient buried relief was analysed in detail; its main features are controlled by variability in the geological structure, geodynamic conditions, and exogenous geological processes. The geological survey data, dating back to the beginning of the 19th century, was studied and allowed information about the different ages of buried relief beneath Moscow to be gathered together.

As a result, thalwegs and the central parts of the pre-Jurassic and pre-glacial buried valleys have been traced within the Moscow area. A geological map of Moscow has been produced at the scale 1:10000, which reflects the most up-to-date ideas on the geological structure and the distribution of the different ages of buried erosional channels. This map is the basis for the investigation of the spatial manifestation of natural and human-induced karst processes. It helps with their prediction, hazard assessment, and the solving of problems related to the protection and rational use of the geoenvironment in the megacity of Moscow.

Résumé: La structure géologique du terrain de Moscou est assez complexe. A la profondeur de 10 – 100 m gisent les dépôts terrigènes carbonatés karstiques et fissurés houillers. Ils se superposent par la série inhomogène argilo-gréseuse mésocénozoïque. Il est connu trois générations de vallées fluviatiles se rapportant à des époques différentes dont l'activité d'érosion a exercé son influence sur les particularités structurelles du relief moderne et ancien, sur la composition, sur la puissance de la formation terrigène au-dessus du massif karstique. On a déterminé que les effondrements et l'affaissement de la surface terrestre se font coïncider d'une manière locale aux zones d'extension des incisions anciennes d'érosion.

On a effectué une analyse détaillée du relief enterré hétérochrone, on a défini ses caractéristiques principales qui déterminent la variation et la mobilité de la structure géologique, du milieu hydrodynamique, de la nature et de l'intensité des processus exogènes géologiques. De ce fait, sur le territoire de Moscou on a observé la présence des thalwegs et de la partie centrale des vallées ensevelies de la période préjurassique et préglaciaire. On a dressé la carte «Carte géologique de la ville de Moscou » à l'échelle 1 : 10 000 qui met en évidence les idées les plus avancées sur la structure géologique et sur l'extension des incisions ensevelies hétérochrones d'érosion. La présente carte est considérée comme une bonne base pour étudier la coïncidence de l'espace des phénomènes karstiques d'origine naturelle et d'origine naturelle et technogène. Outre cela, cette carte sert à faire leur prévision, à évaluer le danger et à résoudre les problèmes liés à la protection et à l'utilisation raisonnable du milieu géologique au sein de la capitale.

Keywords: Collapse, engineering geology maps, erosion, geological hazards, land subsidence, urban geosciences.

INTRODUCTION

The ancient buried valleys and the modern river valleys control the geological heterogeneity beneath the megacity of Moscow. The valleys formed at different times and there are variations if the thickness, mode of occurrence, composition, state, and properties of rocks and deposits within them. The valley areas have concentrations of karstic features that are susceptible to natural and human-induced processes, which can disturb the stability of the territory endangering the urban infrastructure. Consequently, the analysis of the distribution and status of the different ages of buried river valleys is of great geoenvironmental significance.

REVIEW OF THE MOSCOW PALEORELIEF STUDIES

B.M. Danshin (1927-1947) was the first to study the geological structure and the details of the buried ancient relief in the Moscow area. Working with scant information about the pre-Jurassic erosion relief, he outlined a large latitudinal valley, its thalweg lying on the surface of Carboniferous deposits. He also revealed an ancient Cenozoic buried valley crossing the Moscow territory from the northwest to the southeast (Danshin 1947). In 1933, under his editorship, a series of maps was compiled for the Moscow territory at a scale of 1:25000 showing the specific features of the different ages of buried relief.

Following this work, the geological institutions that conducted the subsequent engineering geological survey of Moscow, paid attention to the study of the buried ancient relief. The geological maps of Carboniferous and pre-Quaternary deposits and details of the relief of their upper surfaces were constructed at a scale of 1:50 000; they showed the courses of the pre-Jurassic and Cenozoic paleovalleys (Osipov & Medvedev, eds. 1997). For central Moscow, a distribution map of the buried erosional features and their different age was compiled at a scale 1:10 000 (Kutepov 1999). It was successfully used to guide managerial decisions about urban development, building design, engineering structures and site investigation. From this work, it became obvious that a geological map was required at a 1:10 000 scale for the entire Moscow area taking into account the ancient buried erosional valleys. This map was built in 2004 at the Institute of Environmental Geosciences of the Russian Academy of Sciences under the guidance of its director academician Prof. Victor Osipov. The different ages of buried relief were studied in detail, and the main features revealed, including those that influence the geological structure and geodynamic conditions, plus the type, intensity and manifestation of features formed by exogenous processes. Survey data, dating back to the end of the 19th century, were analysed, including more than 20 000 boreholes and voluminous publications on the structure of the buried relief. The geological map of pre-Quaternary deposits with the relief of the upper surface and the geological map of Carboniferous deposits with the relief of their upper surface were compiled. The resulting geological map was built at a scale of 1:10 000 for the entire Moscow territory. This showed the thalwegs of pre-glacial and pre-Jurassic buried valleys. The “Geological Map of Moscow with Erosional Cuttings of Different Ages” (Figure 1) was built using the MapInfo PC Software and reflects the present-day ideas on the geological structure of Moscow and the distribution and ages of the different buried erosional valleys.

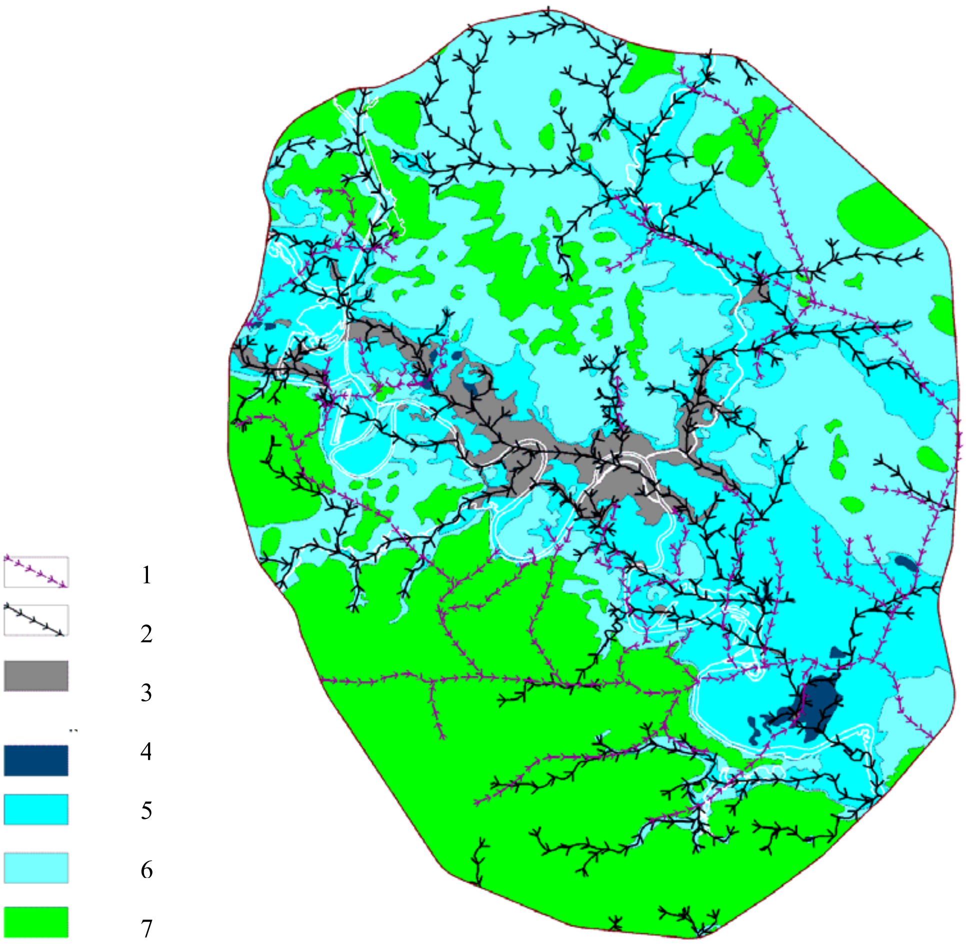

Figure 1. Geological Map of Moscow with Erosional Cuttings of Different Ages. Designations: (1) thalwegs of pre-Jurassic buried valleys; (2) thalwegs of pre-glacial buried valleys; (3) Carboniferous deposits; (4) middle and upper Jurassic deposits of the Bathonian and Callovian stages; (5) upper Jurassic deposits of the Callovian and Oxfordian stages; (6) upper Jurassic deposits of the Volgian stage; (7) Cretaceous deposits.

STAGES OF EROSIONAL RELIEF DEVELOPMENT

Three stages of intense river erosion are distinguished in the geological history of the Russian platform and the Moscow territory.

The first stage lasted from the end of late Carboniferous to the late Jurassic. A deep dendritic pre-Jurassic river valley network was formed cutting into the terrigenous-carbonate Carboniferous deposits. This was later flooded by the late Jurassic sea and buried under marine terrigenous strata.

The second stage of erosion and valley formation started at the end of Cretaceous period, when the Mesozoic sea retreated. This stage lasted until the time of the Quaternary glaciations. During this stage, the river valleys cut through the Mesozoic sand and clay eroding it completely in places down to the underlying Carboniferous massifs. Subsequently, these pre-glacial river valleys were filled with fluvioglacial sand.

The third stage started in the mid-Quaternary after the last (in the Moscow territory) glacier retreated from the area. The modern river network has been developing since then.

As a result, three generations of river valleys have been formed, the erosion activity of which controls the modern geological structure (Danshin 1947; Kozhevnikov 1979). The variability of the geological structure in Moscow is in many respects determined by the modern and ancient erosional activity of the rivers. On one hand, paleovalleys influenced the specific types of sedimentation and controlled both the lithology and thickness of sediments. On the other hand, the development of deep river valleys was accompanied by the destruction of former deposits, the alteration of their mode of occurrence, composition, state, and properties.

GEOLOGICAL STRUCTURE

Fractured and karstified carbonate rocks of middle and upper Carboniferous age occur in Moscow at a depth of 5-100 m. They are represented by limestone, dolomite, and marl with clay interlayers of variable thickness in the carbonate deposits. Fractured zones composed of limestone and dolomite fragments with ground limestone are also present. The degree of karstification in the Carboniferous carbonates changes laterally and with depth depending on the position with relation to the different ages of river valleys. The Carboniferous limestone, dolomite, marl, and clay underlie the Mesozoic and Cenozoic sandy-clayey massif. Carboniferous deposits outcrop at the pre-Quaternary surface in thalwegs and on slopes of pre-glacial and modern river valleys.

Mesozoic deposits are composed of middle and upper Jurassic continental deposits of the Bathonian and Callovian stages, upper Jurassic marine sand and clay of the Callovian, Oxfordian, and Volgian stages, and marine, predominantly sandy Cretaceous deposits. The Bathonian and Callovian deposits are represented by dark grey and brown loam and sandy loam with coal inclusions, and sand lenses and interlayers. Sometimes, bluish grey and brown dense clay with sand interlayers occur. The thickness of Bathonian and Callovian deposits does not exceed 10 m. They overlie the Carboniferous rocks where they are preserved in depressions and are overlapped by the upper Jurassic Callovian and Oxfordian clay. In places, where the upper Jurassic and Cretaceous deposits are eroded, they are overlain by Quaternary sands, sandy loams, and loams.

The Callovian and Oxfordian clay was deposited in the Jurassic sea, which covered the entire Moscow territory. After the sea retreated, it left a continuous mantle of Bathonian-Callovian and Cretaceous deposits; later, in the Cenozoic era, this mantle was partially eroded within river valleys. These deposits are of extremely variable thickness depending on the pre-Jurassic and pre-glacial relief. In the central part of the main Moscow valley, the Jurassic clay reaches 30 m in thickness, whereas, it rarely exceeds 10 m at the Jurassic watersheds and in the central parts of the pre-glacial valleys. These are dark grey and black homogeneous dense micaceous clay with faunal debris. The Callovian and Oxfordian clays are overlain by the marine sandy-clayey deposits of the Volgian stage at the pre-glacial watersheds, and they also occur beneath the lower and mid-Quaternary alluvial and fluvioglacial sand.

The marine sand and clay of Volgian stage are preserved only at the pre-glacial watersheds. These sediments discordantly overlay the Callovian and Oxfordian clay. The thickness of Volgian deposits ranges from 0-1 m at the pre-glacial valley slope brows to 10-30 m at the pre-glacial watersheds. They have their maximum thickness in the southwest of Moscow within the Teplyi Stan elevation. The Volgian deposits remain uneroded there, being overlapped by Quaternary deposits.

Cretaceous rocks are preserved predominantly in the south and southwest of Moscow, where they form the pre-Quaternary and modern watersheds. They are represented by marine deposits up to 40 m thick, which transgressively overlay the upper Jurassic Volgian sediments. The lower part of the layer is composed of brown, dark grey and greenish grey sand and sandstone with a phosphorite pebble layer at the base. Upward, they are gradually replaced by light yellow-grey fine-grained sand with rare interlayers of loose limestone. The Cretaceous sands are overlain by the Quaternary deposits.

Quaternary deposits are represented by the moraine loams of the Oka, Dnieper, and Moscow glaciations. In addition there are interglacial sands, and alluvial sands of the three terraces and the floodplain of the Moscow River and its tributaries. Tecnogenic sediments are also present. The thickness of Quaternary deposits fluctuates from a few metres to 40-50 meters. It appears to be thickest at the Teplyi Stan elevation, which is hardly affected by the modern river erosion. The Quaternary deposits are also very thick within deep preglacial valleys filled with fluvioglacial sands.

PREJURASSIC VALLEYS

Pre-Jurassic river valleys can be traced cut into the surface of Carboniferous deposits. They are preserved from erosion in places where the Carboniferous deposits are overlapped by the Jurassic clay. In Moscow, these are the main Moscow Pre-Jurassic valley and its tributaries. This valley stretches in the latitudinal direction, being located in the south of the city.

The slopes of the main Moscow valley are complicated by numerous tributaries and various karst-related landforms (funnels and cavities). The pre-Jurassic valley reaches a depth of 60 m. Round-shaped karst depressions are found in its thalweg, with the Carboniferous rock surface elevation being 50-70 m above sea level. Similar depressions are also typical of the tributary thalwegs. The central part of the depression is outlined by the 85 m above sea level isoline on the Carboniferous rock surface. Middle Carboniferous limestone of the podol'sk and myachkovo horizons outcrop in the valley thalweg. The central part of the main Moscow valley, as well as its tributaries, are filled with the middle and upper Jurassic continental deposits of the Bathonian and Callovian stages, representing Jurassic alluvium. Thin Bathonian and Callovian sediments (up to 5 m) are also found in some closed depressions in the Carboniferous surface in the upper parts of the slopes of this main valley and its tributaries. Mesozoic marine sandy-clayey deposits have a large thickness within the pre-Jurassic erosional cuttings and exceed 100 m above the thalweg of the Main Moscow valley.

Pre-Jurassic erosion exerted a significant effect on the composition and properties of deposits at the top of Carboniferous massif. The Carboniferous rocks are usually strongly fractured in the thalwelgs of the pre-Jurassic valleys. Fragments of carbonate deposits are cemented by ground limestone; while fractures and cavities are filled with the younger terrigenic sediments. A layer of fragmentary eluvium with limestone and clay filler up to 5 m thick always occurs at the top of the Carboniferous deposits at the pre-Jurassic watersheds. Unfilled fractures and cavities are predominantly recorded on the slopes of the pre-Jurassic valleys, where eluvium is either absent or of low thickness. The carbonate deposits are heavily karstified on the slopes.

PREGLACIAL VALLEYS

Pre-glacial valleys are traced at the surface of the pre-Quaternary deposits. The pre-glacial topography was not affected by the mid-Quaternary and modern erosion in the places, where pre-Quaternary deposits are overlapped by fluvioglacial sands of the Oka-Dnieper interglacial stage. The pre-glacial erosional valleys in Moscow are represented by two paleovalleys and their tributaries. These are of different ages, Tatarovskaya being the older one, and Khoroshevskaya the younger one (Kozhevnikov 1979). The central parts of these valleys are outlined by contours at 110-112 m a.s.l. at the pre-Quaternary surface, and their thalwegs are traced at 80-100 m a.s.l. Carbonate-terrigenic deposits of Carboniferous age usually outcrop in the pre-glacial thalwegs. The slopes of paleovalleys are composed of the upper Jurassic clay of Callovian and Oxfordian stages.

Pre-glacial erosion significantly affected the geological structure, composition and properties of upper Carboniferous and upper Jurassic deposits, which were laid bare in the thalwegs and on the slopes of the major pre-glacial valleys. Here the carbonate rocks are intensely karstified, and they are often crushed to fragments and powder. Upper Jurassic clays are decompacted and rich in sand.

KARST AND SUFFUSION

Karst and suffusion occur in thalwegs and on the slopes of the pre-glacial valleys. In these places, the upper Jurassic clay is either thin or completely eroded. Under certain hydrodynamic conditions, the clay layer may be damaged which induces suffusion of the Quaternary sand into the karst cavities and fractures in limestone, this results in surface collapses. If the clay divide is absent, the suffusion of sand into the limestone spreads out over vast areas; it is accompanied by the decompaction of sand massif and cauldron-like settling at the surface. Karst and suffosion appear to develop most intensely in places where there is a superposition of the pre-Jurassic and pre-glacial valleys. Limestone is highly karstified there, and the overlying Mesozoic deposits are either partially or completely eroded. These areas include the northwest of Moscow, where the Khoroshevskaya pre-glacial valley overlies one of the tributaries of the Main Moscow pre-Jurassic valley. In this north-western district of Moscow, 42 karst collapse funnels have been recorded (Osipov & Medvedev, eds. 1997).

KARST AND KARST-SUFFUSION HAZARD ASSESSMENT

The categories of karst and karst-suffosion hazards are distinguished depending on the locations of the thalwegs of the pre-Jurassic, pre-glacial and modern river valleys.

Karst hazard

The karst hazard is related to the specific structure and state of the karstified carbonate rocks. It is controlled by the presence of large unfilled cavities and fractures in the carbonate massif. Categories of karst hazard are distinguished depending on the site position with respect to the thalwegs of the pre-Jurassic erosion valleys. Bottoms and slopes of pre-Jurassic erosional valleys are classified as the hazardous category, within which limestones have high fracturing and karstification. Pre-Jurassic watersheds, where the limestones are insignificantly affected by secondary processes are referred to the low hazardous category.

Karst-suffosion hazard

The karst-suffosion hazard depends, above all, on the geological structure of the overlying sandy-clayey massif. In the hazardous regions, the clay thickness does not exceed 10 m, and pronounced karst suffusion collapses occur at the surface. These are situated on the slopes and beds of the modern and ancient river valleys. Territories, where the thickness of overlying clay layer exceeds 10 m are referred to the non-hazardous category. These are the pre-glacial watersheds and the upper parts of pre-glacial valley slopes.

CONCLUSION

The "Geological Map of Moscow with the Erosional Cuttings of Different Ages" built at a scale of 1: 10000 is a basis for the preliminary assessment of karst and karst-suffosion hazards used for selecting the locations of buildings and engineering structures. It collates all the facts and knowledge available about the geological structure of the Moscow territory and it shows the up-to-date geological information about the distribution of different ages of buried river valleys. This map can be used to identify possible sites where hazardous geological processes caused by karstified deposits may occur at a certain depths, it is a tool for predicting and avoiding possible disastrous consequences.

Acknowledgments: The authors are grateful to Drs. O. Mironov, S. Groigor'eva, E. Makhorina, and O. Eremina for their valuable contribution to this work.

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