GIS technologies for geological environment studies in urban territories

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Abstract: The Institute of Environmental Geoscience of the Russian Academy of Science has studied urban geological environmental problems in Moscow for many years. These works were required by the Moscow city administration and other planning institutions and firms working in Moscow.

There are various geological hazards in the territory of Moscow such as landslides, karst, karst-suffosion sinkholes, groundwater flooding, etc. Another problem is pollution of geological environments, mostly soils and groundwater. At present, the geological anomalies of the urban territory are under consideration, for example buried pre-glacial erosion valleys and the boundaries between neo-tectonic blocks.

There are many engineering geology and environmental problems concerning civil engineering, tunnel construction, groundwater management, pollution etc.

In the last decade various GIS technologies have been developed for environmental studies because the results of investigations usually are shown on maps and geological cross-sections.

In 2002-2004 the GIS project "Geological map of Moscow and buried erosion valleys" was fulfilled. Total mapped area is about 900 sq. km at scale 1:10000.

The principal lines of development are

- managing source map information (topography and infrastructure maps (GIS layers);
- managing source geological information (borehole database etc.);
- geological mapping technologies;
- geological hazard mapping;
- GIS design for city specialists;
- GIS design for environmental monitoring.

The paper describes various aspects of GIS technologies for environmental studies.

Résumé: L'Institute d'Ecologie Geologique de L'Academie de Sciences de Russie apprendres les problemes de environnement geologique urbain a Moscou. Les travails ont produit pour la mairie de Moscou et les departments construction et ecologique de municipalitet de Moscou.

Il y a les risques geologique variete sur le territoire de Moscou. Ils sont conditionne a processes geologique exogenous (glissements de terrain, karst etc) et les anomalies de environnement geologique.

Ce expose decrire GIS technologies appliquees a l 'investigation de environnement geologique de Moscou.

Le GIS project "Carte geologique de Moscou et vallees ensevelies de la periode prejurassique et preglaciare" a elabore dans 2004.

Keywords: 3D models, database systems, ecology, geographic information systems, geological hazards, urban geosciences

INTRODUCTION

Main objects of geological environmental studies at urban territories are:

- hazardous natural and man-made-natural exogenous processes;
- soil and groundwater pollutions due to human activities.

Geological environmental investigations use source data obtained during engineering geological prospecting, monitoring data, remote sensed data, and results of direct field surveys. The information on the city infrastructure is used for the integration of ecological data with decision making for rational planning of the city development.

Geological maps and cross-sections are the most important kinds of source information. The results of environmental studies are usually maps ranking the territory by some factor (hazard rank or pollution grade) or integrate geological risk maps and the recommendations on the rational land use. City management uses these results for the strategic and tactical decision making.

Moscow is the largest megacity in Europe. Its area is more than 1000 sq. km. Some GIS projects are described below that the Institute of Environmental Geoscience of the Russian Academy of Science have developed for Moscow. For a detailed description of the geological situation in Moscow see OSIPOV, (2006)

GEOINFORMATIC MODELLING

Using GIS technologies is adequate for geological environmental studies because almost all data have spatial coordinates. The geoinformatic approach is based on the use of the *geoinformatic models*, that is, formalized descriptions of natural objects. The model includes the formalization of the geometric representation of an object on the map, its data attributes, and the classification rules for the objects. The models are highly dependant on the scale of the investigation. When the scale of a map is changed then the collection of its objects (or their properties) changes too.

The following hierarchy of geoinformatic models is used in geological environmental studies of urban territories (see Figure 1).

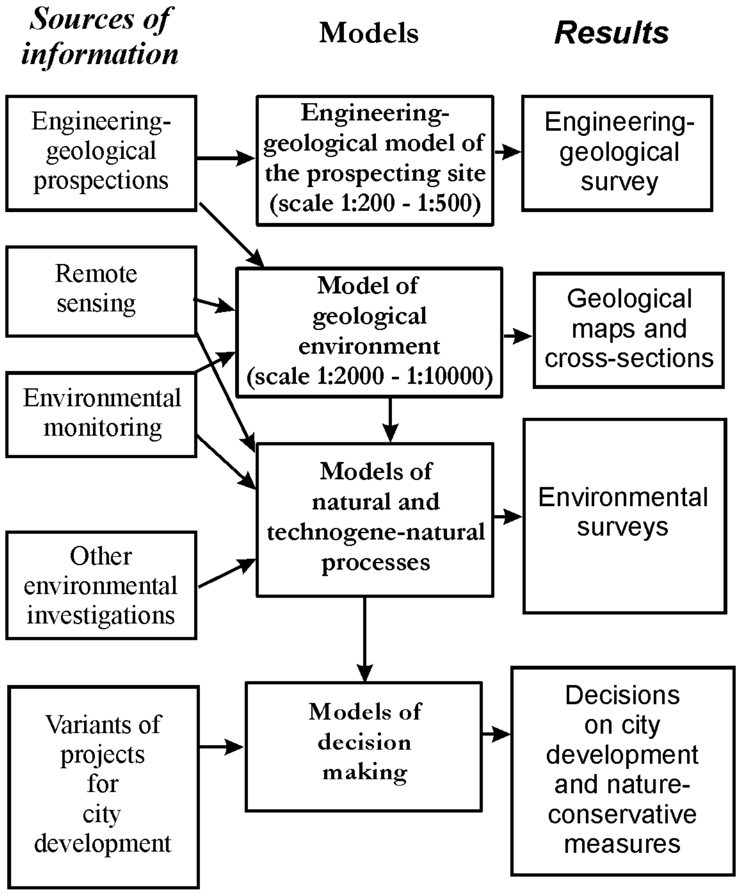

Figure 1. Hierarchy of geoinformatic models

The majority of information about geological environment is obtained during engineering-geological survey. Usually an engineering-geological survey is undertaken for some construction project; therefore the information collected must be revised for environmental studies. Usually the source of geological information concerning the neighbouring sites is collected by various authors and at various times. The engineering-geological survey is made at scales of 1:200 or 1:500 whereas environmental studies use scales from 1:2 000 to 1:10 000. Scales 1:25 000 to 1:100 000 may be used for general maps of megacities. The generalization of geological information for environmental studies must be done both horizontally and vertically. It is not purely formal but the creative task for specialist. The geoinformatic model changes at this stage.

From the other side, regional data are necessary for the complete engineering-geological survey. In Moscow there have been accidents during construction that were caused not by hazardous process, but by the lack of regional geological information.

Environmental models are based on the regional models of the geological environment. The source information is borehole data, remote sensing, geophysical data and data from monitoring systems. Information may be presented graphically as geological maps, cross-sections, and 3d-models. This information may be embedded into city infrastructure.

Results of environmental studies e.g. output data from environmental models are destined for city managers and must have an appropriate form. Typical output is recommendations on rational land use and corresponding maps. The upper level of modelling is an economic model for decision making. Environmental data may be included as constraints upon models of optimal city planning models.

There are 3 interrelated modes of use of geoinformatic technologies:

- automation of traditional cartography (map making and editing);
- creation of geographic information systems (GIS);
- applied mathematical modeling for creating new information (digital elevation models, automatic zoning etc.).

GIS technologies solve many tasks that are needed when using or creating maps: seeking objects, selecting objects by their properties, measuring areas or distances etc.

A GIS model of data is a new model as compared to traditional mapping. It is possible to say that GIS contains many virtual maps but no fixed map. The user may create the required map himself by combining selected information. It is very easy but the correct analysis of information and final map design remain essential problems. Good technology needs good brains.

GEOHAZARDS IN MOSCOW

According the programme "The Safety of Moscow" an atlas of geologic environmental maps at scale 1:50000 was developed. The head of the project was V.I.Osipov. The atlas includes the following digital map layers:

- karst hazard (underground);
- karst-suffosion hazard (sinkhole subsidence collapses at the surface);
- erosion hazard;
- landslide hazard;
- groundwater flooding;
- aggressivity of groundwater;
- thickness of man-made deposits;
- man-made pollution of soils;
- vulnerability of groundwater to pollution from the earth's surface;
- vulnerability of the carbon aquifer to pollution from the earth surface;
- electro-corrosion hazard for underground communications and constructions.

For the map edition some logically connected layers were combined into one map, for example, landslide and erosion hazard.

Each thematic layer contains a scaling of the city territory by degree of intensity of hazardous process or environmental situation. Attribute information on each region is designed for city planners and contains:

- a description f the process or situation;
- bans and restrictions for building and another activities;
- recommendations for land use and nature-conservation measures.

GIS "Moscow geoenvironment" was developed based on this atlas. Then this GIS was embedded into GIS of the ecology department of Moscow department. The query system can output the environmental situation at a selected point – all the grades of thematic layers at that point. For the selected region (e.g. territory of prospective development or city district) the areas and shares of various hazard classes for that region are computed (see Fig 2).

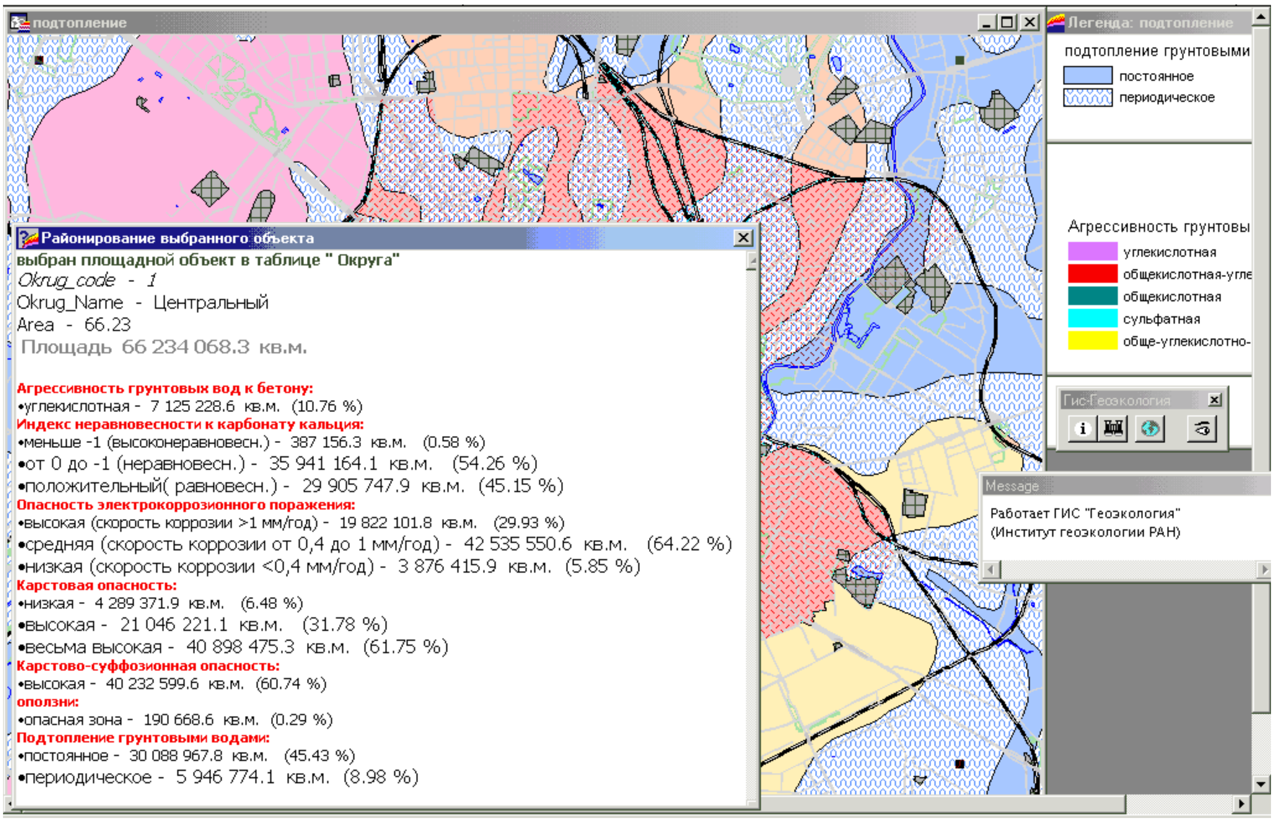

Figure 2. Example of a GIS query (Central district of Moscow)

An integral map of geological risk for the Moscow territory has also been created (see Figure 3). The map was made by means of the Pareto optimum method. Various main colours on the map show approximately equal economic hazard. Hues of the main colour correspond to various combinations of hazards. The most hazardous zones where catastrophic events may occur are shown in light violet for karst collapses, and in dark violet for landslides.

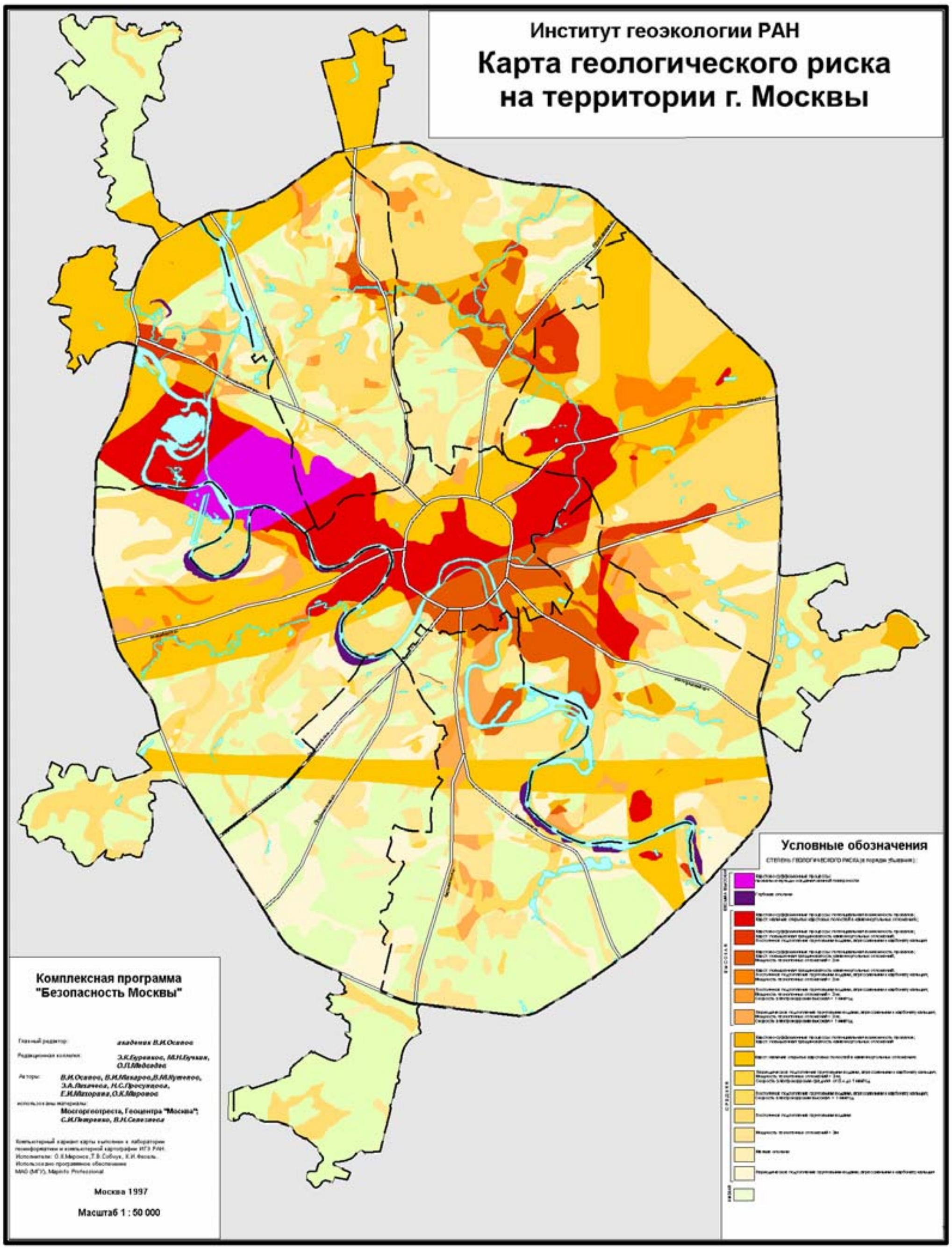

Figure 3. Map of geological risk in Moscow

In 2001 at the request of the Institute of General planning of Moscow IEG RAS has created a map of geological environmental hazards in Moscow at 1:25000 scale. The map contains zoning on hazardous exogenous geological processes in Moscow (landslides, karst-suffosion, groundwater flooding, karst). Environmental data was compared to the functional zoning of the territory provided by the Institute of General planning for prospective Moscow development. The results are presented as tables and graphs of susceptibility of various zones (residential, industrial, natural, ...) to hazardous processes (see Figure 4 for the North-Western district of Moscow). The Moscow architect's department uses geological environmental information for creating the General plan of city development.

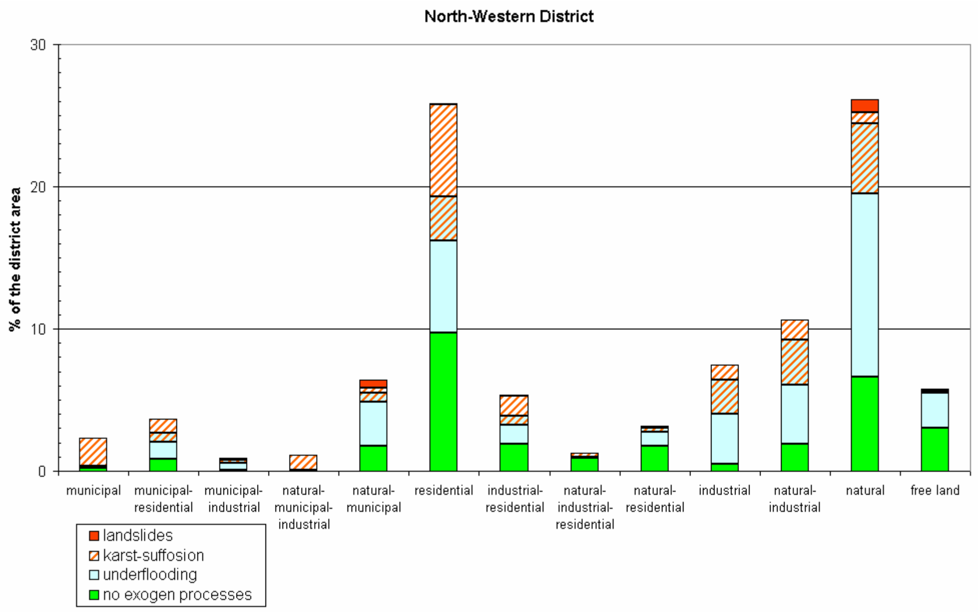

Figure 4. Susceptibility of functional zones to hazardous processes in the North-Western district of Moscow

GIS PROJECT "MAP OF ANCIENT BURIED EROSION VALLEYS IN MOSCOW"

In 2004 the Institute of Environmental Geoscience RAS created the map of ancient buried erosion valleys in Moscow at 1:10000 scale. The territory of Moscow inside the Moscow ring road (about 900 sq. km) is mapped. The work was conducted at the request of the Moscow government. The leader of the geological team is V.M.Kutepov.

This work is important to the city of Moscow; ancient pre-glacial and pre-Jurassic erosional valleys are infilled by weak materials (for example quick sand). These geological conditions may cause difficulties and incidents for underground and surface construction. The exogenous geological processes have more activity in these areas and especially on the slopes of buried valleys. The engineering-geological planning should be carried out with great care near these buried erosional valleys (see KUTEPOV et al. (2006) for the map and the full geological consideration).

The map of buried ancient erosion valleys will be used in planning city development, engineering-geological surveys, and environmental studies in Moscow.

Here we consider only the geoinformatic part of the project.

The project was set-up as GIS project from the very beginning. The source data includes:

- Borehole database;
- Geological maps at 1:50000 scale.

The borehole database now contains information on about 20000 boreholes. All accessible archive information of various Moscow geology organizations was collected. The oldest borehole was drilled in 1907.

The main and most labour-intensive task was database maintenance. The principal problem is to unify the information of various sources. Meaningful comparison and assembly of the data could be done only with GIS technology.

The resulting map consists of the following layers (scale 1:10000):

- Geology of pre-Quaternary deposits,
- Thalwegs of pre-glacial valleys,
- Thalwegs of pre-Jurassic valleys,
- Central parts of pre-glacial valleys,
- Topography layers.

The following auxiliary map layers were created in the project:

- Relief of the surface of pre-Quaternary deposits (rockhead) (see Figure 5),
- Geology of Carboniferous deposits,
- Relief of the surface of Carboniferous deposits.

It is easy to see the difference between modern and pre-Quaternary river valleys.

The main problem for geoinformatic technologies in this and analogous projects is the adequate presentation of the information for geologist and non-sophisticated applications of mathematical methods. The task is to give comfortable instruments to the specialists. The data collected from various sources must be combined together and put in concordance. This can only be done after analysis of many test maps and cross-sections.

Various geoinformatic technologies were used for geological and cartography support. Detailed checking of the information had been done during project work by comparison of maps with the borehole information. Digital elevation models (DEM) were used for drawing intermediate isolines, constructing derivative DEMs (thickness of deposits, angles and exposure of slopes) and definition of thalwegs (lines of greatest slope) and central parts of valleys.

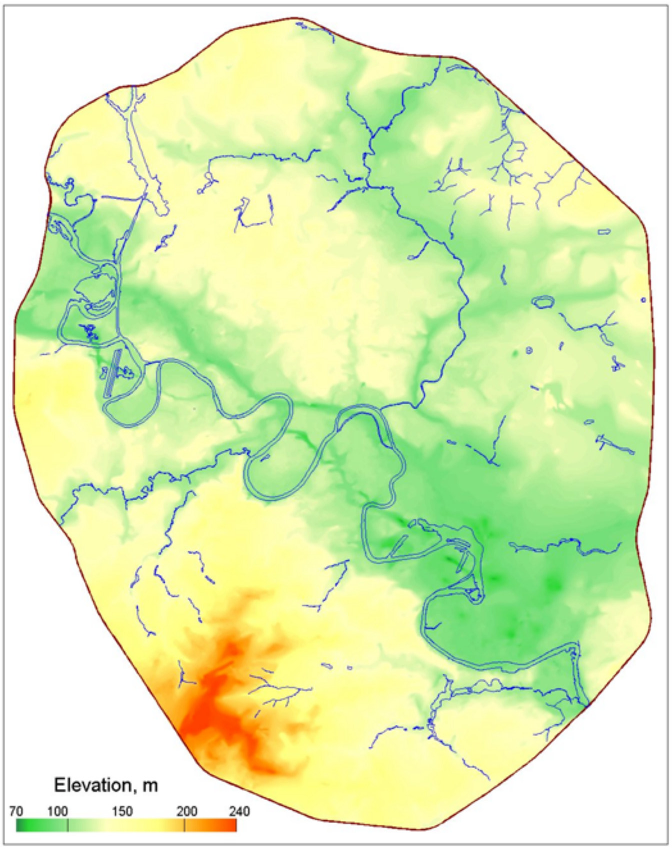

Figure 5. Relief of the surface of pre-Quternary deposits in Moscow (the modern hydrography is shown).

From the mathematical point of view the construction of DEMs of surface is point interpolation. In the project 2 DEMs were constructed for the pre-Quaternary and Carboniferous surfaces.

No single example of GIS technologies of point interpolation (weighted approximation, kriging, Delaunay triangulation – TIN) is applicable for creating DEM for ancient relief. All the mathematical models use assumptions about regularities in fields' generation or points' disposition that cannot be satisfied in this case. The results of such interpolation are mathematically correct but senseless geologically. In the mapping procedures geologists use some non-formal paleo-geomorphological and another concepts and information that still cannot be included into mathematical models.

So in the project the direct drawing and digitizing of isolines were used. DEMs were constructed by the isoline interpolation. The sophisticated interpolation technologies such as TIN reforming are more time-consuming for geologists.

Geoinformatic technologies were also used to provide the correlation of pre-Quaternary and Carboniferous maps in the regions where Mesozoic deposits are absent.

The skeleton of a Voronoy diagram was used as sketch primer for the geological map. Analogous technology is used for making geological cross-sections.

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