Geoscience Frontiers (2010) 1, 133–141

available at www.sciencedirect.com

China University of Geosciences (Beijing)

Geoscience Frontiers

journal homepage: www.elsevier.com/locate/gsf

ORIGINAL ARTICLE

GIS tools for correlation of tectonics and seismicity in the Altay-Sayan area, Russia

Raissa M. Lobatskaya [a,*], **Tatyana G. Krasnoramenskaya** [b]

[a] *Irkutsk State Technological University, Irkutsk 664074, Russia*
[b] *Center for Environment and Resources Conservation, Krasnoyarsk 660049, Russia*

Received 1 July 2010; accepted 25 August 2010
Available online 8 October 2010

KEYWORDS
Fault-block structures;
3-D modeling;
GIS methods;
Earthquake-hazard;
Altay-Sayan folded area;
Russia

Abstract Fault-block structures of the Altay-Sayan folded area (ASFA) southeastern Siberia of Russia were used as the basis for creating a 3-D model. The surface structures were projected to depths by previous correlations between long and deep faults, with all layers and deformation factors defined. The mean deformation factor (Ds) is 0.12 unit/km^3 in the upper layer, 0.012 unit/km^3 in the intermediate layer, and 0.007 unit/km^3 in the lower layer of the 3-D ASFA neotectonic model. Ds allows correlation of the three distinguished layers with rheological bodies that differ in their potential for accumulating elastic energy. 3-D modeling can be used as a methodological approach to projections in seismic prone areas such as the Krasnoyarsk region, for earthquake-hazard monitoring.

1. Introduction

The most densely populated central and southern parts of the Krasnoyarsk region belong to the Altay-Sayan folded area (ASFA). Increasing seismic risks from ASFA called for a system of earthquake-hazard monitoring in the territory. Before 2002, there were only two seismic stations of the Geophysical Surveys of the Russian Academy of Science, one in Obninsk and one in Novosibirsk (Siberian Branch) that mainly recorded teleseismic events. This was despite the fact that the central and southern Krasnoyarsk region and its environs are experiencing considerable local seismicity with frequent earthquakes of moderate magnitude.

Thus, a regional seismological network was set up in 2000–2002, as part of a special regional program for "seismic weather" monitoring by recording small events as a basis for long-term earthquake prediction. The network stations are sensitive to small shocks that were beyond the resolution in earlier networks, and thus have furnished valuable information on the energy potential and earthquake–source parameters in the study area. However, the regional seismological network was deployed and seismic monitoring began without the solid tectonic background that can be provided by detailed neotectonic and seismological data that is processed with advanced tools. Thus, there arose a demand for

* Corresponding author.
E-mail address: lobatskaya@gmail.com (R.M. Lobatskaya).

Peer-review under responsibility of China University of Geosciences (Beijing).
doi:10.1016/j.gsf.2010.08.007

Production and hosting by Elsevier

reliable mapping and for techniques of tectonics–seismicity correlation in the Altay-Sayan area using advanced GIS facilities.

1.1. Research goal and objectives

The goal of the research for the purposes of increasing seismic safety in Krasnoyarsk region consisted of choosing optimum GIS techniques and adapting them to 2D- and 3D-tectonic modeling and subsequent tectonics–seismicity correlation. The respective objectives were:

(1) to make an inventory of the existing GIS tools for neotectonics;
(2) the choice and conceptual justification of GIS tools for 2D- (map) and 3D-models of the Altay-Sayan folded area (ASFA) neotectonic framework;
(3) GIS-derived 2-D modeling of the ASFA;
(4) to transform the 2-D model into a 3-D one, using GIS technology;
(5) to estimate the degree of brittle deformation of the ASFA crust in map and cross-section views, using ArcGIS tools;
(6) to correlate the ASFA deformation pattern and seismicity, using ArcGIS tools;
(7) to identify principal geological-geophysical, tectonic, and geodynamic criteria for monitoring seismic activity in the regional neotectonic setting, for earthquake prediction in ASFA.

2. Data and methods

The neotectonic map of the ASFA territory was compiled using a Global Mapper digital elevation model (DEM) in which we inferred faults and the blocks they bound from elevation gradients. The seismicity pattern was imaged using earthquake catalog data from a special earthquake catalog for Northern Eurasia (Ulomov and Shumilina, 1999), with historic and instrumental seismicity (Sibgatulin et al., 2009).

In order to correlate our results with the deep structure of the area, reference was made to published and unpublished (open-file field reports) survey data and models obtained at several survey, research, and academic institutions (Alakshin et al., 1988, 1991; Pavlenkova, 1996; Egorkin, 1999; Mats et al., 2001; Pavlenkova et al., 2002; Toib, 2002; Lind et al., 2004; Lifshiz et al., 2005). In addition to published and archived literature, we used the available maps of the ASFA (Zyat'kova, 1977; Nikolaev, 1982; Trifonov, 1986; Bezzubtsev et al., 2000; Grachev, 2000); quantitative parameters were calculated and spatially analyzed using the Global Mapper and ArcGIS software (Breunig et al., 2000; Castanie et al., 2005; Cheremisina and Nikitin, 2006).

According to the past experience of geological and geophysical surveys, it is reasonable to adapt GIS tools for specific purposes while creating the appropriate database and processing techniques. Thus, in this study we have applied GIS technology to neotectonic mapping, 2-D and 3-D modeling, and subsequent correlation of the neotectonic and seismicity patterns in ASFA. Correspondingly, the work included three stages: as the first step, we outlined the network of young faults on the topographic base with Global Mapper and then imaged the 2-D neotectonic structure as a 1:1,000,000 map; the second step was to convert the 2-D neotectonic model into a 3-D one by estimating the thicknesses of the blocks, proceeding from known empirical relationships between fault length and depth (Sherman and Lobatskaya, 1972; Sherman, 1977; Lobatskaya, 1987; San'kov, 1989); the third step consisted in ArcGIS 3D modeling of the neotectonic framework of the Altay-Sayan folded area and neotectonics–seismicity correlation (Sadovskii et al., 1987; Sherman, 2005).

The theory behind 2-D neotectonic modeling from the regional fault pattern is that the surface topography produced by neotectonic movements can represents neotectonic units, whereas the boundaries between the topographic highs and lows at regional and local scales of the lithospheric structure correspond to faults of the respective sizes (size ranks). In the course of modeling we successively applied: (i) morphotectonic analysis of elevation (Gerasimov, 1969; Gerasimov, 1970; Pozdnyakov and Chervanev, 1990; Lastochkin, 1991; Ufimtsev, 1998); (ii) high-density fault mapping (Nikonov, 1977; Ponomarev and Trifonov, 1978; Lobatskaya, 2005; Makarov, 2007); (iii) identifying and ranking neotectonic blocks (Lobatskaya, 2005; Seminskii, 2005); (iv) describing the neotectonic relief inside the blocks (Lobatskaya, 2005); and (v) estimating neotectonic slip rates within the blocks (Lobatskaya, 2005).

As noted above, the 2-D neotectonic fault-block model was based on a Global Mapper DEM. At the stage of fault pattern recognition, DEM was found to be advantageous over the classical plane-table survey and aerial- and satellite-imagery data because the program allowed fast and exact tracing of faults, drawing them on the 3-D topographic base, and plotting of gradient hypsometric elevation profiles in a few seconds.

Elevation in the Altay-Sayan folded area is uneven, with highlands in the south and hilly or plainland terrains in the north (Fig. 1). Taking into account the different elevation gradients in the north and south of the area, the minimum elevation contrasts are sufficient to assign two neighboring areas to different blocks: 20–25 m for peneplains; 50 m for denuded plateaus; 100 m for denuded mountains; and 200 m for young mountain provinces (Orlova, 1975).

3-D terrain image, filtered for vegetation and manmade effects, makes it possible to investigate the configuration and parameters of faults at any scale and to run multi-format export and import data. This approach ensures best user comfort, and high accuracy and resolution, which classical contour mapping tools cannot achieve (Krasnoramenskaya and Lobatskaya, 2008; Lobatskaya and Krasnoramenskaya, 2008).

With the use of the lineament layer of faults from Global Mapper 9, it was possible to proceed to automatic generation of the polygonal layer of neotectonic blocks in ArcGIS. The use of GIS tools at this stage saved much time required for delineating neotectonic blocks and became a high-accuracy and high-performance way of automatic tabulation of attributes for 3-D modeling. The procedures performed in 2-D modeling are summarized in Table 1.

The Z component (block thicknesses) in the 3-D neotectonic model was inferred from fault lengths to be $H = 1.04L - 0.7$ for 25–30 km local faults (Sherman and Lobatskaya, 1972), and $H = kL^a$ for regional and transregional (general) faults, with the *H/L* ratio varying from 1/2 to 1/16 (San'kov, 1989). The depths of 6–20 km long local faults (H) were assumed to be proportional to their lengths: $H/L \approx 1$ (Sherman and Lobatskaya, 1972). However, faults shorter than 25 km were neglected in the generalized derivation algorithm, there being few within the chosen mapping scale of 1:1,000,000.

Having synthesized the above relationships using the built-in Excel functions, we derived the generalized relationship for fault depths $H = 12.693\times L^{0.2239}$ km, following the scheme below:

1. calculating fault depths (H, km) for 25–30 km faults as $1.04L - 0.7$ (Sherman and Lobatskaya, 1972);
2. calculating fault depths (H, km) for 40–1000 km faults with *H/L* from 1/2 to 1/16 (San'kov, 1989);
3. plotting the power-law trend and obtaining the relationship $H = 12.693\times L^{0.2239}$ km.