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Interpretation of shallow electrical resistivity images of faults: tectonophysical approach

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Abstract

A new approach to interpretation of shallow electrical resistivity tomography (ERT) data discussed for the case of the Olkhon area (western Baikal region) stems from tectonophysical ideas of faulting phases and deformation levels in rocks. The deformation levels, identified statistically from ERT responses, constrain fault boundaries and subboundaries associated with the formation of main and subsidiary fault planes. Information of this kind creates a basis for solving various fundamental and applied problems of tectonics, mineral exploration, and engineering geology.

Keywords: fault zone; shallow electrical resistivity tomography

Introduction

Resistivity imaging (Bobachev et al., 1995; Griffiths and Barker, 1993) or electrical resistivity tomography (ERT), an updated version of vertical electrical soundings (VES), has been largely used to study faulting in shallow crust to depths of 40 m (Carbonel et al., 2013; Improta et al., 2010; Kuria et al., 2010; Magnusson et al., 2010; Olenchenko and Kamnev, 2014; Ryazantsev, 2012; Schutze et al., 2012; Sokolov et al., 2011). ERT data are interpreted proceeding from known correlations between resistivity and lithology. Faults presumably correspond to zones of resistivity gradients or to centers of linear low-resistivity zones, but this interpretation fails in areas of complex deformation patterns unless *a priori* data is used and/or the results are checked against other geophysical data.

The ways in which faults show up in ρ variations are identified by means of 2D resistivity modeling (mapping) and inversion of ERT responses of heavily deformed rocks (Reiser et al., 2009; Ronning et al., 2014). Research in this line can reveal a set of formal diagnostic features of faults in resistivity sections, but the problem is that faults are heterogeneous geological bodies producing intricate resistivity patterns.

In terms of tectonophysics, a fault zone consist of a main plane delineated by tectonites and smaller subsidiary faults and fractures of different ranks. A complete cycle of faulting consists of three successive phases, without the elastic or ductile prefracture phase (Seminsky, 2003, 2014; Seminsky et al., 2013). Faulting begins within a broad zone of small genetically related fractures called a "fracture zone", a "zone of incipient faulting", etc. (Favorskaya et al., 1985; Khrenov, 1971; Makarov and Shchukin, 1979; Peive, 1990; Radkevich et al., 1956; Rats and Chernyshev, 1970). Then the zone of active faulting narrows down and strongly deformed rocks separate several small fragments of the main fault plane. Finally, at the phase of ultimate failure, a fault becomes a single main plane surrounded by large pinnate faults filled with soft tectonites (fault gouge, breccia, etc.).

Structures that arise during different phases of deformation are superposed one upon another producing transverse subzones within the damage area (Fig. 1) corresponding to three phases of ultimate failure (I) and late (II) and early (III) faulting, grading one to another off the fault axis. This zoning records different deformation levels in rocks, which are expected to show up in resistivity patterns controlled by water-filled porosity and cracks of different sizes.

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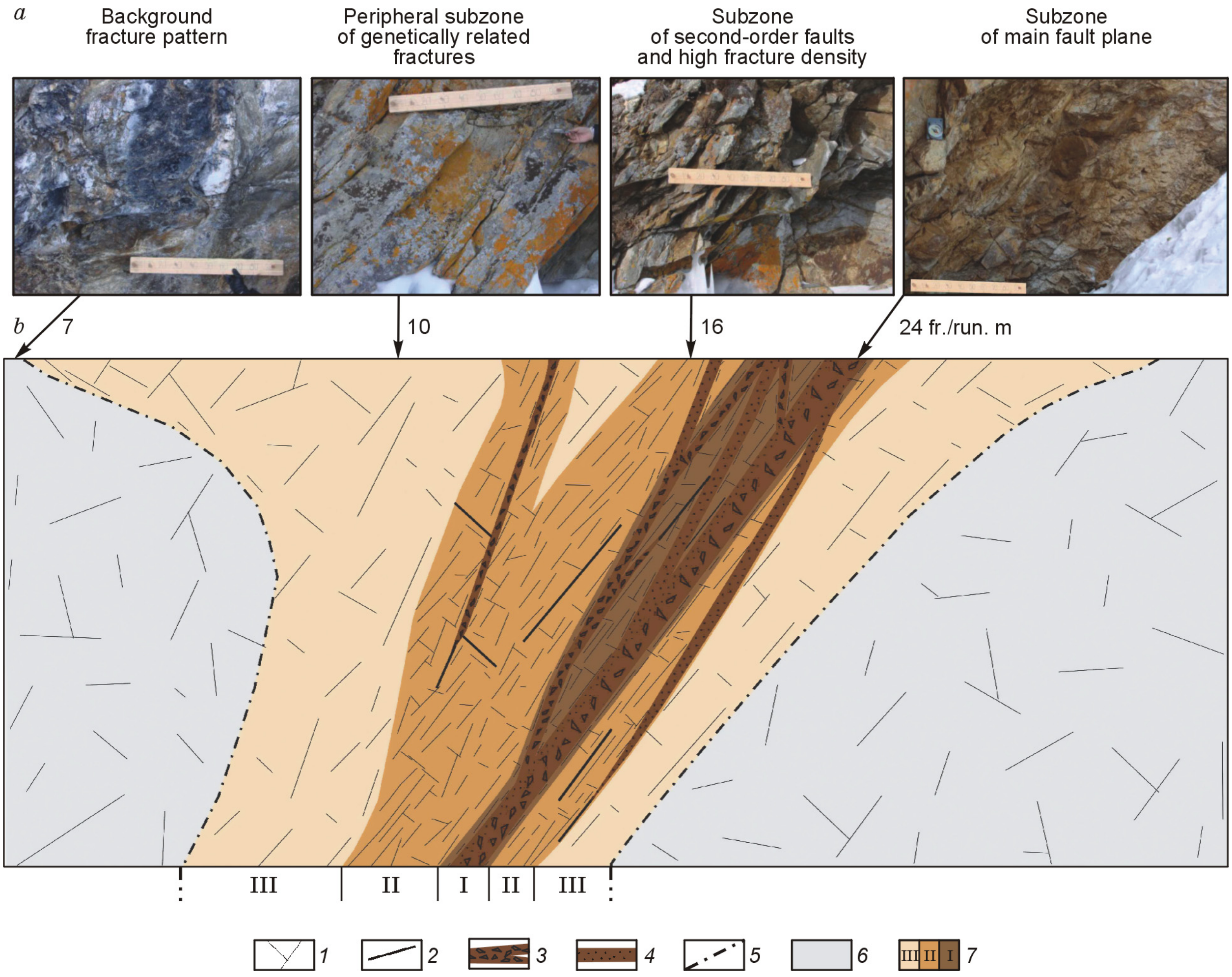

Fig. 1. Cross section of a fault zone: a basic model. *a*, Photographs illustrating typical facture patterns near the main fault plane at a site in the Olkhon area, Western Baikal region (scale bar is 1 m). *b*, transverse zoning of a fault that underwent three evolution phases. *1*, fracture pattern; *2*, large fractures; *3*, fault plane filled with breccia material; *4*, fault plane filled with gouge material; *5*, fault zone boundary; *6*, weakly deformed rocks; *7*, basic elements of fault zone formed during different phases of faulting: peripheral subzone of genetically related fractures (III); subzone of second-order faults and high fracture density (II); subzone of main fault plane (I).

In this study we report principles of a tectonophysical approach to interpretation of resistivity images of active tectonic areas. The specific objectives include (1) collecting resistivity images of reference faults in the Olkhon area (Western Baikal region) documented previously by structural methods; (2) processing ERT responses of shallow crust and correlating them with faulting patterns; (3) explaining the ERT data processing results in terms of the tectonophysical theory and justifying their use as markers of boundaries and subboundaries of fault zones.

Objects and methods

The Olkhon area in the western Baikal region (Fig. 2) belongs to an uplifted margin of the Sayan–Baikal fold belt. It comprises metamorphic complexes of different ages with nearly vertical bedding. The rocks underwent several major events of post-Proterozoic deformation (Delvaux et al., 1995, 1997; Levi et al., 1997; Logatchev, 2003; Makrygina et al., 2014; Mats, 1993; Seminsky et al., 2013; Sherman et al., 1992, 1994; Sklyarov, 2005; Zamaraev et al., 1979; etc.): Early Paleozoic compression, Early Cenozoic shear, and Late Cenozoic extension. The deformation shows up as a dense network of faults and fractures, with motions along them maintaining the NW–SE extension associated with the Cenozoic Baikal rifting.

ERT responses were collected from steep faults bordering large and small Cenozoic basins, at eleven sites (Fig. 2). The faults that were documented previously by direct structural measurements at most of the sites within Lake Baikal coastal cliffs (10, 11, 13, 15, 17, and 19) were used for reference. In other cases (sites 12, 14, 16, 18, and 20), the presence of faults was inferred from geomorhically expressed scarps presumed to correspond to fault planes. Some of them were large faults, such as the Primorsky and Tyrgan–Kuchelga normal faults bordering the Buguldeika–Chernorud graben (Fig. 2).

The sites with reference faults were chosen such that their resistivity patterns could be controlled mostly by deformation, the lithology control being excluded wherever possible. Those