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Neocomian paleogeography, gas hydrate cementation of sediments, and abnormal sequences of the Bazhenov Formation (*West Siberia*)

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Abstract

Abnormal zones of the Bazhenov Formation originated in the Neocomian as a result of protobazhenite reworking by submarine slide and slump waste wedgings, which eroded and deformed slope toe protobazhenite. But gas hydrate (GH) cementation might restrict the rock ability for plastic deformation. The conditions for GH thermodynamic stability in protobazhenites are inferred from reconstructions of paleogeographic and paleo-oceanic evironments. Joint analysis of Neocomian marine paleodepths and deep water paleotemperatures provides an explanation of the Bazhenov abnormal-zone extension.
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Keywords: abnormal zone; submarine slide; paleogeography; paleobathymetry; gas hydrate; cementation; Bazhenov Formation

Introduction

The Bazhenov Formation in the West Siberian basin includes particularly interesting local abnormal zones of thick Neocomian clastic sediments that wedge into Jurassic bituminous shales. These zones result either from slumping (greater part) or from regular sedimentation. The sedimentation has produced interbedded bituminous shales and barren rocks with undisturbed native boundaries. This study focuses on the Neocomian abnormal sequences in which protobazhenites were reworked with soft deformation due to seismically-triggered submarine sliding (Deev et al., 2012; Grishkevich, 2015; Nezhdanov, 2004). The available data on the subject include numerous photographs and descriptions of flow deformations and sliding breccia from the abnormal zones (Grishkevich et al., 2006; Sokolovskiy and Sokolovskiy, 2002; etc.), as well as biostratigraphic support for age difference between injecting sand and slide breccia (Braduchan et al., 2005).

The papers (Grishkevich et al., 2015, 2017) present a mechanic model (Fig. 1) explaining the generation of the Bazhenov Formation abnormal sequences and its experimental testing.

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Abnormal zones in the Bazhenov Formation: a rock mechanic model

Life cycle of any abnormal zone includes six stages (Fig. 1).

I: An earthquake triggers submarine gravity bed sliding of a slope with a flexible clay cap above quicksand; the active slipping block breaks through the sub-Achimov clays and the upper Bazhenov Formation layers and initiates an abnormal zone of deformed rocks (Fig. 1*a*). This scenario requires sufficient thickness (at least 10 m) of the clay cap which is strong enough at these depths to transfer tensile stress; the earthquake magnitude and the slope height likewise have to be quite large. The resulting nearly vertical fracture delineates the clay cap contact with the sub-Achimov clays.

II, III: Quicksand penetrates into the fracture and beneath protobazhenites; the sand-mud pulp flows downslope and spreads over denser (~2 g/cm^3) Lower Bazhenov siliceous-carbonate rocks (Fig. 1*b*, *c*). Fast gravity transport of plastic slump material completes at stage III (Fig. 1*c*) while the slope reaches some stability, with a slump gash and a fan of quicksand, collapsed material, and lifted bazhenites. The equilibrium is transient though.

Sediments that progressively cover the slope and fill the basin from the sides heal up the slump gash and load the fan. The latter encloses the lifted bazhenite sheets lying upon the

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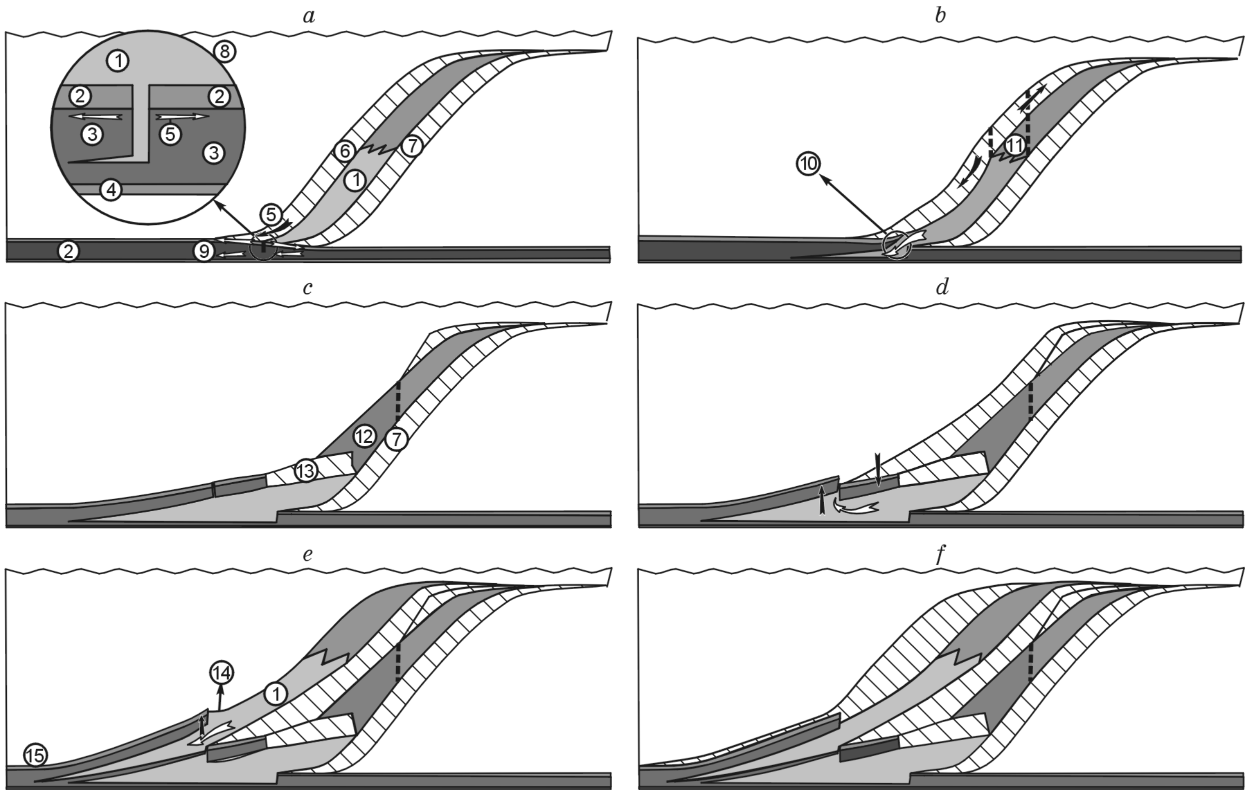

Fig. 1. Generation of abnormal zones in Bazhenov Formation: Geomechanic model. Stages: slipping (bedding) slide (*a*); out-flow slump (*b*), spreading of slump material and cap cracking (*c*); deformation under uneven load (*d*); secondary injection (*e*); burial (*f*). 1, quicksand; 2, sub-Achimov clays; 3, protobazhenite; 4, Georgievka Formation clay; 5, tensile (rupture) stress; 6, active slipping slide's block (clay); 7, stable slide basement; 8, location and rupture depth of slide base; 9, direction of fluid escape from Bazhenov Formation rocks; 10, wedging zone; 11, location of breakdown and volume of rocks collapsed over disappearing base; 12, products of collapse and slump gash healing; 13, slide active block fragment; 14, confined pulp flow; 15, bazhenite mat rest.

former slump pulp which easily acquires a plastic flow state. Even small shocks can cause flow of the unevenly loaded quicksand at the slope toe producing a compensatory swell.

IV: Pressure excess releases through fractures in the bazhenite mats and displaces their fragments. As a consequence, either the quicksand pushes the bazhenite "clog" up or forms a long shifted bazhenite mats, with an open lateral surface (Fig. 1*d*).

V: The presence of this surface that confines the slope sediments marks the next stage of secondary breakup, injection and splitting of bazhenites (Fig. 1*e*).

VI: Multiple splitting events continue until all sheet thickness becomes consumed or the sheet becomes buried under the advancing slope (Fig. 1*f*).

The suggested model was tested in a series of physical modeling experiments simulating the stages: out-flow, spreading, secondary injection, and fracturing of a bazhenite mat (Fig. 1*b*, *c*, *e*). The modeling was performed in an glass box divided into a $40 \times 20 \times 40$ cm modeling domain and a $8 \times 20 \times 40$ cm bin for pulp supply, connected at the bottom by a 5 mm wide horizontal slit. Bazhenite was casted from a mineral-pigmented cement-based tile glue with a density of 1.2 g/cm^3 achieved by adding polystyrene-foam balls.

Cementation of sediments by pore gas hydrates

The physical modeling did not include bed sliding: breakup of the sub-Achimovka shale and primary injection of the Achimovka sand into protobazhenites (stage I). There is another important factor besides the mechanic reconstructions (shear stress and density) relevant to the coseismic behavior of sediments. The stability of submarine slopes also depends on the presence or absence of gas hydrates, which can cement shallow bottom sediments (Sultan et al., 2011). High contents of gas hydrates increase the shear strength of rocks (Makogon, 2003; Uchida et al., 2012), but dissociation of gas hydrates upon eustatic sealevel fall creates abnormal fluid pressure leading to strain softening and slope instability (Berndt et al., 2002). Correspondingly, the presence or absence of pore gas hydrates in protobazhenites mean mechanically strong (III) or weak (I) sediments beneath an unstable slope and, respectively, unfavorable or favorable conditions for the formation of abnormal sequences (Fig. 2). In the present Black Sea, at a deepwater temperature of ~9 °C, hydrated sediments are confined within the –725 m isobath (Naudts et al., 2006). Below we try to apply such division to the Neocomian basin.

Nezhdanov (2004) noted that abnormal zones produced by submarine slumping are widespread in the southern half of

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