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# Mitigating the consequences of extreme events on strategic facilities: Evaluation of volcanic and seismic risk affecting the Caspian oil and gas pipelines in the Republic of Georgia

F.A. Pasquarè [a,*], D. Tormey [b], L. Vezzoli [a], A. Okrostsvaridze [c], B. Tutberidze [d]

[a] Department of Chemical and Environmental Sciences, Insubria University, Como, Italy
[b] ENTRIX Inc., Los Angeles, CA, USA
[c] Department of Petrology and Mineralogy of Geological Institute, Tbilisi, Georgia
[d] Tbilisi State University, Tbilisi, Georgia

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ABSTRACT

In this work we identify and quantify new seismic and volcanic risks threatening the strategic Caspian oil and gas pipelines through the Republic of Georgia, in the vicinity of the recent Abuli Samsari Volcanic Ridge, and evaluate risk reduction measures, mitigation measures, and monitoring. As regards seismic risk, we identified a major, NW-SE trending strike-slip fault; based on the analysis of fault planes along this major transcurrent structure, an about N-S trend of the maximum, horizontal compressive stress ($\sigma 1$) was determined, which is in good agreement with data instrumentally derived after the 1986, M 5.6 Paravani earthquake and its aftershock. Particularly notable is the strong alignment of volcanic vents along an about N-S trend that suggests a magma rising controlled by the about N-S-directed $\sigma 1$.

The original pipeline design included mitigation measures for seismic risk and other geohazards, including burial of the pipeline for its entire length, increased wall thickness, block valve spacing near recognized hazards, and monitoring of known landslide hazards. However, the design did not consider volcanic risk or the specific seismic hazards revealed by this study.

The result of our analysis is that the Baku-Tbilisi-Ceyhan (BTC) oil pipeline, as well as the Baku-Tbilisi-Erzerum South Caucasian natural gas pipeline (SCP) were designed in such a way that they significantly reduce the risk posed by the newly-identified geohazards in the vicinity of the Abuli-Samsari Ridge. No new measures are recommended for the pipeline itself as a result of this study. However, since the consequences of long-term shut-down would be very damaging to the economies of Western Europe, we conclude that the regionally significant BTC and SCP warrant greater protections, described in the final section of or work. The overall objective of our effort is to present the results in a matrix framework that allows the technical information to be used further in the decision-making process, with the goal of reducing the uncertainty in the final decision. This approach is applicable to the study of risks in other pipeline systems.



## 1. Introduction

Volcanic hazard assessment typically evaluates the risks posed to humans and the environment. However, the risk of volcanic activity to strategically-important human infrastructure must also be considered in hazard assessments. The volcanic risk posed to strategic pipelines, for example, was dramatically demonstrated by the 2002 eruption of Reventador Volcano in Ecuador. Lava flows from the volcano severed a Petro-Ecuador oil pipeline, producing a major oil spill and disruption of supply. The event also disrupted construction of the Oleoducto de Crudos Pesados pipeline in the same region (Porter et al., 2005). The Caspian region has the potential to become one of the major oil and gas producing areas in the world. Much of the production will come from the Baku region of Azerbaijan, in particular from the giant Azeri-Chirag-Gunashli (ACG) oil field that lies about 100 km off the coast of Baku, with about 5.4 billion barrels of recoverable petroleum.

The Republic of Georgia, situated in the central part of the Caucasian region, between the mountain ridges of Greater and Lesser Caucasus, provides a natural transportation and pipeline corridor from the Caspian region to the west. The Baku-Supsa (BS) and the Baku-Tbilisi-Ceyhan (BTC) oil pipelines, as well as the

* Corresponding author.
*E-mail address:* federico.pasquare@uninsubria.it (F.A. Pasquarè).

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Baku-Tbilisi-Erzerum South Caucasian natural gas pipeline (SCP) traverse the Caspian region through the Republic of Georgia (Fig. 1). Along this corridor through Georgia, both the BTC and SCP were designed to withstand seismic events. However, there is also a potentially significant volcanic and volcano-seismic hazard (Lebedev et al., 2003; Kuloshvili and Maisuradze, 2004), and recent data indicate that the hypothesis of a renewal of volcanic activity in the area cannot be ruled out (Chernyshev et al., 2006). Lava flows, tephra fall, landslides, and other volcanic hazards differ in their effect on surface facilities from the risks analyzed in the original design.

The likelihood of future volcanic, seismic, and related geohazards along the right of way for these strategic pipelines threatens these vital energy links. In addition to the risk of interrupted oil and gas supply, accidental releases could affect the springs and groundwater that supports the Borjomi bottled water industry in the area, as well as significant flora and fauna resources in the support zone of Borjomi-Kharagauli National Park (Blatchford, 2005).

Despite these threats, the nature of the volcanic and seismic hazard and corresponding mitigation measures have not yet been developed and understood. During a NATO-funded, two-year research project, we attempted to fill this critical gap through an international scientific cooperation aimed at assessing the volcanic and seismic risk in the Georgian section of the Caspian oil and gas pipelines and evaluating the need for additional protective measures for mitigating the consequences of potential volcanic and seismic events. We conducted our assessment of volcanic and seismic hazard in key areas of the active Abuli Samsari Volcanic Ridge (southern Georgia) by integrating the data derived from previous geologic, volcanologic, petrologic, radiometric and remote sensing works with our own data, collected during field surveys aimed at identifying the control of tectonics on the evolution of volcanism in the area.

The potential for an awakening of volcanic activity along the Abuli Samsari Ridge was not considered in the pipeline design, and the potential magnitude of seismic event and failure planes were not known with certainty. More recent study has identified the potential for both volcanic and seismic events at the northern end of the Abuli Samsari Ridge, and this study brings together the data in order to evaluate the adequacy of the existing pipeline protective measures to withstand the consequences of these events.

The potential need for enhanced pipeline design features or additional risk mitigation measures is frequently derived from analysis of compilations of accident data (for example, US DOT, 2005), supplemented by negotiated agreements with stakeholders and government agencies. This was the approach followed by BP in the design and construction of the BTC and the SCP pipelines (Blatchford, 2005). This approach is also well illustrated by the work done to support design and construction of the Trans-Alaska Pipeline (Johnson et al., 2003; Cluff et al., 2003) and the Sakhalin pipeline (Sakhalin Energy, 2010). These studies considered seismic risk and other geohazards, including post-construction pipeline evaluation following large earthquakes. This paper proposes a more transparent risk communication method for presenting the results of risk assessments, which allows a greater use of scientific information in the final decision-making process regarding acceptability of risks and consequences. The overall objective of this paper is to quantify the volcanic and seismic risks based on the previous literature and new field information, and to provide a risk management tool consisting of a matrix that ranks risks and mitigation strategies to reduce risks that is applied to re-evaluate the adequacy of the design and operation of the pipeline in light of the new risk assessment.

## 2. Geological and structural framework

The Republic of Georgia and nearby territories of Armenia, eastern Turkey, and northwest Iran represent a seismically active, geologically complex area located in the Alpine–Himalayan fold-thrust belt. From north to south, this area includes the following structural domains: The Greater Caucasus, the Transcaucasus, the Lesser Caucasus suture zone, the Izmir–Ankara–Erzincan suture zone, the east Anatolian microplate, the Bitlis-Zagros suture zone, and the Arabian plate (Fig. 1). The formation of this complex domain is related to the convergence and continental collision between the Arabian and Eurasian plates; some studies suggest that this continental collision began as recently as 10 Ma (Sengör and Kidd, 1979) or 5–3.5 Ma (Philip et al., 1989). The collision resulted in the lateral ejection of the Anatolian block westward and the Iranian block eastward (Ketin, 1948; McKenzie, 1972; Sengör and Kidd, 1979; Jackson and McKenzie, 1984; Dewey et al., 1986; Taymaz et al., 1991). Along with this process of lateral extrusion,

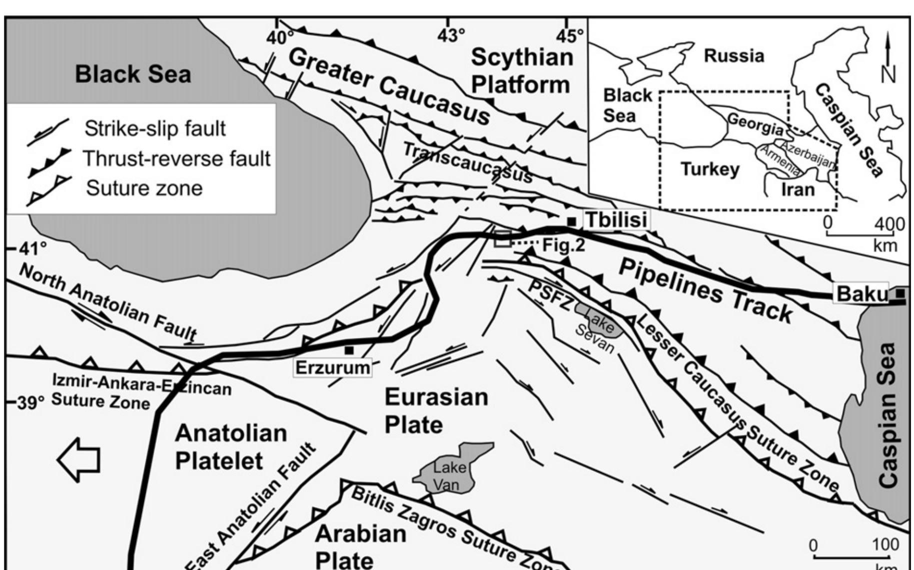


**Fig. 1.** Geodynamic framework of the Caucasian area with indication of BTC and SCP pipelines track. PSFZ = Pambak-Sevan Fault Zone. Redrawn after Koçyigit et al. (2001).