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Getting to the bottom of an old problem

by GRAHAM CHANDLER on JULY 10, 2017

The eastern Black Sea basement structure has long been debated. A recent project creatively combines old and new data—reflective and refractive seismic, and potential field—to form a new model.

The history and dynamics of the Black Sea basin formation have long been a topic of debate, largely due to a shortage of data. At the end of the 19th century it was popularly thought to be a gradually subsiding geosynclinal area. A later interpretation suggested it was the relics of oceanic crust formed as a result of the paleo-Tethys ocean closure.

By the late 1970s, a new concept was brought forward assuming the main mechanism of the Black Sea basin formation was horizontal crustal extension, localized rifting and further crustal basification.

The debate goes on. A key issue continues to be the presence of oceanic crust in both the eastern and western basins but existing interpretations of geophysical data had been ambiguous and inconsistent. It was time for a more accurate model particularly of the deep structure of the eastern Black Sea basin, based on an analysis of recent geophysical data in conjunction with available historical geological data.

Enter Geology Without Limits (GWL), a company with a new approach to regional integrated seismic exploration to extend current understandings of entire marine basins. The Moscow, Russia-based firm merges the expertise of a number of scientific institutions and organizations and applies cutting-edge geophysical technologies.

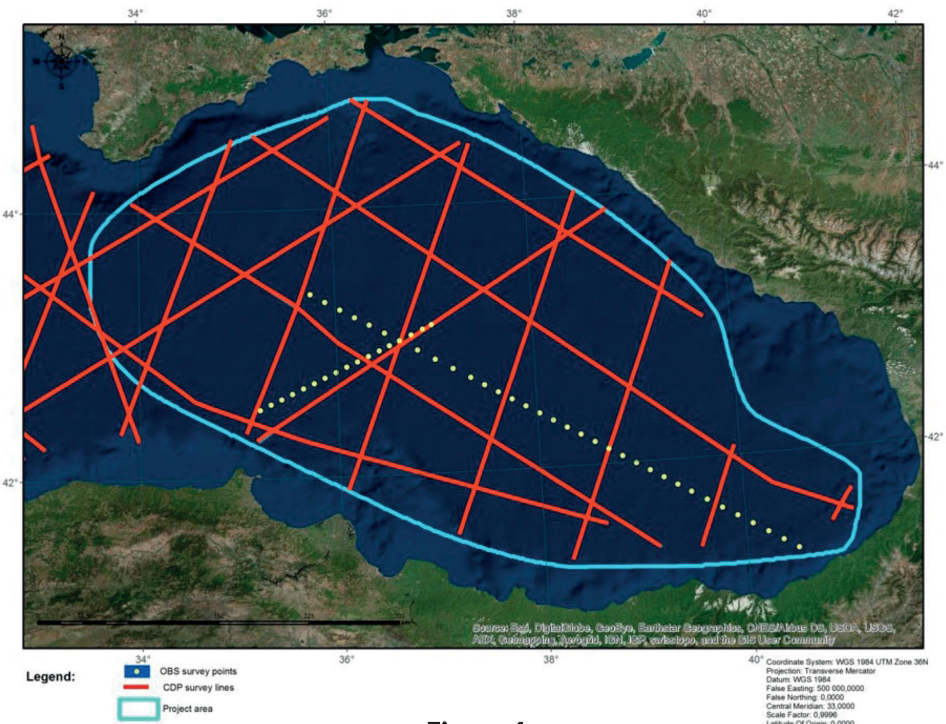


Figure 1

Project area map showing the survey data used in the study - Common Depth Point (CDP) survey data acquired by GWL in 2010 and Deep Seismic Sounding (DSS) survey data collected by the University of Southampton in 2005.

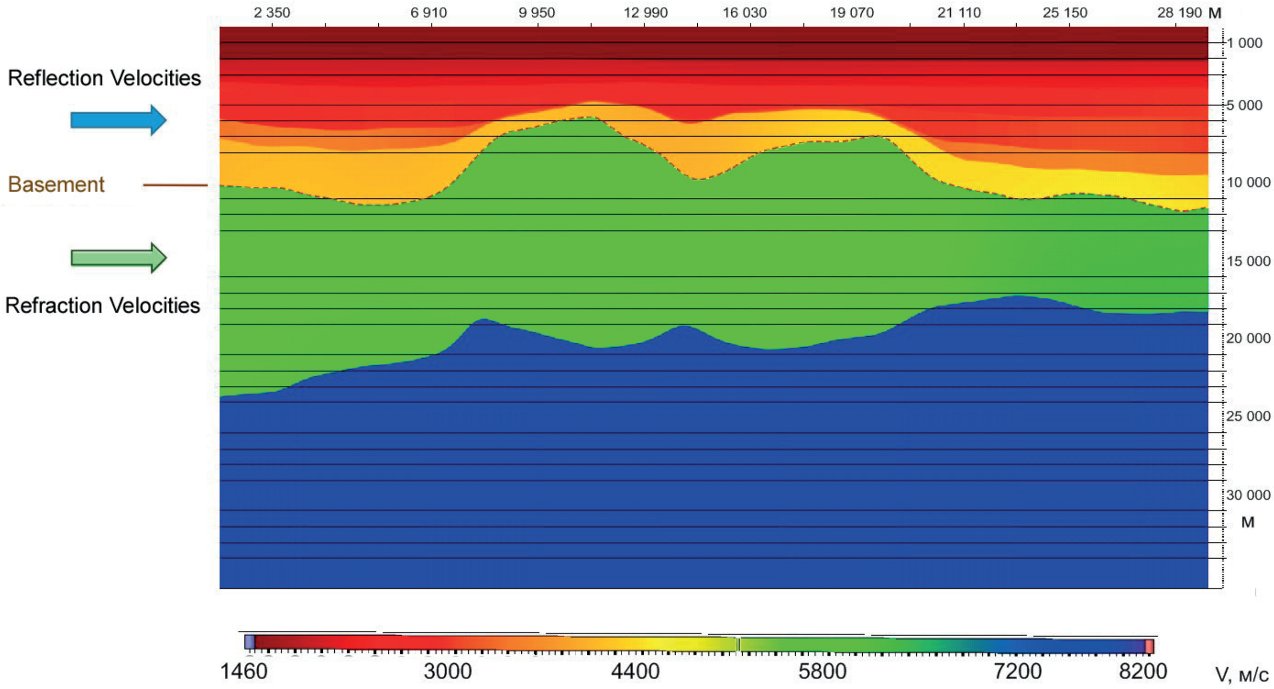


Figure 2

Velocity model derived from reflection velocities (smooth version) and depth section as a result of Pre-Stack Depth Migration (PSDM).

In 2015, one of its employees, Evgenii Grigoryev, was a doctoral student at Saint Petersburg State University needing a theme for his PhD research thesis. An ideal topic was to try and combine all available geophysical data, including potential field data, into one complex model of the geological structure of the eastern Black Sea basin. "It's very important to use all new and historical data to extract more information about it," says Egor Krasinskiy, deputy CEO and director of scientific cooperation at GWL.

And what was the best way to do it? "The most important tool for solving this problem was Geosoft Oasis montaj software, especially VOXI inversion technology," he says.

Drilling had been restricted to onshore and shallow water zones, so those data were of little use for studying the deepwater part of the basin. "There are only three boreholes, which were drilled as part of the Deep Sea Drilling Project in 1975," says Krasinskiy. Only one of those was in the eastern basin and it had just 624.5m of depth penetration within the sediment cover. "So geophysics remains the most useful dataset to understand/model the deep structure of the eastern Black Sea basin."

Some of the required seismic data resulted from a 2015 cooperative arrangement between GWL and the University of Southampton to investigate the geology of the Black Sea. In return for Common Depth Point (CDP) survey data acquired by GWL in 2010, GWL received four lines of Deep Seismic Sounding (DSS) survey data collected by Southampton in 2005. For the potential data, the marine gravity model of Sandwell v 23.1, derived from satellite altimetry was used, and for magnetic, the global Earth Magnetic Anomaly Grid EMAG3. It was noted however that the existing magnetic anomaly grid was insufficiently detailed and accurate within the boundaries of the Black Sea basin, which meant lower reliability of the magnetic data for interpretation schemes.

The first task was to test the technology of complex integrated processing of the CDP reflected wave data and the DSS refracted wave data in order to achieve a more detailed image of the seismic section in depth. The advantage of an integrated model created on the basis of data received by both CDP reflected and DSS refracted waves methods is that it allows a more detailed and accurate study of the deeper layers of a geologic profile—by enhancing the velocity model used for the depth migration of CDP data.

The integrated seismic model was created using an eight-step sequence starting with creation and iterated correction of a smooth velocity model on the basis of CDP data and transformation of the smooth velocity model (reflected waves) into a layered one. Reprocessing of seismic profiles in this sequence enabled definition of the sedimentary cover horizon surfaces and of the acoustic basement geometry, providing a depth structure map of the top of the acoustic basement.

Next came the density modeling. Based on previously obtained depth horizons of the sediments and the acoustic basement, the gravity effect of the sedimentary cover of the eastern Black Sea basin was calculated. In the absence of direct measurements, the sediments density were determined by applying velocity-density conversions. Different functions were considered to find the optimum density model for the sediments. Final selection of densities for individual horizons of the sedimentary cover was based on the correlation of the velocity-density conversion and published data on petrophysical properties of the rocks in the surveyed region. Then the effect of the bathymetry, or water-sediment density contrast, was calculated using Geosoft GM-SYS 3D.

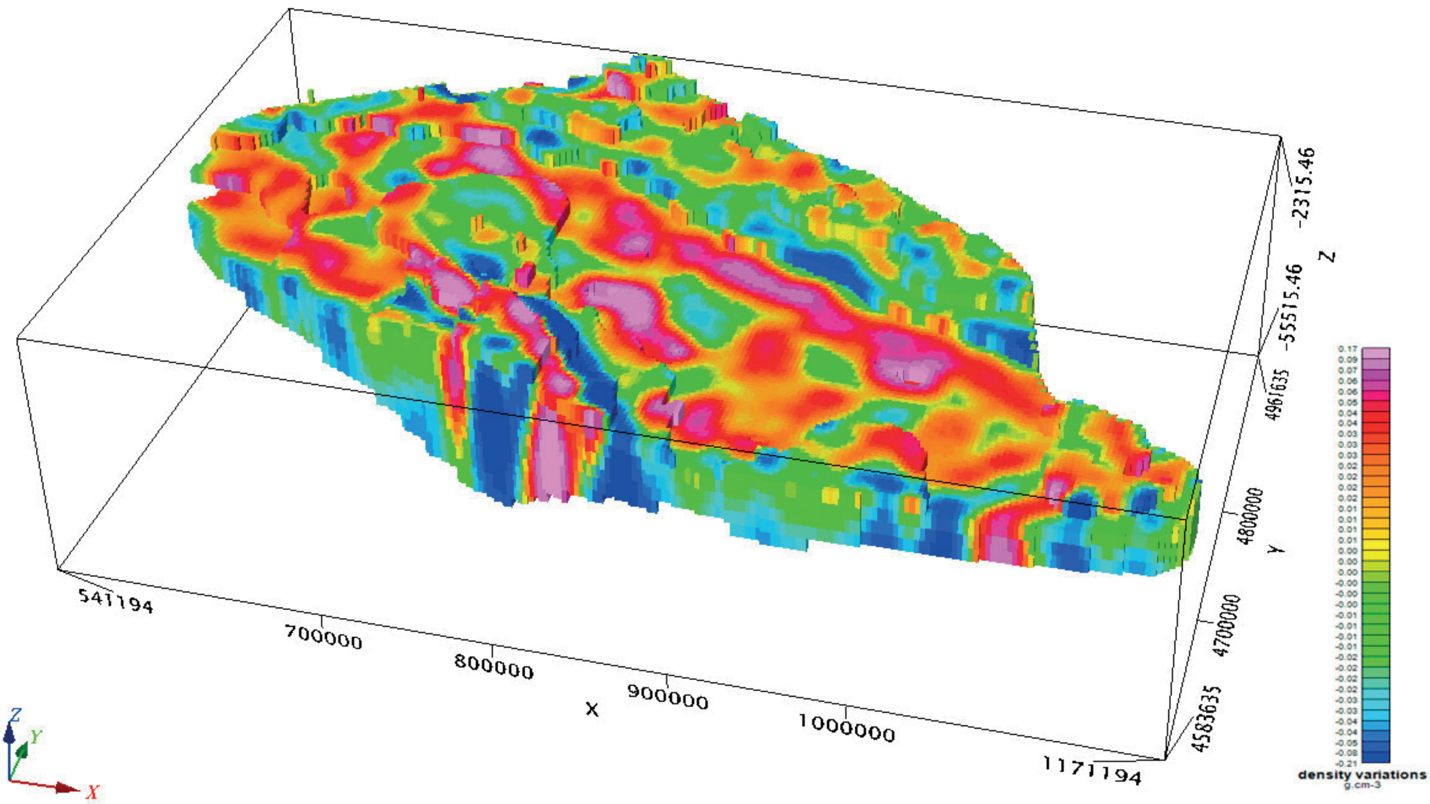
Finally Geosoft VOXI Earth Modelling was used to invert the residual gravity anomaly and recover a 3D distribution of density (Figure 3), which in turn helped mapping crustal types over the area. The inversion was constrained between seismic acoustic basement and Moho inferred from refraction/reflection.

The final result addresses a key issue pointed out earlier: is the oceanic crust present in both the eastern and western basins? This study showed no evidence of seafloor spreading in the eastern Black Sea basin. The researchers assumed the presence of a highly rifted basalt-rich crust in this basin, which was generated by the influence of permanent low power upward mantle flow. Analysis of seismic data showed rising of the Moho boundary, and abrupt thinning of the continental granite-metamorphic crust (Figure 4).

So, using their integrated analysis of CDP, DSS and public domain potential field data they proposed an updated interpretation of the nature and geometry of the eastern Black Sea crystalline basement—suggesting the presence of a thinned continental crust in the central, or axial, zone of the eastern Black Sea basin. This interpretation mainly differs from more regional analysis by the absence of oceanic

Figure 3

Density variations distribution recovered through inversion in VOXI Earth Modelling.



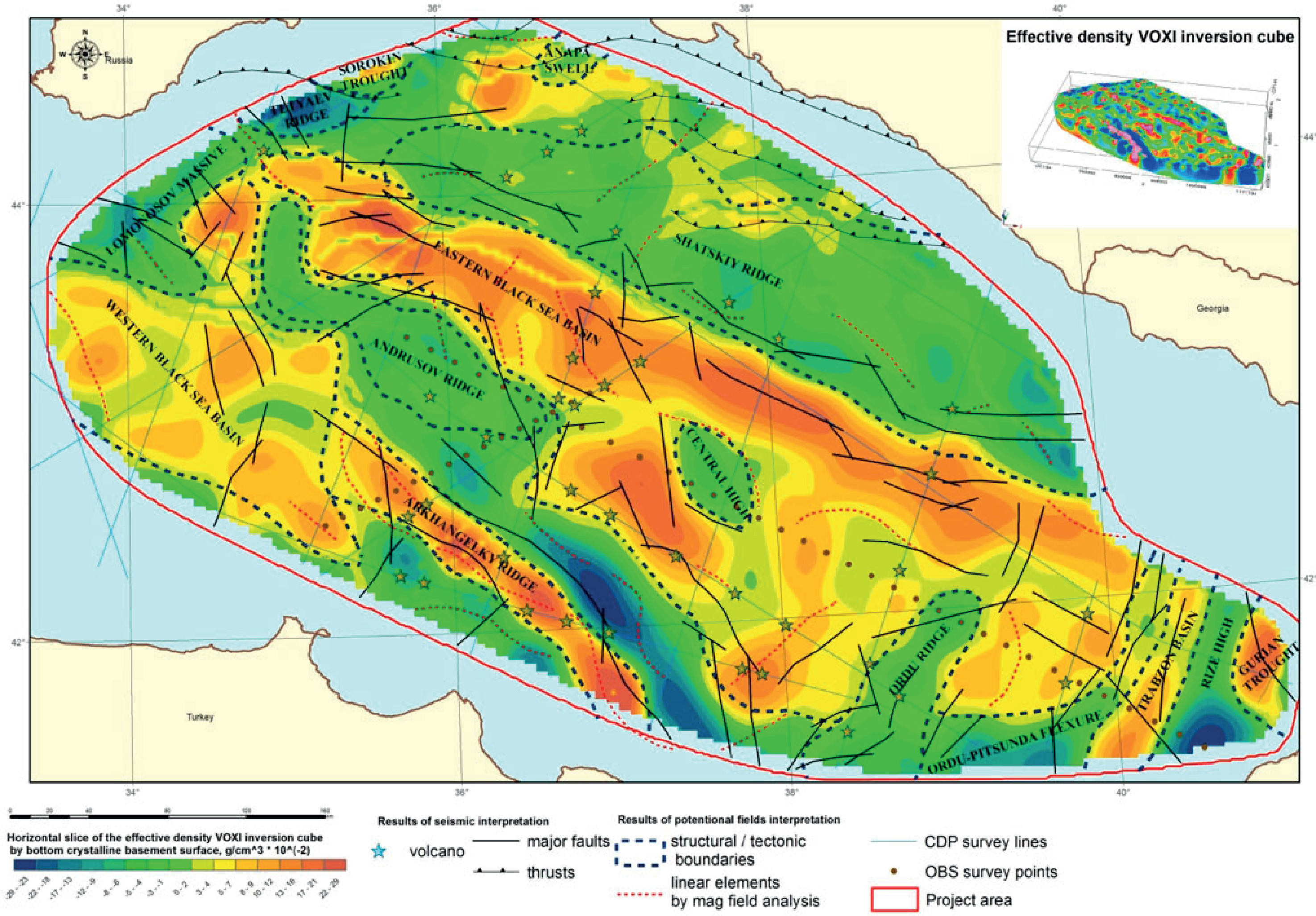


Figure 4

Horizontal density section at basement depth. The final density model suggests a significant increase in the density over late Cretaceous basement within the Eastern Black Sea basin, over the Arkhangelskiy ridge, and within the Western Black Sea basin.

crust within the eastern Black Sea basin, and a more accurate delineation of boundaries of the crystalline basement structural elements.

Krasinskiy says the project had its challenges. “The most complicated task was to create the geological-geophysical model of the region,” he says. “We had to match all known petrophysical parameters of sedimentary and basement rocks, information about effective density, velocity and magnetic susceptibility distribution and fit it to observed fields and geometry of seismic horizons.”

He is pleased with Geosoft software’s capabilities in meeting those challenges. “First of all, in our experience Geosoft Oasis montaj is the most practical software for processing and interpretation of gravity and magnetic field data,” he says. “The advantage of using Geosoft GM-SYS 3D, and Geosoft VOXI is the possibility of an integrated analysis of potential fields and seismic data. We used GM-SYS 3D for calculation of the gravitational effect of layers of sedimentary cover, and Geosoft VOXI for inversion of potential fields data, using different seismic a priori information.”

Krasinskiy says the integrated analysis of CDP, DSS and potential fields data allowed mapping regional patterns and updating the nature of the eastern Black Sea basement (Figure 5). He says this included determination of the horizontal position and depth of the submerged blocks of sub-continental crust: the

Shatsky Rise, the Andrusov Rise, the Arkhangelsky Ridge, the Ordu Ridge, and local elements of the eastern Black Sea basin tectonic structure. There is more possible in future. "In further works we will try to create a paleodynamic reconstruction of the Cretaceous and Post-Cretaceous," he adds.

The program was more than an academic exercise; the Black Sea has immense oil and gas potential. The Turkish Petroleum Company has estimated there may be as many as ten billion barrels of oil in the area. The sea borders on Romania, Bulgaria, Turkey, Ukraine, Georgia and Russia; all of which have undertaken exploration programs. The latest is Black Sea Oil & Gas, which in April this year contracted to drill two exploration wells in the Romanian sector.

"Our study was not directly related to hydrocarbon investigations," says Krasinskiy. "But reconstruction of geodynamic conditions of the eastern Black Sea basin formation could give us an opportunity to make assumptions about sedimentation parameters and potential hydrocarbon resources in further works."

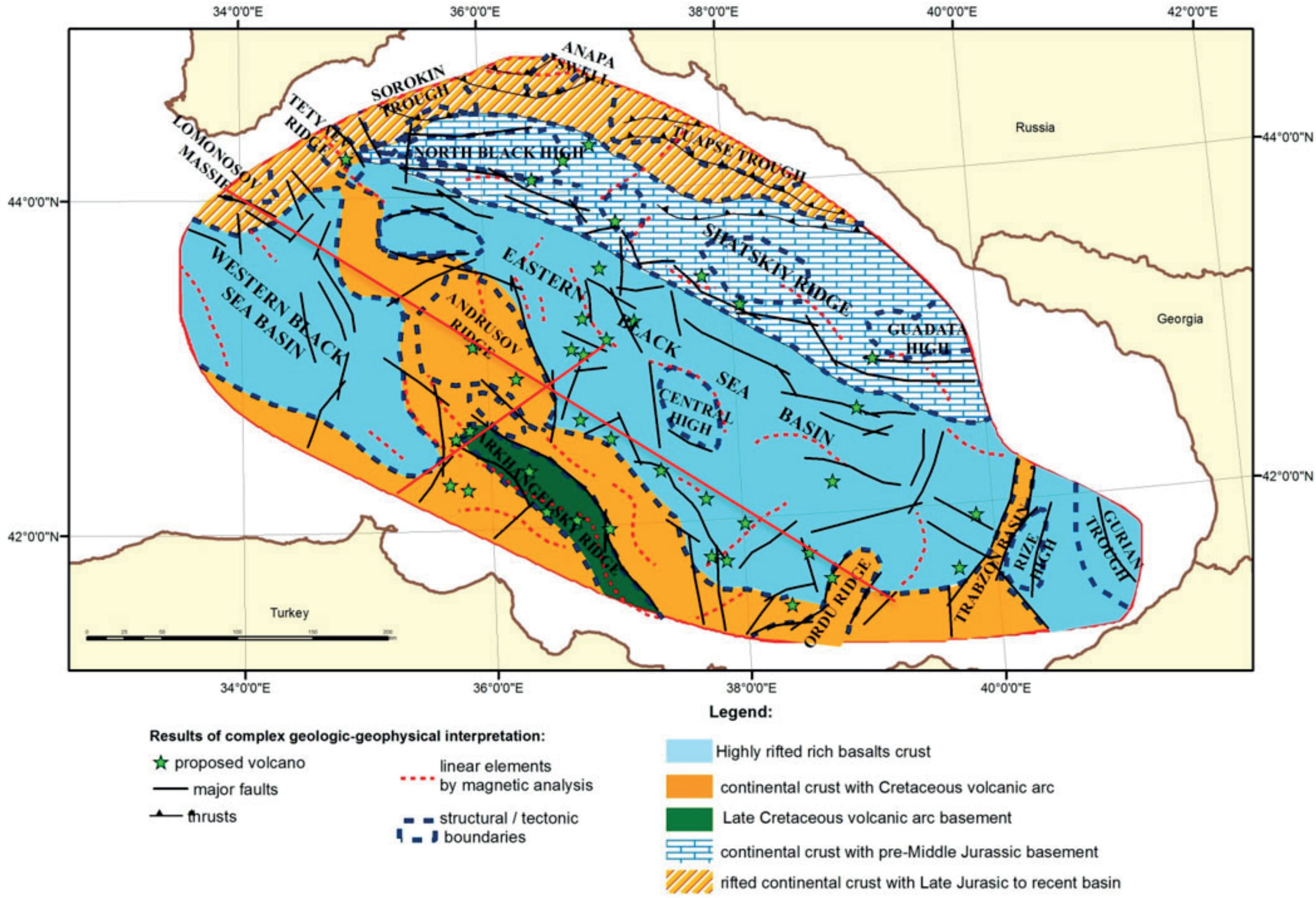


Figure 5

Seismic and gravity interpretation are combined to produce this interpretative map of the basement structure and crustal zoning.