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DYNAMICS and ACTIVE PROCESSES: The ALBANIAN NATURAL LABORATORY and ANALOGUES

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1- Introduction

This special issue of the Italian Journal of Geosciences provides a selection of 7 papers which have been presented during the sixth workshop of the ILP Task Force on Sedimentary Basins, hosted at the Polytechnic University of Tirana on November 7-12, 2010. More than 100 Earth scientists, professionals and students participated to this workshop, including 70% of Albanian colleagues, mainly from the Polytechnic University, geological survey, academy and oil industry, and 30% of participants from universities, research centers and companies from other European countries (Austria, Belgium, France, Germany, Italy, the Netherlands, Romania, Switzerland), as well as North and South America and the Middle-East. Plenary sessions and further discussions during the pre- and post-conference field trips (Figure 1), were dominantly focused on Albania, which, thanks to its extensive petroleum exploration and modern seismological and GPS networks, constitutes the best documented natural laboratory for the study of active onshore compressional systems in Europe.

This conference generated excellent discussions on the 3 main topics developed below.

2- Geodynamic evolution and paleogeography of Albania and adjacent Offshore

Numerous oral presentations and posters focused on the overall tectono-stratigraphic evolution, crustal architecture of the Albanides and adjacent Adriatic Offshore as well as their relationships with the Dinarides and Italian counterparts, which are well documented by a wide set of seismic profiles and exploration wells from the industry (see for instance Roure et al., 1995; Nieuwland et al., 2001; TRANSMED transect III in Carminati et al., 2004 and Cavazza et al., 2004a & b; Roure et al., 2004, Schmid et al., 2008; Matenco and Radivojevic, 2012; and references therein).

Regional studies have shown that the Albanian foothills result from the Neogene deformation of the former eastern passive margin of Apulia. Located west and south of the Mirdita ophiolite and the Kruja Zone (Fig. 2), the outer zones of the Albanian thrust belt are subdivided in two very distinct tectonic provinces by the NE-trending Vlora-Elbasan lineament, with up to 10 km of Oligocene to Plio-Quaternary clastics being still currently preserved in the Peri-Adriatic Depression in the northwest, and Mesozoic carbonates of the Ionian Zone being directly exposed at the surface in the south. As evidenced on seismic profiles, the main décollement level is localised within Triassic evaporites and salt in the south, ramp anticlines accounting for the tectonic uplift of Mesozoic carbonates in the Ionian Zone, whereas it is located within the Cenozoic clastics in the north, where no carbonate reservoirs are exposed at the surface (Fig.3). Accordingly, the Vlora-Elbasan transfer zone,

which is still seismically very active (Aliaj et al., 2000; Papazachos et al., 2001; Jouanne et al., 2012), is best described as a lateral ramp connecting these two distinct décollement surfaces (Roure et al., 1995).

The tectono-stratigraphic evolution of the outer Albanides can be summarised as follows.

Evolution of the Adriatic passive margin and deposition of carbonate reservoirs:

Presently situated at the transition between two major orogenic belts, the Hellenides and the Dinarides, the kinematic evolution of the Albanides demonstrates common causalities during the opening and closure of the same major oceanic embayment, i.e. the Neotethys (e.g. Schmid et al., 2008; Robertson et al., 2011). The rifting of the Neotethys that started during Middle Triassic times was associated with the emplacement of significant acid to intermediate volcanism (e.g., Monjoie et al., 2008). It also led to the formation of an extensional system that deposited Upper Triassic to locally Cretaceous deep water dominantly carbonatic but also clastic sediments in subsiding grabens, while Upper Triassic to locally Eocene shallow water carbonates reaching more than 2 km dominated the basins highs (e.g., Vlahovic et al. 2005; Cadjenovic et al., 2008). The facies furthermore deepens northwards towards the internal units of the Dinarides, Albanides and Hellenides, where deep-water radiolaritic sedimentation was deposited directly over the oceanic crust presently exposed as Jurassic obducted ophiolites or as Triassic blocks in ophiolitic melanges (e.g. Gawlick et al., 2008; 2009; Vishnevskaya e.g., 2009; Saccani et al., 2011). The contractional history started with the late Jurassic-earliest Cretaceous ophiolitic obduction and was followed by Cretaceous-Eocene moments of thin-skinned thrusting and nappe emplacement (e.g. Schmid et al., 2008; Schlagintweit et al., 2008; Meshi et al. 2010; Robertson et al., 2010). Thin-skinned thrusting continued during Neogene times with offsets gradually increasing along the strike of the orogenic belt from the Dinarides to Albanides and Hellenides. At the same time, the thrusting was accompanied by Neogene back-arc collapse that is recorded along the strike of the entire orogenic belt (e.g., Muceku et al., 2008; Jolivet et al, 2010; Schefer et al., 2011; Jouanne et al., 2012; Matenco and Radivojevic, 2012).

In the external Albanides, the Middle Triassic (late Anisian) onset of the opening of the Neotethys created a system of local Late Triassic to Liassic tilted blocks and grabens, thick organic-rich limestones and dolomitic platform carbonates characterising the paleo-horsts, whereas deep-water facies such as Liassic black-shales (Posidonia shale) were deposited in the grabens (Zappaterra, 1994), thus accounting for the two main source rocks intervals of the basin. Post-rift thermal subsidence resulted in the deposition of deepwater cherts during the Middle and Upper Jurassic in the Ionian Basin, whereas prograding Cretaceous carbonate platforms from the Kruja Zone in the east, and from the Sazani Zone in the west, contributed as a distal source for the thick carbonate turbidites deposited in the Ionian Basin during the Late Cretaceous and Paleocene (Vilasi, 2009, Vilasi et al., 2006, 2009). These turbidites, which reworked platform carbonate material (Van Geet et al., 2002), are interbedded within finer grained pelagic carbonates, and constitute the main hydrocarbon reservoirs onshore Albania, but also offshore in the Italian part of the Adriatic Sea.

Foothills development and sedimentary records of the deformation:

Up to 10 km of synflexural and synkinematic siliciclastic series have been deposited in the Peri-Adriatic Depression, ranging from near-shore and littoral facies in the east and south, toward deeper water and turbiditic facies in the north and in the west (offshore), providing a

unique and continuous sedimentary record of the deformation (Fraseri et al., 1996). Sequence stratigraphy and biostratigraphy by means of foraminifer and nannoplankton in pelagic facies are able to provide accurate correlations of very good resolution for the dating of geologic events in this basin:

Tectonic loading applied by the hinterland (Mirdita ophiolite) from the Upper Cretaceous onward and westward thrusting of far travelled basinal units of the Krasta Zone induced the progressive development of a wide flexural basin, which ultimately impacted the outer Albanides lithosphere in Oligocene times.

Growth anticlines started to develop in Late Oligocene-Aquitainian in the Ionian Basin (Nieuwland et al., 2001), accounting for the development of Burdigalian reefal facies and paleo-karst at the crest of the Kremenara anticline, this main episode of shortening being sealed by Langhian-Serravalian clastics (Van Geet et al., 2002).

The second episode of tectonic shortening is best documented near the Vlora-Elbasan transfer zone (Roure et al., 1995; Argnani, this volume) and farther north in the Peri-Adriatic Depression, where Pliocene backthrusts account for major lateral and vertical offsets of a pre-Messinian erosional surface. Although Neogene deposits are mostly absent from the Ionian Zone itself, it is obvious that this post-Messinian tectonic episode strongly affected also the southern part of the Albanian Foothills.

Apart of thrusting and development of ramp anticlines, these Neogene episodes of deformation have also contributed to remobilise former salt diapirs, i.e. in the Dümre area (Fig. 2; Jardin et al., 2011), where an allochthonous salt unit has been thrust along a low angle fault over underlying carbonate duplexes and deformed Cenozoic clastics.

Further details and a good illustration of the lateral changes observed in the structural style and its paleogeographic controls along the Albania Coast are provided by **Andrea Argnani (2013)** in the first paper of this special issue.

Post-nappe refolding of the Mirdita allochthon was already documented by Collaku et al. (1990), who identified a wide tectonic window where the Oligocene flysch and Triassic diapirs of the Outer Albanides crop out again in the core of a wide nappe anticline located within the hinterland domain, east of the Mirdita ophiolite. However, new apatite fission tracks and (U-Th)/He thermo-chronology from the Mirdita allochthon (Muceku, 2006; Muceku et al., 2006) have now provided also evidence for the early unroofing of the hinterland, which indeed predates the thrust emplacement of the allochthon over the Outer Albanides. The western Internal Albanides are characterised by slow cooling and low exhumation rate (0.1 km/my) throughout the Late Eocene that are related to isostatic uplift as a consequence of crustal thickening near the frontal thrust.

Apart of providing new challenges for Topo-Europe (Cloetingh and Topo-Europe team, 2007), such paleo-topographic constraints may open new perspectives for the exploration of sub-thrust units located east of the Kruja front as they may have escaped cracking beneath a thinner-than-expected allochthon. Proper risk appraisal would however still require to perform a complete coupled kinematic and thermal modelling across the Inner Albanides, using these new data, in order to reconstruct the complete burial and maturation history of potential source rocks in the underthrust foreland (Lacombe et al., 2009; Roure et al., 2010a & b).

3- Seismic hazards and present day topography of Albania

Albania as a whole is still a very active tectonic province, and since a long time, Albanian geophysicists have build a national seismologic network and documented the most active areas (Aliaj et al., 2000; Sulstarova et al., 2003). Paleomagnetic data have also documented a strong decoupling of the Ionian allochthon and its progressive rotation with respect to the stable Adriatic foreland (Speranza et al., 1992, 1995).

Two projects supported by NATO (Science for Peace Programme) have also provided new information on tectonically active features of the Albanian foothills, providing an updated synthesis on the gravimetry (Fig. 4), current seismicity, focal mechanisms, recent deformation and uplift of river terraces as well as GPS measurements (Papazachos et al., 2001; Muco et al., 2002a & b; Kiratzi and Muço, 2004; Guzman et al., 2011; Jouanne et al., 2012).

Alltogether, the focal mechanisms of Albanian earthquakes and the new GPS data outline three distinct tectonic provinces in Albania, i.e. (1) the relatively stable foreland in the Adriatic Offshore, (2) the still active compressional system of the Outer Albanian Foothills, and (3) a currently extensional domain that extends over the former hinterland units, near the Macedonian and Greek borders, in relation with the opening of the Aegean back-arc system.

Within this overall background, the second chapter of this issue is dedicated to the seismic hazard in Albania. It starts with a summary of the focal mechanisms and slip models of moderate size earthquakes in Albania and adjacent counties by **Anastasia Kiratzi (2013)**, and probabilistic seismic hazard assessment in Albania by **Bettim Muco (2013)**.

This chapter comprises also a detailed discussion of 2009 Albanian earthquakes by **Ormeni et al. (2013)**, as well a discussion on liquefaction probability of non-cohesive soils in Semani area by **Daja et al. (2013)**.

4- Petroleum systems and HC exploration in the Albanides and adjacent Adriatic Offshore

Albpetrol and the Albanian Petroleum Institute in Fieri have studied since a long time the petroleum occurrences and petroleum systems of the Outer Albanides, even before the opening of the country to foreign exploration companies (Curi, 1993; Frasheri, 2005, and references therein). However, further objectives in subthrust carbonate units have not yet been tested in Albania, making this country still attractive for the exploration (Bega, 2010).

IFP-EN and the Albanian Petroleum Institute in Fieri initiated extensive collaboration in the 90's, which resulted in the review of the petroleum potential and the co-organization of a field trip for the AAPG in 1995 (Roure et al., 1995). From 1996 to 2002, collaborative studies dedicated to the prediction of reservoir characteristics, coupling both petrographic work and basin modelling, have been the driving force of the SUBThrust Reservoir Appraisal joint industry project (SUBTRAP Consortium; Roure et al., 2005), with case studies dedicated to sandstone reservoirs in Sub-Andean Basins in Venezuela and Colombia, and to carbonate reservoirs in Pakistan, Mexico, Canada, as well as in Albania. During the Albanian part of the SUBTRAP project and more recent collaborations with the Albanian Petroleum Institute and Geological Survey, as well as with the university of Tirana, Triassic dolomites (Muska, 2002) and Upper Cretaceous carbonate turbidites (Swennen et al., 2000; Van Geet et al., 2002; Vilasi, 2009) have been extensively studied. We have also extended the quantification to kinematic and sedimentary modelling in the Outer Albanides by coupling Thrustpack with Dionisos, as well as to fluid flow, pore fluid pressure and hydrocarbon migration modelling with Ceres (Vilasi, 2009; Vilasi et al., 2006 and 2009; Roure et al., 2010a & b; and references therein).

In addition to the oral presentations which documented the results of these already published petroleum modelling studies, the last Chapter of this issue is dedicated to the petroleum systems of Albania, with a special focus on the geochemistry of the various families of Albanian oils by **Irakli Prifti and Kristak Muska (2013)**, and on the overall characteristics of Neogene clastic reservoirs of the Vlora-Elbasan region by **V. Silo and others (2013)**.

5- Conclusions

The final discussion of the ILP Conference in Tirana focussed on on-going projects and perspectives for further international collaborative and integrated projects aiming at the study of the Albanian natural laboratory.

Because Albania is still tectonically very active, it has a very long historical record of earthquakes, and it is very important to secure here for the long term the instrumentation and recording of such natural hazards with a dense network of seismometers and GPS stations.

Field studies dedicated to the search for surface ruptures in the vicinity of major earthquakes are also likely to provide a better understanding of active faults, whereas the integration of both onshore and offshore high resolution seismic profiles recorded by the industry are expected to provide direct constraints on the average velocity and long term history of faults which have been active since the Plio-Pleistocene.

In the perspective of the Topo-Europe initiative, Albania is likely to become one of the most federative arena for the study of active tectonics and vertical motion, with quite challenging questions to be solved. Among others, one very intriguing question is to know how and where does operate the decoupling between the western compressional domain, which extends from the foothills to the Adriatic and Ionian offshore, and the eastern extensional domain, which develops in the hinterland, from the crest of the Mirdita ophiolite to the Macedonian and Greek borders.

TerMex (Terra Mediterranean Experiment) network is also likely to provide soon new opportunities for dedicated training and collaborative work for earth sciences projects aiming at societally relevant topics such as natural hazards, energy and water resources, paleoenvironment and paleo-climate, multi-national databases and long term monitoring.

ICDP plans for drilling in the Ohrid Lake are also expected to generate a strong network among the international earth sciences teams but also among the biodiversity and paleoclimate scientific communities (Hoffmann et al., 2009; Wagner et al., 2009).

Last but not least, the Geological Society of Albania is now holding the flag of the Carpatho-Balkan association, and will host its next meeting in 2014 in Tirana.

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8- Figures caption

Figure 1: Group picture of the participants to the post-conference field trip in the Ionian Basin from Vlora to Saranda and back to Tirana via Girokastra.

Figure 2: Schematic map of the Adriatic Offshore and Albanides..

Figure 3: Regional cross-section in the Outer Albanides, outlining the basal intra-Triassic decollement level, as well as the results of an integrated petroleum modelling with Ceres (modified after Vilasi et al., 2009).

Figure 4: Bouguer anomaly map of Albania (after Alba-Seis, Kiratzi and Muco).



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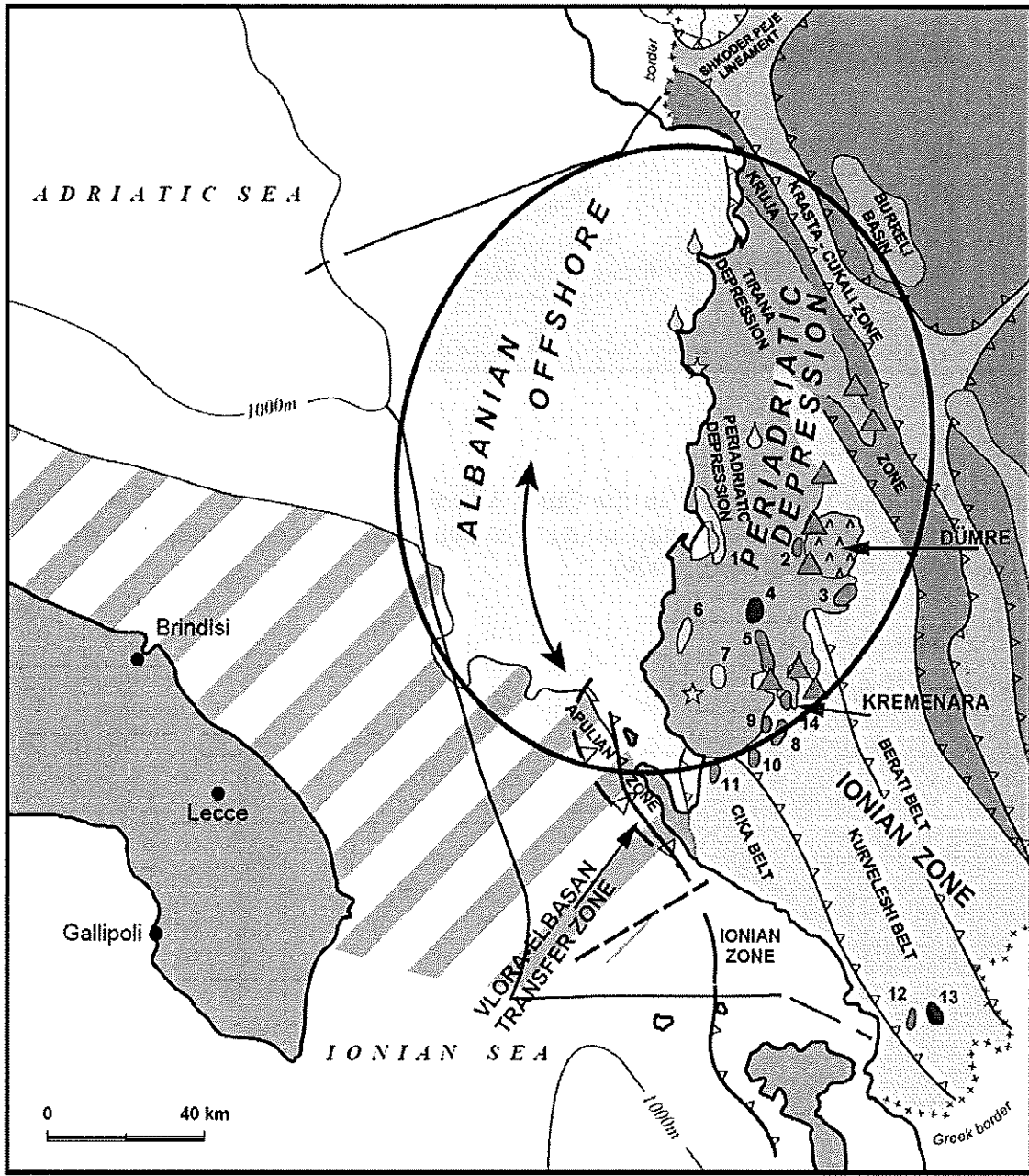


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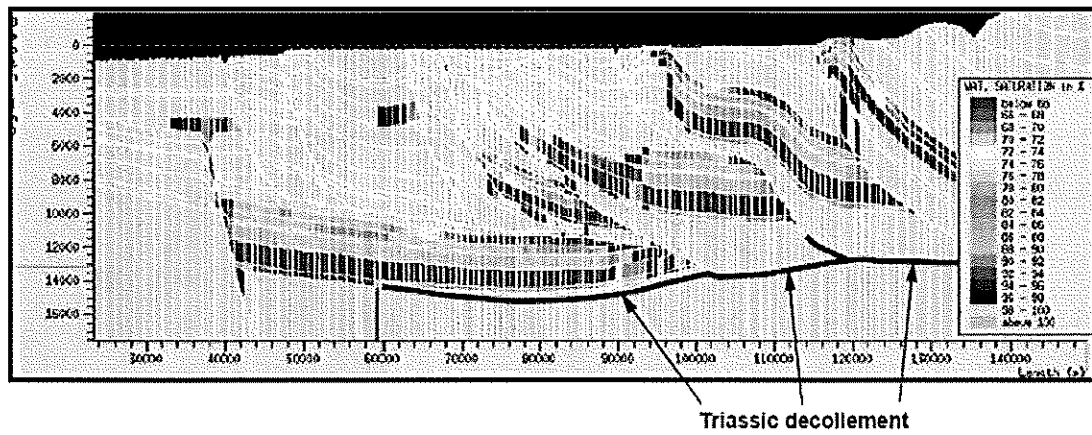


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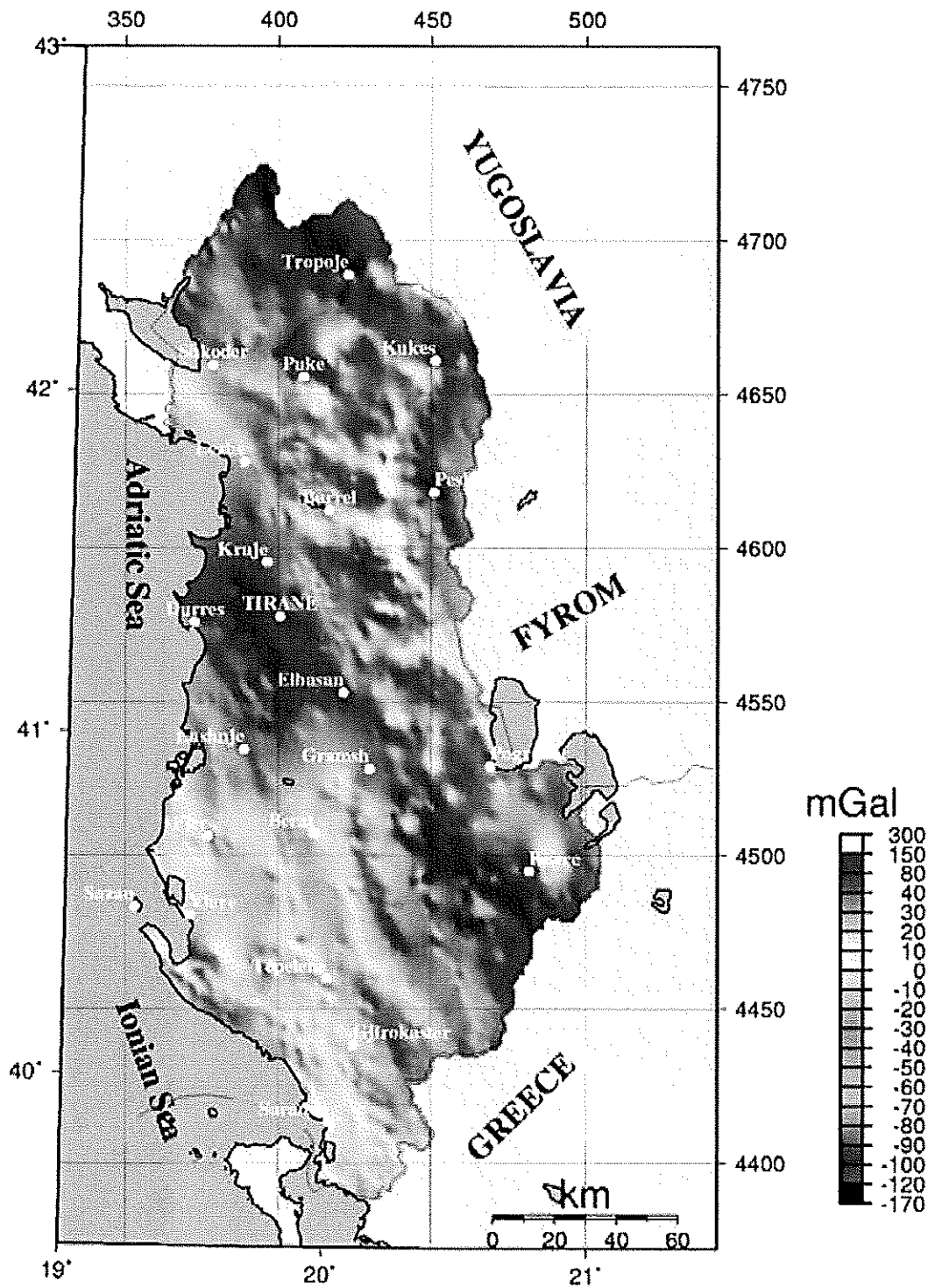


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