Neotectonic study of Northwestern Greece

Dimitrios Ntokos

School of Mining and Metallurgical Engineering, National Technical University of Athens, Athens, Greece; Department of Civil Engineering, School of Engineering, University of Thessaly, Volos, Greece

ABSTRACT

In this paper, a neotectonic map with active faults, at a scale of 1:500,000, of the northwestern Greece is presented and discussed. The elaboration of the Neotectonic Map chiefly aimed at the identification, mapping and assessment of the faults in the region of Epirus, for the added purpose of assessing the area’s seismic hazard. To this end, the related research was largely directed to the detailed study of the tectonic structures, which were classified as active, potentially active and non-active (or unknown age). It is noted that the activity of many old structures continues to this day, as shown by the Neotectonic analysis, in conjunction with the region’s seismicity. The presence of extensive scree deposits on the hanging wall of many faults also indicates their re-activation. For the final compilation and presentation of the map, geological, geomorphological and seismological data were used and assessed. The objective of this map is to provide information about the neotectonic evolution of northwestern Greece.

1. Introduction

Neotectonic mapping is an important tool for reconstructing both long-term and short-term neotectonic evolution and for assessing an area’s seismic hazard. The present study aims at a better understanding of the neotectonic regime of Northwestern Greece during the Plio-Quaternary through neotectonic mapping at 1:500,000 scale.

Greece is known for the frequent occurrence of earthquakes throughout its territory. Cities keep expanding at an unusually high rate, in most cases lacking proper urban development designs, and pay a high price for it when earthquakes hit and cause extensive damages, loss of lives and major social and financial problems. It is now understood that a seismic design, covering the entire Greek territory, is absolutely necessary. A key step towards protection and prevention of the disastrous consequences of earthquakes is the compilation of Neotectonic Maps.

Northwestern Greece covers an area of 9203 km², extending over 100 × 150 km, occupying 7% of the Greek territory and is located by the Ionian Sea (northwestern Greece), in a tectonically active area (Figure 1). Four neotectonic zones (Subpelagonian, Pindos, Gavrovo, and Ionian) develop in this area (Bornovas & Rondoyanni-Tsiambaou, 1983; Ntokos, 2017a, 2017b), overthrusting one another, due to compressional stresses of NE-SW direction. Post-alpine sediments, mainly of Neogene and Quaternary age, have been deposited on the geological formations of these neotectonic zones (Ntokos, 2017a, 2017b). Normal, reverse, and strike-slip faults with main directions NNW-SSE, NE-SW, and E-W have influenced the geological formations. In geomorphological terms, the area is identified by its uneven terrain, dominated by the Pindos Mountain Range (Smolikas, 2637 m). Its drainage network is formed by the following main rivers: Aoos, Arachthos, Kalamas, Louros, Acherontas, as well as other minor streams and torrents (Ntokos, 2017c, 2018).

2. Methodology

For the purposes of the research and in the scope of neotectonic mapping and field works, the following tasks were performed (Figure 2): (a) field observations of lithological units, tectonic structures and the relations between them, (b) identification of geological formations, (c) measurements of the strike and dip of geological formations, and (d) measurements of the geometric elements (strike, dip, and pitch) of tectonic structures (overthrusts, thrusts, and faults). All the above steps produced valuable information, leading to a better understanding of the region’s geodynamic evolution.

Observations and measurements were made along the length of major tectonic structures, providing a better illustration of the geodynamic regime of northwestern Greece, as well as smaller structures of particular interest, which as a whole help draw safer conclusions as to the distribution of stresses.
Taking into account, the classifications of faults throughout the Greek territory and particularly those proposed by the Earthquake Planning and Protection Organisation (EPPO – OASP; source: www.oasp.gr), by Pavlides, Chatzipetros, and Valkaniotis (2007, 2008), Pavlides, Valkaniotis, Chatzipetros (2007) and Rondoyanni, Lykoudi, Triantafyllou, Papadimitriou, and Foteinos (2013), the tectonic structures of northwestern Greece were divided into three categories as follows:

- **Active tectonic structures:** These are tectonic structures, which were either formed or re-activated, with substantiated displacement, from the Upper Pleistocene until present (aged < 120,000 years). These structures have a potential for future activation and present geometric and kinematic features consistent with the active stress field.

- **Potentially active tectonic structures:** These include the tectonic structures which were formed or re-activated during the Quaternary Age (aged between approximately 120,000 and 2,000,000 years). In some cases, depending on the current stratigraphy, potentially active structures also include structures activated during the Upper Pliocene.

- **Non-active tectonic structures or structures of unknown activity:** Structures falling under this category have not been activated since the Upper Pliocene and therefore present no chance of re-activation or, in some cases, they cannot be assessed due to insufficient data.

It is noted that the seismic tectonic structures are not mentioned as a separate class of the active ones, as in this area, there are few cases of seismic faults.

The data gathered from the measurements were computer processed, by use of the WinTensor 5.0.1 software by Damien Delvaux (Delvaux, 1993; Delvaux & Sperner, 2003; Delvaux, Moeys, Stapel, Melnikov, & Ermikov, 1995; Zain Eldeen, Delvaux, & Jacobs, 2002), and produced resulted to the determination of the tectonic stresses, responsible for the faults reactivation.

In order to produce the neotectonic map, a Geographic Information System (GIS) spatial database was designed, organized and implemented using the
ArcGIS 10.3 software (source: www.esri.com) aiming at the creation of a number of thematic and synthetic layers and maps in a common projection system Hellenic Geodetic Reference System 1987 – HGRS’87 – Greek Grid.

Specifically, input data were analogue maps, which were scanned and georeferenced in the Greek Grid. These data were the source for the creation of the primary thematic layers (with point-to-point on screen digitizing). Moreover, all the information gathered from the field work was added to such data, while through the algorithm in ArcGIS 10.3 (e.g. ArcHydro), secondary layers (e.g. stream networks) were produced. The most significant layers include coastline, contour lines, elevation points, faults, thrusts, overthrusts, geological boundaries, geological formations, stream networks, and talus cones.

Results from the above methods were summarized in a 1:500,000 scale neotectonic map (Supplemental material: Neotectonic Map of Northwestern Greece, Main Map). Notably, the background of this map is the area’s terrain in 3D form, as produced by the ArcGIS software, for the reader’s improved understanding and the optimum illustration of the real picture.

3. Data

The data presented in this work were acquired through an integrated geological, neotectonic, geomorphological, and seismotectonic study. The field work and processing of the data, for the elaboration of the neotectonic map with active tectonic structures, was performed periodically during the years 2009–2015.
The data were supplemented and updated during the years 2015–2016.

The distinction of Neogene – Quaternary formations was made in accordance with the specifications of the Earthquake Planning and Protection Organization – EPPO for Neotectonic Maps. For the unification of pre-Neogene formations were used the geological maps of Institute of Geology and Mineral Exploration – IGME, in scale 1:50,000, Agnanda (Savoyat, Monopolis, Lalechos, Filippakis, & Bizon, 1970a), Arta (Latreille, Savoyat, Monopolis, Bizon, & Bizon, 1969), Vassilikou-Pogonian (Perrier, Koukouzas, Perrier, & Bizon, 1973), Vonitsa (Manacos, Skourtsi-Koronaiou, & Ioakim, 1996), Doliana (Perrier, Koukouzas, Bizon, & Bizon, 1968a), Thestepikon (Savoyat, Monopolis, Lalechos, Filippakis, & Bizon, 1963), Ioannina (Perrier, Potier et al., 1967), Kanallakion (Bizon et al., 1967), Klimatia (Perrier, Koukouzas, Lalechos, & Bizon, 1968b), Konitsa (Mavridis, Manacos, Skourtsi-Koronaiou, & Dimou, 1987), Metsovion (Brunn, 1959), Mirofillon (Manacos & Skourtsi-Koronaiou, 1983), Panayia (Koumantakis, Matarangas, Tsaila-Monopolis, Georgiadou, & Economou, 1980), Parainthia (Perrier, Katsikatsos, Lalechos, Filippakis, & Bizon, 1966), Parga (Perrier, Koukouzas, & Bizon, 1969a), Pentalofon (Brunn, 1960), Peta (Savoyat, Monopolis, & Bizon, 1966), Pramantla (Auboin, 1961), Raptopoulon (Savoyat, Monopolis, Lalechos, Filippakis, & Bizon, 1970b), Sayiadha (Perrier, Koukouzas, & Bizon, 1969b), Tsimadas (Perrier, Koukouzas, & Bizon, 1967a), Tsepelovon (Perrier et al., 1970), Filiates (Perrier, Koukouzas, & Bizon, 1967b) and Chioniades-Grammos (Plastiras, Tsaila-Monopolis, & Bizon, 1985) and geological map of recent research for northwestern Greece by Ntokos (2017b).

The topography obtained from the digitalization of topographic maps: Agnanda, Arta, Vassilikou-Pogonian, Vonitsa, Doliana, Thestepikon, Ioannina, Kanallakion, Klimatia, Konitsa, Metsovion, Mirofillon, Panayia, Paramithia, Parga, Pentalofon, Peta, Pramantla, Raptopoulon, Sayiadha, Tsimadas, Tsepelovon, Filiates and Chioniades-Grammos, in scale 1:50,000, of Hellenic Military Geographical Service - HMGS and their compilation, using the NASA’s DEM, with a 25 m cell size, at the locations where the contours were more sparse, in order to achieve the optimum simulation of the terrain of northwestern Greece.

The study of tectonic structures (faults, thrusts, and overthrusts) was performed through examination of aerial photographs, on a scale of 1:33,000 and detailed field research. Satellite images were also used, to add to the information derived from Neotectonic Mapping and the study of geological formations. Part of the field work involved looking for evidence-indications of potential recent activations of old faults, both included in the mapping of previous studies and maps, as well as new faults identified within the scope of the present research. Seismological data and earthquake foci were collected by Geodynamic Institute National Observatory of Athens.

4. Neotectonic study

In the region of Epirus, fault tectonics is either of the same age as the Alpine folds, with the same trends, or of a later age and therefore independent of them. In tectonic terms, the following structures are identified, which form its present-day configuration (Figure 3):

- A large number of normal or reverse folds (Aubouin, 1959; IGRS – IFP, 1966; Mountrakis, 1985).
- Large sections of anticlinoria and synclinoria: generally trending NNW-SSE, resulting from strong compressive stresses (IGRS – IFP, 1966).
- Multiple thrusts and overthrusts, creating a system of parallel imbrications, generally trending NNW-SSE, along many km (IGRS – IFP, 1966; Makris, 1985).
- Extensive fractured zones: at a transverse as well as a parallel angle to the folds, along with a series of smaller faults, trending in various directions (Ntokos, 2017a; Traganos, Vrellis, Papaspurou, Saimakis, & Mpimpou, 2001).
- Rotational movements (Horner & Freeman, 1983; Kissel & Laj, 1988; Kissel, Laj, & Muller, 1985; Kissel, Laj, Poisson, & Gorir, 2003; Kissel, Laj, Poisson, & Simeakis, 1989; Mauritsch, Scholger, Bushati, & Ramiz, 1995).
- Diapirism phenomena (Caputo & Zouros, 1993; Karakitsios, 1995; Mascle, Auroux, & Rossi, 1984; Perrier et al., 1967b; Traganos et al., 2001; Vrellis, Vekios, Efthimiopoulos, & Spyridonos, 2007).

The data collected during the Neotectonic Mapping, along with the synthesis of older bibliographic data, resulted in the classification of tectonic structures, i.e. thrusts, overthrusts, and faults, according to their activation age in: active, potentially active and non-active or indeterminable age and therefore active. Although many of these structures are very old, they remain active to this day, as shown by Neotectonic analysis, in conjunction with the region’s seismicity rate. The extensive presence of scree deposits is also a factor indicating their re-activation.

According to the observations made on the field and the microtectonic analysis performed in the studied tectonic structures, it was established that northwestern Greece is affected by reverse, normal and strike-slip faults. This is due to the combination and the
alternation of compressive and extensive stresses. Reverse faults generally trend NW-SE and are typically encountered on the fronts of old thrusts. Normal and oblique-normal faults mainly trend NE-SW and strike-slip faults generally trend E-W. The western side of the region, mainly along the coast of the Ionian Sea, mainly features reverse and strike-slip faults, resulting from the dominant activity of compressive stresses (compression axes trending NE-SW to ENE-WSW), intersecting transversely the major existing synclinal and anticlinal structures, thrusts and overthrusts. These faults are not encountered as much in the eastern part, which is dominated by normal and oblique-slip faults, due to the major presence of

**Figure 3.** Tectonic structure of northwestern Greece (Note: 1 – synclinal axe, 2 – anticlinal axe, 3 – thrust and overthrust, 4 – visible fault, 5 – probable or cover fault, 6 – River, KNF – Konitsa Fault, HDF – Hani Dhelvinaki Fault, MF – Mitsikeli Fault, NVF – Nerochori-Vrosina Fault, PSF – Petousi-Souli Fault, VF – Variadhes Fault, PF – Pesta Fault, KAF – Kokkinopilos-Arta Fault, ZZF – Zaloggo-Ziros Fault, and KMF – Kamarina-Arta Fault). The gray lines indicate the locations of the active faults.
extensive stresses, generally trending NW-SE. The measurements of the geometric features of the tectonic structures of northwestern Greece, as well as the tectonic striations on their surfaces, show that the majority of such tectonic structures demonstrate a significant presence of horizontal displacement.

More specifically, the main active tectonic structures of northwestern Greece, as derived from neotectonic mapping, which contributed to the configuration of Epirus’s present-day morphology, based on their geographical distribution from North to South, are as follows (Figure 3):

- Konitsa oblique-slip fault
- Hani Dhelvinaki reverse strike-slip fault
- Mitsikeli oblique-slip fault
- Nerochori-Vrosina strike-slip fault
- Petousi-Souli strike-slip fault
- Variadhes strike-slip fault
- Pesta oblique-slip fault
- Kokkinopilos-Arta strike-slip fault
- Zaloggio-Ziros oblique-slip fault
- Kamarina-Arta oblique-slip fault

Among them, there are four which stand out, due to their recent activity and great length, which are presented hereunder in further detail:

### 4.1. Konitsa Fault

In the greater area of Konitsa, at the foot of Mount Timfi and in the southern margin of Aoos basin, a fault extending along approximately 15.5 km, trending NE-SW, with a northwestern inclination, creates a highly uneven terrain (Figure 4(A,B)). Known as the Konitsa Fault, it extends along the contact of the carbonate formations with the Ionian Zone flysch. Major quantities of talus cones form along the length of the fault. It should be noted that the Holocene scree is affected by the fault’s activity, as it features displacements, thereby indicating the fault’s activity.

The recent activity of this fault (one of the few seismic faults of northwestern Greece) is also revealed by its association with the relatively recent (26-07-1996), powerful earthquake, measuring \( M = 5.7 \) on the Richter scale (Doutos & Koukouvelas, 1998; Doutos & Kokkalas, 2001; Vannucci & Gasperini, 2003, 2004; Galanakis et al., 2007; Figure 4(C)).

### 4.2. Petousi-Souli Fault

The central part of northwestern Greece features one of its largest tectonic structures, of a total length of approximately 36.5 km, generally trending E-W, with a southern inclination. The Petousi-Souli Fault constitutes the largest fault zone of northwestern Greece, while forming at the same time a natural boundary, separating the entire region of Epirus between north and south. This tectonic structure has caused the displacement of pre-existing structures, such as the synclines and anticlines formed during the Alpine fold, as well as recent Quaternary deposits (Figure 4 (D–F)). It has affected the morphology and relief of a large area, while a typical example of the displacements it has caused can be found in the syncline structure of Voutsaras, which is transversely intersected in the middle, by the Petousi-Souli fault. The Voutsaras syncline seems to present a displacement in the order of 2 km to the east, while the displacements of the geological boundaries, along the length of the fault’s trace, often exceed 4 km.

The western and eastern ends of the Petousi-Souli strike-slip active fault feature a series of minor normal and strike-slip active faults, running in a parallel direction to the orientation of the fault, whose high concentration is similar to an enechelon layout, which is typically observed in strike-slip zones. Observations show that this tectonic structure fans out into numerous smaller branches, typical in cases on strike-slip faults (imbricate fans; Biddle & Christie-Blick, 1985; Boccaletti, Caputo, Mountrakis, Pavlides, & Zouros, 1997; Caputo & Zouros, 1993). Since these faults are consistently oriented from E-W to NE-SW (right stepping faults), they may well constitute Riedel faults, which have impacted the sedimentary nappe and which are associated with a large-scale sinistral movement of the bedrock (Eggink, Riegra, & Suzanne, 1996).

Geomorphological features, paleoseismological data (Boccaletti, Caputo et al., 1997; Boccaletti, Caputo, Pavlides, & Zouros, 1992; Pavlides, 1996; Ntokos, 2017a, 2017c, 2018) and recently recorded microseismic activity (Hatzfeld et al., 1995; King et al., 1983; Tselentis, Sokos, Martakis, & Serpetsidaki, 2006) point towards the recent, active state of the fault. According to Boccaletti, Caputo et al. (1997), over the last 30,000 years, at least three incidents of tectonic paleo-activity are associated with this fault, while it is estimated that it was first activated several millions of years ago. It should be noted, however, that no earthquakes, either recorded by modern instruments (twentieth century) or substantiated by means of historical seismic data, are directly linked to the Petousi-Souli tectonic structure.

The impact and the tectonic regime, which created the Petousi-Souli strike-slip fault, has left its imprint throughout the area, where many minor faults, trending E-W were observed, as well as other faults, which are affected by the same regime that caused the rupture of the main fault, albeit developing in a different direction. A number of surfaces were detected; the nature however of the geological materials at their contact did not enable the identification of kinematic evidence, since their surfaces and tectonic striations have largely disintegrated due to erosion.
4.3. Kokkinopilos-Arta Fault

The greater area of Filippiada, between the settlement of Galini and up to the Arta Plain, features a major fault, extending along a total length of 46.5 km. The Kokkinopilos-Arta Fault is a part of the highly significant fault zone of Arta-Amfilochia, which represents a series of particularly long faults, generally trending NNW-SSE, which are parallel to the direction of thrusts and continue to the south, thereby defining the tectonic evolution in the eastern margin of Amvrakikos Gulf (Ntokos, Lykoudi, & Rondoyanni, 2016). This fault zone consists of a series of sinistral strike-slip faults and oblique-slip faults, generally trending NNW-SSE, same as the thrusts, with a southwestern dip.

Polished surfaces are mainly observed in the area of Kokkinopilos, at the northern section of the fault zone. This area reveals a polished surface that is 3 m high, where five different zones of tectonic breccias are distinguished (Figure 5(A–C)). These mylonite zones are divided by smooth ruptured surfaces, bearing tectonic striations, designating the successive reactivation stages of the Kokkinopilos-Arta Fault. At the locations where such polished surfaces were observed, at the contact of the Mesozoic limestones with the terra rossa the
The southern part of the Kokkinopilos-Arta Fault, in the area of Arta, cannot be identified from the surface, as it is covered by Neogene and Quaternary deposits, whose thickness exceeds 600 m, as shown by geothermal drillings performed in the area (Vrellis et al., 2007).

4.4. Kamarina-Arta Fault

Another major structure, identifying the neotectonic regime of the southern section of northwestern Greece, is the Kamarina-Arta Fault, extending along approximately 43.5 km, with a general direction trending E-W and a southern inclination. This fault is for the most part covered by the alluvial deposits of the Arta Plain, although it transversely intersects the Kokkinopilos-Arta Fault. Information about its kinematics can be drawn from its appearances in the west, in the settlement of Kamarina, where its trace is detected at the contact of the carbonate formations with Neogene deposits (Figure 5(D–F)). According to the geophysical profiles, performed within the scope of the research of Vrellis et al. (2007), it could be concluded that this is a younger fault than the Kokkinopilos-Arta Fault, as a displacement was observed of faults trending N-S by faults trending E-W. Moreover, the displacement of...
the course of Arachthos River is observed along the length of this fault, which may be attributed to the fault’s recent activity.

5. Conclusion

The neotectonic map of northwestern Greece, on a scale of 1:500,000 (Supplemental material: Neotectonic Map of Northwestern Greece, Main Map), presented in this paper, portrays the distribution of active tectonic structures and earth surface processes and leads to conclusions about the recent evolution of the area. Neotectonic mapping has shown Epirus as a region of intense tectonic activity, which has resulted in producing an uneven terrain, featuring the alternation of high masifs and low valleys. It has also identified it as a structurally complex domain, resulting from: (a) strong alpine tectonism, which caused extended folding structures, large synclines and anticlines and numerous thrusts and overthrusts, generally trending NNW-SSE, (b) diapiric movements of Triassic evaporites, which contribute to the development of compressive stresses and – acting as a lubricant medium – facilitate the manifestation of horizontal displacements, the activation of reverse faults and the displacement of tectonic structures in the form of thrusts and imbrications, and (c) neotectonic activity, chiefly manifesting compressive stresses and in some cases extensive stresses.

Software

ESRI ArcGIS 10.3 was used to digitize the data collected during field survey, by geological and topographic maps and aerial photo interpretation. The same software was used to produce the final layout of the neotectonic map.

Disclosure statement

No potential conflict of interest was reported by the author.

ORCID

Dimitrios Ntokos http://orcid.org/0000-0002-1434-0300

References

Aubouin, J. (1959). Contribution à l’étude géologique de la Grèce septentrionale: le confins de l’Epire et de la Thessalie. Annales Géologiques des Pays Helléniques, 10, 525, Athènes.

Aubouin, J. (1961). Geological map of Greece in scale 1:500,000, “Pramanta’ sheet. Athens: Institute of Geology and Mineral Exploration.

Biddle, TK, & Christie-Blick, N. (1985). Strike-slip deformation, basin formation and sedimentation. Soc. Econ Paleont-Mineral. Spec. Publ. 37, Tulsa, OK, USA.

Bizon, J., Douthe, P., Latreille, M., Perrier, R., Rochet, J., Savoyat, E., ... Bizon, G. (1967). Geological map of Greece in scale 1:50,000, “Kanallakion” sheet. Athens: Institute of Geology and Mineral Exploration.

Boccaletti, M., Caputo, R., Mountrakis, D., Pavlides, S., & Zouros, N. (1997). Paleoseismicity of the Souli Fault, Epirus, Western Greece. Journal of Geodynamics, 24 (1–4), 117–127.

Boccaletti, M., Caputo, R., Pavlides, S., & Zouros, N. (1992). Preliminary results on the geometry, kinematics and recent reactivations of the Souli active fault zone, Epirus, NW Greece. Recent Advances Meeting: Abstracts of the meeting Neotectonics, London, June 16–17, 56.

Bornovas, J., & Rondoyanni-Tsiambou, T. (1983). Geological map of Greece, Scale: 1:50,000, Athens: Institute of Geology and Mineral Exploration.

Brunn, J. H. (1959). Geological map of Greece in scale 1:50,000, “Metsovon” sheet. Athens: Institute of Geology and Mineral Exploration.

Brunn, J. H. (1960). Geological map of Greece in scale 1:50,000, “Pentalofon” sheet. Athens: Institute of Geology and Mineral Exploration.

Caputo, R., & Zouros, N. (1993). Examples of Alpide deformation from Epirus: Local anomalies or need to re-evaluate the amount of shortening in the Western Hellenides? Bulletin of the Geological Society of Greece, 28(1), 315–326.

Delvaux, D. (1993). The TENSOR program for paleoearth reconstruction: examples from the East African and the Baikal rift zones, Terra Abstract, Abstract Supplement No. 1, to Terra Nova, 5, 216.

Delvaux, D., Moey, R., Stapel, G., Melenkov, A., & Ermikov, V. (1985). Paleostress reconstruction and geodynamics of the Baikal region, Central Asia. Part I. Pre-rift evolution: Paleozoic and Mesozoic. Tectonophysics, 252, 61–101.

Delvaux, D., & Sperner, B. (2003). Stress tensor inversion from fault kinematic indicators and focal mechanism data: The TENSOR program. In D. Nieuwland (Ed.), New insights into structural interpretation and modelling (Vol. 212, pp. 75–100). Special Publications London: Geological Society.

Doutos, T, & Kokkalas, S. (2001). Stress and deformation patterns in the Aegean region. Journal of Structural Geology, 23 (2), 455–472. doi:10.1016/S0191-8141(00)00119-X

Doutos, T, & Koukouvelas, I. (1998). Fractal analysis of normal faults in northwestern Aegean area, Greece. Journal of Geodynamics, 26(2), 197–216. doi:10.1016/S0264-3707 (97)00052-5

Eggink, J. W., Riegstra, D. E., & Suzanne, P. (1996). Using 3D seismic to understand the structural evolution of the UK Central North Sea. Petroleum Geoscience, 2, 83–96.

Galanakis, D., Paschos, P., Rondoyanni, T., & Georgiou, C. (2007). Neotectonic activity of Konitsa area and the earthquake of 1996. Hellenic Journal of Geosciences, 42, 57–64.

Hatzfeld, D., Kassaras, I., Panagiotopoulos, D., Amorese, D., Makropoulos, K., Karakasis, G., & Coutant, O. (1995). Microseismicity and strain pattern in northwestern Greece. Tectonics, 14(4), 773–785. doi:10.1029/95TC00839

Horner, F., & Freeman, R. (1983). Palaeomagnetic evidence from pelagic limestones for clockwise rotation of the Ionian zone, western Greece. Tectonophysics, 98, 11–27. doi:10.1016/0040-1951(83)90208-1

IGRS - IFP (Institut de Géologie et Recherches du Sous-Sol, Athènes - Institut Français du Pétrole). (1966). Etude Géologique de l’Epire (Grèce Nord-occidentale). Editions Technip., Paris, 306.

Karakitsios, V. (1995). The influence of preexisting structures and halokinesis on organic matter preservation
and thrust system evolution in the Ionian basin, Northwest Greece. AAPG Bulletin, 79(7), 960–980.

King, G., Tselentis, A., Gomberg, J., Molnar, P., Roecker, S., Sinval, H., & Stock, J. (1983). Microearthquake seismicity and active tectonics of northwestern Greece. Earth and Planetary Science Letters, 66, 279–288.

Kissel, C., & Laj, C. (1988). The Tertiary geodynamical evolution of the Aegean arc a paleomagnetic reconstruction. Tectonophysics, 146, 183–201.

Kissel, C., Laj, C., & Muller, C. (1985). Tertiary geodynamical evolution of northwestern Greece: Paleomagnetic results. Earth and Planetary Science Letters, 72, 190–204. doi:10.1016/0012-821X(85)90005-6

Kissel, C., Laj, C., Poisson, A., & Goriir, N. (2003). Paleomagnetic reconstruction of the Cenozoic evolution of the Eastern Mediterranean. Tectonophysics, 362, 199–217.

Kissel, C., Laj, C., Poisson, A., & Simeakis, K. (1989). A pattern of block rotations in central Aegea. In C. Kissel, & C. Laj (Eds.), Palaeomagnetic rotations and continental deformation (pp. 115–129). Dordrecht: Kluwer Academic Publishers.

Koukouzas, C., Perrier, R., & Bizon, G. (1973). Geologic map of Greece in scale 1:50,000, “Vassilikos-Poigamoni” sheet. Athens: Institute of Geology and Mineral Exploration.

Koumantakis, J., Matarangas, D., Tsaila-Monopolis, S., Latreille, M., Savoyat, E., Monopolis, D., Bizon, J. J., & Bizon, G. (1985). Geologic map of Greece in scale 1:50,000, “Panayia” sheet. Athens: Institute of Geology and Mineral Exploration.

Latreille, M., Savoyat, E., Monopolis, D., Bizon, J. J., & Bizon, G. (1969). Geological map of Greece in scale 1:50,000, “Aria” sheet. Athens: Institute of Geology and Mineral Exploration.

Makris, J. (1985). Geophysics and geodynamic implications for the evolution of the Hellenides. In J. D. Stanley, & F. C. Wezel (Eds.), Geological evolution of the Mediterranean Basin (pp. 231–248). New York, Berlin, Heidelberg, Tokyo: Springer Verlag.

Manacos, K., & Skourtsi-Koronaiou, B. (1983). Geological map of Greece in scale 1:50,000, “Myrofyllo” sheet. Athens: Institute of Geology and Mineral Exploration.

Manacos, K., Skourtisi-Koronaiou, V., & Ioakim, C. (1996). Geological map of Greece in scale 1:50,000, “Vonitsa” sheet. Athens: Institute of Geology and Mineral Exploration.

Mascele, J., Auroux, C., & Rossi, S. (1984). Structure géologique superficielle et évolution récente de la dorsale apulienne (Mer Ionienne). Revue de l’Institut Français du Pétrole, 39(2), 127–142.

Mauritsch, H. J., Scholger, R., Bushati, S. L., & Ramiz, H. (1995). Paleomagnetic results from southern Albania and their significance for the geodynamic evolution of the Dinarides, Albanides and Hellenides. Tectonophysics, 242, 5–18.

Mavridis, A., Manacos, K., Skourtisi-Koronaiou, V., & Dimou, E. (1987). Geological map of Greece in scale 1:50,000, “Konitsa” sheet. Athens: Institute of Geology and Mineral Exploration.

Mountrikas, D. (1985). Geology of Greece, 207 (in Greek).

Ntokos, D. (2017a). Neotectonic - Geomorphological study of Epirus, Northwestern Greece and Compiling of Neotectonic Map, by use of Geographic Information Systems, PhD Thesis, National Technical University of Athens, 404 (in Greek). http://dspace.lib.ntua.gr/handle/123456789/44623

Ntokos, D. (2017b). Synthesis of literature and field work data leading to the compilation of a New geological Map—A review of geology of northwestern Greece. International Journal of Geosciences, 8(2), 205–236. doi:10.4236/ijg.2017.82009

Ntokos, D. (2018). Formulation of the conceptual model for the tectonic geomorphological evolution of an area: five main rivers of Greece as a case study. CATENA.

Ntokos, D., Lykoudi, E., & Rondoyanni, T. (2016). Geomorphic analysis in areas of low-rate neotectonic deformation: South Epirus (Greece) as a case study. Geomorphology, 263, 156–169. doi:10.1016/j.geomorph.2016.04.005

Pavlidis, S. (1996). First palaeo-seismological results from Greece. Annal. Geofis., 34, 545–555.

Pavlidis, S., Chatzipetros, A., & Valkaniotis, S. (2007). Seismically Capable Faults In Aegean Broader Area: Criteria For Classification. Geological Society Bicentenary Conference: Earth Sciences in the Service of Society, 10–12 September 2007, London. Abstract Book, 124–125.

Pavlidis, S., Chatzipetros, A., & Valkaniotis, S. (2008). Active faults of Greece and surroundings. Paper presented at the 33th International Geological Congress, Oslo, Norway. Abstract.

Pavlidis, S., Valkaniotis, S., & Chatzipetros, A. (2007). Seismically Capable Faults In Greece and their use in seismic hazard assessment. Poster presentation at the 4th International Conference on Earthquake Geotechnical Engineering, 24–28 June 2007, Thessaloniki.

Perrier, R., Katsikatsos, G., Lalechos, N., Filippakis, N., & Bizon, G. (1966). Geological map of Greece in scale 1:50,000, “Parnamithia” sheet. Athens: Institute of Geology and Mineral Exploration.

Perrier, R., Koukouzas, C., & Bizon, G. (1967a). Geological map of Greece in scale 1:50,000, “Tsamadas” sheet. Athens: Institute of Geology and Mineral Exploration.

Perrier, R., Koukouzas, C., & Bizon, G. (1967b). Geological map of Greece in scale 1:50,000, “Filaiotes” sheet. Athens: Institute of Geology and Mineral Exploration.

Perrier, R., Koukouzas, C., & Bizon, G. (1969a). Geological map of Greece in scale 1:50,000, “Parga” sheet. Athens: Institute of Geology and Mineral Exploration.

Perrier, R., Koukouzas, C., & Bizon, G. (1969b). Geological map of Greece in scale 1:50,000, “Sayidotta” sheet. Athens: Institute of Geology and Mineral Exploration.

Perrier, R., Koukouzas, C., Bizon, G., & Bizon, J. J. (1968a). Geological map of Greece in scale 1:50,000, “Doliana” sheet. Athens: Institute of Geology and Mineral Exploration.

Perrier, R., Koukouzas, C., Lalechos, N., & Bizon, G. (1968b). Geological map of Greece in scale 1:50,000, “Klimatia” sheet. Athens: Institute of Geology and Mineral Exploration.

Perrier, R., Potier, R., Savoyat, E., Koukouzas, C., Monopolis, D., Bizon, J. J., & Bizon, G. (1967). Geological map of Greece in scale 1:50,000, “Ioannina” sheet. Athens: Institute of Geology and Mineral Exploration.
Plastiras, V., Tsaila-Monopolis, S., & Bizon, G. (1985). *Geological map of Greece in scale 1:50,000, “Chionades-Grammos” sheet*. Athens: Institute of Geology and Mineral Exploration.

Rondoyanni, T., Lykoudi, E., Triantafyllou, A., Papadimitriou, M., & Foteinos, I. (2013). Active faults affecting linear engineering projects: Examples from Greece. *Geotechnical and Geological Engineering*, 31, 1151–1170. doi:10.1007/S10706-013-9641-7

Savoyat, E., Monopolis, D., & Bizon, G. (1966). *Geological map of Greece in scale 1:50,000, “Peta” sheet*. Athens: Institute of Geology and Mineral Exploration.

Savoyat, E., Monopolis, D., Lalechos, N., Filippakis, N., & Bizon, G. (1963). *Geological map of Greece in scale 1:50,000, “Thesprotiiko” sheet*. Athens: Institute of Geology and Mineral Exploration.

Savoyat, E., Monopolis, D., Lalechos, N., Filippakis, N., & Bizon, G. (1970a). *Geological map of Greece in scale 1:50,000, “Agnanta” sheet*. Athens: Institute of Geology and Mineral Exploration.

Savoyat, E., Monopolis, D., Lalechos, N., Filippakis, N., & Bizon, G. (1970b). *Geological map of Greece in scale 1:50,000, “Rafiptopoulo” sheet*. Athens: Institute of Geology and Mineral Exploration.

Traganos, G., Vrellis, G., Papaspurou, A., Simaiakis, K., & Mpimpou, A. (2001). *Research and identify of the geothermal energy in Epirus, Report*. Institute of Geology and Mineral Exploration, Athens.

Tselentis, G., Sokos, E., Martakis, N., & Serpetsidaki, A. (2006). Seismicity and seismotectonics in Epirus, western Greece: Results from a microearthquake survey. *Bulletin of the Seismological Society of America*, 96, 1706–1717. doi:10.1785/0120020086

Vannucci, G., & Gasperini, P. (2003). A database of revised fault plane solutions for Italy and surrounding regions. *Computers & Geosciences*, 29, 903–909.

Vannucci, G., & Gasperini, P. (2004). The database of Earthquake Mechanisms of the Mediterranean area (EMMA): a call for contributions. *CSEM/EMSC Newsletter, N*, 21, 3–6.

Vrellis, G., Vekios, P., Efthimiopoulos, T., & Spyridonos, E. (2007). *Final Study Report of the Sykies-Arta Geothermal Field* (Vol. 119). Athens: Institute of Geology and Mineral Exploration (in Greek).

Zain Eldeen, U., Delvaux, D., & Jacobs, P. (2002). Tectonic evolution in the Wadi Araba Segment of the Dead Sea Rift. *South-West Jordan, European Geosciences Union Stephan Mueller Special Publication Series*, 2, 63–81.