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Correspondence to:
Dina Ghikas
notconstandina@hotmail.com

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A BILLION YEARS OF HISTORY WITHIN THE GREVENA-DESKATI WATERSHED

Dina Ghikas[1*], Anne Ewing Rassios[2]

[1] **Velissariou 5 Grevena 51100, Greece** [*]notconstandina@hotmail.com

[2] **Institute of Geology and Mineral Exploration, Kozani 50100, West Macedonia, Greece** rassannie@gmail.com

Abstract

The river system of West Macedonia comprises the headwaters and western extent of the Aliakmon watershed. This region has a unique and highly complex geologic history (Rassios, 2008; Rassios, 2011), many aspects of which can be inferred by examining conglomerate (river-cobble) formations in the region. These formations contain all rock types found within the modern-day river basin, as well as some which are not found within today's basin. River-deposited sediments and cobbles found along today's Aliakmon and Venetikos River systems trace the courses of ancient river flows, and thus provide information about past climatic conditions and tectonic events. The sediments making up conglomerate formations in the region are mature, containing cobbles which have been transported, consolidated, eroded and redeposited up to five times (Rassios and Grivas, 1998). This recycling of cobbles leaves only the most durable rocks while softer rocks are destroyed via abrasion. Prehistoric peoples availed themselves of this concentrated and convenient selection of high-quality stones for the purpose of fashioning tools and weapons.

Keywords: *Cobbles, River deposits, West Macedonia, Geohistory*

Περίληψη

Το ποτάμιο σύστημα της Δυτικής Μακεδονίας περιλαμβάνει πηγές ύδατος καθώς και τη δυτική επέκταση της υδρολογικής λεκάνης του Αλιάκμονα. Αυτή η περιοχή έχει μια μοναδική και εξαιρετικά σύνθετη γεωλογική ιστορία (Rassios 2008, Rassios 2011), πολλές πτυχές της οποίας μπορούν να συναχθούν με την εξέταση των κροκαλοπαγών (ποτάμιων-λίθινων) σχηματισμών στην περιοχή. Αυτοί οι σχηματισμοί περιέχουν όλους τους τύπους πετρωμάτων που βρίσκονται στη λεκάνη απορροής του σύγχρονου ποταμού, καθώς και ορισμένους που δεν βρίσκονται μέσα στη σημερινή λεκάνη. Τα ιζήματα ποτάμιων αποθέσεων και οι λίθοι που βρέθηκαν στα σημερινά συστήματα του Αλιάκμονα και του Βενέτικου ποταμού εντοπίζουν τις πορείες των αρχαίων ροών των ποταμών και παρέχουν πληροφορίες για παλαιότερες κλιματικές συνθήκες και τεκτονικά γεγονότα. Τα ιζήματα που σχηματίζουν κροκαλοπαγείς σχηματισμούς στην περιοχή είναι ώριμα, περιέχουν κροκάλες που έχουν μεταφερθεί, συμπαγοποιηθεί, διαβρωθεί και εναποτεθεί μέχρι πέντε φορές (Rassios and Grivas, 1998). Αυτή η ανακύκλωση των κροκαλών αφήνει μόνον τα πιο ανθεκτικά πετρώματα, ενώ τα μαλακότερα πετρώματα καταστρέφονται διαμέσου της τριβής. Οι προϊστορικοί λαοί επωφελήθηκαν αυτής της συγκεντρωμένης και βολικής επιλογής υψηλής ποιότητας πετρωμάτων με σκοπό την κατασκευή εργαλείων και όπλων.

Λέξεις κλειδιά: *Λίθοι, Ποτάμιες αποθέσεις, Δυτική Μακεδονία, Γεωλογική Ιστορία*

1. Scope of the Present Paper

The present study is a synthesis of published and unpublished geoenvironmental, archeological and industrial research and general observations of the cobbles found in the Aliakmon-Venetikos drainage basin of West Macedonia, Greece. Our intent is to present an accessible introduction and summary of this information for geoscientists of various specialty fields and experience, as well as archeological interests. These river deposits also make for popular destinations of geotouristic interest.

2. The Setting

The drainage basin of the Aliakmon River and Venetikos River systems of West Macedonia (Greece) contains the headwaters and western reaches of these river systems (Figure 1): the drainage basin is bordered to the west by the Pindos

Mountain range, and to the east by the Vourinos range. The Aliakmon River flows south-southeastward between these two cordilleras within the geologic terrain referred to as the Mesohellenic Trough, a subsiding piggyback basin of Paleocene to mid-Miocene age (Vamvaka et al., 2006; Brunn, 1956). The surface geomorphology of this basin today is characterized by a topography of flat-topped buttes and steep-walled stream valleys. Downstream from the confluence of the Aliakmon and Venetikos Rivers, the Aliakmon curves eastward towards Mt. Vounassa (Fig. 1), then northward towards Mt. Vourinos and finally bends northeastward and continues into the neighboring province of Central Macedonia, where it empties into the Thermaic Gulf along the Aegean Sea.

The lithology of the Mesohellenic Trough in the region of the catchment basin of these river systems consists of a thick (up to 5 km) sequence of sedimentary rocks. The oldest rocks at the base of the sequence were deposited in the Paleocene on the remnant floor of an ancient ocean, the Tethys, which itself dates from the Triassic.

The base of the Mesohellenic Trough sedimentary sequence consists of conglomerate deposits including clasts as large as ~4 m down to several cm. As the Tethys ocean slowly receded, the environment transitioned from deep sea to shallow coast, then to tidal flats and deltas by the Miocene, and finally to a completely continental environment where rivers were the defining hydrous feature. Conglomerate interlayers are common throughout the Mesohellenic section (Ferriere et al., 2004).

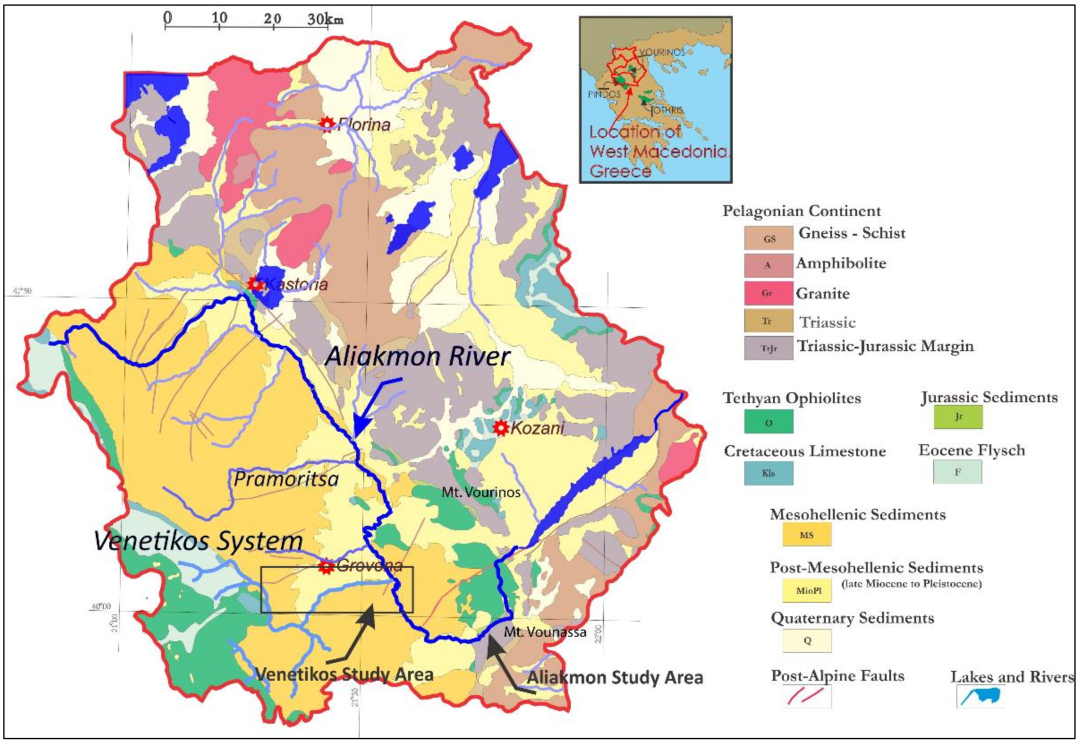

Fig. 1: Geological map of West Macedonia with the Aliakmon River and tributaries. Box shows the area of detailed in Figure 4.

3. The Action of Water

Rivers erode, accumulate, shape, transport, deposit and recycle rock material. They are one of the most powerful forces on Earth. The land around rivers is continuously shifting as river banks grow, shrink, jump or collapse. Unlike the annually miniscule movements of plate tectonics, the effects of rivers on the landscape are observable by everyone over the human lifespan. On a short term, rivers can break out in a terrifying spectacle of catastrophe; their day-to-day action is an endless process of carrying material away and putting it elsewhere. Water will pick up anything it can, carry it as far as it can, and drop it when it becomes too burdensome for its flow to support. This simple, prosaic property of moving water creates the different kinds of sedimentary rock of West Macedonia: the finely bedded mudstones are the work of "lazy" water, while the coarse conglomerates were formed by more "energetic" water.

Fig. 2: (a) Loose cobbles along the Aliakmon River. (b) Same image, ages of cobbles labeled.

Thus, the type of sediment in a rock formation is indicative of the environmental conditions at the time it was being deposited. Large cobbles or boulders were dislodged and carried by highly energetic flows such as floods or rapids. The abrasion of larger rocks produces fine sand and silt—tiny particles which can be carried great distances, suspended in the water in low-energy, meandering rivers. This material is eventually deposited in sand bars or large deltas (Reineck and Singh, 1973).

Thick sedimentary sequences made up of huge volumes of coarse-grained rock indicate rapid changes in the environment such as uplift (mountains rising) or the retreat of glaciers, which would have released torrents of water and sediment down the mountain slopes as the Ice Ages waned (Blatt et al, 1972). The water of ancient rivers has long since been dispersed, but the rocks and sediment left behind can shed light on the conditions of the past (Figure 2).

We can take an overview of the history of tectonic plate movements and climatic change by examining river cobble deposits, making them a valuable first stop at the beginning of any geologic investigation of this region.

Fig. 3: Conglomerate formations in various stages and types of abrasion, forming new cobble deposits alongside the Venetikos River.

(a) Outcrop of mature consolidated conglomerate (Tertiary) along the Venetikos River, with stream erosion channels. Cobbles are mainly derived from crystalline rock units within or adjacent to the Pindos ophiolite.

(b) Close-up of the clast-supported conglomerate within 3a.

(c) Aerially exposed section of the conglomerate showing facies changes and erosion of vertical joints, creating vertical cliffs.

(d) Close-up of aerially exposed section showing distinctive erosion by precipitation.

(e) Cobble (Tertiary erosion) of older conglomerate. This formation has been recycled numerous times, leaving only the most resistant material.

4. History of the Stones

River stones in West Macedonia have been through the cycle of erosion, transport and deposition many times (Figure 3). As ancient rivers shifted their banks, dried up or changed direction, the same cobbles were again and again eroded from their beds and tumbled downstream, eventually dropping to become part of a new sedimentary conglomerate formation. Mapping the location and extent of these formations, we can see the courses of ancient rivers which flowed in directions different from those of today. Some of the cobbles we see along today's river banks have been recycled up to five times (Figure 4).

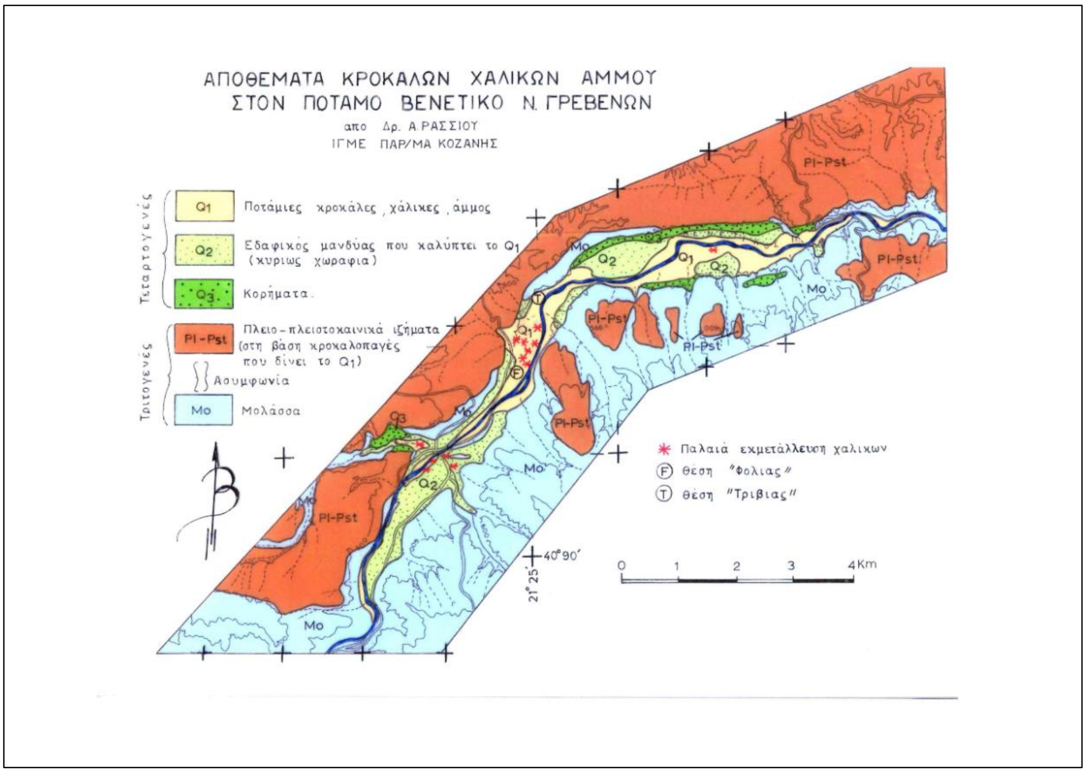

Fig. 4: Map of a section of the Venetikos River (see Fig. 1), a tributary of the Aliakmon. Much of the modern, unlithified sediment (cobbles, gravel and sand) along the banks of the current river is derived from conglomerates of the Plio-Pleistocene, which were derived from still older conglomerate formations. "Q1" is the present cobble formation within the river banks. "Q2" consists of a soil-sediment formation covering parts of "Q1." "Q3" is talus, including cobbles, from hillside erosion of older rock formations. Pl – Plst are Plio-Pleistocene layered rocks, including cobble-bearing conglomerate horizons. "Mo" is Tertiary-age Mesohellenic Sediments, well-layered series of sand and mudstones with cobble-bearing horizons. From these relations, the present cobble formation is exposed and covered in the areas of Q1, Q2, and Q3. From Rassios and Grivas, (1998).

West Macedonia has a diverse geological profile, including lithologies dating from the late Precambrian, upper Paleozoic metamorphics, limestone dating from the Cretaceous, lithospheric rocks of the Jurassic ophiolitic units of region (mantle peridotite, ultramafic and mafic cumulate rocks, lavas, cherts and ocean floor sediments) (Figure 5): these are overlain by Tertiary and Quaternary sandstones and mudstones. Non-metamorphosed sedimentary rocks formed in the vast, ancient ocean Tethys, which disappeared from this area about 40 million years ago. In the eastern part of the province are metamorphic rocks of the Pelagonia massif, an even more ancient (oldest rocks identified so far at nearly one billion years old; Zlatkin et al., 2014) continental fragment. River-deposited formations are therefore a “rock salad” with cobbles derived from all rock types in the region (Figure 5). A person walking along the banks of the present-day Aliakmon or one of its tributaries may pick up cobbles derived from rocks that were originally far apart geographically, geologically, and chronologically.

When a piece of rock is eroded from its parent rock and picked up by moving water, the tumbling and scouring action of the water and suspended sediments wears down the rock until it becomes nearly spherical (Domokos et al., 2014). Only the most durable rocks can withstand repeated cycles of erosion and transport, while softer rocks disintegrate quickly, thus “winnowing” the variety of rock types down to leave only the hardest cobbles (as exemplified in the representative cobble count shown in Figure 6). Mature conglomerates such as those along the Venetikos River are made up of highly rounded cobbles of hard crystalline rocks in a sandy matrix composed of remnants of softer rock units.

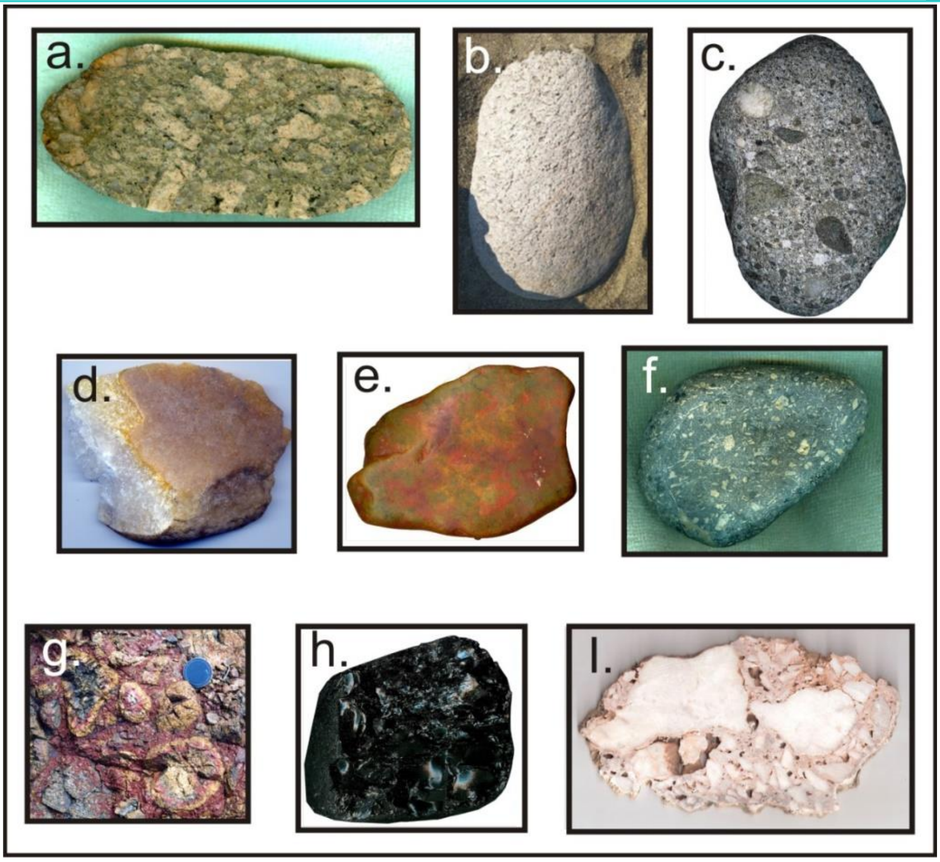

Fig 5: Representative river cobbles of major provenance areas in West Macedonia, Greece.

(a) Late Proterozoic granitic rock (*unakite*) from the Pelagonian formation. Recovered from Sourtsa River.

(b) Granite of Paleozoic age, Pelagonian Formation. Recovered from Venetikos River.

(c) Greywacke conglomerate cobble from Pelagonian formation (Permian?) Recovered from Aliakmon River.

(d) Cobble derived from a late Permian quartz vein, provenance Pelagonian formation. Recovered from Venetikos River system.

(e) Mid-Triassic chert of early Tethyan. Recovered from Aliakmon River.

(f) Jurassic basalt from the Pindos ophiolite upper lithospheric section. Recovered from Venetikos River.

(g) Late Jurassic (?) oceanic conglomerate derived from the Vourinos Ophiolite.

(h) Jet (*gem-quality lignite*) from Aliakmon River, source rock Mesohellenic Sediments near Felli Village.

(i) Consolidated breccia-conglomerate from late Pleistocene debris fall of Mt Vounassa (Deskati). From Aliakmon river cobble deposit.

We estimate the following periods of erosion of material from provenance localities, formation of cobble deposits and conglomerates, and periodic recycling of cobbles:

1. Permian (?): The Pelagonian formation (Proterozoic – Jurassic) was eroded and contributed lithologies to the conglomerate formations in both recent (Plio-Pleistocene) and Miocene eras. Intraformational conglomerate deposits, such as the wackestone of Figure 5c date to even older erosional events.

2. Jurassic-Cretaceous Unconformity: The ophiolitic massifs of Vourinos and the Pindos were rotated prior to deposition of Cretaceous reefal formations. Conglomerate formations are noted along this horizon.

3. Cretaceous: Reefal limestone has been eroded both in geologically recent times (within the Orliakas area, during Portitsa Gorge formation), and includes several horizons of presumably late Tethyan period intraformational conglomerate or debris flows.

4. Miocene: The base of the Miocene within the Mesohellenic Trough consists of coarse conglomerates derived from the lithologies onto which they were deposited. For example, above a gabbroic formation, the cobbles within the conglomerate at the Mesohellenic base are gabbroic.

5. Plio-Pleistocene: Base of Plio-Pleistocene consists of gravel-cobble rich deposit that comprises the regional aquifer of the area.

6. Quaternary: Quaternary cobble deposits include material from at least three phases of erosion of parent rocks (including Tertiary and Plio-Pleistocene deposits) as well as recycling and redepositing pre-existing (pre Tertiary and older Quaternary) cobble formations.

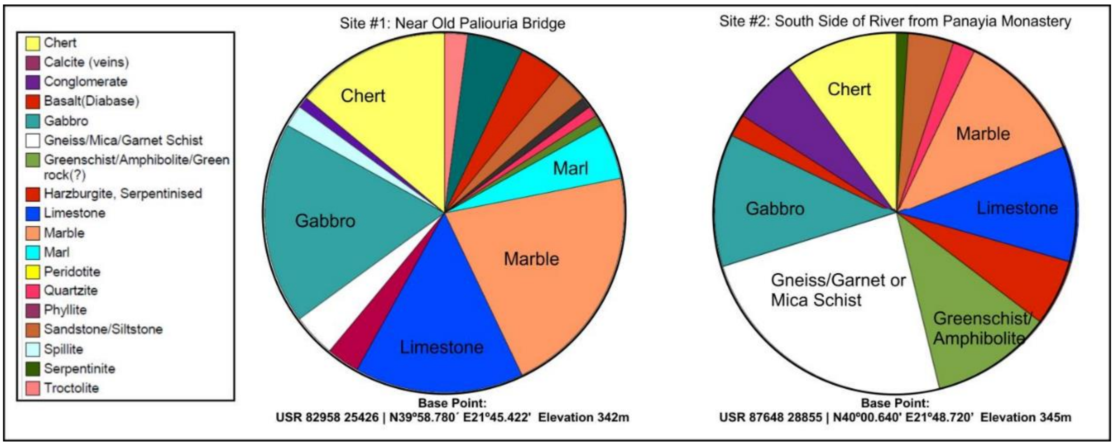

Fig. 6: An example of a cobble-counting study from two locales along the Aliakmon River. From Lau, 2006. Students used the results of cobble counts to pinpoint in situ outcrops and contacts that were obscured by vegetation.

Owing to the constant recycling of conglomerate deposits within previous river formations, today's river sometimes contains rocks from outside the modern-day river basin. One example is the occurrence of occasional gneissic or granitic cobbles found along the Venetikos River, a west-east-flowing tributary of the Aliakmon (Figures 1, 4), that have provenance to the east of the Aliakmon within the Paleozoic rocks of the Pelagonian (near Deskati) and even perhaps from as far as Florina: that is, far from the drainage basin of the Venetikos. Today, the Venetikos flows west to east, into the Aliakmon and thence to the Aegean. These scattered Paleozoic-late Precambrian cobbles were therefore carried away from their parent rocks in the east and deposited by a predecessor river (or perhaps many predecessors) that flowed east to west, likely into the Ionian Sea. This older contrary stream flow implies that "something" caused the predecessor Venetikos to change flow direction: it seems that this "something" most likely correlates with the tectonic uplift of the Pindos Mountains during the lower Tertiary. Thus, the distribution of cobble lithology and provenance is related to the uplift of the Pindos range.

6. River Stones and Humans

Hominids inhabiting the West Macedonia area during the Pleistocene and onwards certainly took advantage of the proximity of rivers for water, food and migration corridors (Panagopoulou et al., 2006), but they also benefited from the condensed mixture of durable rocks to be found among the local river cobbles, compared with many other cobble-poor regions of Greece (Wilke and Savina, 1997). They would have been able to choose from among a variety of stones with different properties, suitable for making various tools, and already of a convenient, transportable size and shape. Coarsely crystalline rocks like granite or gabbro would have been ideal for grinding and pounding tools, while fine-grained rocks like chert and serpentinite were suitable for shaping into delicate blades or the heads of weapons. In particular, stone tools made of ophiolitic-source plagiogranite are common within the Neolithic museum collections across Greece. While plagiogranite occurrences are somewhat rare (limited to minor regions within the Vourinos and Pindos ophiolites regionally), they are originally a hard lithology of small homogeneous grainsize (feldspar, quartz, amphibole; ~0,3 – 1 mm; Rassios, 1981) and are well-represented in the cobble deposits along Aliakmon and Venetikos River (Figure 7). Plagiogranite stone tools in other regions of Greece lacking plagiogranite provenance rocks suggest early trade among prehistoric populations. The river bank would have been in effect a Stone-age hardware store where people could pick and choose from all the available compositions, sizes and shapes of rock, in one location.

In 1998, the Institute for Geologic and Mineral Exploration (IGME) of Greece conducted a study of various rock units of West Macedonia, including Quaternary cobble deposits along the Venetikos River, to determine their suitability for high-friction surfacing material (highways and rail lines). Various abrasion tests and environmental/feasibility studies ultimately rejected the cobble deposits for this use, but the abrasion tests showed that as a bulk material, the cobbles are highly resistant to abrasion, and were even reported to have broken the testing apparatus (eg., Test LA Abrasion 20.3 – 24.8% and Micro-deval; Grivas and Rassios, 1998). Our manmade contraptions are no match for rocks that have passed Nature's abrasion tests for so many millions of years. They are the toughest of the tough.

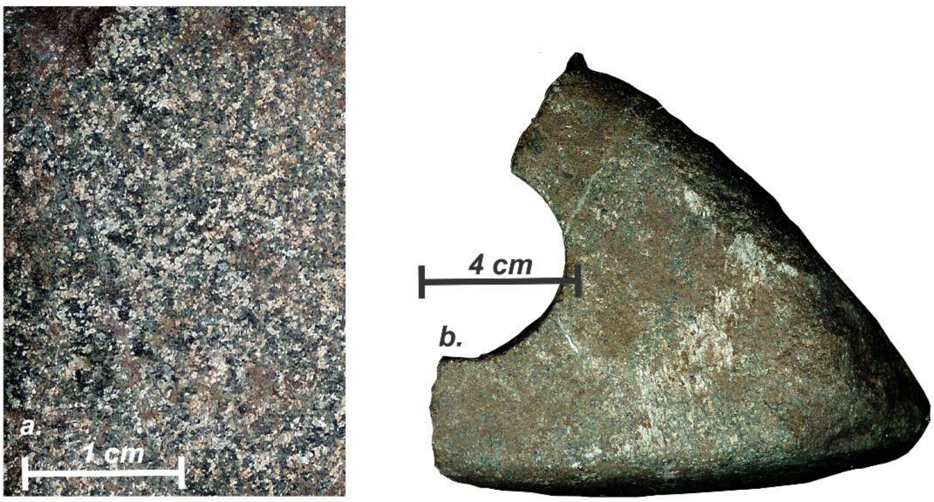

Fig. 7: Neolithic Hand Axe. (a) Macrophoto of plagiogranite within cracked surface. Plagiogranite is an isotopic-fabric lithology, all minerals (quartz, feldspars) with hardness of 6-7 on Moh's hardness scale. (b) Remnant of Neolithic hand axe found along banks of Venetikos Rivers (M. Wilke pers. comm.)

7. Conclusion

River-deposited formations in the west Macedonia region reflect the complexity of the area's geology and offer many clues to past tectonic and climatic events. Cobbles from this region have also had an impact on the history of human civilization and modern industry.

The sedimentary deposits left behind by rivers in this region tell the story of the Earth, from the remains of billion-year-old landmasses and lost oceans, to the rise of mountains, the Ice Ages, and the dawn of human civilization. Pieces from these old chapters in the story are continually finding their way into the new chapter, recycled by the relentless action of moving water.

8. References

Brunn, J., 1956. Contribution a L'Étude Géologique du Pinde Septentrional et D'une Partie de la Macédoine occidentale. *Ann. Geol. Pays. Hellen. 7*, 1-358.

Blatt, H., Middleton, G., Murray, R., 1972. *Origin of Sedimentary Rocks*. New Jersey: Prentice-Hall, Inc.

Domokos, G., Jerolmack, D. J., Sipos, A. Á., Török, Á., 2014. How river rocks round: solving the shape-size paradox. *PloS One*, 9(2): e88657. doi:10.1371/journal.pone.0088657.

Ferriere, J., Reynaud, J., Pavlopoulos, A., Bonneau, M., Migiros, G., Chanier, F., Proust, J., Gardin, S., 2004. Geologic evolution and geodynamic controls of the Tertiary intramontane piggyback Meso-Hellenic basin, Greece. Bull. Soc. Geol. Fr., 175, 361-381.

Grivas, E., Rassios, A., 1998. Resistant stones for use in road construction and high-friction surfacing material, West Macedonia. Internal Report Institute of Geology and Mineral Exploration, Kozani Branch, ~49 pages. *In Greek.*

Lau, H. Y. V., 2006. Geological Sciences Mapping Project: Zavordas Monastery Area, Aliakmon River Region Macedonia, Greece. Cambridge University (unpublished report). 15pp + map.

Panagopoulou, E., Harvati, K., Karkanas, P., Athanassiou, A., Elefanti, P., Frost, S., 2006. *The West Macedonia Palaeolithic survey*. To archeologiko ergo sti Makedonia kai Thraki. 18. 632-638. *In Greek.*

Rassios, A., 2008. *A Geologist's Guide to West Macedonia, Greece.* Grevena: AnGre.

Rassios, A., 2011. *A Geologist's Guide to the Greveniotiki Pindos, Greece*. Athens: Institute of Geology and Mineral Exploration.

Rassios, A., 1981. Geology and Evolution of the Vourinos Complex, Northern Greece. PhD. Thesis, University of California Davis, 499 pp.

Rassios, A., and Grivas, E., 1998. Reserves of Hard Inert Material in Grevena Prefecture. Internal Report Institute of Geology and Mineral Exploration, Kozani Branch ~100 pages. *In Greek.*

Reineck, H.-E., and Singh, I. B., 1973. *Depositional Sedimentary Environments*. New York: Springer-Verlag.

Vamvaka, A., Kilias, A., Mountrakis, D., Papaoikonomou, J., 2006. Geometry and structural evolution of the Mesohellenic Trough (Greece): a new approach. Geol. Soc. Lond. Spec. Publ. 260, 521–538.

Wilke, N. C., Savina, M. E., 1997. The Earliest Farmers in Macedonia. Antiquity 71: 201–207.

Zlatkin, O., Avigad, D., Gerdes, A., 2014. Peri-Amazonian provenance of the Proto-Pelagonian basement (Greece), from zircon U-Pb geochronology and Lu-Hf isotopic geochemistry. Lithos, 184-187, 379–392.