Functional role of Mikri Gourna Cave in the karstic system of Mount Olympus (Greece)

Article · August 2023

2 authors:

Georgios Lazaridis
Aristotle University of Thessaloniki

Despoina Dora
Aristotle University of Thessaloniki

Cave and Karst Science, Vol.50, No.2, (2023) 79–82
Transactions of the British Cave Research Association

ISSN 1356-191X

Functional role of Mikri Gourna Cave in the karstic system of Mount Olympus (Greece)

Georgios LAZARIDIS [1*] and Despoina DORA [1]

[1] School of Geology, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece.
[*] Corresponding author: geolaz@geo.auth.gr.

Abstract: Mikri Gourna Cave lies at 40° 4′ 8.05″N and 22° 19′ 58.47″E, in the neighbourhood of the Christaki refuge on the northwestern slope of Mount Olympus, at an altitude of 2,386m asl (above sea level). The cave, which is part of a karst depression in a cirque valley that feeds into the Xerolakki drainage basin, was investigated and monitored for four successive years (2014 – 2017). Although Mikri Gourna Cave has formerly been considered an ice cave (Lazaridis *et al*., 2018), fieldwork has since shown that firn accumulation at its deepest point melts during the early autumn. This excludes it from the list of ice caves in Greece and supports an assumption that the annual firn accumulation is a transient aspect of the current climatic regime. Karstic dissolution forms, including scallops, inside the cave indicate an inward flow direction. Scallop analysis suggests a maximum flow velocity of 1.57m/s, which corresponds to the maximum discharge/recharge velocities that occur in a conduit (e.g., Lauritzen, 1989).

The geomorphology of the landscape reveals that the area was occupied by a glacier with distinct retreat phases. Mikri Gourna Cave developed horizontally, with a slightly downward-sloping entrance, located at the lowest point in the rim of a large karst depression. New evidence re-classifies it as a ‘simple dynamic’ cave with firn, active during the Pleistocene glaciation. The term ‘dynamic’ is derived from Luetscher and Jeannin’s (2004) process-based alpine ice cave classification scheme, while the term ‘simple’ refers to its one entrance (Ford and Williams, 2007). The probability that Mikri Gourna functioned as a recharge point to the mountain’s karst system during mainly periglacial periods is strengthened by the estimated maximum flow velocity and associated evidence of inward flow.

Keywords: alpine cave, ice cave, caves in Greece, scallops, subterranean geomorphology, karst depression, Olympus.

***Received**: 23 January 2023; **Accepted**: 08 May 2023.*

Introduction

Caves hosting perennial ice accumulations are found where the balance between the prevailing climate and the cave morphology creates favourable conditions for the formation and persistence of ice (Perşoiu and Lauritzen, 2018). In general, the lower the latitude the higher is the altitude required for ice cave development and ice survival. Almost all currently known ice caves are reported from the northern hemisphere. An exception is Qaqa Mach’ay (Cliff Cave) at 4,930m above sea level (asl) in the Peruvian Andes, which contains large permanent masses of clear (locally banded), ponded-water, ice (McKenzie, 2006, 2023).

Ice caves are recorded in the mountains of mainland Greece, but there are also significant occurrences on some of the islands. The most indicative examples, have been described from the Lefka Ori (White Mountains) range of western Crete, Mount Tymphe (in the Pindus Range), Mount Olympus (Thessaly), Skoteini Mountain (on Euboea Island), Falakro Oro (eastern Macedonia), Oligyrtos Mountain (northeastern Peloponnese), Menoikio Mountain (Macedonia) and Mount Parnassos (Central Greece), which are spread throughout the Country’s latitude. Lazaridis *et al*., (2018) monitored 76 ice caves in Greece and applied Luetscher and Jeannin’s (2004) process-based alpine ice cave classification scheme. The dominant ice cave type was confirmed as the “static cave with firn”, and Mikri Gourna (identified more recently) is also of this type. The term “static” refers to the predominant air circulation type in the cave and specifically to the absence of forced air convection (Luetscher and Jeannin, 2004), whereas the snow accumulation has been identified as firn after Ford and Williams (2007).

The alpine climate of Mt. Olympus is characterized by an average of three snowfalls at altitudes greater than 2,500m during the summer season (Sahsamanoglou, 1989). The mountainous area of Olympus (covering some 300km^2 at its base level) is the area of Greece with the highest proportion of ice caves among its total recorded caves (60%; Lazaridis *et al*., 2018). Some karstic features of the area that diverge from the dominant ice cave morphology type, require further investigation. The formation of Mikri Gourna Cave is a case in point. Located on the edge at the lowest point of a large karst depression, the cave has developed horizontally, with a slightly downward-sloping entrance. Newly observed evidence suggests that it should be reclassified.

Geological setting

The research site is on the flank of Mount Olympus (2,918m asl), the highest mountain in mainland Greece. Mount Olympus exposes a tectonic window comprising a sequence dominated by Triassic, Cretaceous and Palaeogene platform carbonates that has been superposed by thrust sheets of augen gneiss, mica schists, amphibolites, granites and ophiolites (Godfriaux, 1968; Barton, 1975; Schmitt, 1983; Latsoudas and Sonis, 1985; Katsikatsos *et al*., 1986; Schermer, 1990, Shermer *et al*., 1990; Mountrakis, 1986; Mountrakis *et al*., 2006). Although Olympus is part of the Pelagonian tectonic zone, its carbonate core is considered to be part of the Gavrovo zone. Extension events during the Tertiary revealed the Gavrovo's limestone, whereas tectonic uplift of the Olympus massif is ongoing (Caputo and Pavlides, 1993). With a total thickness of about 2,650m, the carbonate sequence comprises calcitic limestones that pass gradually into more-dolomitic beds. Mikri Gourna Cave has formed within part of the 800m-thick Cretaceous carbonate sequence, which comprises medium- to thick-bedded limestones with dolomite intercalations.

During the Pleistocene, the Olympus massif was a significant glaciation centre, and studies place the snowline at 1,900m asl (Smith *et al*., 1994; Smith *et al*., 1997). The glaciation involved development of piedmont lobes on the adjacent lowland areas that were fed by ice moving from the cirque valleys of the upland.

Whereas maritime influences affect the eastern side of the Olympus massif, resulting in mild climatic conditions and temperate glacial formation, climate characteristics on the northwestern slope are more continental, with higher precipitation during the summer months and lower mean annual temperatures. Above 2,200m asl, there are fewer than 20 dry days per year, and precipitation from October to May is mainly snow (Styllas *et al*., 2016). The area is covered with the low and sparse vegetation typical of Alpine climatic conditions. Karst landforms noted in the broader neighbourhood of the study site include dolines, uvalas, small shafts and caves. Also in the area, a NE–SW normal fault has guided much of the upland course of the Xerolakki valley (Fig.1).

Mikri Gourna Cave: description and discussion

Mikri Gourna Cave (Figs 2–5) is located at 40° 4′ 8.05″N and 22° 19′ 58.47″E, on the northwestern slope of Mount Olympus, at an altitude of 2,386m asl, very close to the Christaki refuge. Though previously listed as an ice cave (Lazaridis *et al*., 2018), new evidence indicates that the cave does not meet the related criteria. The cave is part of a karst depression in a cirque valley that feeds the Xerolakki surface drainage system (Fig.1). Like the other glacial valleys of Olympus, the cirque valley lacks a typical U-shaped morphology, because of the effects of rapid tectonic uplift, the limestone's high susceptibility to erosion, and fluvial activity (Smith *et al*., 1997). Notwithstanding its sub-horizontal entrance passage, the cave has been observed to host firn and snow throughout the year. Mikri Gourna's morphology begins as a rock-shelter, with a wide entrance, and then becomes low and narrow. The floor, which is covered with limestone blocks and clastic sediments, is inclined inwards, and the deepest part hosts a firn accumulation. The cave lies at the lowest edge of a 200m-diameter karst depression, which promotes snow accumulation even though, unlike the acknowledged ice caves elsewhere Greece, the cave does not exhibit a typical pothole morphology. However, complete wasting of the firn was recorded in September 2017 (Fig.5), and the current study's field work has confirmed similar melting in successive years. This situation is a result of equilibrium being achieved between winter snow precipitation/accumulation and subsequent summer ablation (Ohmura *et al*., 1992), supporting the assumption that the longevity of the firn accumulation is adjusting to modern climatic conditions. The passage cannot be explored further without removal of rocks that are blocking the way forward.

Discontinuities measured in the entrance area are southwest-dipping at moderate angles (220°–225°/~36°) and on N–S and W–E orientation with medium to high dip angles (55°–80°). Their major involvement in the shaping and enlargement the entrance is clearly visible in Figure 3. In the absence of any dissolution features, frost weathering (Oberender and Plan, 2015) must be considered to be playing an important part in developing the entrance area.

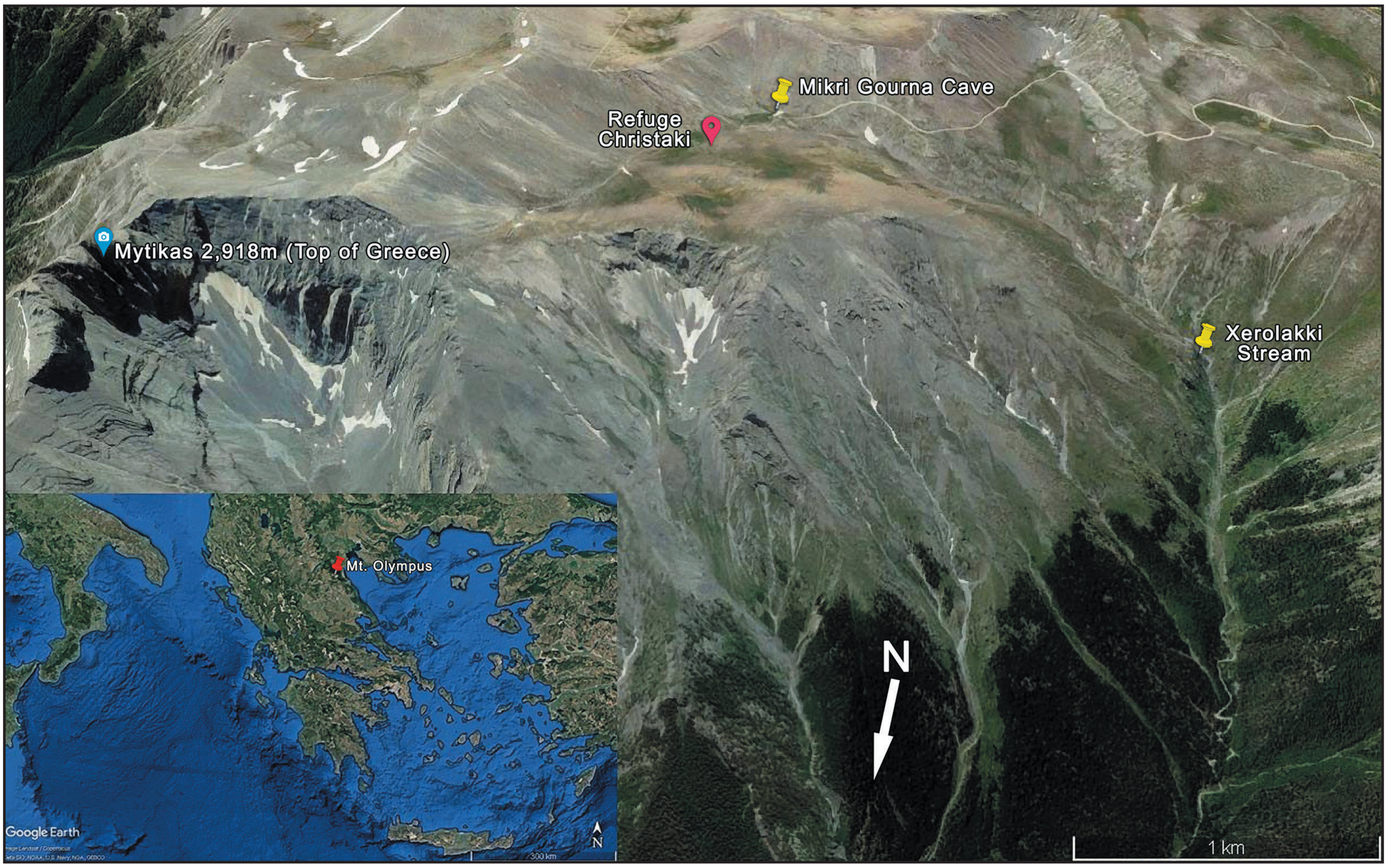

Figure 1: *Mikri Gourna's position relative to the karst depression and the Xerolakki stream. [Satellite image sourced from: ©Google Earth 2022.]*

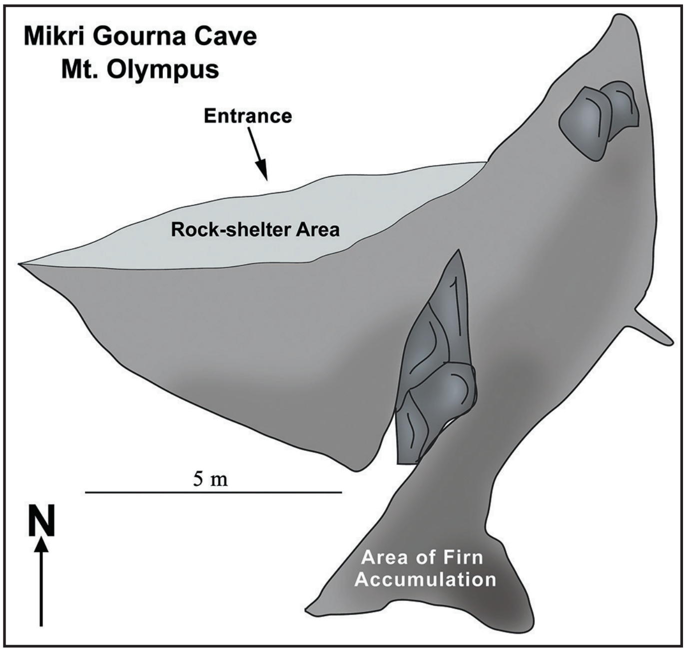

***Figure 2**: Ground plan of Mikri Gourna Cave, which was formerly categorized as an ice cave.*

Methods of reclassification

At low temperatures in high-alpine environments the solubility of CO_2 in water is greater than in warmer waters at lower altitudes, and hence the aggressiveness of the water is also increased. Theoretically at least, this provides a distinct speleogenetic advantage (Pavuza, 1993). Small fracture-guided tubes with asymmetrical dissolution pockets characterize the eastern part of the cave (Fig.4). These features are formed by turbulent lateral flow, and consideration of their asymmetry can be used to interpret flow direction. The dissolutional forms (scallops) and their formation process are well-known from theoretical, experimental, and empirical approaches (e.g. Curl, 1966, 1974; Murphy, 2012). Scallop size depends upon the water-flow velocity, where (for a given diameter of conduit) smaller scallops are related to higher flow velocities.

In the case of Mikri Gourna, the size of the scallops ranges from 1.3 to 3.5cm, and their asymmetry indicates an inward water flow. Scallop lengths are processed in the spreadsheet program scallopex (Woodward and Sasowsky, 2009), based upon assumption of a 5°C water-temperature and a rectangular passage profile. The low temperature value corresponds broadly to the lowest water-temperatures in the caves of Greece, even during colder periods. Thus, the velocity estimations approximate the maximum possible water velocities in the cave. Statistical analysis is carried out using PAST 4.03 software (Hammer *et al*., 2001).

***Figure 3**: The entrance area of the Mikri Gourna Cave.*

***Figure 4**: Karst conduits along discontinuities, with small scallops. The general conduit width is about 35cm.*

***Figure 5**:*
***A**: Firn accumulation in Mikri Gourna Cave in July 2013.*
***B**: The same location with no ice remaining, in September 2017.*

Results based upon the data collected in Mikri Gourna suggest a maximum velocity of 1.57 m/s. It should be noted that the scallops investigated provide data that represent the maximum discharge/recharge velocities that occur in a conduit (e.g., Lauritzen, 1989).

The scallop-related measurements and derived data are indicative of laterally flowing, presumably vadose, water rather than suggesting a phreatic environment. They occur in the currently "dry" part of the cave because denudation of the area has changed the relative positions of the cave and the karst depressions. The cave is functionally related to the glaciation of Mount Olympus (Styllas *et al*., 2018), which explains the former availability of large amounts of flowing water and its estimated velocity.

Concluding remarks

Mikri Gourna Cave on Mount Olympus was monitored for a period of 4 years (2013–2017) and in the early Autumn of 2017 was found to retain no remnant of its former firn. Thus, Mikri Gourna is no longer included in the catalogue of ice caves in Greece (Lazaridis *et al*., 2018). Because the small dimensions allow air circulation throughout all of the accessible parts of the cave, it is reclassified as a '*simple dynamic cave*' that supports the presence of seasonal ice. The term '*dynamic*' (as used here) is derived from Luetscher and Jeannin's (2004) process-based alpine ice-cave classification scheme, whereas use of the term 'simple' acknowledges its (current) single entrance (Ford and Williams, 2007).

This is not the first time that this type of ice wasting has been observed in Greek caves. It was previously documented during the successive explorations of the Chionotrypa Cave on Mount Falakro (northern Greece), where ice volume decreased significantly during the period 2007–2015 (Lazaridis and Makrostergios, 2014; Lazaridis *et al*., 2018). Further study of the caves in the related neighbourhoods is recommended, in order to help evaluate any possible patterns of ice retreat, in particular with regard to caves on Mount Olympus. In the case of Mikri Gourna Cave, two processes – karst dissolution and frost weathering – have contributed to the development of the cave's morphological features. The presence and analyses of scallops have indicated and confirmed Mikri Gourna's active role at some stage (or stages) during the several glaciations and deglaciations within the Pleistocene Epoch. The cave's functional role as a recharge point of the underlying karst system. and its direct relationship to flowing glacial/deglacial water, are linked to the cave's position within the rim of the karst depression.

Acknowledgements

We are deeply grateful to Dr Kostantinos Stamoulis (Department of Physics, University of Ioannina), Iraklis Kalogeropoulos, Sakis Ntavlis and Vassilis Sidiropoulos (cavers of the Hellenic Speleological Society, Department of Northern Greece) for their contribution during the fieldwork and sampling, and Dr Didier Cailhol for reviewing this paper. We also thank an anonymous BCRA reviewer and Dr David Lowe for comments and suggestions that helped to improve the manuscript.

References

Barton, C M, 1975. Mount Olympos, Greece: new light on an old window. *Journal of the Geological Society*, Vol.131(4), 389–396. [https://doi.org/10.1144/gsjgs.131.4.0389]

Caputo, R and Pavlides, S, 1993. Late Cainozoic geodynamic evolution of Thessaly and surroundings (central-northern Greece). *Tectonophysics*, Vol.223(3–4), 339–362. [https://doi.org/10.1016/0040-1951(93)90144-9]

Curl, R L, 1966. Scallops and flutes. *Transactions Cave Research Group of Great Britain*, Vol.7(2), 121–160.

Curl, R L, 1974. Deducing flow velocity in cave conduits from scallops. *National Speleological Society Bulletin*, Vol.36(3), p.22.

Ford, D and Williams, P, 2007. *Karst Hydrogeology and Geomorphology*. [John Wiley and Sons Inc.]

Godfriaux, I, 1968. Etude géologique de la région de l'Olympe (Grèce). *Doctoral dissertation, Université de Lille*.

Hammer, Ø, Harper, D A and Ryan, P D, 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia electronica*, Vol.4(1), p.9.

Katsikatsos, G, Migiros, G, Triantaphyllis, M and Mettos, A, 1986. Geological structure of internal Hellenides (E Thessaly, SW Macedonia, Euboea, Attica, Northern Cyclades islands and Lesvos). *Greek Institute for Geologic and Mining Research, Geological and Geographical Research*, Special Issue, 191–212.

Latsoudas, C and Sonis, C, 1985. Geological map of Greece, Kantariotissa–Litochoro sheet, Scale 1:50 000. [Athens, Greece: Institute of Geology and Mineral Exploration.]

Lauritzen, S-E, 1989. Scallop dominant discharge. Paper presented at the 10th International Congress of Speleology, International Union of Speleology, Budapest, 1989.

Lazaridis, G, Theodosiadis, T and Athanasopoulos, V, 2018. Ice caves in Greece. *Cave and Karst Science*, Vol.45(1), 33–38.

Lazaridis, G and Makrostergios, L, 2014. Geology and morphology of the Chionotrypa Cave (Falakro Mt, Macedonia, Greece). Balkan Speleological Conference "Sofia 2014". Sofia, Bulgaria.

Luetscher, M and Jeannin, P Y, 2004. A process-based classification of alpine ice caves. *Theoretical and Applied Karstology*, Vol.17(5), 5–10.

McKenzie, I, 2006. A hole in the sky. *Alpine Journal*, Vol.2, 129–131.

McKenzie, I, 2023. *Personal communication* [e-mail confirmation that Qaqa Mach'ay (Peruvian Andes) is an ice cave as currently defined – see, *for example*, Perşoiu and Lauritzen, 2018.]

Mountrakis, D, 1986. The Pelagonian zone in Greece: a polyphase-deformed fragment of the Cimmerian continent and its role in the geotectonic evolution of the eastern Mediterranean. *Journal of Geology*, Vol.94(3), 335–347. [https://doi.org/10.1086/629033]

Mountrakis, D, 2006. Tertiary and Quaternary tectonics of Greece. [Chapter *in*] Dilek, Y and Pavlides, S (eds), *Postcollisional Tectonics and Magmatism in the Mediterranean Region and Asia*. Special Papers of the Geological Society of America, 409. [https://doi.org/10.1130/2006.2409(07)]

Murphy, P J, 2012. Scallops. 679–683 *in* White, W B and Culver, D C (eds), *Encyclopedia of Caves*. [Amsterdam: Elsevier.]

Oberender, P and Plan, L, 2015. Cave development by frost weathering. *Geomorphology*, Vol.229, 73–84. [https://doi.org/10.1016/j.geomorph.2014.07.031]

Ohmura, A, Kasser, P and Funk, M, 1992. Climate at the equilibrium line of glaciers. *Journal of Glaciology*, Vol.38(130), 397–411. [https://doi.org/10.3189/S0022143000002276]

Pavuza, R, 1993. Observations on the corrosion potential in alpine caves. *Bulletin de la Société géographique de Liège*, Vol.29, 67–71.

Perşoiu, A and Lauritzen, S-E, 2018. *Ice Caves*. [Elsevier.] 752pp.

Sahsamanoglou, H, 1989. Summer snowfalls over the Mount Olympus area. *International Journal of Climatology*, Vol.9, 309–319. [https://doi.org/10.1002/joc.3370090307]

Schermer, E R, 1990. Mechanisms of blueschist creation and preservation in an A-type subduction zone, Mount Olympos region, Greece. *Geology*, Vol.18(11), 1130–1133. [https://doi.org/10.1130/0091-7613(1990)018<1130:MOBCAP>2.3.CO;2]

Schermer, E R, Lux, D R and Burchfiel, B C, 1990. Temperature-time history of subducted continental crust, Mount Olympus Region, Greece. *Tectonics*, Vol.9(5), 1165–1195. [https://doi.org/10.1029/TC009i005p01165]

Schmitt, A, 1983. Nouvelles contributions à l'étude géologique des Pieria, de l'Olympe, et de l'Ossa (Grèce du Nord). PhD dissertation, Mons, Belgium, Faculté Polytechnique de Mons, 215pp.

Smith, G, Nance, R and Genes, A, 1994. A re-evaluation of the extent of Pleistocene glaciation in the Mount Olympus region, Greece. *Bulletin of the Geological Society of Greece*, Vol.30(1), 293–305.

Smith, G W, Nance, D R and Genes, A N, 1997. Quaternary glacial history of Mount Olympus, Greece. *Geological Society of America Bulletin*, Vol.109(7), 809–824. [https://doi.org/10.1130/0016-7606(1997)109<0809:QGHOMO>2.3.CO;2]

Styllas, M N, Schimmelpfennig, I, Benedetti, L, Ghilardi, M, Aumaitre, G, Bourlès, D and Keddadouche, K, 2018. Late-glacial and Holocene history of the northeast Mediterranean mountain glaciers - new insights from in situ-produced ^{36}Cl-based cosmic ray exposure dating of paleo-glacier deposits on Mount Olympus, Greece. *Quaternary Science Reviews*, Vol.193, 244–265. [https://doi.org/10.1016/j.quascirev.2018.06.020]

Styllas, M N, Schimmelpfennig, I, Ghilardi, M and Benedetti, L, 2016. Geomorphologic and paleoclimatic evidence of Holocene glaciation on Mount Olympus, Greece. *The Holocene*, Vol.26(5), 709–721. [https://doi.org/10.1177/0959683615618259]

Woodward, E and Sasowsky, I D, 2009. A spreadsheet program (ScallopEx) to calculate paleovelocities from cave wall scallops. *Acta Carsologica*, Vol.38(2–3), 303–305. [https://doi.org/10.3986/ac.v38i2-3.130]