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NEW FINDING~~S~~ OF THE CAMPANIAN IGNIMBRITE ASH WITHIN SLOPE DEPOSITS OF THE TRESKA VALLEY (FORMER Y~~O~~UGOSLAVIA REPUBLIC OF MACEDONIA)

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ABSTRACT

In this paper we describe the first finding of the Campanian Ignimbrite tephra layer in a subaerial succession in the Former Yugoslavian Republic of Macedonia ~~(FYROM)~~. The tephra is interbedded within slope deposits mixed with colluvial loess. The identification of this fundamental stratigraphic marker allows correlating the investigated succession to lacustrine records from Ohrid and Prespa lakes, numerous archives of central and eastern Mediterranean, and mainland Ukraina and Russia. ~~The~~ field observations and ~~the~~ correlation to lacustrine records (i.e. pollen) indicate that accumulation of the ash ~~layer~~ occurred in a dry environment characterized by low vegetation cover and important wind activity, which promoted loess deposition~~s~~. The recognition of the Campanian Ignimbrite tephra allows the correlation of the loess sediments to the H4 event, defined in the North Atlantic event climatic stratigraphy.

RIASSUNTO

In questo lavoro si riportano i primi dati relativi al ritrovamento di un livello vulcanico attribuibile all'Ignimbrite Campana nella valle del fiume Treska (Repubblica Macedone ~~– FYROM~~). Questo livello, che si ritrova intercalato a livelli di detrito di versante, associati a depositi più fini di origine eolica-colluviale è stato correlato con i livelli vulcanici recuperati nei registri pollinici dei laghi Prespa e Orhid (FYROM), con numerosi archivi del Mediterraneo centrale e orientale, e le pianure dell'Ucraina e della Russia. Ciò ha permesso di attribuire al periodo di deterioramento climatico corrispondente all'evento H4 nella stratigrafia marina del Nord Atlantico la deposizione del livello vulcanico e degli associati detriti di versante misti a depositi loessici

KEY WORD: *Campanian Ignimbrite, Slope deposits, loess, FYROM*

INTRODUCTION

The Campanian Ignimbrite (CI), is the largest explosive eruption occurred in the Mediterranean basin in the last 200 ka (BARBERI *et alii*, 1978; PYLE *et alii* 2006). ~~In the marine sediments of the Central and Eastern Mediterranean~~ the CI has long been identified ~~since the Keller's stratigraphic work~~ (KELLER *et alii*, 1978) where it has been named Y5 layer. Its large dispersion makes it one of the most impressive stratigraphic marker for sedimentary successions downwind of the volcanic source (e.g. WULF *et alii*, 2004; PYLE *et alii*, 2006; GIACCIO *et alii*, 2008; SULPIZIO *et alii*, 2010; COSTA et al., 2012; LOWE *et alii*, 2012), identified in the Campi Flegrei caldera in the Campanian region (e.g. BARBERI *et alii*, 1978; ORSI *et alii*, 1996). The CI has a robust chronological ~~constrain~~ obtained by $^{40}Ar/^{39}Ar$ dating ~~technique~~ (ca. 39.28 ± 0.11 ka, De Vivo et al., 2001), and represents a fundamental anchoring point for the construction of correct age models (e.g. WAGNER *et alii*, 2008, 2009; VOGEL *et alii*, 2010; BLOCKLEY *et alii*, 2014). Detailed climate-stratigraphic works indicate that the CI has occurred at the beginning of the Heinrich event 4 (H4) (e.g. GIACCIO *et alii*, 2008; FEDELE *et alii*, 2008; MÜLLER *et alii*, 2011; BLOCKLEY *et alii*, 2014), one of the most dramatic cooling events related to the disruption of North Atlantic thermohaline circulation and associated to the collapse of Laurentide ice sheet (HEMMING, 2004; ROCHE *et alii*, 2004; NAAFS *et alii*, 2013). During these events, the reduction of efficiency of the North Atlantic thermohaline circulation produced temperature lowering and moisture transport decreasing from Atlantic to Mediterranean, inducing cold and dry conditions on land (e.g. FLETCHER AND SANCHEZ-GOÑI, 2008; LÒPEZ-GARCÌA *et alii*, 2013). Because Heinrich events have occurred quasi-periodically during the last Pleniglacial (HEINRICH, 1988), their secure identification is fundamental for understanding their timing and propagation over different regions. In this regards tephra layers ~~are~~ considered among the best stratigraphic markers for synchronising different archives and their proxies (e.g. ZANCHETTA *et alii*, 2008; 2011; GIACCIO *et alii*, 2008; ALBERT *et alii*, 2014).

The very large dispersion of the CI had, presumably, a severe impact on the environment in a period of strong climate deterioration (COSTA *et alii*, 2012; BLACK *et alii*, 2015).

The CI event is of particular interest not only to investigate the role of volcanism as climate forcing, but also because its timing roughly coincides with the arrival into Europe of the anatomically modern humans, the demise of the Neanderthals, and an associated major shift in lithic technology (MELLARS, 2004~~,~~ LOWE *et alii*, 2012; HIGHAM *et alii*, 2014 DOUKA *et alii*, 2014). This has fuelled a long standing debate on the role of this eruption in triggering, or more generally in contributing to~~,~~ the extinction of Neanderthal humanity, ~~to~~ human cultural evolution during the Late Pleistocene and ~~to the role on~~ the arrival of anatomically modern humans (FEDELE F.G. *et alii*, 2003,2007,2008; FEDELE L. *et alii*, 2007; LOWE *et alii*, 2012; COSTA *et alii*, 2012; BLACK *et alii*, 2015).

In this paper we report the recognition of ~~the~~ CI interlayered in slope deposits along a sector of the Treska River valley (Fig. 1) in the Former Yugoslavia Republic of Macedonia (FYROM). Despite the CI tephra is already reported for lacustrine settings of ~~the~~ FYROM (WAGNER *et alii*, 2008; SULPIZIO *et alii*, 2010; VOGEL *et alii*, 2010; CARON *et alii*, 2010, DAMASKE *et alii*, 2013) and in the Golema Pesht cave archeological succession (LOWE *et alii*, 2012) this is the first finding in ~~on~~ subaerial deposits and represents a unique opportunity to compare lacustrine and subaerial environments.

LOCAL GEOLOGY

~~In~~ our knowledge~~,~~ there are no specific geological works on ~~Quaternary deposits of~~ the investigated area~~,~~ if we exclude the geological map at 1:200.000 and 1:100.00 scale (PENDŽERKOVSKI, 1977). ~~In the following we will refer to t~~his cartography for the geology of the substrate whereas ~~for Quaternary deposits~~ we will report our field observations. Several geological exposures ~~occur on the valley bottom along the border of the national road R1 106, between the Belica and Modriste villages (Fig. 1)~~. ~~Apart~~ the recent alluvial deposits, at least ~~3~~ different lithostragraphic units separate by disconformities ~~can be described~~, ~~which~~ ~~lie~~ above the carbonate bedrock ~~(a Cambrian limestone and dolostone),~~. ~~The lowest unit (LU1),~~ is composed by a ~~basal~~ fluvial member of polygenic gravels (carbonate rock, phyllites, marbles) interlayered with sands~~,~~ ~~followed on top by a~~ finer grained member~~,~~ ~~progressively passing to a~~ reddish polygenic paleosol with characteristic carbonate concretions ~~(Fig. 2a,b)~~. ~~L~~ocally ~~this paleosol preserves~~ lenses of a yellowish altered volcanic ash (Fig. 2a,b). A first ~~generation~~ of slope deposits ~~caps this unit~~ (LU2, Fig. 2a)~~. A~~ clear erosional surface ~~separates LU1 and LU2~~. ~~A~~n alternation of beds of angular, clast-supported gravels with whitish to yellowish~~,~~ often abundant~~,~~ matrix~~,~~ and finer grained beds ~~composes the LU2~~. In the ~~main~~

finer grained deposits there are preserved lenses, ~~locally~~ up to 1 m thick, of pale-grey fine ash deposits (Fig. 2c). LU2 occurs ~~also~~ ~~at~~ direct contact with the bedrock. The ~~last~~ unit ~~(~~LU3~~)~~ is similarly composed by slope and colluvial deposits, and lies ~~over~~ LU2 ~~with~~ a marked erosional ~~disconformity~~ (Fig. 2a). ~~Differently from LU2,~~ matrix is darker ~~for~~ the presence of organic matter and several buried A horizons are also preserved, indicating phases of slope stabilization. ~~The~~ LU3 fades into the present soil, suggesting that part of this unit is Holocene in age. ~~L~~aterally to LU2 and LU3 ~~occur some alluvial fan deposits~~, locally dissected by quarrying activity. An erosive surface is visible ~~also in~~ these alluvial fans, separating an older phase, ~~rich in~~ debris flow deposits with yellowish matrix, and a younger one, richer in organic matter and buried A soil horizons. ~~The samples discussed in this paper are from the LU2, which includes the identified ash deposit.~~

METHODS

~~Two samples were collected in the LU2, one for characterising the fine-grained matrix of slope deposits and one for characterizing the ash deposits~~. The~~y~~ were dried at room temperature and then observed and described under binocular microscope. A fraction of the bulk samples ~~were~~ embedded in epoxy resin and screened for glass shards using scanning electron microscopy (SEM) at the Earth Sciences Department of the University of Pisa. Energy-dispersive spectrometry (EDS) of glass shards was performed using an EDAX-DX micro-analyzer mounted on a Philips SEM 515 (operating conditions: 20 kV acceleration voltage, 100 s live time counting, 200–500nm beam diameter, 2100–2400 shots s^{-1}, ZAF correction). The ZAF correction procedure does not include natural or synthetic standards for reference, and requires analysis normalization at a given value (chosen at 100%). Detailed discussion on the SEM-EDS performance, inter-calibration trials and standards can be found in MARIANELLI & SBRANA, (1998), CIONI *et alii* (1998), CARON *et alii* (2010,2012), VOGEL *et alii* (2010), ZANCHETTA *et alii* (2012). Analytical precision is 0.5% for abundances higher than 15 wt%, 1% for abundances around 5 wt%, 5% for abundances of 1 wt%, and less than 20% for abundances close to the detection limit (around 0.5 wt%).

RESULTS AND DISCUSSION

Compositional correlation

The ~~tephra~~ layer shows almost pure volcanic components (Fig. 3a). ~~Compositionally they show~~ relatively low variability in SiO_2 content (ca. 60 to 62 wt%~~, Fig. 4a~~) and total alkali between ca. 12 and 14 wt.%, but significant changes in the ~~K_2O/Na_2O~~ ratio (Fig. 4b). ~~This variability, with a~~

~~presence of at least 2-3~~ different magma compositions ~~identified by alkali ratio~~, is a characteristic marker of the CI (e.g. Civetta *et alii*, 1997; Wulf *et alii*, 2004; Pyle *et alii*, 2006; Giaccio *et alii*, 2008; Vogel *et alii*, 2010; Sulpizio *et alii*, 2010). ~~Figure 4 compares~~ our compositional data with those of CI from Lake Monticchio (Italy, Wulf *et alii*, 2004), Lake Prespa (~~Core Co1204;~~ Sulpizio *et alii*, 2010) and the Golema Pesht ~~layer~~ (Lowe *et alii*, 2012). ~~From these figures~~ the correlation ~~of ash deposits interbedded in the LU2 with the CI appears~~ robust. ~~Although often~~ three main compositions ~~are~~ observ~~able~~ in the proximal deposits (Civetta *et alii*, 1997; Pappalardo *et alii*, 2002), in the distal settings ~~this is not always the case~~, ~~with~~ often only two (and not always the same) compositions recognized (~~Fig. 3;~~ Wulf *et alii*, 2004; Giaccio *et alii*, 2008; Vogel *et alii*, 2010). The~~se~~ compositional variations of ~~the~~ CI ~~deposits~~ have suggested magma withdrawal from a compositionally-zoned magma chamber (Signorelli *et alii*, 1999). ~~The~~ compositional zoning was recognized in both fallout and ignimbrite deposits, with the relationships between magma composition and timing of the eruption inverted during the fallout and the pyroclastic flow phase (Pappalardo *et alii*, 2002). This makes it possible that in distal areas (especially if ~~not all~~ the succession is preserved or sampled), different dispersion and timing of deposition of the tephra may create lateral-vertical zoning of the settled ash and/or selective preservation.

Depositional environment

The sample of the yellowish matrix of the fine-grained layer that embeds the CI shows the presence of abundant calcite (both clastic and secondary as concretion over crystals and crystal aggregates), dolomite, quartz, albite, and relatively abundant flakes of white micas (presumably muscovite) (Fig. 3b). ~~In the sample collected, no volcanic glass shards were identified. If~~ calcite and dolomite ~~would be directly~~ derived from the local bedrock, the presence of quartz, albite and white mica could be indicative of an external input probably ~~as~~ aeolian ~~component~~. During Late Pleistocene widespread loess deposition occurred ~~over~~ the Balkans and ~~in~~ particular ~~over~~ the Lower Danube valley (~~e.g.~~ Costantin *et alii*, 2012; Fitzsimmons *et alii*, 2012,2013; Veres *et alii*, 2013), demonstrably associated with CI deposits and thus in agreement with our findings. Local processes of aeolian accumulation ~~might have increased~~ the thickness of ~~the~~ CI in the studied succession, ~~and eventually subjected~~ to further displacement by slope processes. Therefore the thickness here reported cannot be assumed as primary. ~~This process~~ probably affected many other distal deposits, a factor which need to be carefully considered when thickness of ~~the~~ CI is used for total volume estimations of the erupted magma.

Palaeoclimate considerations

The finding of the CI in the Balkans is not a novelty (WAGNER *et alii*, 2008; VOGEL *et alii*, 2010; VERES *et alii*, 2013). Also in FYROM, the CI has been repeatedly found in the cores retrieved in Prespa and Ohrid lakes (WAGNER *et alii*, 2008, 2019 VOGEL *et alii*, 2010, SULPIZIO *et alii*, 2010), with thickness up to ca. 15 cm and reported to cap the arheological succession of the Golema Pesht cave (Fig. 1). However, it has never been described directly in terrestrial deposits. The finding reported in this paper provides insights on the environment of the area at time of CI deposition. Pollen data associated to the CI in the Mediterranean usually indicate a period of reduction in arboreal pollen, consistent with general drier and cooler conditions (e.g. MARGARI *et alii*, 2007; BRAUER *et alii*, 2007). Specifically in the FYROM, pollen data from Ohrid and Prespa lakes confirm that the deposition of CI correspond to a period interval of climatic deterioration (WAGNER *et alii*, 2009; LÉZINE *et alii*, 2010; PANAGIOTOPOULOS *et alii*, 2014), opening of the forest and increasing of herbs. In particular at Lake Prespa the CI has been found to correspond to the interval of lowest percentage of the arboreal pollen identified in the 92 ka long record, associated to a sustained increase in *Artemisia* pollen grains (PANAGIOTOPOULOS *et alii*, 2014). This suggests steppe-like conditions at that time of CI deposition in the area. The proposed environmental reconstruction is suggestive of a landscape prone to dust transportation, with areas favorable for wind deflations and areas of deposition (traps). This is in agreement with the deposition of alloctonous material within the morphological setting that characterizes by carbonate substratum during phases of slope degradation indicated by the development of coarse slope deposits.

CONCLUDING REMARKS

The new finding of CI within slope deposits along the Treska Valley (FYROM) allows a confident correlation of these slope deposits to the Pleniglacial and in particular can indicate stronger dust and wind transportation at time of H4 in the area. This is supported by pollen evidence obtained in the nearby Ohrid and Prespa lakes (WAGNER *et alii*, 2009; LÉZINE *et alii*, 2010; PANAGIOTOPOULOS *et alii*, 2014). The CI recognition provides new perspectives for research on loess deposits in the FYROM, where more detailed studies should be carried out in the future. New researches can allow identifying new outcrops and possibly additional tephra layers (e.g. the Y3 tephra layer, which has cm thickness in successions of Ohrid and Prespa lakes, SULPIZIO *et alii*, 2010; VOGEL *et alii*, 2010) in similar terrestrial successions. This could add important information for the reconstruction of climate in the region, allowing a strictly correlation between terrestrial deposits, often discontinuous, and continuous, high resolution lakes records in the area (WAGNER *et alii*, 2014ab). This would allow a more refined reconstruction of climatic changes in the Balkans with respect to those previously obtained using single archives. Moreover, the recent identification and description of glacial deposits in the area (RIBOLINI *et alii*, 2011) can give a further interests in intensify tephrostratigraphic researches in the area, with the aims to link and synchronize different terrestrial archives by means of tephra layers.

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Table and Figure Captions

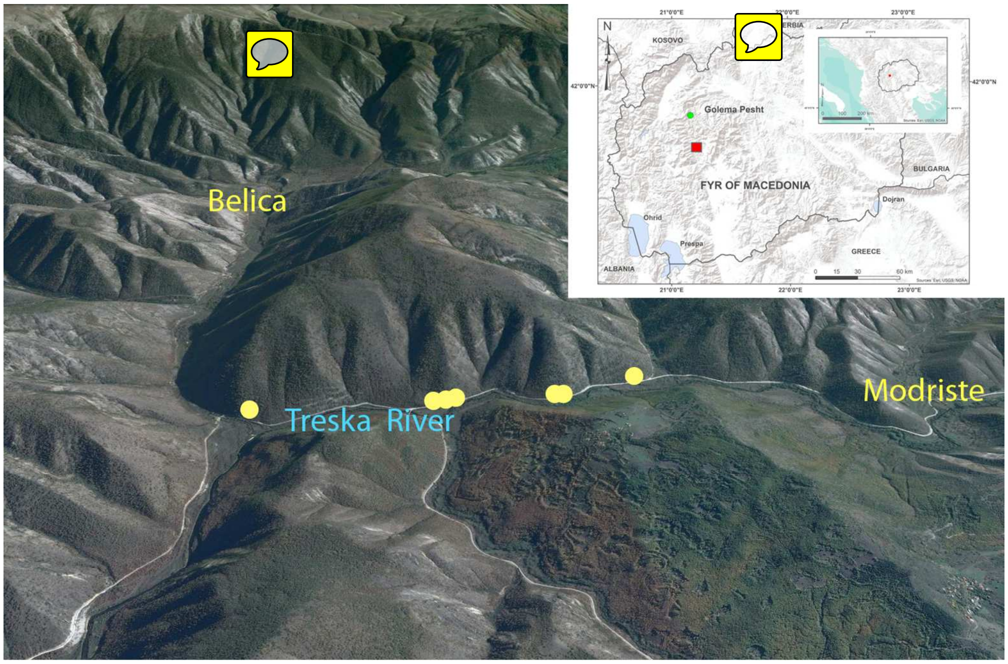
Table 1 – SEM-EDS chemical data for the tephra layer identified in LU 2.

Fig. 1 – Location map. Yellow dots indicate the position of the section considered and showed in figure 2.

Fig. 2 – (A) Lithostratigraphic Unit 1 (LU1). Upper and lower members are present (LU1U and LU1L). The picture shows the weathered yellowish tephra layers preserved (ash) on top of the succession; LU2) and LU3 separated by disconformity are also observable (B) Upper member of the LU2 (LU2L), a thin ash layer is also visible; (C) LU2 with the CI; (D) Details of the basal contact of IC with slope deposits. Note the abundance of the matrix of the slope deposits consistent with Aeolian deposition.

Fig. 3 SEM images of (a) tephra layers with almost pure different kind of glass shards and micropumices, and (b) of the fine grained yellowish matrix of slope deposits. C: Calcite; Q: Quartz; Al: Albite; WM: White mica.

Fig. 4 (Left) Total Alkali – siliaca diagram (Le Bas *et alii*, 1986), (right) Alkali ratio (K_2O/Na_2O) *vs* SiO_2. Data from Co1204 by Sulpizio *et alii*, 2010; data from Monticchio by Wulf *et alii*, 2004; data from Golema Pesht by Lowe *et alii*, 2012.



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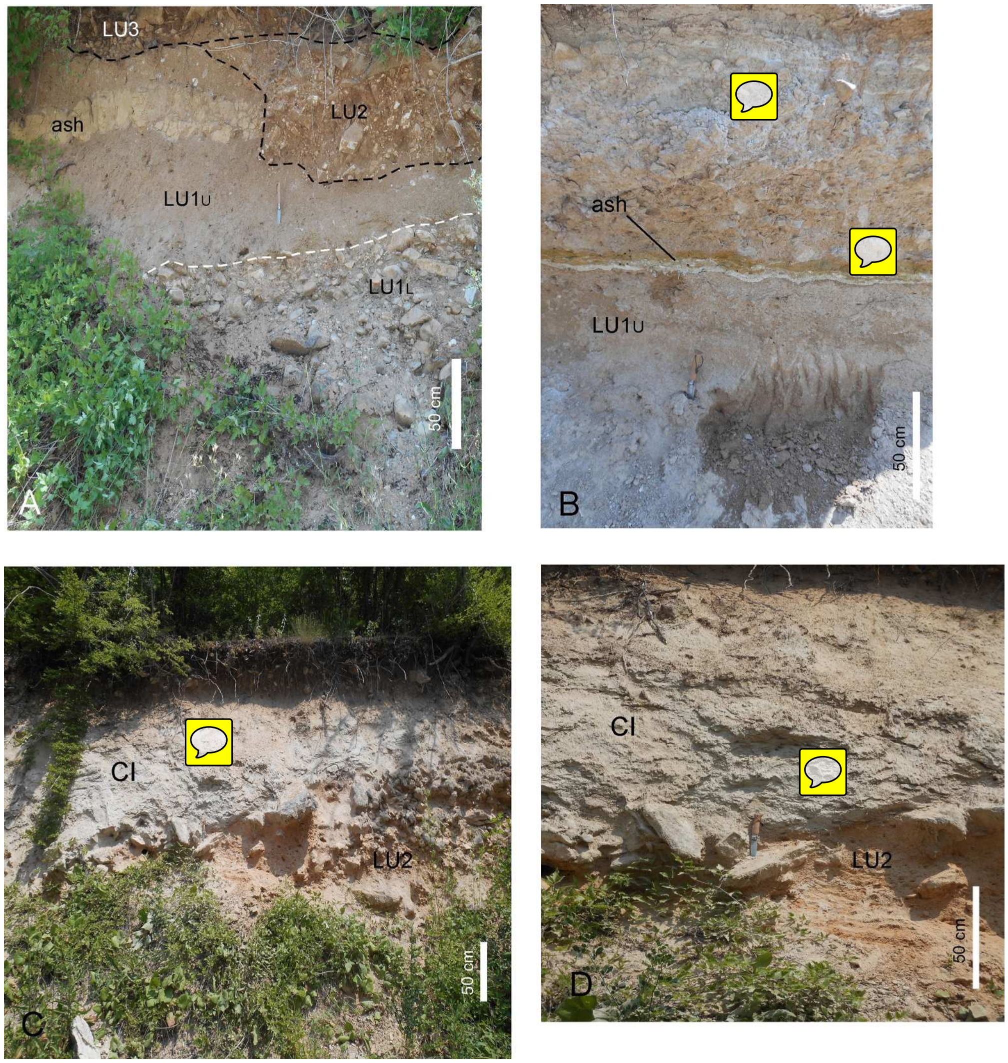

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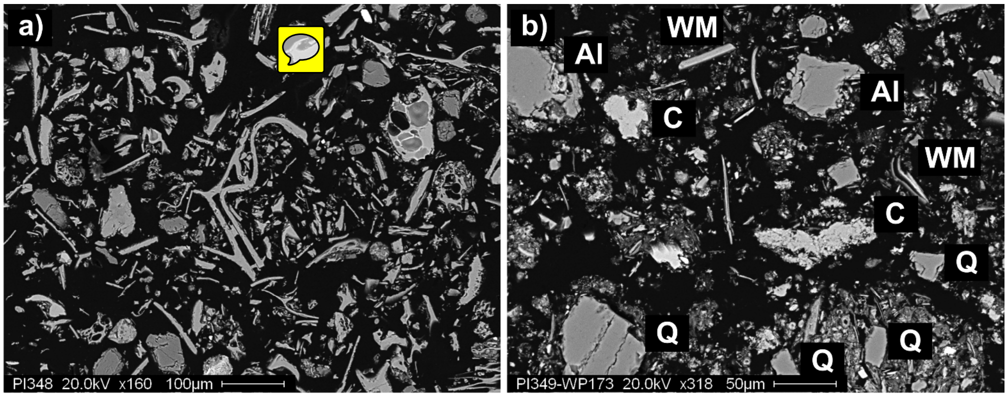

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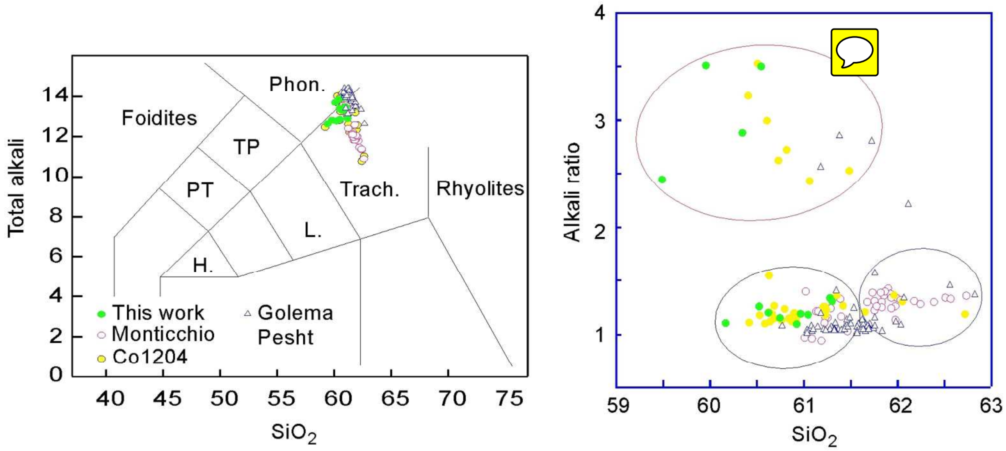

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