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Content

Micropetrographic analysis as a tool for the determination of limestone sources in Istria – applications and limitations

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Determining the source of a stone raw material, for example, limestone for building a villa rustica, can be very useful in enlightening the distribution networks of different types of raw material. One of the analyses that can help locate the sources is the micropetrographic analysis. This method, to an extent, allows us to identify the type and geological age of raw material used for an activity. This data can be a starting point in raw material provenance study, using geological maps of the potential area of procurement. However, micropetrographic analysis besides obvious advantages has some shortcomings, and its results are not always enough for answering specific archaeological questions. This paper will showcase the application and limitations of the micropetrographic analysis in determining the archaeological raw material sources.

Keywords: *raw material sources, micropetrographic analysis, limestone, Istria, Antiquity*

Introduction

The Istrian peninsula is characterized by predominantly carbonate surface deposits of Jurassic, Cretaceous and Paleogene age, as well as with terra rossa and alluvium deposits of Quaternary age. Figure 1 shows a lithostratigraphic map of the deposits in Istria. The blue shades represent the limestones and dolomites of Jurassic age, while shades of green represent the Cretaceous limestones and dolomites. The yellow and orange colours represent various rocks of Paleogene age, mainly foraminiferal limestones, and flysch deposits. The youngest deposits are the Quaternary terra rossa and alluvium (Miko et al. 2013).

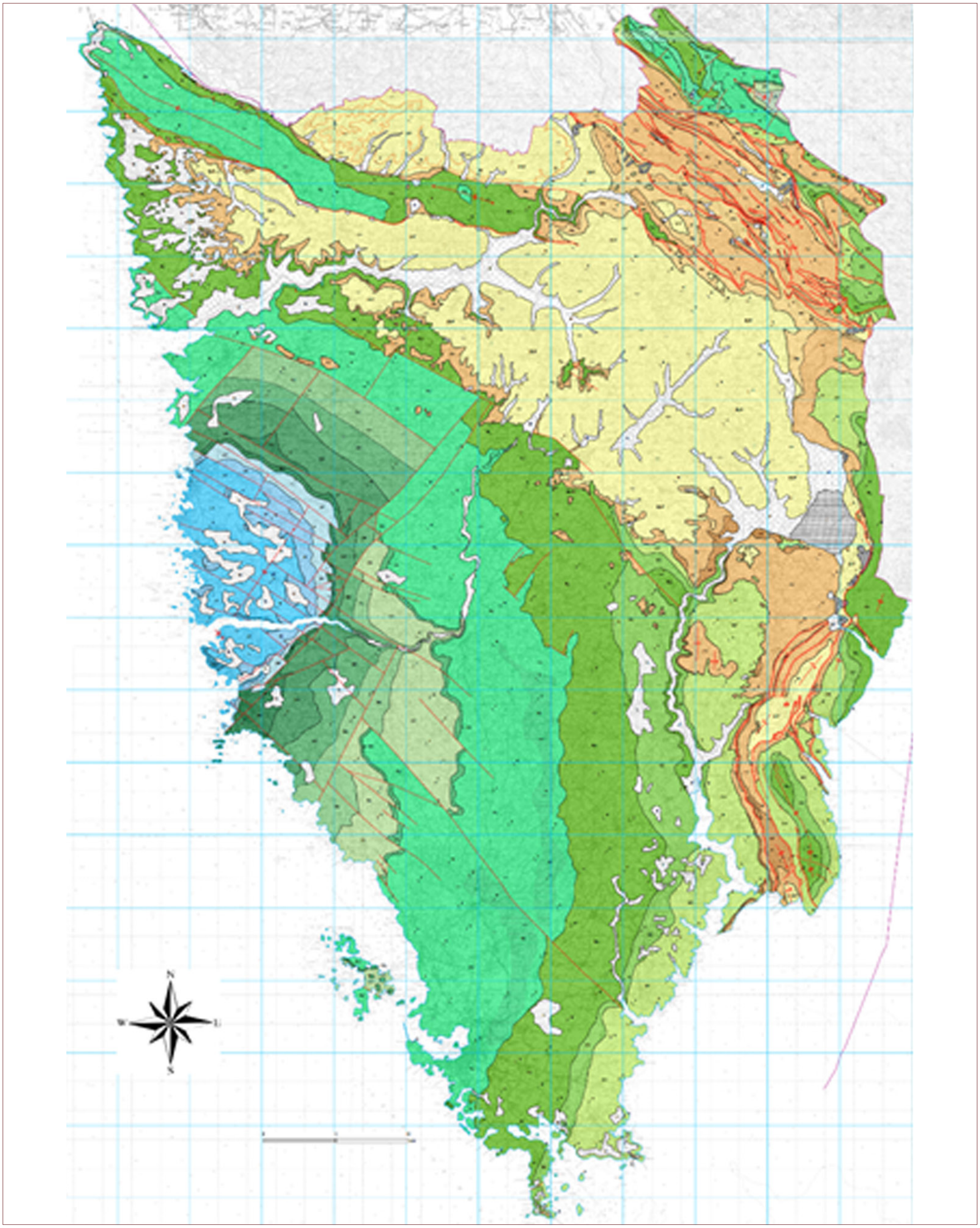

Figure 1. Lithostratigraphic map of the Croatian part of Istria, Istria County. Shades of blue – Jurassic limestones and dolomites, shades of green – Cretaceous limestones and dolomites, shades of orange and yellow – Paleogene foraminiferal limestones and flysch deposits, other - Quaternary (after Miko et al. 2013).

Stone trade in roman Istria

The relatively high-quality limestone has been quarried since Prehistory. Limestone was used for the construction of ramparts and houses in some places as early as the end of the Early Bronze Age (Hänsel et al. 1997), as well as for the construction of stone tombs or monuments (Buršić Matijašić 2008: 20). It is assumed that for the construction of the ramparts of prehistoric forts, stone was extracted from the very tops and slopes of the hills or in the immediate vicinity of the construction of settlements (Buršić Matijašić 2008: 91). However, Istrian limestone was exploited more systematically in Antiquity. We have several Roman quarries mentioned in the bibliography of the last several decades (Šonje 1980; Matijašić 1998), and more have been discovered in the last few years. Some of them were discovered using Airborne Laser Scanning data and targeted field surveys as a part of the ArchaeoCulTour project,[1] while others were discovered using geographical and topographical maps (Šprem 2021). All Roman quarries in the Croatian part of Istria can be seen on Figure 2.

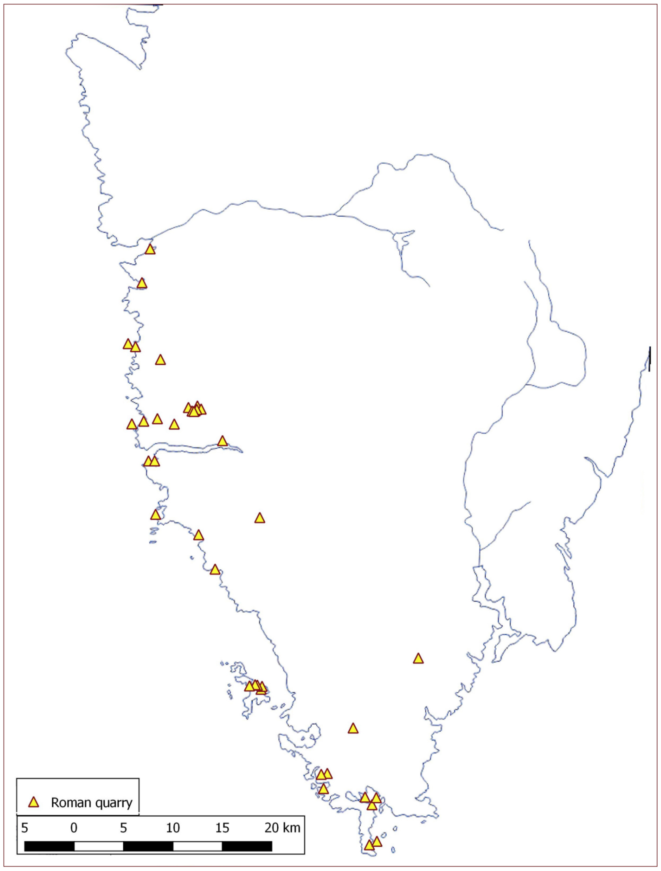

Figure 2. A map of Roman quarries in the Croatian part of the Istrian peninsula. (After Šonje 1980; Matijašić 1998; Šprem 2021; map source www.d-maps.com).

In their time in the Istrian peninsula, the Romans have produced a large number of stone monuments, whether funerary or otherwise in nature, most of them made from local limestone. We have recently sampled several stone monuments from *Pola* and *Parentium* in an attempt to discover the provenance of the stone used for their manufacture using micropetrographic analysis. A prime example of the use of micropetrographic analysis in determining the provenance of stone is that of Crnković (1991). He determined that the stone for the outer curved wall of the Pola Amphitheatre derives from the Cave Romane quarry in Vinkuran near Pola (Crnković 1991). Since the Romans mostly used the stone that was closely available, our hypothesis is that for the manufacture of the *Pola* and *Parentium* monuments, they used stone from the nearest Roman quarry; for *Parentium* that may be the quarries in the broader Vrsar area and for *Pola* the famous Cave Romane quarry in Vinkuran (Fig. 5) or the newly discovered Pješčana Uvala quarry, also in the vicinity of Pula (Fig. 3).

Stone blocks from the aforementioned quarries could have also been transported throughout Istria by land or by sea. The fragment of Diocletian's Price Edict (*Edictum De Pretiis Rerum Venalium*) found in *Aphrodisias* in *Caria*, gives us an approximate price ratio of different modes of transport. Thus, the ratio of the sea to the river downstream to the river upstream to land transport costs of 1: 3,9: 7,7: 42 was extrapolated (Russell 2014: 95) which clearly shows that maritime transport was the cheapest mode of transport. The indented western coast of Istria was connected to the surrounding areas already in prehistoric times by maritime trade, but also by looting and pirating (Gabrovec and Mihovilić 1987: 322-324). Every bay from Medulin in the south to Savudrija in the north could have provided anchorage and shelter for ships and later had an even larger economic impact due to the import and export of various products. On the other hand, the eastern, Liburnian coast of Istria, was steep and inaccessible (Matijašić 1998: 419). The short-distance navigation along the eastern Adriatic coast was especially developed, and this type of navigation almost completely replaced land transport. The main route ran between the larger islands and the mainland so that the vessels were protected from the high seas, and also close enough to a cove to take shelter if needed (Matijašić 2009: 201). In addition to the larger cities, which all had ports, smaller settlements, as well

Figure 3. Pješčana Uvala Roman quarry near Pola. (Photo by: D. Bulić).

as individual villae rusticae or villae maritimae had their own port. Municipii also had ports (Matijašić 2009: 201) and through these ports, local products were exported further (Koncani Uhač 2018: 151). The main economic activity of Roman Istria was the production of olive oil or wine, while other important products were stone, lime, timber, fish products and others (Koncani Uhač 2018: 162-166).

Micropetrographic analysis

Limestones and dolomites, the most common and widespread rocks in Istria, are mainly marine carbonate sedimentary rocks composed exclusively of calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) minerals or their various mixtures. They commonly contain fossils or microfossils, as well as their fragments or debris, which are also mainly made of carbonate minerals. Along with the macroscopic descriptions in the field, a common method for the description and determination of sedimentary rocks is the micropetrographic analysis. Micropetrographic analysis of limestones aims to identify its composition (skeletal and non-skeletal components of rock, together with the binding material), its fabric (arrangement of all constituents within a rock) and diagenetic changes (processes occurring within the sediment after its deposition). Marine limestones can be then classified after Folk (1959; 1962), or after Dunham (1962) with modifications after Embry and Klovan (1972). For more specific investigation purposes, it can be important to determine facies, a body, or a pocket of sedimentary rock with specific features that distinguish it from other facies. According to specific features observed, the concepts of lithofacies, biofacies or microfacies can be applied for limestones.

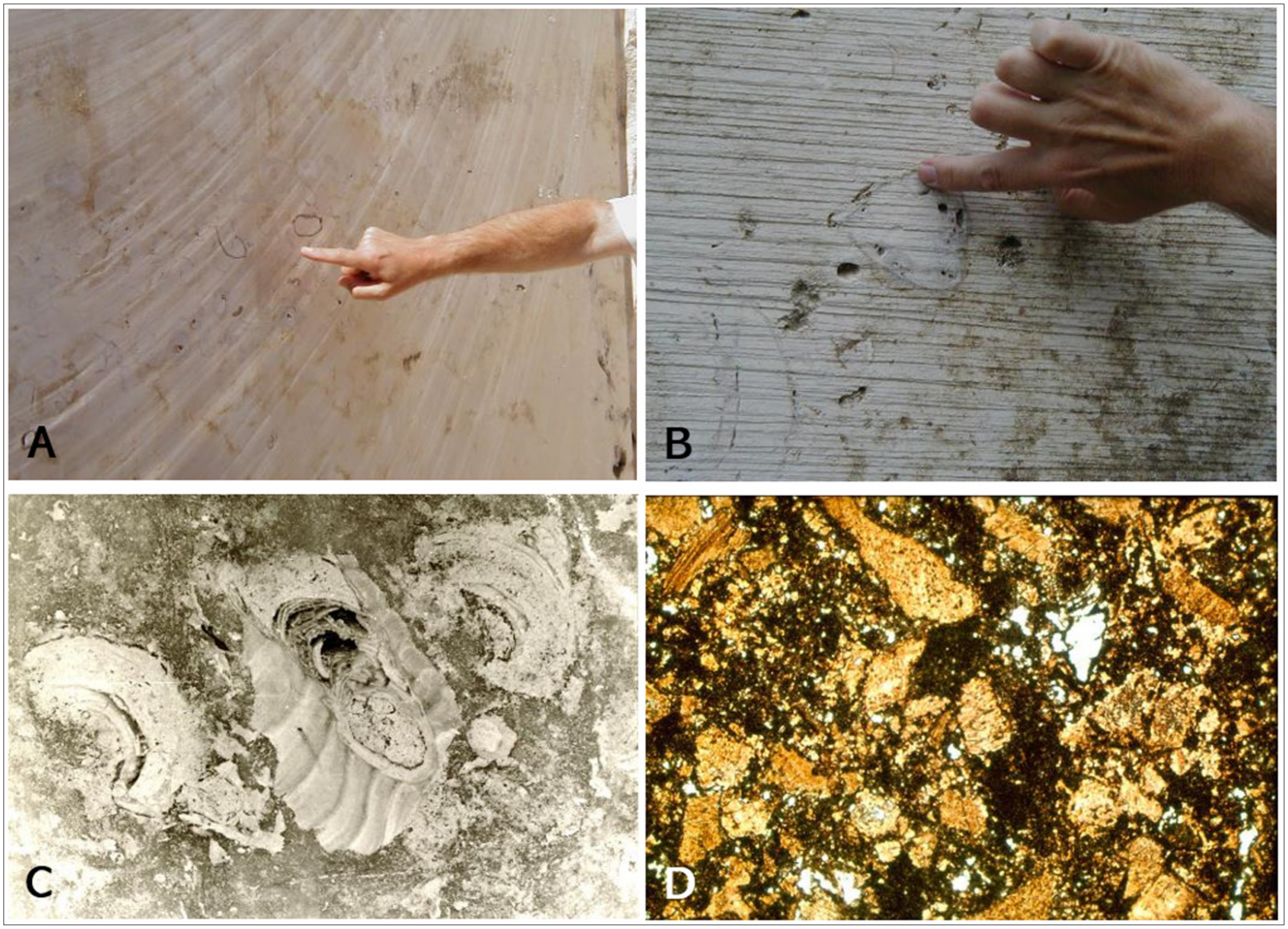

Figure 4. A, B and C showing rudist limestone in the Cave Romane quarry with skeletons of rudist bivalves. C – field of view approximately 10 cm; D – photomicrograph of limestone with rudist debris also from the Cave Romane, Vinkuran (field of view 1,5 mm).

More refined descriptions and concepts of microfacies of carbonate rocks are extensively described in Flügel (2004).

However, application of the results obtained from micro-petrographic analysis for some specific (i.e., archaeological or conservation) purposes is not always simple and straightforward, and some precautions should be considered (see examples in Maričić et al. 2020). To unambiguously compare thin sections of rock samples taken from the outcrops or quarries, with the samples of stone taken from the archaeological objects (buildings or monuments), the following facts need to be taken into account and strongly considered:

a) The samples of sedimentary rocks taken from the specific outcrop represent larger area, due to lateral extension of the sedimentary layer along its strike. Sometimes, lateral extension can be even tens to hundreds of kilometres (see on the lithostratigraphic map of Istria – Miko et al. 2013). Therefore, one cannot be undoubtedly positive about the exact position of the outcrop or quarry from which the compared stone material came from.

b) Sedimentary facies change in the vertical succession of sedimentary rocks randomly, or more often, cyclically (ABAB, ABCABC or similar). Samples taken vertically one upon the other at the outcrops or in the quarries reflect these vertical changes in sedimentation within a given timeframe, sometimes even at the centimetre scale (see numerous examples from Istria in Tišljar 2001; fig. 4). Therefore, more frequent and precise sampling is needed while investigating vertical successions of limestones in quarries and outcrops in detail.

Figure 5. Tool traces on a quarry wall in the Roman part of the quarry, Cave Romane, Vinkuran. Height of the wooden meter – two meters.

Discussion

One common problem arising in archaeological research is how to precisely identify the stone sources or quarries from which stone materials used in buildings and monuments originated. Geological fieldwork and approach can be of great help, and additional knowledge about compared materials can be obtained by micropetrographic analysis of stone from archaeological objects and rock samples taken from the quarries and outcrops. For carbonate sedimentary rocks, especially marine limestones, application of the microfacies concept (after Flügel 2004) can often be of more advantage than standard classification schemes (Folk 1959; 1962; Dunham 1962; Embry and Klovan 1972).

Two previously highlighted facts, possible large lateral extension of sedimentary layer along its strike and sedimentary facies change in the vertical succession, complicate straightforward interpretation and comparation of the results obtained by micropetrographic analysis. There is no unique solution for all possible problems and situations, but general guidelines can be drawn. It may be pointed that justifiable application of micropetrographic analysis largely depends on the scale or size of the object investigated, as well as on its archaeological context (i.e., possible and probable transportation routes).

An example of such a large archaeological object is the Roman Amphitheatre (Arena) in Pola, closely associated with the Cave Romane quarry in Vinkuran near Pola as its possible (and probable) source of stone material (Fig. 4). Fieldwork and macroscopic determination of similar rudist limestone lithotypes in Arena and Vinkuran quarry would be enough to connect these two objects, and archaeological context (possible transportation routes) will be a decisive factor for final interpretation. Micropetrographic analysis and microfacies determination can be applied while analysing later stages of quarry development and Arena reconstructions.

On the other hand, micropetrographic analysis should not be avoided while investigating smaller scale objects (i.e., monuments), because its archaeological context allows for a broader set of solutions (they can be more easily and likely imported). With microfacies determination, one can at least eliminate or narrow the local sources of stone materials, or even determinate its origin within the broader research area, and then incorporate results within the archaeological context.

Conclusion

Micropetrographic analysis of limestones is the identification of its composition, its fabric and diagenetic changes. This method, to an extent, allows us to identify the type and narrow the geological age of limestone used for a certain activity. Data gathered with this analysis can be a starting point in raw material provenance study, with the help of available geological and lithostratigraphic maps of the potential area of procurement.

While micropetrographic analysis is a valuable tool for answering certain archaeological questions, the application of the results obtained with this analysis is not always simple or straightforward. Sedimentary layers of limestone can be laterally extended along its strike tens or even hundreds of kilometres. This prevents us from undoubtedly locating the exact source of limestone blocks used in a building since similar petrographic samples can be taken from Vinkuran in the south of Istria and Umag in the northwestern part of the peninsula (see the lithostratigraphic map of Istria – Fig. 1). However, we can safely assume that the probable source of limestone blocks was the one closest to the site being investigated (the example of the Pola Amphitheatre). Nevertheless, the western Istrian coastline is rich in well-protected bays and coves and since maritime transport was the cheapest during Antiquity it almost completely replaced land transport (Matijašić 2009: 201). The low cost of maritime transport is also one of the reasons Roman quarries were mostly situated on the coastline (see Fig. 2) – the stone blocks could easily have been loaded onto ships and transported further, whether to a different place in Histria or even further away.

Furthermore, sedimentary facies of limestones can also change in vertical succession randomly or cyclically which reflects the changes in sedimentation within a given timeframe. This means that a more frequent, precise, and detailed sampling of a quarry or an outcrop is needed for the investigation of the provenance of raw material. These facts need to be strongly pondered while considering micropetrographic analysis.

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