Provenance of Lapis Lazuli Rocks Processed at the Bronze Age Archaeological Site of Shahr-i Sokhta: First Results from Ion Beam Analysis

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INTRODUCTION

In the early 1970s, archaeologists discovered and investigated lapis lazuli working areas located in Shahr-i Sokhta.

The site, located in eastern Iran and dated back to the 3rd millennium BCE, was a consumer of high quality lapis lazuli beads, and, in part, a hub for the trade routes of this semi-precious blue stone. Caravans linked the city and other towns on the Iranian Plateau to a widespread network of long-distance exchanges towards the western markets. A large amount of production waste fragments or partially carved rocks was retrieved during the archaeological excavation and the examinations have been focused so far on the study of the manufacturing processes [1].

For a first screening on provenance determination of the source material, we were able to analyse a total of 6 small samples, part of the manufacturing waste, following our multi-technique approach [2]. The employment of optical microscopy, SEM-EDX and cold-cathodoluminescence allows to determine the mineralogical phases present in the samples, their abundance and possible alterations. Moreover, the application of Ion Beam Analyses (IBA) can add more information on the provenance of the raw lapis lazuli: the amount of trace elements present in diopside and pyrite, two of the main phases, helps in the discrimination between several known quarries [3].

EXPERIMENTAL

The 6 lapis lazuli fragments did not have artistic value, so it was possible to embed them in resin and cut them to expose and analyse the core, untouched by weathering agents. They were later carbon-coated to make them conductive.

Preliminary IBA measurements were performed on 12 diopside and 9 pyrite crystals. In particular micro-Particle Induced X-rays Emission (μ-PIXE) is employed for the elemental analysis and micro-Ion Beam Induced

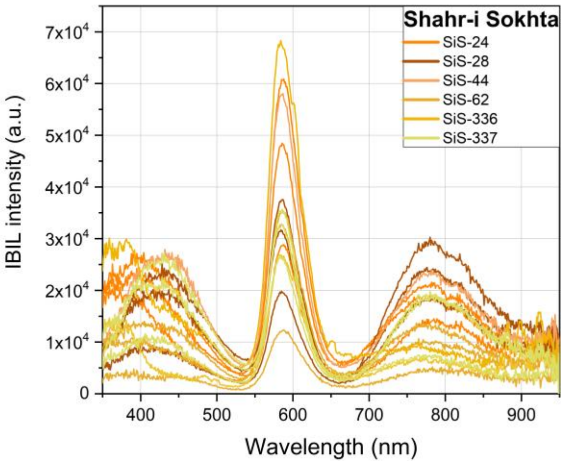

Fig. 1. μ-IBIL spectra of diopside crystals analysed on Shahr-i Sokhta cross sections.

Luminescence (μ-IBIL) signal is simultaneously collected, providing spectra with characteristic shapes that can be used as well as provenance markers. All the IBA analyses have been carried out at the microbeam line of the AN2000 accelerator facility, using accelerated protons with an energy of 2 MeV. The focused beam was about 8 μm in size and the current detected on sample during acquisitions was ~ 1 nA. An aluminium funny filter [4] with a small hole in the centre was placed in front of the detector window in order to analyse both light and heavy elements.

On each crystal, a 30×30 μm^2 area was acquired in scanning mode. The luminescence signal emitted by the sample was collected by a lens and transported to an Ocean Optics QEPro Peltier-cooled spectrometer via optical fibers and vacuum feed-through.

RESULTS AND DISCUSSION

A quick survey of the samples with the ion beam excluded the presence of wollastonite (and therefore a correlation with a Chilean provenance) for the absence of the characteristic μ-IBIL spectra.

For all the 12 diopside crystals analysed in Shahr-i Sokhta samples, besides the main μ-IBIL band at 585 nm, a broad band centred at 770 nm was present (figure 1): this band is a weaker marker for an Afghan provenance of the source material [3]. Moreover, only in spectra from sample SiS-336, two additional small peaks can be seen at 600 nm and 650 nm, while several others are located around 900 nm.

Quantitative analysis from μ-PIXE measurements on diopside revealed that Sr content remains below 100 ppm, excluding also the Siberian provenance. Moreover, all the samples present high Cr (220-450 ppm) and V (180-560 ppm) contents, weaker markers for the Afghan provenance. Diopside is particularly low in Fe, while Zn is below the limit of detection in almost all crystals except for one in sample SiS-62, with a content of 17 ppm only.

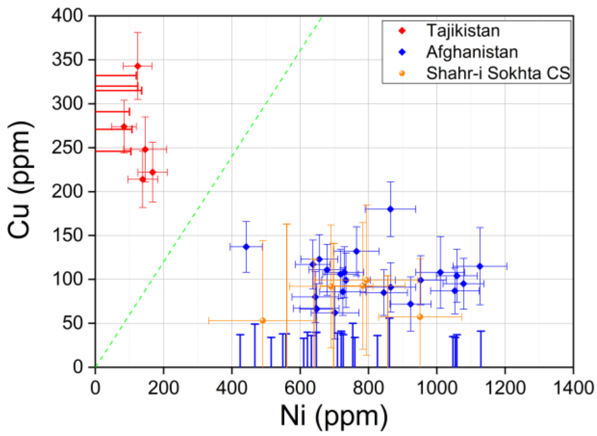

Fig. 1. Results for strong markers in pyrite crystals from Shahr-i Sokhta cross sections. The green dashed line indicates the Cu = 0.6·Ni separation proposed in the updated protocol [3].

Finally, samples SiS-28, SiS-44 and SiS-24 presented too small pyrite crystals on the cross section for a μ-IBA analysis. However, it was possible to analyses 9 pyrites on the three remaining samples: they all show a Ni content above 350 ppm and a Cu content below 200 ppm (figure 2).

All these results allow to classify the analysed Shahr-i Sokhta samples with quite good confidence as Afghan.

CONCLUSION

Six lapis lazuli fragments coming from the working site of Shahr-i Sokhta have been analysed with micro-Ion Beam Analyses. According to the analytical protocol for provenance determination developed by our group, the results obtained from this preliminary set of samples indicate a compatibility with an Afghan origin of the source material.

[1] M. Vidale and A. Lazzari. Lapis lazuli bead making at Shahr-i Sokhta, Antilia, Treviso, 2016.

[2] A. Lo Giudice et al., Anal. Bioanal. Chem. 395 (2009) 2211.

[3] L. Guidorzi et al., Eur. Phys. J. Plus 138 (2023) 175.

[4] Gama S. et al., Nucl. Instrum. Methods Phys. Res. B 181 (2001) 150.