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Regular Article

Study of compositional and luminescence properties of calcite in lapis lazuli for provenance investigations of archaeological findings

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Abstract In this study, calcite crystals within 42 lapis lazuli reference rocks coming from four distinct mining regions (in present-day Afghanistan, Tajikistan, Siberia and Myanmar) were characterised in terms of their compositional and luminescence properties in order to identify potential provenance markers. A non-destructive approach based on Ion Beam Analysis was employed, in particular using μ-Particle Induced X-rays Emission (μ-PIXE) and μ-Ion Beam Induced Luminescence (μ-IBIL). The results indicate that calcite crystals in Afghan rocks are characterised by the highest quantity of Mg and Mn; whereas, Siberian calcite exhibit the highest Sr content. The application of Principal Component Analysis also enhanced the possibility of discriminating between the Myanmar and Tajik rocks, as well as between the four provenances in general, by exploiting the compositional variability of Mg, Mn, Sr and Y elements. Regarding the luminescence properties, notable differences in the intensity ratio between the 360 nm and the 620 nm luminescence bands were detected among the provenances. In the second part of this study, the new results were employed to infer the origin of the raw material of certain archaeological findings discovered in two different historical sites: four lapis lazuli fragments from Shahr-i Sokhta (Iran, 3rd millennium BCE) and a lapis lazuli tessera from the city of Tanis (Egypt, 1050–700 BCE). The results of the analysis indicate that, among the four provenances considered in the reference rocks database, the best compatibility of the data from both case studies is found with the Afghan dataset. This suggests that the area of Afghanistan is the most probable source for the raw materials of the investigated findings.

1 Introduction

Ion Beam Analysis (IBA), and in particular μ-Particle Induced X-rays Emission (μ-PIXE) and μ-Ion Beam Induced Luminescence (μ-IBIL) techniques using proton microbeams, have proven to be a highly effective tool for investigating the provenance of lapis lazuli raw material used in artworks and archaeological objects, due to their high sensitivity, non-destructiveness and the possibility to be applied on a micro-scale [1–3]. Lapis lazuli is in fact a highly heterogeneous material; therefore, it is very challenging to identify characteristic features useful for provenance discrimination from the analysis of the entire rock. For this reason, in previous studies, we focussed on the characterisation of single mineral phases in lapis lazuli, in particular diopside, pyrite and wollastonite. This led to the development of a provenance protocol able to distinguish between five different source areas (in present-day Chile, Tajikistan, Afghanistan, Siberia and Myanmar) [3, 4]. The protocol aims at assisting archaeologists in addressing the issue of lapis lazuli sourcing in antiquity by providing a scientific method to differentiate rocks of different origins on the basis of their compositional and luminescence features. Indeed, Afghanistan is widely regarded as the primary source of this semi-precious blue stone in antiquity, although other geological extraction sites have been debated by scholars [5–7]. However, the protocol demonstrated a limited capacity to differentiate between the Myanmar–Afghanistan and Myanmar–Tajikistan groups of reference

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