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Application of principal component analysis to μ-PIXE data in lapis lazuli provenance studies

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ABSTRACT

The application of multivariate analysis is extremely useful when dealing with large datasets and can be applied also in provenance studies. In this work, Principal Component Analysis (PCA) was applied for the first time to the study of the provenance of lapis lazuli rocks used for glyptic art in ancient times, on a database including four different sources in Afghanistan, Tajikistan, Siberia and Myanmar. Results of the application of PCA on μ-PIXE data collected in mineralogical phases contained in lapis lazuli rocks, in particular diopside and pyrite, confirmed the role of some trace element contents as characteristics for different provenances, i.e. as provenance markers. As an additional important result, PCA seems to strengthen the role of previously found weaker markers (i.e. trace elements not sufficient alone to distinguish univocally among provenances) such as, for example, the coexistence of high Ti, V, Cr and Mn concentrations in diopside in Afghan lapis lazuli. This can be relevant when other discriminant phases like pyrite cannot be found in the sample or are not suitable for analysis.

Moreover, for geological purposes and to try to distinguish among different quarries inside an extraction area, a study on intra-provenance variability was carried out on diopside data for Myanmar and Siberian samples. The separation into three groups for Myanmar samples, previously identified by means of minero-petrographic and elemental analysis, is confirmed and a partial differentiation was identified also for samples coming from the two Siberian areas of Sludyanka River and Malaya Bistraya River.

1. Introduction

Lapis lazuli is a semi-precious blue stone widely used for different purposes since the antiquity [1] but, at present, information about both its ancient trades and the quarries exploited from different civilizations is still lacking [2,3]. The restraining geological conditions in which this rock can form limit its sources to only a few places around the world [4]. This represents a possibility for tracing back the original quarry exploited for the manufacturing of an ancient object on the basis of the physico-chemical characteristics of the material.

A wide provenance study on lapis lazuli was started almost fifteen years ago by the group at the Physics Department of the University of Torino, in collaboration with the Italian National Institute of Nuclear Physics (INFN). The study on reference geological rocks is based on a multi-technique approach, including both invasive (optical microscopy, cold-cathodoluminescence and SEM-EDX on thick and cross sections) and non-invasive (X-ray fluorescence and Ion Beam Analyses) techniques and involving a multidisciplinary team [5–10].

As lapis lazuli can present a wide variety of mineral phases, the provenance study has been focused so far on the most widespread ones, as lazurite ($(Na, Ca)_{7.5\text{-}8}$ $(Si, Al)_{12}$ $(O, S)_{24}$ $(SO_4, Cl)_{1.3\text{-}2}$), pyrite (FeS), wollastonite ($CaSiO_3$) and diopside ($CaMgSi_2O_6$). The investigation of single mineral phases requires the use of techniques that can go down to the microscale employing microbeams. Some provenance markers have been defined so far for five different lapis lazuli provenances (Afghanistan, Tajikistan, Siberia, Myanmar and Chile) and used in the compilation of a provenance protocol based on Ion Beam Analyses (IBA), in particular micro-Particle Induced X-ray Emission (μ-PIXE) and micro-Ion Beam Induced Luminescence (μ-IBIL) [11,12]. The use of IBA to identify markers is necessary because they are microbeam techniques able to measure simultaneously trace elements and luminescent properties in single mineral phases and are non-invasive techniques (in-air IBA), which is required in many cases for archaeological objects due to their preciousness. The markers at the base of the protocol were identified by comparing trace element contents one by one in different mineral phases and for all provenances. According to their occurrence

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