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Green, grey and black: A comparative study of Sierra de las Navajas (Mexico) and Lipari (Italy) obsidians

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ABSTRACT

Sierra de las Navajas (State of Hidalgo, Mexico) and Lipari (Aeolian Islands, Italy) were among the most important sources for obsidian trade in Mesoamerica and in the Mediterranean during the Stone Age. In this paper obsidians from these two localities were compared in terms of their aspect, chemical composition, microcrystallinity and microvesiculation. In Sierra de las Navajas, the typical deep green obsidian with a golden hue has been analyzed together with a less common dark grey, porphyritic variety. Lipari obsidian is commonly black, but a light grey variety also occurs. Obsidian of both varieties was analyzed for this paper. Microvesicularity was investigated through Scanning Electron Microscope (SEM) observation, microporosimetry and, for Sierra de las Navajas green obsidian, through a preliminary X-ray computed microtomographic study. Crystallinity and micro- or nano-crystallinity were investigated through X-Ray Powder Diffraction and EDS (Energy Dispersion System) microanalyses. Finally, the chemical composition in terms of major and trace elements, including rare earth elements, was determined using X-Ray Fluorescence (XRF) and Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). The comparison of samples of different colors suggests that the characteristic green color of Sierra de las Navajas obsidians could be related to their relatively high iron content, and to the occurrence of many elongated and iso-oriented vesicles which may also be responsible for the obsidian's golden hue. Low iron and an absence of vesicles give Lipari obsidian its "normal" black color. The light grey obsidian from Lipari probably owes its color and imperfect conchoidal fracture to numerous bubbles of less than 1 μm in size and to nano-crystallinity.

Sierra de las Navajas obsidians show a significant chemical variability in terms of trace elements, that can be explained by common evolutionary processes in the magma chamber. However, this variability is also internal to a single volcanic complex and this makes the trace element contents unsuitable to differentiating between the different sub-sources of the same area. On Lipari, our data do not allow us to distinguish between the two sub-sources of Vallone del Gabellotto and Canneto Dentro on the basis of major and trace elements. On the whole, our study suggests that caution should be used for both Lipari and Sierra de las Navajas when identifying obsidian sub-sources on the basis of trace element contents.

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1. Introduction

Obsidian is a hard, dark, crystal-free glass-like volcanic product

formed during both explosive and effusive eruptions of viscous, silica-rich magmas, often associated with highly vesicular pumices. The rapid solidification and the high viscosity inhibit crystallization and originate an optically isotropic glass with a high mechanical strength. Due to its glassy structure, obsidian is highly attractive and relatively easy to work, as it breaks in very predictable and controlled ways via conchoidal fracturing. Moreover, the working

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edges obtained by its fracturing are sharper than other types of tool-making stones, making obsidian a highly sought after material for the production of sharp-edged implements (Glascock et al., 1998). The volcanic glass was a strategic material in ancient times before the use of metals, and it was widely used for the production of weapons and jewelry, as well as in medicine and magic-religious activities. The control of its exploitation, production and distribution, via commercial, tributary or direct control systems, was one of the most important activities of the ancient cultures of Europe and America (Hirth, 2006).

Although black is the most common color of obsidians, different color varieties also occur, such as grey, mahogany (a combination of a reddish/brown and black color; see Doland and Shackley, 2017), green or “rainbow” (bands of various colors, ranging from red to purple; see Ma et al., 2001). Different varieties of color very frequently occur in the same locality (e.g. Glass Butte in Oregon, USA; see Ambroz et al., 2001). The different colors have been attributed to physical features or chemical composition. The vibrant color of “fire” obsidians has been related to thin layers of concentrated nanometric crystals of magnetite, which give rise to brilliant colors in reflection (Ma et al., 2007), while Argote-Espino et al. (2012) attributed the green color of Sierra de las Navajas obsidians to an abundance of specific trace elements.

The circulation and exchange of obsidian artifacts is of great importance in the investigation of cultural, social, and economic development in ancient societies and reconstruction of ancient maritime or terrestrial trade routes (Glascock, 2002; Cortegoso et al., 2016; Pintar et al., 2016; Kuzmin, 2017; Freund, in press). This requires the possibility to ascribe archaeological artifacts to a specific source. In recent decades, a number of studies have been conducted in order to identify the sources of obsidian artifacts through the use of different analytical methodologies ranging from the Optical Emission Spectrometry adopted in the pioneering work of Cann and Renfrew (1964) for Mediterranean sources to back-scattered electron images (Burton and Krinsley, 1987), ^{57}Fe Mössbauer spectroscopy, Electron Paramagnetic Resonance and magnetization properties (Poupeau et al., 2001) or fission-track dating (Bigazzi and Bonadonna, 1973; Bigazzi and Radi, 1998). Chemical fingerprinting of natural and archaeological obsidians proved to be the most successful way to correctly ascribe artifacts to a specific source in various regions: e.g. in Syria and Iraq (Khalidi et al., 2016), in Korea (Yi and Jwa, 2016), in the Mediterranean (Barca et al., 2007; De Francesco et al., 2008; Tykot, 2002, 2017; Orange et al., 2017), in Russia (Grebennikov and Kuzmin, 2017), in Central America (Cobean et al., 1991; Glascock, 2002) and in Southern America (Cortegoso et al., 2016; Escola et al., 2016; De Francesco et al., in press). The chemical composition, and particularly the trace element contents, can also help to discriminate between sub-sources in the same area - Glasse Butte, Oregon (Ambroz et al., 2001) and Monte Arci, Sardinia (Tykot, 2002, 2017) - thus, contributing to a better understanding of the exploitation and trade of obsidians in the past.

This paper presents a multidisciplinary work aimed at the chemical and micro- and nano-textural characterization of macroscopically different obsidians from Sierra de las Navajas (State of Hidalgo, Mexico) and Lipari (Aeolian Islands, Italy) through different analytical techniques. The two localities were key sources for obsidian trade in Mesoamerica and in the Mediterranean during the Stone Age. Obsidians from these two sources are very different in color (green in Sierra de las Navajas and black on Lipari) and geochemical affinity (calc-alkaline on Lipari and peralkaline in Sierra de las Navajas). This makes them particularly useful for investigating the factors influencing the macroscopic differences between obsidians. Therefore, the first aim of this work is to test the

roles of chemical composition and microtexture in the color and type of fracturing, the most important features determining the use of obsidian in the past.

A second aim is to verify the possibility of using the chemical data to identify sub-sources within the same main source area, so providing a more precise determination of provenance in the archaeological studies.

2. Geological setting and obsidian occurrences

2.1. Lipari

With its surface area of 38 km², Lipari is the largest island in the Aeolian Archipelago, a Quaternary volcanic arc which developed at the southern periphery of the Tyrrhenian basin (Italy). The magmatism in this area mainly relates to the subduction and southeast rollback of the Ionian slab below the Calabrian Arc (Patacca and Scandone, 1989; Faccenna et al., 2001; Gvirtzman and Nur, 2001; Chiarabba et al., 2008; Ventura, 2013). This process has, in turn, induced the upwelling and SE migration of the asthenospheric mantle (Gvirtzman and Nur, 1999; Chiarabba et al., 2008), causing extensional strain and volcanism in the last 0.7–1 Ma (Ventura, 2013).

A simplified geological map of Lipari is shown in Fig. 1. The eruptive history of Lipari started about 270 ka ago and can be divided into nine Eruptive Epochs separated by periods of quiescence (Forni et al., 2013; Lucchi et al., 2013). One of these periods, occurring between 81 and 43 ka, marked an important change in the composition of erupted products, which changed from the basaltic andesites and andesites of the first six epochs to the rhyolites of the more recent activity (Crisci et al., 1991; Forni et al., 2013). Rhyolitic obsidians were emplaced both effusively, as lava flows, and explosively, in association with pumices, over the last 43 ka.

During Epochs 7 and 8 three main eruptions occurred, each starting with an explosive phase and ending with the emplacement of endogenous lava domes: Punta del Perciato (Epoch 7, age unknown), Falcone (Epoch 7, 43–40 ka) and Monte Guardia- Monte Giardina (Epoch 8, 27–20 ka). Obsidian clasts are common in the explosive sequences; locally, the rhyolitic lava forming the domes has a vitreous aspect. About 20 ka ago, several minor domes, aligned in a N-S direction, formed on the eastern coast of the island (Gioncada et al., 2003). One of these, the dome of Canneto Dentro, was preceded by a low energy explosive eruption which formed obsidian-rich breccias (Forni et al., 2013).

The ninth and last eruptive Epoch (8.7 ka- AD 1220) included both effusive and explosive phases, all occurring in the northern sector of Lipari and producing rhyolitic lavas and pumiceous successions that are rich in obsidian clasts. The first eruption of this Epoch was the Vallone del Gabellotto explosive eruption (8.7–8.4 ka, Zanchetta et al., 2011), leading to the formation of a widespread pumiceous succession and followed by the emplacement of the obsidian coulee of Pomiciazzo (8.6 ka; Wagner et al., 1976; Arias et al., 1986; Forni et al., 2013). After a period of quiescence, activity restarted on the northeastern side of the island in medieval times with the historical eruptions of Monte Pilato pumice cone (AD 776, Forni et al., 2013) and Forgia Vecchia lava flow (ca. AD 400, Bigazzi and Bonadonna, 1973; Forni et al., 2013). The Monte Pilato cone is mainly made up of highly vesiculated rhyolitic pumices; obsidian clasts and lava lithics are also common. Forgia Vecchia is a bilobate obsidianaceous lava flow outcropping south of Monte Pilato and overlying a pumiceous pyroclastic sequence (Forni et al., 2013).

Finally, the last eruption on the island occurred in AD 1220 (Tanguy et al., 2003) and formed the Rocche Rosse obsidianaceous

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