# Comment on Manuella et al. "The Hyblean xenolith suite (Sicily): an unexpected legacy of the Ionian–Tethys realm"

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## Introduction

This comment raises some scientific concerns regarding a recent paper titled the "Hyblean xenolith suite (Sicily): an unexpected legacy of the Ionian–Tethys realm" by Manuella et al. (2015), published on the International Journal of Earth Sciences (DOI:10.1007/s00531-015-1151-9), which states that the Hyblean Plateau of southern Sicily and the Pelagian Sea are "unquestionably" characterized by an "oceanic" basement.

Volcanic rocks (and associated xenoliths) collected throughout the Mediterranean area have been investigated by our research group for more than 20 years, and based on this experience, we cast some doubts on the theory put forward by Manuella et al. (2015).

We want to inform the scientific community on the ongoing debate, underlining that the mentioned hypothesis is "questionable" and far to be accepted, as indicated by many geologists who consider the Hyblean plateau and the Pelagian Sea as the northernmost part of the African continental plate (Finetti and Del Ben 2005; Catalano et al. 2010; Civile et al. 2010; Accaino et al. 2011; Roure et al. 2012; Musumeci et al. 2014).

Besides this, we underline that several petrological constraints on the Hyblean volcanism and associated xenoliths, which are essential for the understanding of the geological scenario of the area, have been omitted (Bianchini et al. 1998, 1999, 2010; Suiting and Schmincke 2009), underestimated, or misunderstood (Tonarini et al. 1996; Beccaluva et al. 1998; Sapienza et al. 2007, 2009).

## Inferences on the representativeness of the Hyblean xenolith population

Manuella et al. (2015) emphasize that the Hyblean xenolith suite includes only ultramafic (peridotites and pyroxenites) and mafic (gabbros s.l.) lithotypes, whereas felsic rocks are not observed. On this ground, they attest that rocks having a "continental" affinity are totally absent within the Hyblean basement. This statement can be criticized for various reasons because the representativeness of the crust provided by the xenoliths is often biased, as xenolith populations worldwide are often monotonous, i.e., mainly represented by a limited number of lithologies (see also Rudnick and Fountain 1995; Coltorti et al. 2011). The observation suggests that:

host magmas entrained xenoliths at a specific depth, and not all along the path toward the surface. The restricted type of lithologies is generally ascribed to the mechanism of xenolith uptake, which is related to the fluid (mainly CO2) release and bubble nucleation, which trigger discrete event of crack formation and breaking of the surrounding host rocks; in other words, fluid nucleation leads to "explosion," fracturing the wall rocks and forming the xenoliths (Lensky et al. 2006); the specific depth of xenolith formation is distinctive of each magma type, and usually Cenozoic alkaline basalts of the Mediterranean region entrain xenoliths from either the uppermost lithospheric mantle or the lower crust (at ca 30–50 km depth), whereas sampling of shallower depths is rarer (Beccaluva et al. 2005);

basic magmas easily resorb and assimilate felsic rocks as indicated by experimental and numerical modeling (Sachs and Stange 2012), thus explaining the worldwide predominance of mafic and ultramafic (mantle and lower crust) compared to upper crust lithotypes in xenoliths entrained in basic magmas.

Nevertheless, felsic xenoliths of upper crust origin have been found among Hyblean xenoliths, as mentioned by several authors who reported the rare, but significant, presence of polycrystalline quartz aggregates (fragments of granitoids), syenites, and anorthosites among the Hyblean xenolith suite (Scribano 1987; Pompilio and Scribano 1992; Sapienza and Scribano 2000).

Moreover, in our view, caution has to be paid on the congruence and representativeness of xenoliths with respect to the original remote rock masses of the lithospheric column, because the sample population can be biased by the xenolith collectors, including failure to recognize certain types of samples as significant (Griffin and O'Reilley 1987). Philosophically speaking, it is also difficult to prove something based on the absence of the proof.

**Petrological inferences on the Hyblean ultramafic xenoliths**

The parageneses of Hyblean peridotite xenoliths sometimes record metasomatic phases such as phlogopite, pargasite amphibole, apatite, and glassy patches (Sapienza and Scribano 2000; Beccaluva et al. 2005; Scribano et al. 2009), which are generally not observed in abyssal peridotites or their Tethyan ophiolitic analogues (Piccardo and Guarnieri 2010). Another important difference is that abyssal peridotites often equilibrated at very shallow depth within the plagioclase peridotite facies, i.e., at pressure <0.8 GPa, whereas the Hyblean peridotite xenoliths do not contain plagioclase and equilibrated at comparatively higher pressures between 0.9 and 1.5 GPa (Beccaluva et al. 2005; Perinelli et al. 2008). Their bulk rock and clinopyroxene trace element compositions appear enriched in the most incompatible elements (Beccaluva et al. 2005; Perinelli et al. 2008) at a level that is unknown in abyssal peridotites and their Tethyan ophiolite analogues. These enrichments are related to metasomatic processes occurring deep in the mantle and not to seawater/hydrothermal fluid interaction.

The occurrence of metasomatic enrichments is confirmed by the available Sr–Nd isotopic analyses, which confirm that the Hyblean peridotite xenoliths have a HIMU isotopic signature (Bianchini et al. 2010; Correale et al. 2012), totally distinct from the DM (depleted mantle) isotopic fingerprint that usually characterizes the abyssal peridotites and their ophiolitic counterparts. Osmium isotope data carried out on sulfides hosted in the Hyblean peridotite xenoliths also differ from those typically recorded in abyssal peridotites, showing comparatively lower 187Os/188O values, which yields Archean depletion ages (Sapienza et al. 2007) that plausibly are proxies of ancient melting episodes typically recorded in the subcontinental mantle (Coltorti et al. 2010, and references therein). As the timing of the subsequent metasomatism is concerned, a Sm–Nd pseudo-isochron obtained using isotope data from Tonarini et al. (1996), Bianchini et al. (2010) and Correale et al. (2012) yields an age of 320 Ma that could indicate that important metasomatic processes occurred in the Carboniferous, well before the Permo-Triassic oceanization as stated by Manuella et al. (2015).

**Petrological inferences on the Hyblean mafic xenoliths**

Manuella et al. (2015) described the Hyblean mafic xenoliths as gabbroids s.l. emphasizing their similarities with abyssal and ophiolitic gabbros, possibly originating from an Oceanic Core Complex (OCC). Earlier descriptions of the Hyblean mafic xenoliths (Scribano 1987; Pompilio and Scribano 1992; Tonarini et al.

1996; Sapienza and Scribano 2000; Scribano et al. 2006), where most of the considered samples were carefully described and classified as mafic granulites, are not discussed by Manuella et al. (2015); these granulites are characterized by polygonal granoblastic textures characterized by 120° triple junctions and gneissic banding, by the presence of complex coronitic and symplectic textures and frequent pyroxene unmixing, which indicate a complex subsolidus P–T–t path that is uncommon in oceanic settings. Indeed, basic granulites having similar textures have been observed in gabbroic rocks of Tethyan ophiolitic complexes, but only in those usually interpreted as subcontinental sections approaching the ocean–continent transition (Marroni and Tribuzio 1996; Molli 1996; Kaczmarek and Muntener 2005). Moreover, Pompilio and Scribano (1992) emphasized the recurrent occurrence of pyroxene compositions that conform to metamorphic conditions incompatible with oceanic igneous cumulate rocks. Early papers also described the presence of anorthosites having plagioclase characterized by anorthite content up to An92, which are very uncommon in oceanic settings.

Manuella et al. (2015) reinterpreted the whole suite of mafic xenoliths as oceanic cumulates, suggesting that their whole-rock composition never fits a basaltic composition; for this reason, it is the incorrect use of elemental ratios (e.g., Zr/Nb, Yb/Nb) as tectono-magmatic proxies and is not possible to relate the considered rocks to MORB (Mid-Ocean Ridge Basalt) melts. The use of K2O versus SiO2 and K2O versus MgO for a tectono-magmatic classification of gabbros and distinction between oceanic and continental settings is also unwarranted, as all THOLEIITIC gabbros related to both anorogenic oceanic, continental, and even orogenic settings plot in the same field. In fact, tholeiitic gabbros with K2O < 0.5 wt% are known in continental areas affected by Cenozoic intense magmatic activity and rifting (Gamble 1979; Küster et al. 2005). Tholeiitic gabbroic rocks, compositionally analogous to the Hyblean mafic xenoliths, are common in continental settings as can also be observed in exhumed deep crust/mantle sections such as in Ivrea-Verbano near Finero (Lu et al. 1997) or in northern Calabria (Liberi et al. 2011). Summarizing, gabbros with K2O < 0.5 wt% (or their metamorphic equivalent, i.e., basic granulites) are widespread in continental sections that were affected by magmatic underplating, especially in ocean–continent transition zones similar to those recorded in various sectors of the western Tethys (Piccardo 2008).

The subcontinental nature of the Hyblean mafic xenoliths is also supported by bulk rock isotopic analyses of Sapienza et al. (2009) who indicate that 87Sr/86Sr is systematically higher and 143Nd/144Nd systematically lower of what expected in present-day MORB or their Tethyan Mesozoic analogues (Rampone et al. 1998). 176Hf/177Hf is also systematically lower of what expected in MORB or their Tethyan Mesozoic analogues (Schaltegger et al. 2002). A 176Hf/177Hf versus 143Nd/144Nd diagram shows that the composition of the Hyblean mafic xenoliths displaces from the MORB-OIB mantle array, as properly shown by the ΔHf parameter (Johnson and Beard 1993), which quantifies the displacement of these isotopic values from the mantle array as defined by Vervoort et al. (1999) for oceanic magmas: $\varepsilon Hf(OIB) = 1.33 * \varepsilon Nd(OIB) + 3.19$. Notably, the Hyblean mafic xenoliths are invariably characterized by negative ΔHf ranging between −4 and −22, thus speaking for a subcontinental nature of the Hyblean basement. Additional information has been given by in situ 87Sr/86Sr analyses carried out on the intercumulus pockets of the Hyblean gabbroic xenoliths, which highlight the occurrence of metasomatic agents generated by "enriched" subcontinental sources (Sapienza et al. 2009).

As concerns the age of these rocks, the Early–Middle Triassic period suggested by Manuella et al. (2015) has to be taken with caution. Tonarini et al. (1996) state that Sm/Nd whole-rock mineral pairs performed on Hyblean mafic granulite yield ages of 370 ± 110 and 190 ± 40 Ma. In situ U–Pb zircon dating carried out on similar gabbroic xenoliths reported 66 analyses on distinct zircon grains, indicating that near-euhedral/weakly zoned and ovoid structureless grains were generally Archean, whereas those pitted and spongy-textured mainly cluster around 246 ± 10 Ma (Sapienza et al. 2007); the authors of these datings concluded that the incontestable presence of Archean crustal material underneath the Hyblean plateau argues against the oceanic nature of the Hyblean lithosphere. Noteworthy, Archean zircons sporadically recorded in gabbroids from oceanic settings have been invariably related to a continental lithosphere derivation (Pilot et al. 1998; Skolotnev et al. 2010).

**Inferences on the "secondary" mineral assemblages recorded by xenoliths**

Manuella et al. (2015) are convinced that "secondary" mineral assemblages, particularly abundant in the Hyblean ultramafic xenoliths (i.e., serpentinization s.l.), provide "unquestionable" evidence for an oceanic origin concomitant to the occurrence of oceanic hydrothermal processes. Within the wide collection of Hyblean ultramafic xenoliths at our disposal (described in Beccaluva et al. 2005), ubiquitous serpentinization is not observed, mantle parageneses are not completely obliterated and primary minerals are perfectly recognizable, as also observed by other researchers (Perinelli et al. 2008; Bianchini et al. 2010; Correale et al. 2012). Eighty-five percent of our samples are characterized by loss on ignition (LOI) <4 %, that is distinctly lower than those observed in abyssal peridotites and their Tethyan ophiolitic analogues (>10 %; Rampone et al. 1998; Paulick et al. 2006).

Noteworthy, serpentinization is quite common for xenoliths collected in diatreme structures, often characterized by a remarkable fluid activity, during and after eruption (Gernon et al. 2008; Hayman et al. 2009), as is the case for the xenolith-bearing Hyblean diatremes, where the explosive volcanism has been triggered by the interaction between $CO_2$-rich nephelinite magma and seawater in shallow submarine conditions (Suiting and Schmincke 2009).

**Inferences based on the study of the Hyblean lavas**

Manuella et al. (2015) reported that on a Nb/Yb versus Th/Yb discrimination diagram, the Hyblean volcanic rocks have a remarkable affinity with MORB-OIB magmas. This observation does not proof the oceanic character of the Hyblean lithosphere. In fact, this diagram is commonly used to discriminate between "orogenic" and "anorogenic" volcanic products, and many within-plate, anorogenic volcanic suites are totally overlapped with the MORB-OIB.

Manuella et al. (2015) omit other tectono-magmatic models proposed for the Hyblean volcanism which includes a wide range of basic magmas varying from quartz tholeiites to alkali basalts, basanites, nephelinites, and ankaratrites (Beccaluva et al. 1998; Bianchini et al. 1998). The most alkaline types are extremely silica undersaturated and calcium rich ($SiO_2$ down to 36.4 wt%; CaO up to 14.9 wt%), also containing a high amount of incompatible trace elements. These products cannot be generated by partial melting of "depleted" oceanic mantle domains.

Southward, the presence of peralkaline volcanic rocks as pantellerites in the Sicily Channel provides additional clues against the oceanic nature of the Pelagian block, because these evolved rocks are by far more common in continental rifts than in oceanic settings (Avanzinelli et al. 2004).

Sr–Nd–Pb isotopic features of the Hyblean basic lavas (Bianchini et al. 1999) reveal significant differences with respect to MORB, and compositional similarities with the within-plate continental volcanic districts located in the African plate and its Adriatic extension (Wilson and Bianchini 1999; Beccaluva et al. 2005, 2007; Bianchini et al. 2008; Avanzinelli et al. 2012).

**Geological and geodynamic remarks**

Manuella et al. (2015) proposed that huge amount of oceanic serpentinites constitutes the Hyblean basement, being affected by hydration/dehydration reactions which acted as source of the strain and driven the vertical uplift the Hyblean Plateau. According to their hypothesis, the occurrence of these processes ultimately led to an uplift and the exposition offshore of a vast sector of oceanic lithosphere. The authors do not present other regional analogues, i.e., comparable examples of similar geodynamic processes, which makes the Hyblean study case therefore to represent a geological worldwide uniqueness.

On the contrary, geological and geophysical data suggest that the Hyblean plateau is paved by continental crust, sharply separated from the adjoining Ionian domain which represents the only remnant of the Mesozoic Tethys (Finetti and Del Ben 2005; Catalano et al. 2010; Civile et al. 2010; Accaino et al. 2011; Roure et al. 2012; Musumeci et al. 2014). During the Permo-Triassic, the opening of the Ionian basin caused stretching and thinning coupled with multiple basic intrusions (Yellin-Dror et al. 1997; Rocchi et al. 1998), as observed in ocean–continent transitional settings worldwide. In the Tertiary, the area evolved as impactogenic rift, where the basement was reactivated as results of far-field geodynamic effects of the neighboring subduction and collision processes that induced deep mantle dynamics responsible for the observed Neogene-Quaternary uplift and volcanism (Beccaluva et al. 1998, 2011).

**Conclusion**

In this contribution we document that the Hyblean peridotite xenoliths show petrographic, geochemical and isotopic signatures conforming to a subcontinental mantle domain. Analogously, the Hyblean mafic xenoliths (mainly constituted by fully recrystallized granulites) show petrographic, geochemical and isotopic signatures conforming to a lower continental crust realm. As consequence, the Hyblean Neogene-Quaternary lavas are necessarily derived from subcontinental mantle sources.

In our view, the hypothesis concerning an oceanic nature of the Hyblean basement is speculative on the basis of the available data. Hopefully, the reported comment will stimulate further research. It would be important to avoid a sterile debate, inviting new groups of researchers to collect new samples and perform new and more sophisticated analyses with the aim to develop independent ideas. As far as it concerns us, we are also open to go back in the field and collaborate directly with Manuella and other Sicilian colleagues, collecting together new samples, and planning a suitable work plan that could confirm or discard the existing hypotheses.

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