Reply to "Comment on Manuella et al. 'The Hyblean xenolith suite (Sicily): an unexpected legacy of the Ionian–Tethys realm' by Beccaluva et al. (2015)"

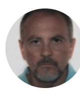
ARTICLE *in* INTERNATIONAL JOURNAL OF EARTH SCIENCES · SEPTEMBER 2015

Impact Factor: 2.09 · DOI: 10.1007/s00531-015-1197-8

4 AUTHORS, INCLUDING:

Fabio Carmelo Manuella

23 PUBLICATIONS **75** CITATIONS



Vittorio Scribano

University of Catania

40 PUBLICATIONS **449** CITATIONS

Alfonso Brancato

National Institute of Geophysics and Volca…

18 PUBLICATIONS **76** CITATIONS

Int J Earth Sci (Geol Rundsch)
DOI 10.1007/s00531-015-1197-8

REPLY

Reply to "Comment on Manuella et al. 'The Hyblean xenolith suite (Sicily): an unexpected legacy of the Ionian–Tethys realm' by Beccaluva et al. (2015)"

Fabio Carmelo Manuella[1] · Vittorio Scribano[2] · Serafina Carbone[2] · Alfonso Brancato[3]

Received: 19 April 2015 / Accepted: 9 May 2015

Introduction

In our paper (Manuella et al. 2015), which arose from our 30-year-long research on the Hyblean xenoliths, we discussed an exhaustive dataset retrieved from the literature. We concluded that the unexposed basement of southeastern Sicily and neighboring areas consists of a remnant of the Paleo–Mesozoic Ionian–Tethyan oceanic lithosphere. Our viewpoint is opposite to the most popular theory that the Hyblean–Pelagian foreland domain is part of the Africa continental plate.

We acknowledge some comments by Beccaluva et al. (2015) since they prompted us to explicit some background information given as implicit in our paper and hence to reaffirm with more emphasis fundamental aspects of our research, strongly confirming our previous conclusions.

✉ Fabio Carmelo Manuella
fmanuella@alice.it

Vittorio Scribano
scribano@unict.it

Serafina Carbone
carbone@unict.it

Alfonso Brancato
alfonso.brancato@ingv.it

[1] Via Dell'Oro 137, 95123 Catania, Italy

[2] Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Sezione di Scienze della Terra, Università di Catania, 95129 Catania, Italy

[3] Istituto Nazionale di Geofisica e Vulcanologia-Osservatorio Etneo, 95123 Catania, Italy

Recalling the basis of our viewpoint

One of the most important pieces of background information left in our pen (Manuella et al. 2015) regards the circumstance that, during the last 25 years, international marine geology expeditions brought crucial advances in understanding the composition and tectonic evolution of present and fossil oceanic lithosphere (e.g., Pearce 2002; Dick et al. 2003; Boschi et al. 2006; Snow and Edmond 2007; Ildefonse et al. 2007; Miranda and Dilek 2010; Silantyev et al. 2011). In particular, we would draw attention to some fault-bounded abyssal highs, called oceanic core complexes (OCCs), located in the crest zone of (ultra) slow-spreading mid-ocean ridges. OCCs mostly consist of serpentinized mantle peridotites and gabbroic rocks exhumed to the ocean floor along systems of detachment faults, related to serpentinite diapirism. Most elevated blocks even reach the ocean surface to form non-volcanic ocean islands, as well as the St. Peter and St. Paul Rocks located near the axial zone of MAR in the equatorial region (e.g., Campos et al. 2010; Sharkov 2012). More in general, magmatic layers of the normal oceanic crust are very thin or even absent at OCCs sites, seismic profiles being compatible with a serpentinite layer overlying almost unaltered mantle ultramafics (e.g., Blackman et al. 2004a, b). In this respect, the concept of a "crust" had to be called into question, and hence, the Moho can be regarded as a serpentinization front (e.g., Minshull et al. 1998).

Oxide-rich gabbros with sheared texture are considered obliged components of the gabbroic suite of present and fossil OCCs (e.g., Sharkov 2012). Veins of plagiogranites are also relatively common in these oceanic structures, intruding both gabbros and peridotite bodies. Oxide gabbros and plagiogranites from OCCs typically bear zircon as accessory phase (e.g., Aranovich et al. 2013). OCC basalts,

Published online: 07 June 2015

if present, show petrological and geochemical characteristics in line with those from ocean island basalts or ridge basalts near major hotspots (e.g., Snow and Edmond 2007 and references therein). Seawater-related "abyssal" hydrothermal systems are always associated with OCCs along slow-spreading ridges (e.g., Bach and Früh-Green 2010; Silantyev et al. 2009, 2015). Dihydrogen, abiotic methane and higher molecular weight hydrocarbons are common, though minor, components of the fluids issuing from hydrothermal vents at seafloor (e.g., Fu et al. 2007; Konn et al. 2009). Metasomatic processes affecting the ultramafic and mafic rocks of OCCs primarily consist of hydration of anhydrous minerals (e.g., serpentinization), Na/Ca/K-silicate metasomatism and carbonation.

Reply to: Petrological inference on the Hyblean ultramafic xenoliths

The petrologic and geochemical characteristics of Hyblean peridotite xenoliths (Manuella et al. 2015) including the sporadic occurrence of metasomatic phases are close similar to those dredged and drilled in modern OCCs. Nevertheless, we did not report in our paper that peridotites are crucial rocks for discriminating between different geodynamic settings: In fact, we recall that spinel-facies harzburgites and lherzolites from several modern OCCs appear enriched in some incompatible elements (as well as the light rare earth elements: LREE) at a level that is unknown in most of abyssal peridotites, being therefore close similar to mantle rocks commonly found as xenoliths in intraplate basalts of oceans and continents (e.g., Snow and Edmond 2007 and therein references).

Furthermore, Beccaluva et al. (2015) stated that the enrichment in LREE observed in the Hyblean peridotite xenoliths is related to metasomatic processes occurring deep in the mantle and not to seawater/hydrothermal fluid interaction. In this respect, we would like to remark that the dating (200–270 Ma) by Tonarini et al. (1996) of the "metasomatic" event recorded in Hyblean peridotites "surprisingly" corresponds to the age of hydrothermal zircons (246 ± 10 Ma) gathered by Sapienza et al. (2007). For a more exhaustive discussion, see Manuella et al. (2015). Strontium isotope systematics also suggests metasomatism by seawater related to hydrothermal fluids as evidenced by Tonarini et al. (1996).

Another issue raised by Beccaluva et al. (2015) deals with Os isotope data carried out by Sapienza et al. (2007) on sulfides hosted in the Hyblean peridotite xenoliths. The authors stated that the Os isotope values range from 0.1104 to 0.1244 and hence differ from those typically recorded in abyssal peridotites. We recall that no primary sulfides occur in the Hyblean peridotites (Manuella 2011), and therefore, Sapienza et al. (2007) considered *secondary* sulfide grains hosted in serpentine veins crosscutting olivine grains, formed as products of the serpentinization reactions (Manuella 2009): Indeed, serpentinization is an effective sink for seawater sulfur (Alt and Shanks 2003). Nevertheless, the data reported by Sapienza et al. (2007) are also compatible with sulfides hosted in abyssal peridotites ($^{187}Os/^{188}Os$ 0.1176–0.1500, 15 analyses; PetDb 2015).

Finally, Beccaluva et al. (2015) remarked that Hyblean peridotite xenoliths equilibrated in the spinel-facies, unlike abyssal peridotites which should equilibrate at lower pressure, in the plagioclase-peridotite facies. We would like to reconfirm (Manuella et al. 2014) that spinel is a ubiquitous mineral phase in peridotites dredged at floor of present oceans (Bodinier and Godard 2014). Spinel is often the only relict of the peridotite primary mineral assemblage left by intense seafloor alteration. Plagioclase, where present, is often related to trapped melt (Baker and Beckett 1999; Warren and Shimizu 2010).

Moreover, Beccaluva et al. (2015) claim that the Hyblean peridotite xenoliths equilibrated at pressures between 0.9 and 1.5 GPa. In this respect, we recall that experimental phase diagrams in the CaO–MgO–Al_2O_3–SiO_2 (CMAS) system (e.g., Gasparik 1984) clearly indicate that no reliable mineralogical geobarometers exist for spinel-facies peridotites. Nevertheless, admitting that Beccaluva et al. (2015) reported the pressure values, the authors must be aware that their considered mineral assemblages may have metastably stationed at a shallow crustal depth for a long interval time before their entrainment into the diatreme eruptive system. Such a circumstance was plenty confirmed by fluid inclusion geobarometry (De Vivo et al. 1990; Sapienza et al. 2005).

Reply to: Petrological inference on the Hyblean mafic xenoliths

Among the Hyblean gabbroids, those characterized by a great abundance of Fe–Ti oxides and crystal-plastic and brittle deformations (sheared oxide gabbros or *ferrogabbros*) have a crucial role for unraveling the geodynamic affinity of the Hyblean lithospheric block. Indeed, these rocks exhibit an intimate connection between magmatism and shear as is typical for gabbros formed at oceanic settings with a slow-spreading regime (Scribano et al. 2006a; Manuella et al. 2015). Beccaluva et al. (2015) did not consider or discuss such fundamental evidence.

In addition, Manuella et al. (2015) did not reinterpret the suite of mafic xenoliths as oceanic cumulates, as erroneously reported by Beccaluva et al. (2015): Such an interpretation was already reported by Scribano et al. (2006a).

Manuella et al. agreed that these gabbros mostly display a tholeiitic affinity: Indeed, the lack of olivine, the late-stage crystallization of Fe–Ti oxides and hence some *averaged* geochemical proxies (and hence their variation ranges) are consistent with such an interpretation.

Moreover, the information reported by Beccaluva et al. (2015) that Hyblean gabbroic xenoliths mostly consist of mafic granulites may fit into *their* xenolith collection, and/or it was retrieved from some preliminary papers published by our research group when the xenolith collection was not yet complete (e.g., Scribano 1986, 1987). In addition, Sapienza et al. (2007) recognized a petrographic continuum from gabbros with clearly igneous microstructure to those with mainly granuloblastic microstructures. More in general, although spinel-bearing two-pyroxene granulites may occur in deepest layers of a thinned continental crust, fully recrystallized gabbros (i.e., mafic granulites), sometimes displaying gneissic banding, are also common in OCCs structures as well as in MAR axial zones (e.g., between 12°58′ and 14°45′N; Silantyev et al. 2011) and the in the SWIR (e.g., the "Atlantis Bank": Natland and Dick 2001).

The occurrence of green aluminous spinel in the Hyblean recrystallized gabbros (and hence in some oxide gabbros) suggests that the diatremic blast entrained portion of the deepest parts of the core complex, far below the depth reached by subseafloor drilling in modern analogues. Moreover, the circumstance that Hyblean recrystallized gabbros sometimes display complex coronitic and symplectic textures and frequent pyroxene unmixing is consistent with the aged nature of the Hyblean lithospheric block that experienced a long-lasting, but discontinuous, period of tectonic uplifting. This fact is also confirmed by the stratigraphic record from Lower Jurassic to Upper Miocene, the time when samples entrained in the eruptive as xenoliths system (Grasso et al. 1990).

About the Hf and Nd isotope systematics of Hyblean mafic xenoliths reported by Sapienza et al. (2009), these authors reported that ε_{Hf} values do not distribute along the crust–mantle array in Hf–Nd space, but trend vertically toward negative values. These isotopic trends cannot be explained by crustal contamination, which would have required a simultaneous change in Nd isotope composition. In addition, Sapienza et al. (2009) reported that eight out of ten samples display positive $\varepsilon(0)_{Hf}$ values laying between those of HIMU and DMM representative compositions, whereas only two samples display slight negative values.

About the rare anorthosite xenoliths, it is well known the occurrence of cumulate layers of anorthosites in oceanic crust, as especially evidenced from worldwide ophiolite sequences. In particular, the cumulus feldspars show compositional variations from Ca-rich early cumulates (An_{94}) to more sodic, lower-temperature end-members (An_{63}: e.g., Jaques 1981).

Finally, the millimeter-sized fragments of polycrystalline quartz, certainly related to granitoids, mentioned by Pompilio and Scribano (1992), may be consistent with the core complex hypothesis, since plagiogranite veins are ubiquitous in these oceanic structures (e.g., Sharkov 2012). Nevertheless, we omitted (not forgot, as stated Beccaluva et al. 2015) to report such a circumstance since we had the chance, several years ago, to recognize that above-mentioned polycrystalline quartz fragments did not derive from the Hyblean deep lithospheric root. In fact, we realized that these unique quartz-bearing xenoliths were found in a Quaternary nephelinite lava flow along the westernmost limit of the Plateau, close to the allochtonous terrains of the Gela Nappe. There, a coarsely bedded conglomerate deposit crops out, mostly consisting of quartzite clasts deriving from the Numidian Flysch deposits. No quartz-bearing xenoliths were found up to now in the Hyblean tuff-breccia pipes, as correctly stated by Manuella et al. (2015).

Reply to: Inferences on the "secondary" mineral assemblages recorded by xenoliths

The question of the hydrothermal mineral assemblages in Hyblean ultramafic and mafic xenoliths was exhaustively discussed in our paper (Manuella et al. 2015), and we refer to the section "Hydrothermal mineral assemblages in Hyblean xenoliths" for a specific report.

Moreover, we highlight that most of Hyblean ultramafic xenoliths, sampled in the volcaniclastic deposits of Hyblean diatremes, are often serpentinized and carbonated as also reported by Tonarini et al. (1996), Scribano et al. (2009) and Manuella (2011), albeit the analyzed xenoliths represent the freshest samples collected in the diatremes. The abundance of secondary minerals, such as serpentine and carbonates, is supported by the L.O.I. values measured in Hyblean peridotite xenoliths. Considering data extracted by us from the GEOROC database on December 5, 2014, the average value of L.O.I. is of 4.07 wt% on the basis of 19 analyses, which correspond to a range from 0.58 wt% (Perinelli et al. 2008) up to 7.91 wt% (Tonarini et al. 1996). In addition, Punturo (1999) reported values of L.O.I. from 3.82 to 9.74 wt%, with an average value of 7.12 wt% on the basis of 18 analyses.

Among the Hyblean gabbroic xenoliths, there is a number of evidence of mineralogical and textural changes as a consequence of hydrous, alkaline and carbonate metasomatic processes involving fluid flow and mass transfer (Manuella et al. 2015). The most common secondary minerals found in the hydrothermally altered gabbros are Na-rich alkali feldspar, pargasite, aegirine–augite, chlorite/

smectite (C/S) and/or smectite/illite (S/I) mixed layers, Fe–Ti oxide/hydroxide, aragonite, calcite, dolomite, titanite, and zircon. In some cases, complete replacement of the original texture and mineral assemblage generated metasomatites (Scribano et al. 2006b). On these grounds, serpentinization, albitization and aegirinization are metasomatic processes typical of *long*-living abyssal hydrothermal systems.

Reply to: Inferences on the representativeness of the Hyblean xenoliths population

Beccaluva et al. (2015) cast doubts on the representativeness of the Hyblean xenolith population. Xenoliths from Hyblean lava flows are certainly monotonous, mostly consisting of mantle peridotites displaying wide reaction rims (Scribano 1986). On the contrary, xenoliths from the diatreme tuffsite-breccia are plenty assorted: In fact, there are sedimentary rocks belonging to the entire Meso–Cenozoic sequence, mantle peridotites and pyroxenites and varytextured crustal gabbroids. The entire xenolith suite represents a continuous sampling of wall rocks, with increasing depth from the sedimentary and volcanic succession, down to the crystalline basement and the upper mantle (e.g., Tonarini et al. 1996). Indeed, it is widely acknowledged that worldwide diatremes carried out a more extensive sampling of the wall rocks than any other type of magmatic activity. The model of xenolith entrapment in mantle melts suggested by Lensky et al. (2006) derived from experiments performed on a CO_2-rich trachytic basalt at 1–1.5 GPa, that may not fit with the composition of the juvenile lava clasts in Hyblean diatremes and their potential fluid contents (e.g., Suiting and Schmincke 2009). Therefore, the lack in the Hyblean xenolith suite of felsic granulites, granitoids and felsic metasedimentary lithotypes, which are typical components of the continental crust, is certainly an important circumstance to take into account for a lithospheric model.

In addition, it appears evident that, although the xenolith suite from Hyblean diatremes fully represents the underneath lithospheric column, a given xenolith collection may be not representative. In this respect, we remark that since 1984 we continuously added samples to our collection. Beccaluva et al., as skillful xenolith collectors, certainly agree that achieving a statistically significant collection implies an extremely time-consuming, often largely unrewarded, long-lasting field work. On this ground, it is not surprising that our early collection was not fully representative, as clearly indicated by the preliminary character of our papers from 1986 to 2000. The latter was the year of our first comprehensive, though not yet exhaustive, reports (Punturo et al. 2000; Sapienza and Scribano 2000). In addition, we started our research from the common, though erroneous, viewpoint of the (Africa) continental nature of the Hyblean basement. This is the reason why we recently considered "unexpected" the Ionian Tethys affinity of the Hyblean xenolith suite (Manuella et al. 2015).

Reply to: The crucial role of the Hyblean "Archean" zircons

An important issue repeatedly raised by Beccaluva et al. (2013, 2015) is that in situ U–Pb zircon dating carried out on 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). Therefore, Beccaluva et al. (2015) concluded that an Archean continental crust is located at roots of the Hyblean Plateau. We reject this conclusion because only two out of 66 zircons (ca. 3 %), Archean in age, do not represent a suitable percentage to support their conclusion. In addition, the authors did not mention that the entire population of Hyblean zircons derive from a single, few cm in size, hydrothermally altered gabbroic xenolith (that we provided to Sapienza and coauthors). In this respect, we remark that the occurrence of different types of zircon grains in a single rock sample is a typical feature of gabbros and plagiogranites from OCCs (Zinger et al. 2010; Aranovich et al. 2013).

Moreover, as we mentioned in our paper (Manuella et al. 2015), ancient, even Archean, xenogenic zircons are quite common in gabbroic and differentiated intrusives from the MAR axial zones (e.g., Pilot et al. 1998; Skolotnev et al. 2010). Although the latter authors tentatively inferred that such an occurrence of ancient xenogenic zircons may be related to fragments of continental crust incorporated in the convective mantle, they never questioned the oceanic affinity of the *present* lithosphere beneath the Middle Atlantic Ridge. In this regard, we would like to consider the surprising discovery by Kusiak et al. (2013) of nanometer- to micrometer-scale patchy distribution of uranogenic Pb in some zircon grains from East Antarctica. Such a feature was interpreted as artifacts of intracrystalline redistribution of radiogenic Pb, a process that can occur for different causes during the geologic history of the zircon grains, generating meaningless ages. More precisely, aforementioned authors reported that radiogenic Pb-enriched patches will yield spuriously old $^{207}Pb/^{206}Pb$ ages that are not true ages, but the result of sampling by the probe beam that integrates areas with both unsupported and supported radiogenic Pb. Therefore, zircon grains much older than the averaged population (even older than age of the Earth; Kusiak et al. 2013) were not considered relicts of ancient zircons.

On the above premises, we confirm (Manuella et al. 2014) that the two "Archean" zircon grains from the aforementioned Hyblean hydrothermally altered gabbro, likewise Archean zircons found in MAR gabbros, cannot be used to invoke a continental setting of the region as claimed by Sapienza et al. (2007, 2009) and Beccaluva et al. (2013, 2015).

Reply to: Inferences based on the study of the Hyblean lavas

Beccaluva et al. (2015) concluded their comment emphasizing that the Hyblean ultramafic and mafic xenoliths show petrographic, geochemical and isotopic signatures conforming to a subcontinental mantle domain. As a *consequence*, the Hyblean Neogene–Quaternary lavas are *necessarily* derived from subcontinental mantle sources. On the contrary, we substantially documented (Manuella et al. 2015) that Hyblean ultramafic and mafic xenoliths are akin to those found in present and fossil oceanic core complexes; hence, Hyblean Neogene–Quaternary lavas are *necessarily* derived from a suboceanic mantle.

Meanwhile, the trace element distribution and isotope geochemistry of Hyblean volcanic rocks exclude any continental crust contamination (Bianchini et al. 1999) and support the oceanic affinity of portions of the Sicilian lithosphere that may belong to the adjacent Ionian abyssal plain (Trua et al. 1998).

Beccaluva et al. (2015) also remark that we misused the diagram Th/Yb–Nb/Yb which should be applied only to discriminate orogenic and anorogenic magmas. Nevertheless, Pearce (2008) proposed the aforementioned diagram as a robust method to identify and classify oceanic basalts, lying within a diagonal MORB–OIB array, and to distinguish them from basalts from continental settings and subduction zones which plot above the cited array.

Reply to: Geological and geodynamic remarks

Beccaluva et al. (2015) remarked that our model for the fossil OCC-type lithosphere of southeastern Sicily and neighboring areas is not confirmed by other modern regional analogues, and the Hyblean study case would therefore represent a geological worldwide uniqueness. In this regard, we recall that sunken tectonic islands capped by carbonate platforms occur along the Vema and Romanche transforms in the equatorial Atlantic; in detail, a 50-km-long narrow paleo-island flanking the Vema transform, underwent subsidence, erosion, and truncation at sea level and is capped by a 500-m-thick carbonate platform; past islands on the crest of the Romanche transverse ridge are now at ~900 m bsl, showing horizontal truncated surfaces of oceanic crust capped by ~300-m-thick carbonate platforms (e.g., Palmiotto et al. 2013). In addition, the islets called St. Peter and St. Paul Rocks consist of strongly serpentinized mantle peridotites, which are considered as the top of a huge OCC rising from the equatorial Atlantic Ocean floor (Campos et al. 2010; Sharkov 2012). A further tectonic submerged island is Atlantis Bank, an uplifted gabbroic block along the Atlantis II transform (SW Indian Ridge) ~700 m bsl (Natland and Dick 2001). Another OCC, called Atlantis Massif, located along the MAR, never reached the sea level but evolved in an undersea setting with nearly over 4000 m of vertical relief. The upper surface of Atlantis Massif consists of partially serpentinized mantle peridotites (e.g., Blackman et al. 2004a, b). Looking at possible fossil examples, the central part of the Trodos Ophiolite (Cyprus) around Mt. Olympus can be considered the exposed portion of a large and deep serpentinite diapir (e.g., Mackenzie et al. 2006; Schuiling 2011).

In this respect, we would recall that the main driving force for a serpentinite diapiric rise is the volume increase associated with the transformation of peridotite to serpentinite, that was reported up to 50 % in case of complete serpentinization (e.g., Jamtveit and Austheim 2010). On the contrary, volume decreasing due to deserpentinization controls the downward motion of the former diapir. Although some authors suggested that transpressive tectonics at ridge–transform intersections plays an important role for vertical motion of blocks of oceanic lithosphere (Palmiotto et al. 2013), in some cases it was demonstrated that such a transpressive tectonic post-to date their diapiric vertical motion (e.g., Campos et al. 2010).

Conclusions

We acknowledge the comments reported by Beccaluva et al. (2015) since they gave us the opportunity to broaden and discuss the results of our research on the Hyblean xenoliths, including the widespread occurrence of sheared ferrogabbros closely resembling those from modern and fossil Oceanic Core Complexes. The scientific concerns raised by Beccaluva et al. (2015) did not adequately consider recent advances in understanding the oceanic lithosphere provided by marine geology expeditions at slow- and ultraslow-spreading middle oceanic ridges. In this regard, Hyblean peridotite xenoliths show petrographic, geochemical and isotopic signatures perfectly compatible with those from a suboceanic mantle at (ultra)slow-spreading ocean ridges, as we concisely reported in the introduction section of this reply.

Results from a 30-year collecting and laboratory studying of deep-seated xenoliths from Hyblean tuff-breccia pipes, as clearly summarized and discussed by Manuella et al. (2015), unquestionably suggest the early development of core complex structures in the Ionian section of the ultraslow-spreading Paleo–Mesozoic Tethys Ocean. Indeed, serpentinites and partially serpentinized peridotites, with minor gabbroids, constitute the unexposed basement of the present Ionian–Hyblean–Pelagian domain.

Further researches have to start from this standpoint, aiming at better evaluating the different implications of our discovery in the geological framework of Sicily mainland and the entire Central Mediterranean area, as preliminarily indicated by Scribano et al. (2006a, b), Ciliberto et al. (2009), Scirè et al. (2011) and Manuella et al. (2013) and more exhaustively reappraised by Manuella et al. (2015).

Acknowledgments We are indebted to W.-C. Dullo for his careful editorial managing and his suggestions, which helped us to improve the present manuscript.

References

Alt JC, Shanks WC III (2003) Serpentinization of abyssal peridotites from the MARK area, Mid-Atlantic Ridge: sulfur geochemistry and reaction modeling. Geochim Cosmochim Acta 67:641–653

Aranovich LY, Zinger TF, Bortnikov NS, Sharkov EV, Antonov AV (2013) Zircon in gabbroids from the axial zone of the MidAtlantic Ridge, Markov Deep, 6° N: correlation of geochemical features with petrogenetic processes. Petrology 21:1–15

Bach W, Früh-Green GL (2010) Fluids in metamorphism: alteration of the oceanic lithosphere and implications for seafloor processes. Elements 6:173–178

Baker MB, Beckett JR (1999) The origin of abyssal peridotites: a reinterpretation of constraints based on primary bulk compositions. Earth Planet Sci Lett 171:49–61

Beccaluva L, Bianchini G, Coltorti M (2013) Comments on the paper “A crustal–upper mantle model for southeastern Sicily (Italy) from the integration of petrologic and geophysical data” by Manuella et al. (2013). J Geodyn 70:58–60

Beccaluva L, Bianchini G, Coltorti M (2015) Comment on Manuella et al. “The Hyblean xenolith suite (Sicily): an unexpected legacy of the Ionian-Tethys realm”. Int J Earth Sci (Geol Rundsch) (in press)

Bianchini G, Bell K, Vaccaro C (1999) Mantle sources of the Cenozoic Iblean volcanism (SE Sicily-Italy): Sr–Nd–Pb isotopic constraints. Mineral Petrol 67:213–221

Blackman DK, Ildefonse B, John BE, MacLeod CJ, Ohara Y, Miller DJ, the Expedition 304/305 Project Team (2004a) Oceanic core complex formation, Atlantis Massif-oceanic core complex formation, Atlantis Massif, Mid-Atlantic Ridge: drilling into the footwall and hanging wall of a tectonic exposure of deep, young oceanic lithosphere to study deformation, alteration, and melt generation. IODP Sci Prosp 304/305, http://iodp.tamu.edu/publications/SP/304305SP/304305SP.PDF

Blackman DK, Karson JA, Kelley DS, Cann JR, Früh-Green GL, Gee JS, Hurst SD, John BE, Morgan J, Nooner SL, Ross DK, Schroeder TJ, Williams EA (2004b) Geology of the Atlantis Massif (Mid-Atlantic Ridge, 30°N): implications for the evolution of an ultramafic oceanic core complex. Mar Geophys Res 23:443–469

Bodinier J-L, Godard M (2014) Orogenic, ophiolitic and abyssal peridotites. Treatise on geochemistry, 2nd edn. Elsevier, pp 103–167

Boschi C, Früh-Green GL, Delacour A, Karson JA, Kelley DS (2006) Mass transfer and fluid flow during detachment faulting and development of an oceanic core complex, Atlantis Massif (MAR 30°N). Geochem Geophys Geosyst 7:Q01004. doi:10.1029/2005GC001074

Campos TFC, Bezerra FHR, Srivastava NK, Vieira MM, Vita-Finzi C (2010) Holocene tectonic uplift of the St Peter and St Paul Rocks (Equatorial Atlantic) consistent with emplacement by extrusion. Mar Geol 271:177–186

Ciliberto E, Crisafulli C, Manuella FC, Samperi F, Scirè S, Scribano V, Viccaro M, Viscuso E (2009) Aliphatic hydrocarbons in metasomatized gabbroic xenoliths from Hyblean diatremes (Sicily): genesis in a serpentinite hydrothermal system. Chem Geol 258:258–268

De Vivo B, Lima A, Scribano V (1990) CO_2 fluid inclusions in ultramafic xenoliths from the Iblean Plateau, Sicily, Italy. Mineral Mag 54:183–194

Dick HJB, Lin J, Schouten H (2003) Ultra-slow spreading: a new class of ocean ridge. Nature 426:405–412

Fu Q, Sherwood Lollar B, Horita J, Lacrampe-Couloume G, Seyfried WE Jr (2007) Abiotic formation of hydrocarbons under hydrothermal conditions: constraints from chemical and isotope data. Geochim Cosmochim Acta 71:1982–1998

Gasparik T (1984) Two-pyroxene thermobarometry with new experimental data in the system CaO–MgO–Al_2O_3–SiO_2. Contrib Mineral Petrol 87:73–87

Grasso M, De Dominicis A, Mazzoldi G (1990) Structures and tectonic setting of the western margin of the Hyblean-Malta Shelf, central Mediterranean. Ann Tecton 4:1140–1154

Ildefonse B, Blackman DK, John BE, Ohara Y, Miller DJ, MacLeod CJ, Integrated Ocean Drilling Program Expeditions 304/305 Science Party (2007) Oceanic core complexes and crustal accretion at slow-spreading ridges. Geology 35:623–626

Jamtveit B, Austhreim H (2010) Metamorphism: the role of fluids. Elements 6:153–158

Jaques LG (1981) Petrology and petrogenesis of cumulate peridotites and gabbros from the Marum ophiolite complex, northern Papua New Guinea. J Petrol 22:1–40

Konn C, Charlou JL, Donval JP, Holm NG, Dehairs F, Bouillon S (2009) Hydrocarbons and oxidized organic compounds in hydrothermal fluids from rainbow and lost city ultramafic hosted vents. Chem Geol 258:299–314

Kusiak MA, Whitehouse MJ, Wilde SA, Nemchin AA, Clark C (2013) Mobilization of radiogenic Pb in zircon revealed by ion imaging: implications for early Earth geochronology. Geology 41:291–294

Lensky NG, Niebo RW, Holloway JR, Lyakhovsky V, Navon O (2006) Bubble nucleation as a trigger for xenolith entrapment in mantle melts. Earth Planet Sci Lett 245:278–288

Mackenzie GD, Maguire PK, Coogan LA, Khan MA, Eaton M, Petrides G (2006) Geophysical constraints on the crustal architecture of the Troodos ophiolite: results from the IANGASS project. Geophys J Int 167:1385–1401

Manuella FC (2009) Serpentinizzazione e produzione abiogenica di idrocarburi nel basamento ultrafemico degli Iblei: inferenze mineralogiche e petrologiche dagli xenoliti. PhD thesis, Department of Earth Sciences, University of Catania

Manuella FC (2011) Vein mineral assemblage in partially serpentinized peridotite xenoliths from Hyblean Plateau (Southeastern Sicily, Italy). Per Mineral 80:247–266

Manuella FC, Brancato A, Carbone S, Gresta S (2013) A crustal upper mantle model for southeastern Sicily (Italy) from the integration of petrologic and geophysical data. J Geodyn 66:92–102

Manuella FC, Brancato A, Carbone S (2014) Reply to comments on the paper “A crustal-upper mantle model for southeastern Sicily (Italy) from the integration of petrologic and geophysical data” by Manuella et al. (2013). J Geodyn 73:81–82

Manuella FC, Scribano V, Carbone S, Brancato A (2015) The Hyblean xenolith suite (Sicily): an unexpected legacy of the Ionian–Tethys realm. Int J Earth Sci. doi:10.1007/s00531-015-1151-9

Minshull TA, Muller MR, Robinson CJ, White RS, Bickle MJ (1998) Is the oceanic Moho a serpentinization front? In: Mills RA, Harrison K (eds) Modern ocean floor processes and the geological record, vol 148. Geological Society, London, Special Publications, pp 71–80

Miranda EA, Dilek Y (2010) Oceanic core complex development in modern and ancient oceanic lithosphere: gabbro-localized vs. peridotite-localized detachment models. J Geol 118:95–109

Natland JH, Dick HJB (2001) Formation of the lower ocean crust and the crystallization of gabbroic cumulates at a very slowly spreading ridge. J Volcanol Geotherm Res 110:191–233

Palmiotto C, Corda L, Ligi M, Cipriani A, Dick HJB, Douville E, Gasperini L, Montagna P, Thil P, Borsetti AM, Balestra B, Bonatti E (2013) Nonvolcanic tectonic islands in ancient and modern oceans. Geochem Geophys Geosyst 14:4698–4717. doi:10.1002/ggge.20279

Pearce J (2002) The oceanic lithosphere, achievements and opportunities of scientific ocean drilling. Spec. Issue JOIDES J 28:61–66

Pearce JA (2008) Geochemical fingerprint of oceanic basalts with applications to ophiolite classification and the search for Archean oceanic crust. Lithos 100:14–48

Perinelli C, Sapienza GT, Armienti P, Morten L (2008) Metasomatism of the upper mantle beneath the Hyblean Plateau (Sicily): evidence from pyroxenes and glass in peridotite xenoliths. Geol Soc Lond Spec Publ 293:197–221

Pilot J, Werner CD, Haubrich F, Baumann N (1998) Paleozoic and proterozoic zircons from the Mid Atlantic ridge. Nature 393:676–679

Pompilio M, Scribano V (1992) Nature and evolution of crystalline basement beneath the Hyblean plateau (Sicily) inferred from xenoliths in volcanic rocks. In: Carmignani L, Sassi FP (eds) Contributions to the geology of Italy with special regard to the Paleozoic basements, vol 5. IGCP no 276, Newsletter, pp 381–390

Punturo R (1999) Caratterizzazione petrologica e petrofisica di xenoliti di origine profonda nelle tufo-brecce mioceniche di Valle Guffari (Altopiano Ibleo, Sicilia). PhD thesis, Department of Earth Sciences, University of Catania

Punturo R, Kern H, Scribano V, Atzori P (2000) Petrophysical and petrologic characteristics of deep-seated xenoliths from Hyblean Plateau, south-eastern Sicily, Italy: suggestions for a lithospheric model. Mineral Petrogr Acta 43:1–20

Sapienza G, Scribano V (2000) Distribution and representative whole-rock chemistry of deep-seated xenoliths from the Iblean Plateau, southeastern Sicily, Italy. Per Mineral 69:185–204

Sapienza G, Hilton DR, Scribano V (2005) Helium isotopes in peridotite mineral phases from Hyblean plateau xenoliths (southeastern Sicily, Italy). Chem Geol 219:115–129

Sapienza G, Griffin WL, O’Reilly SY, Morten L (2007) Crustal zircons and mantle sulfides: archean to triassic events in the lithosphere beneath southeastern Sicily. Lithos 96:503–523

Sapienza G, Griffin WL, O’Reilly SY, Morten L (2009) Petrology and Sr–Nd–Hf isotope geochemistry of gabbro xenoliths from the Hyblean Plateau: a MARID reservoir beneath SE Sicily? Contrib Mineral Petrol 157:1–22

Schuiling RD (2011) Troodos: a giant serpentinite diapir. Int J Geosci 2:98–101

Scirè S, Ciliberto E, Crisafulli C, Scribano V, Bellatreccia F, Della Ventura G (2011) Asphaltene-bearing mantle xenoliths from Hyblean diatremes, Sicily. Lithos 125:956–968

Scribano V (1986) The harzburgite xenoliths in a Quaternary basanitoid lava near Scordia (Hyblean Plateau, Sicily). Rend Soc It Mineral Petrol 41:245–255

Scribano V (1987) The ultramafic and mafic nodule suite in a tuff-breccia pipe from Cozzo Molino (Hyblean Plateau, SE Sicily). Rend Soc It Minerel Petrol 42:203–217

Scribano V, Sapienza GT, Braga R, Morten L (2006a) Gabbroic xenoliths in tuff-breccia pipes from the Hyblean plateau: insights into the nature and composition of the lower crust underneath Southeastern Sicily, Italy. Mineral Petrol 86:63–88

Scribano V, Ioppolo S, Censi P (2006b) Chlorite/smectite-alkali feldspar metasomatic xenoliths from Hyblean Miocenic diatremes (Sicily, Italy): evidence for early interaction between hydrothermal brines and ultramafic/mafic rocks at crustal levels. Ofioliti 31:161–171

Scribano V, Viccaro M, Cristofolini R, Ottolini L (2009) Metasomatic events recorded in ultramafic xenoliths from the Hyblean area (Southeastern Sicily, Italy). Mineral Petrol 95:235–250

Sharkov EV (2012) Cyclic development of axial parts of slow spreading ridges: evidence from Sierra Leone Area, the Mid-Atlantic Ridge, 5–7°N. In: Sharkov EV (ed) Tectonics—recent advances, InTech. doi:10.5772/39372. http://www.intechopen.com/books/tectonics-recent-advances/cyclic-development-ofaxial-parts-of-slow-spreading-ridges-evidence-from-sierraleone-area-the-mid-a

Silantyev SA, Mironenko MV, Novoselov AA (2009) Hydrothermal systems hosted in peridotites at slow-spreading ridges. Modeling phase transformations and material balance: upwelling limb of the hydrothermal cell. Petrology 17:523–536

Silantyev SA, Novoselov AA, Mironenko MV (2011) Hydrothermal systems in peridotites at slow-spreading ridges. Modeling phase transformations and material balance: role of gabbroids. Petrology 19:227–248

Silantyev SA, Bortnikov NS, Shatagin KN, YaV Bychkova, Krasnova EA, Beltenev VE (2015) Peridotite–basalt association at MAR between 19°42′ and 19°59′N: evaluation of petrogenetic conditions and material balance during hydrothermal transformation of the oceanic crust. Petrology 23:1–21

Skolotnev SG, Bel’tenev VE, Lepekhina EN, Ipat’eva IS (2010) Younger and older zircons from rocks of the oceanic lithosphere in the Central Atlantic and their geotectonic implications. Geotectonics 44:462–492

Snow JE, Edmond HN (2007) Ultraslow-spreading ridges rapid paradigm changes. Oceanography 20:90–101

Suiting I, Schmincke H-U (2009) Internal vs. external forcing in shallow marine diatreme formation: a case study from the Iblean Mountains (SE-Sicily, Central Mediterranean). J Volcanol Geotherm Res 186:361–378

Tonarini S, D’Orazio M, Armenti P, Innocenti F, Scribano V (1996) Geochemical features of Eastern Sicily lithosphere as probed by Hyblean xenoliths and lavas. Eur J Mineral 8:1153–1173

Trua T, Esperança S, Mazzuoli R (1998) The evolution of the lithospheric mantle along the N. Africa Plate: geochemical and isotopical evidence from the tholeiitic and alkaline volcanic rocks of the Hyblean plateau, Italy. Contrib Mineral Petrol 131:307–322

Warren JM, Shimizu N (2010) Cryptic variations in abyssal peridotite compositions: evidence for shallow-level melt infiltration in the oceanic lithosphere. J Petrol 51:395–423

Zinger TF, Bortnikov NS, Sharkov EV (2010) Influence of plastic deformations in zircon on its chemical composition: evidence from gabbroids of the spreading zone of the MidAtlantic Ridge, Markov Trough, 6°N. Dokl Earth Sci 433:1098–1103