Serpentinite mud volcanism and exhumation of forearc and lower plate material in the Mariana convergent margin system (IODP Expedition 366)

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GEOLOGICAL SETTING

IODP Expedition 366 recovered cores from three serpentinite mud volcanoes at increasing distances from the Mariana trench along a south-to-north transect: Yinazao (Blue Moon), Fantangisña (Celestial), and Asùt Tesoru (Big Blue) (Fig. 1). These cores consist of serpentinite mud containing lithic clasts derived from the underlying forearc crust and mantle as well as from the subducting Pacific Plate. Additionally, in situ pelagic sediments and volcanic ash deposits underlying the serpentinite mud volcanoes were recovered at Fantangisña. A thin cover of pelagic sediment was found at many sites.

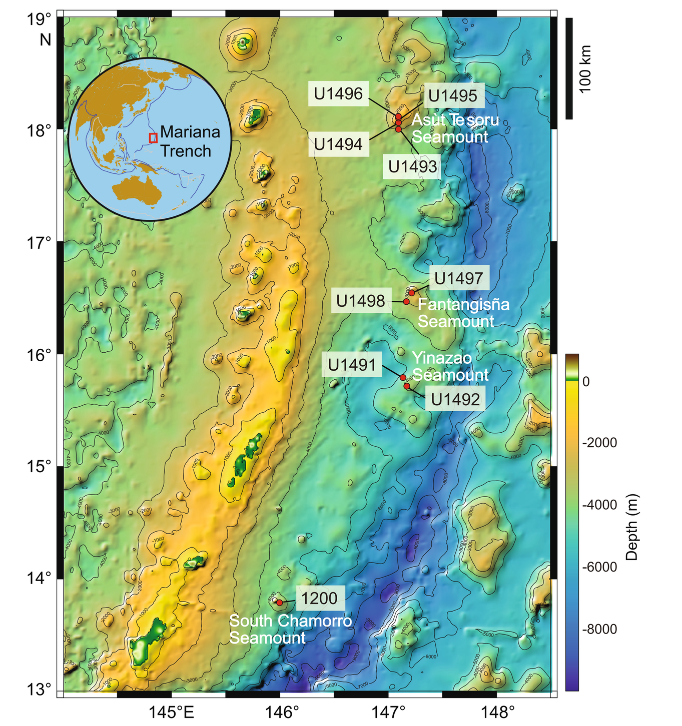

Figure 1: Location map of Sites on Expedition 366 (U1491 – U1498) and CORK Site 1200 on South Chamorro Seamount.

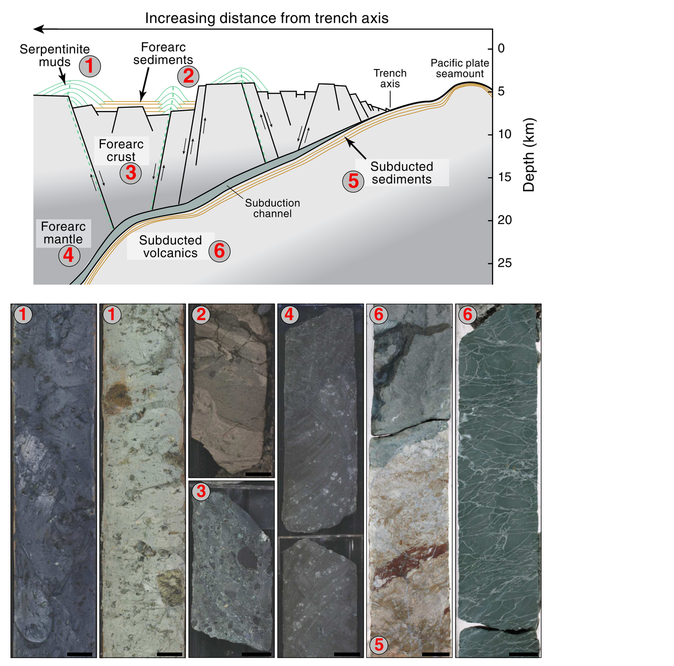

Figure 2: Cartoon cross-section of the forearc setting of the mud volcanoes targeted on Expedition 366. Tectonic Zones 1 to 6 in the forearc subduction zone complex are keyed to core images in this figure. Scale bars in lower images are 2 cm. Cores are, from left to right, U1492A-1H-4, 2–30 cm, U1492A-1H-3, 67–94 cm, U1498B-23R-3, 0–27 cm, U1498A-3R-2, 85–96 cm, U1498B-23R-1, 12–34 cm, U1498B-21R-1, 108–128 cm, and U1498B-27R-1, 15–41 cm. Figure modified after Fryer (2012).

The main component in all cores is serpentinite mud (Zone 1 in Fig. 2). Ultramafic clasts are the dominant clast type at all of the seamounts (Zone 4). These are mainly harzburgite (<<5% clinopyroxene) with less common dunite and pyroxenite. The clasts display serpentinization degrees from 30 to 100%.

Crustal rocks derived from both the underlying forearc crust (Zone 3) and from the subducting Pacific plate (Zones 5 and 6) are found at several sites. Low-grade metamorphosed sedimentary rocks and basalts were recovered at the summit site of Asùt Tesoru Seamount (U1496). The sedimentary clasts are fossiliferous cherty limestones. The mafic volcanic clasts are dolerites and augite-phyric vitrophyres, both with pink titan-augite.

Volcanic clasts from Fantangisña include forearc basalts (Zone 3), boninite and volcanic glass (boninitic), as well as greenstones and subgreenschist (prehnite-pumpellyite facies) metavolcanics (Zone 6). The metasediments are characterized by re-crystallization of calcareous and siliceous microfossils (Zone 5).

The seamounts overlie pelagic sediment, sampled at site U1498, composed of volcanic ash, calcareous nannofossils (discoasters and coccoliths), foraminifera, radiolarian and sponge spicules (Zone 2). A similar pelagic sediment overlies most sites as well. The underlying volcanic ash with nannofossils establishes a minimum age for mud volcano activity, as the samples are from the distal edge of the edifice and presumably edifice building began much earlier at the central vents; the overlying pelagic mud that blankets the surface of the volcanoes (Fig. 3) constrains their most recent activity.

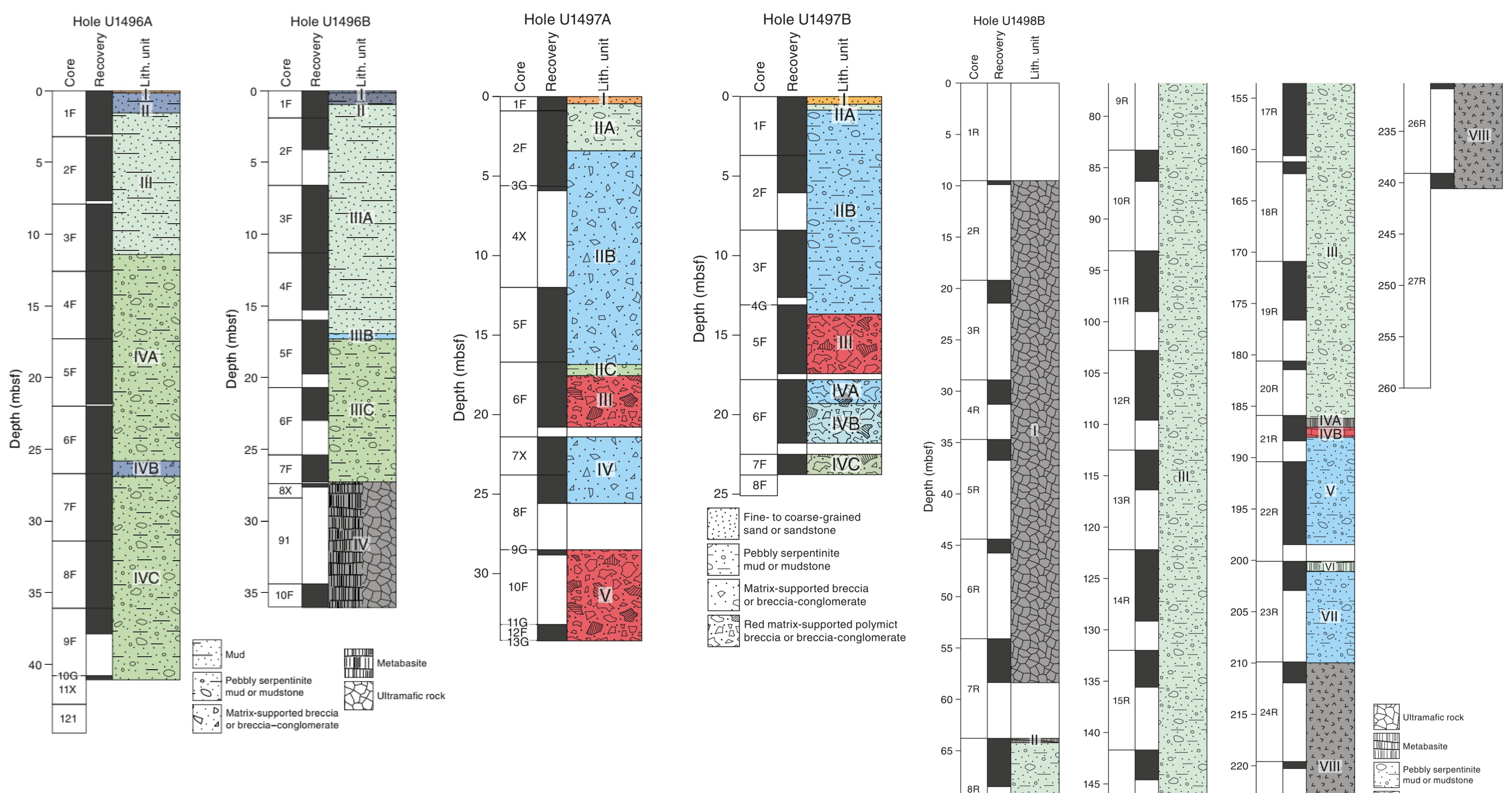

Figure 3: Lithostratigraphic summary of Holes U1497A, U1497B, U1498A and U1498B. Colors are according to Tab. (VCD explanatory Table/Figure on Munsell colors) with slight changes for subunits or when representative for the particular unit (Freyer et al. 2018).

PRELIMINARY RESULTS: PETROLOGY

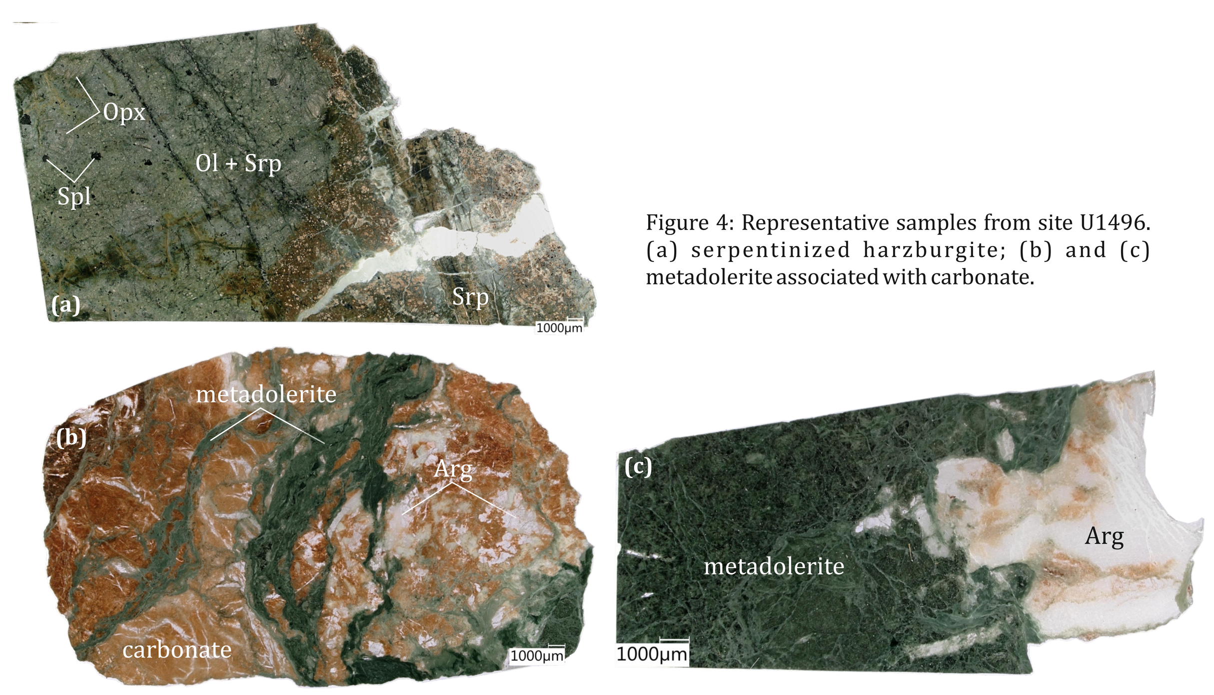

Figure 4: Representative samples from site U1496. (a) serpentinized harzburgite; (b) and (c) metadolerite associated with carbonate.

Site U1496 on the summit of Asùt Tesoro Seamount recovered mainly serpentinite mud with less common lithic clasts comprising ultramafic rocks as well as mafic metavolcanics and sedimentary clasts.

The ultramafic rocks are dominantly harzburgite composed of olivine and orthopyroxene and accessory spinel (Fig. 4a). They are derived from the underlying forearc mantle lithosphere and display various degrees of serpentinization. Dunite and orthopyroxenite can also occur.

Metadolerites crosscut by thick aragonite veins as well as in association with reddish brown carbonate occur in the lowermost parts of Hole U1496B (Fig. 4b and c). These clasts my represent recycled material from the subducting Pacific plate. However, further studies on their mineralogy and geochemistry are required for confirmation.

Site U1497A, drilled at the summit of Fantangisna Seamount, contains among others crustal sedimentary rocks of probable Pacific plate provenance. These consist of red cherty limestone breccia, red shale and mud-siltstone transected by a network of very thin (< 1 mm) to well-developed single veins (up to 8 mm) (Fig. 5a and b). Initial investigation revealed that the brecciated limestone clasts contain primary calcite veins, whereas the latest veins are composed of aragonite ($CaCO_3$) and barite ($BaSO_4$).

At the bottom of the site a serpentinized dunite sample was recovered, containing a several mm-thick vein made up of analcime ($NaAlSi_2O_6{\cdot}H2O$) (Fig. 5c).

Chemical and isotope composition analyses of the veins would provide information on the pore fluids and trace element composition through the forearc evolution as well as the mechanisms of their transport. However, obtaining data on that point is still in progress.

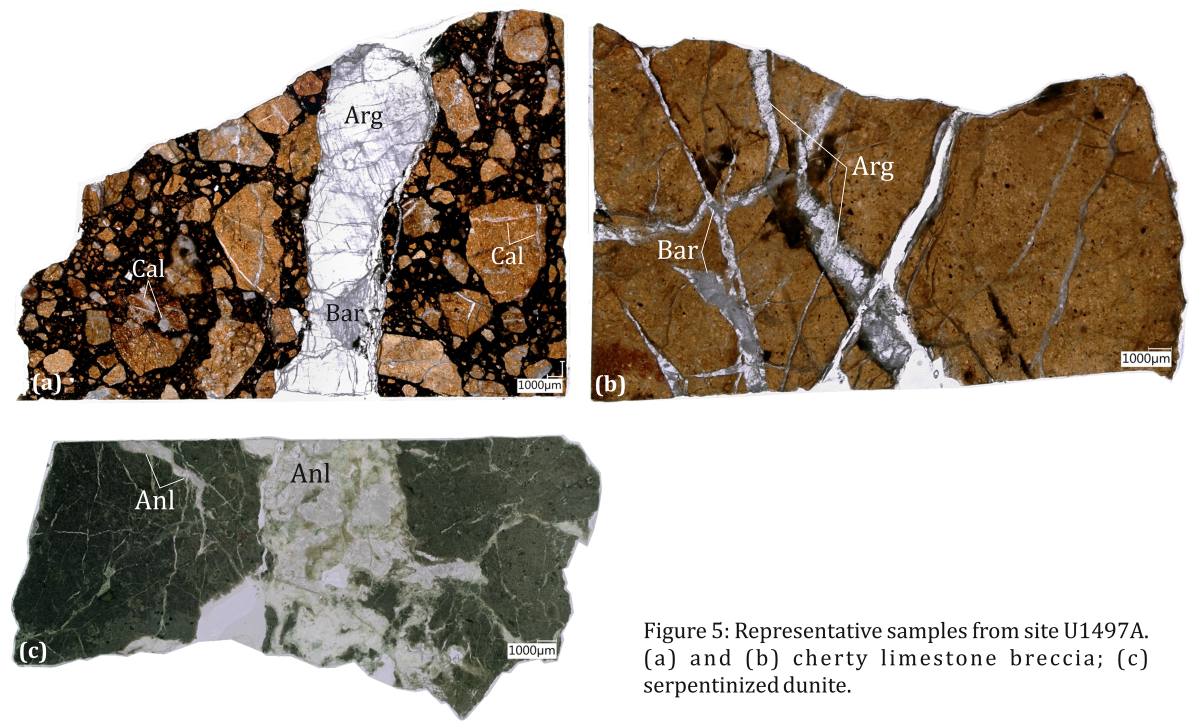

Figure 5: Representative samples from site U1497A. (a) and (b) cherty limestone breccia; (c) serpentinized dunite.

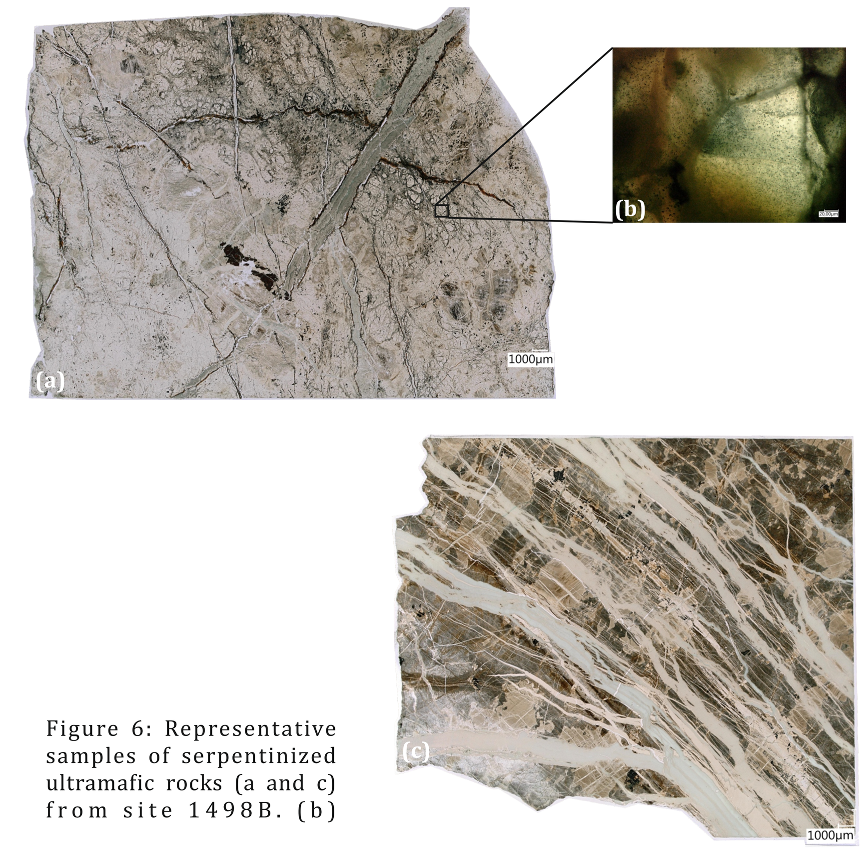

Figure 6: Representative samples of serpentinized ultramafic rocks (a and c) from site 1498B. (b)

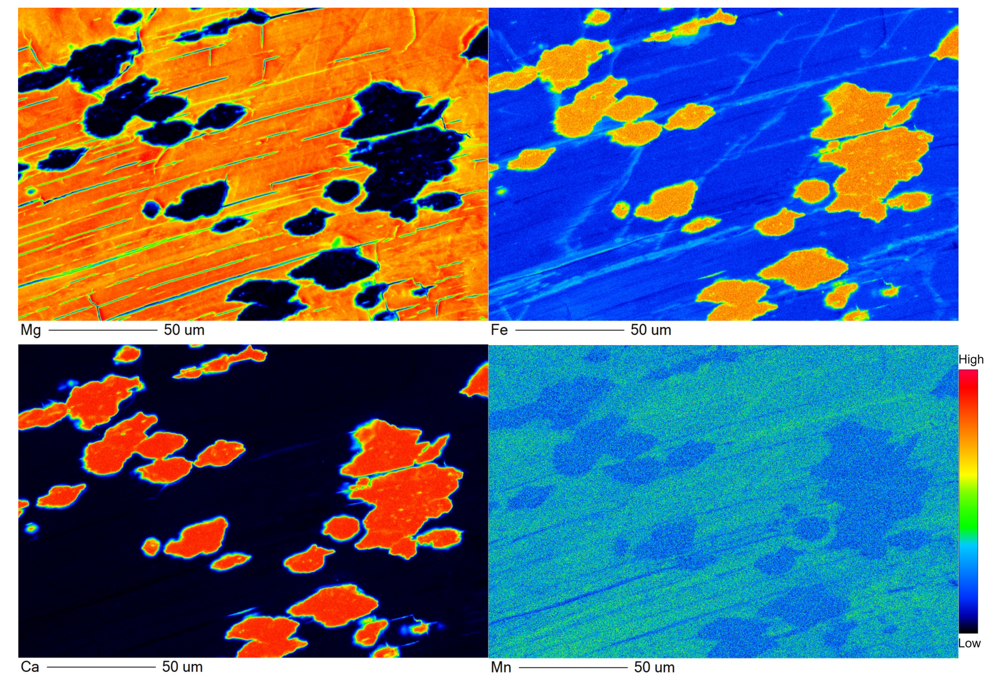

Figure 7: Major element distribution maps of garnets within serpentinized matrix in ultramafic rock from site U1498B. The garnets are small in size (d < 50 µm) and have andraditic composition ($Ca_3Fe_2Si_3O_{12}$).

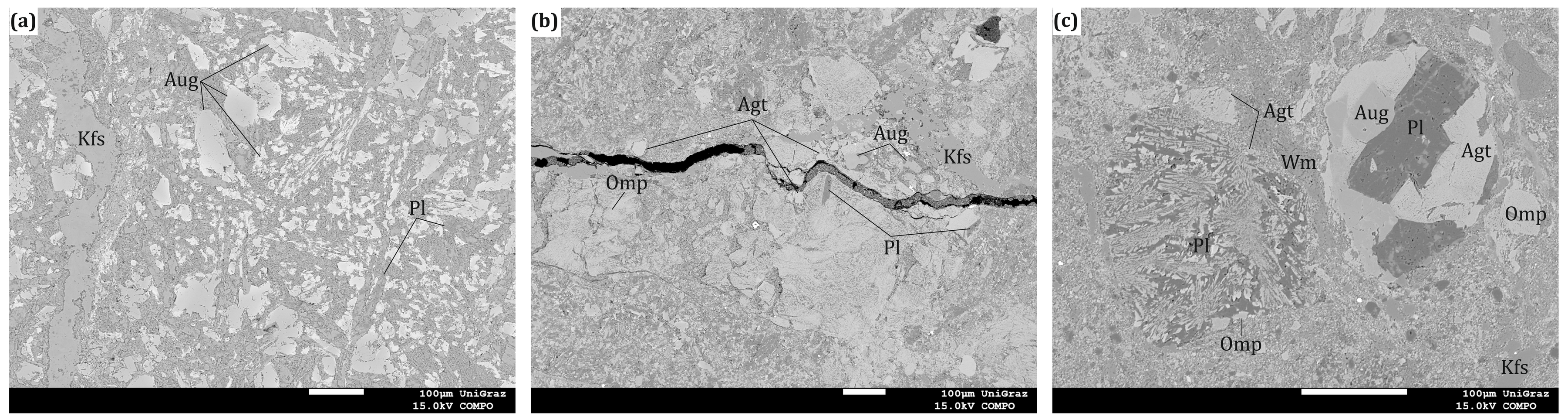

Figure 8: Back-scattered electron (BSE) images of samples 1-1498B-272 (a), 1-1498B-273 (b) and 1-1498B-252 (c).

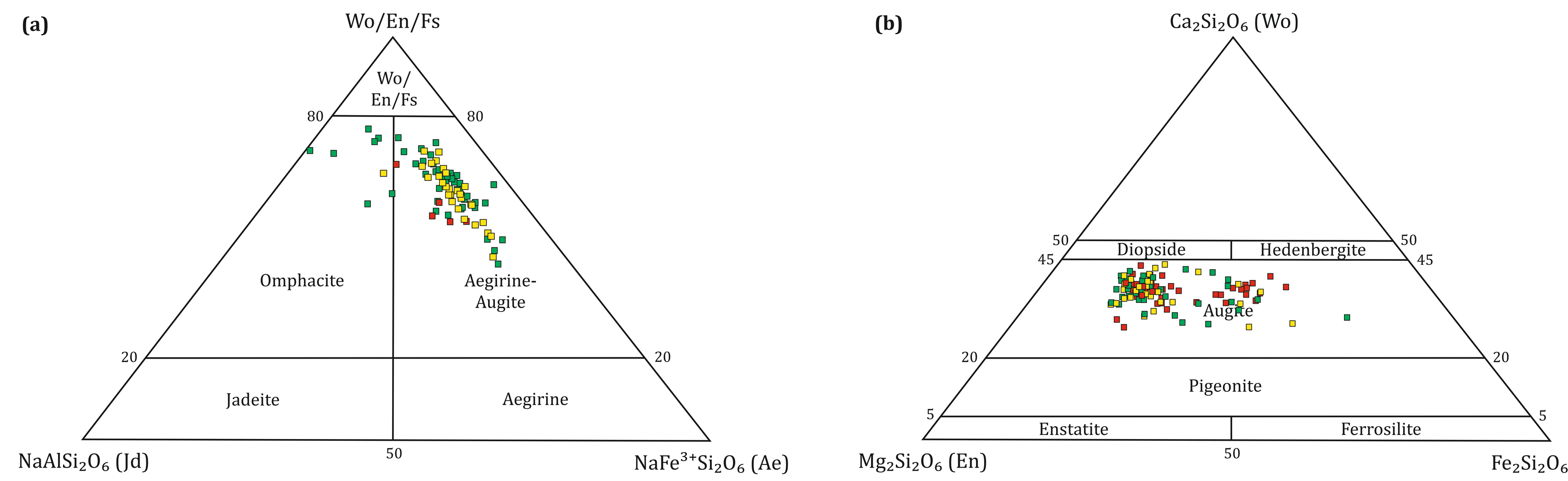

Figure 9: Plots of Na (a) and Mg-Fe-Ca (b) pyroxene compositions after Morimoto (1998). Red squares represent sample 1-1498B-272; yellow squares belong to sample 1-1498B-273 and green squares depict sample 1-1498B-252.

Unit IV from site U1498B (core 21R) recovered brecciated metabasalt and an interval of (metamorphic) cherty limestone. The primary contact between the two rock types is well preserved, however, it is inverted (Zones 5 and 6 in Fig. 2).

Petrological analysis of the metabasalt showed changes in the mineral composition within the different intervals of the core (Fig 8a, b and c). Clinopyroxene is mainly primary magmatic classified as augite in sample 1-1498B-272 (45-48 cm; Fig. 9b). In sample 1-1498B-252 (112-116 cm) clinopyroxene is either aegirine-augite or omphacite, but augite is also present (Fig. 9a and b). The jadeite content in the Na-pyroxenes ranges between 23 and 36 wt%, which suggests minimum pressure of 0.7 GPa at ~250 °C.

Amphibole with pargasitic composition is present mainly in samples 1-1498B-273 and 1-1498B-252. White mica is also abundat in these two samples, but it ts rare in 1-1498B-272. It has a phengite composition with Si content of c. 3.5 a.p.f.u.

Feldspars with various compositions are present in all three samples. Albite-rich plagioclase as well as alkalifeldspar with variable Na and K content are abundant. Pure K feldspar is present as single crystals but also in veins cross-cutting the matrix, suggesting a metasomatic nature.

Site U1498B, located at the flank of Fantangisna Seamount, contains a wide variety of materials, including ultramafic rocks with various degrees of serpentinization, mafic metavolcanics as well as low-grade metasediments (cherty limestones) (Fig. 6).

In the ultramafic rocks serpentine fullly replaces olivine and pyroxene by forming mesh and bastite textures. Small magnetite crystals are abundant throughout the mesh (Fig. 6b). Rare hematite is observed only on the serpentine veins boundary suggesting oxidation of magnetite. Andraditic garnet occurs throughout the serpentinized matrix mainly in association with bastite (Fig. 7). It may have formed from diopside by the following reactions:

magnetite + diopside + fluid = andradite + serpentine + alloy + fluid
magnetite + diopside + fluid = andradite + brucite + alloy + fluid
magnetite + diopside + brucite + fluid = andradite + serpentine + alloy

Initial investigation of the vein composition of the serpentinized ultramafic rocks showed that they are made up of lizardite and chrysotile (Fig. 5a and b), which indicates rather low temperatures of serpentinization (below 200 °C). This is supported by the occurance of andradite within the serpentinized matrix, which is typically stable at c. 225°C in the presence of brucite (e.g., Frost & Beard 2007). However, brucite has not been thus far indicated in the garnet-containing serpentinites. The andradite stability is strongly dependent on the silica activity, which suggests that it may be also stable at higher temperatures in the absence of brucite. Further petrological study is ongoing.

References:
Frost, B.R., Beard, J.S. (2007): On silica activity and serpentinization. J. Petrol., 48, 1351-1368. Fryer, P. (2012): Serpentinite mud volcanism: observations, processes, and implications. Annual Rev. Mar. Sci. 4, 345–73. Fryer, P., Wheat, C.G., Williams, T., and the Expedition 366 Scientists (2018): Mariana Convergent Margin and South Chamorro Seamount. In: Proceedings of the International Ocean Discovery Program 366 (2018). Morimoto, N. (1988): Nomenclature of pyroxenes. Mineral. Mag., 52, 535-550.