Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SCG04-01 Room:302 Time:May 21 09:00-09:30

The yin and yang of continental crust creation and destruction by plate tectonic processes

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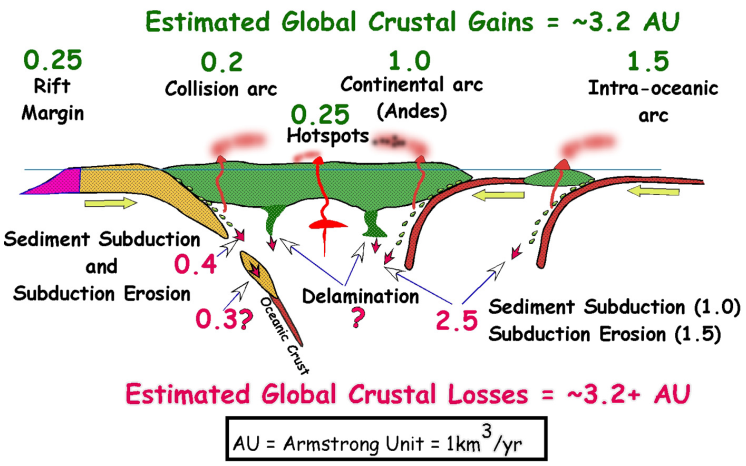
It is generally assumed that the volume of continental crust has grown with time, but there is increasing evidence that continental crust volume is approximately constant or is decreasing. On modern Earth, continental crust is both created and destroyed, especially by plate tectonic processes. Continental crust creation and destruction both mostly occur at convergent plate margins, added by arc magmas and subtracted by sediment subduction and subduction erosion. Crust is also created and destroyed by non-plate tectonic processes, including magmatic rifts and hotspot additions as well as losses by lower crust foundering (delamination) and subduction of continents. Estimates for losses by foundering and for subducted continental crust are especially poorly constrained. Stern and Scholl (2010) estimate that creation and destruction of continental crust is either in balance (˜3.2 km3/year, or 3.2 Armstrong Units, AU) or that more crust is being destroyed than created. These estimates, which do not include a term for crustal foundering (delamination), are comparable to, but distinctly lower than, those of Clift et al. (2009) (additions <5 AU, losses ˜4.9 AU) or losses estimated by C.R. Stern (2011) (5.25 AU). The range of these estimates (growth of 3.2-5 AU, loss of 3.2-5.3 AU) usefully captures our present understanding and uncertainty.

The near-balance of continental crust formation and destruction by plate tectonics is encapsulated by the traditional Chinese concept of yin-yang, whereby dualities act in concert as well as in opposition. The yin-yang creation/destruction balance changes over a supercontinent cycle, with crustal growth being greatest during supercontinent break-up due to high magmatic flux at new arcs and crustal destruction being greatest during supercontinent amalgamation due to subduction of continental material and increased sediment flux due to high mountains formed by collision. The balance may change during a supercontinent cycle. For example, there have been 1.5 supercontinent cycles over the past 630 million years. The first supercontinent cycle encompassed Ediacaran and most of Paleozoic time (630-300 Ma). Continental collisions to form Greater Gondwana (Pannotia) at 630-500 Ma created great mountain chains that were eroded down and much of the detritus that this shed was likely transported to trenches and subducted. It is also likely that a significant but unknown volume of continental crust was subducted (net destruction). Greater Gondwana break-up encompassed much of Paleozoic time and was accompanied by formation of new hotspots, rifts, and intra-oceanic subduction zones, forming new welts of juvenile continental crust (net growth). Laurasia and Gondwana came back together in Late Paleozoic time (350-250 Ma) to form Pangea, the assembly of which again created great mountains and much detritus and continental crust subducted (net destruction). Mesozoic and younger breakup of Pangea again produced new hotspots, rifts, and intra-oceanic subduction zones, forming new welts of juvenile continental crust (net growth). Yin-yang balance is shifting once again towards net destruction, as significant proportions of the continental crusts of Africa, Arabia, India, and Australia are being subducted beneath the growing supercontinent of Asia. We do not understand the relationship between foundering losses and supercontinent cycle; delamination has been inferred to occur beneath rifts and arcs as well as collision zones.

Keywords: continental crust, plate tectonics, island arc, subduction erosion, crustal growth



SCG04-02 Room:302 Time:May 21 09:30-09:45

Crustal growth along a triple plate junction: Tectonic processes and geochemical variation in the Philippine arc

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The present location of the Philippine archipelago along a complex boundary among three plates, Eurasian, Philippine, and Indo-Australian, makes it a natural laboratory for studying and understanding the early stages of continental growth. Prior to this present stage, the archipelago may have undergone previous histories of multiple arc and back-arc basin generation, crustal accretion, as well as tectonic displacements from a more southerly location. Crustal accretion along this convergent margin is accomplished by ocean floor and arc amalgamation and oceanic plateau collision along the eastern margins and micro-continent collision and ocean floor incorporation along the western margins. Oceanic plateau collision along the eastern border in Early Miocene not only led to subduction flipping but also crustal thickening along its eastern margins as evidenced by the occurrence of highly alkalic rocks. Crustal growth may have been dominated by arc magmatism since Late Miocene.

The geochemistry of igneous rocks in the Philippine arc is a microcosm of that found along the East Asian margins. This may reflect the tectonic processes from its birth to its present stage of development and indicate a record of the changing or evolving mantle source regions that accompanies the evolution of the arc. However, the presence of accreted crustal fragments may complicate this simple interpretation and, instead, the variation may reflect inherited geochemical signatures from different mantle domains brought together by previous history of crustal accretion.

Keywords: crustal growth, arc magmatism, Philippine arc, tectonic processes, triple plate junction, geochemistry

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SCG04-03 Room:302 Time:May 21 09:45-10:00

Incoming Pacific Plate beneath NW Pacific Subduction Zones: Igneous Variation in Subduction Inventories

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It is well known that the chemical composition of subduction zone magmas reflects chemical variation of the incoming plate materials. Sediments are one of the key components that can form the variation [e.g., Plank, 2005 Journal of Petrology]. Radiogenic isotope ratios of fluid mobile elements, such as Sr and Pb, are particularly sensitive to the subduction materials, and show that the arc magmas clearly reflect geochemical compositions of the incoming sediment and oceanic igneous crust [e.g., Kimura et al., 2010 G3]. The oceanic plate materials have been well described for the NW Pacific subduction zones and are useful for these examinations [e.g., Plank & Languir, 1992 JGR; Kelley et al., 2003 G3; Hauff et al., 2003 G3; Chauvel et al., 2009 G3]. Regional variation in the radiogenic isotopes of lavas has also been reported for NW Pacific arcs [e.g., Straub et al., 2009 NGeo; Nakamura & Iwamori, 2009 GR]. An interesting proposal was made by Straub et al. (2009) suggesting that the variation of the Pb isotopes in the igneous NW Pacific Plate affect to the along arc variation of the erupted lavas between Marianas and Kamchatka. They supposed that the radiogenic 207Pb and 208Pb in the basalts between Izu and Kurile are from a particular igneous oceanic crust of Indian MORB mantle domain in origin rather than widely distributed oceanic crust of the Pacific MORB mantle domain in origin. They correlated spatial distribution of the lavas to the age distribution of the Pacific Plate beneath the regions, which are all younger than 120Ma. The NW Pacific Plate slab was formed at the Pacific-Izanagi ridge by the easterly spreading between 180-60 Ma. The ridge began to subduct at 40?60 Ma beneath the Eurasia continent by ridge subduction [Miller et al., 1996 Nature]. Thus the chemistry, whether or not it was from Indian or Pacific mantle domain, has never been able to be examined for the slab younger than 120 Ma as it has already been subducted. Moreover, the studies on isotopic inventories of the NW Pacific Plate slab are still poor to verify the proposal. We here present Sr-Nd-Hf-Pb isotope compositions of the igneous oceanic crust from all the available ODP/IODP core samples. MORB-like basalts intruded into the Eo-Oligocene Shimanto accretionary prism at 40-60 Ma have also been analyzed in order to examine the immediate remnants from the Pacific-Izanagi ridge. The results indicate a quite uniform isotopic composition of the NW Pacific plate including the paleo-MORBs from the Pacific-Izanagi ridge precluding the proposal by Straub et al. (2009).

Keywords: Pacific Plate, Igneous oceanic crust, subduction zone, radigenic isotiope

Japan Geoscience Union Meeting 2012
(May 20-25 2012 at Makuhari, Chiba, Japan)

SCG04-04 Room:302 Time:May 21 10:00-10:15

Geochemical evidence for delamination from the Jurassic Talkeetna arc crustal section: missing pyroxenites from the Moho

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Earths crust is primarily generated in oceanic settings via divergent and convergent margin processes. In divergent margins, the crust is ultimately recycled back into the mantle, whereas at convergent margins, the resulting island arc crust becomes the buoyant nucleus of new continental crust. If we accept that collision of island arcs with continental margins is a dominant process of post-Archean continental growth, then understanding the processes that modify arc crust, such as delamination, are imperative to understanding the creation of continental crust. The Early to Middle Jurassic Talkeetna Arc section exposed in the Chugach Mountains of south?central Alaska is 5 to 25 km wide and extends for over 150 km. This accreted island arc has been tilted on end to produce exhumed exposures of upper mantle through volcanic upper crust. The rocks that represent the deepest sections of the arc, beneath the paleo-Moho, include residual mantle harzburgite (with lesser proportions of dunite) that grade upward to cumulate pyroxenite and garnet-bearing gabbronorite. The paleo Moho is exposed where pyroxenites grade into plagioclase bearing lithologies (gabbronorite with or without garnet), with some interfingering of the two units along their high temperature contact. Lower crustal gabbronorite (>10 km thick) includes abundant rocks with well-developed modal layering. The mid to upper crust of the arc consists of a heterogeneous assemblage of gabbroic rocks, dioritic to tonalitic rocks, and concentrations of mafic dikes and chilled mafic inclusions. The plutonic rocks are overlain by basaltic to dacitic volcanic rocks. Many of the evolved volcanic compositions are a result of fractional crystallization processes whose cumulate products are directly observable in the lower crustal gabbronorites. For example, Ti and Eu enrichments in lower crustal gabbronorites are mirrored by Ti and Eu depletions in evolved volcanic rocks. In addition, calculated parental liquids from ion microprobe analyses of clinopyroxene in lower crustal gabbronorites indicate that the clinopyroxenes crystallized in equilibrium with liquids whose compositions were the same as those of the volcanic rocks. The compositional variation of the main series of volcanic rocks can be modeled through fractionation of observed phase compositions and phase proportions in lower crustal gabbronorite (i.e. cumulates). Primary, mantle-derived melts in the Talkeetna Arc underwent fractionation of pyroxenite at the base of the crust. However, even the most Mg-rich cumulates currently exposed in the arc were fractionated from liquids that had already themselves been fractionated. In order to bring the most mafic Talkeetna liquid composition in Fe/Mg equilibrium with the mantle, our calculations suggest that a mantle-derived parental basaltic magma must have fractionated ~25 wt % pyroxene (as pyroxenites) at the base of the crust. The discrepancy between the observed proportion of pyroxenites (less than 5% of the arc section) and the proportion required by crystal fractionation modeling (more than 25%) may be best understood as the result of gravitational instability, with dense ultramafic cumulates, probably together with dense garnet granulites, foundering into the underlying mantle during the time when the Talkeetna Arc was magmatically active, or in the initial phases of slow cooling (and sub-solidus garnet growth) immediately after the cessation of arc activity. Given the missing pyroxenites, the Talkeetna arc lower crust was interpreted by Behn and Kelemen (2006) to be an equilibrium configuration that was convectively stable relative to the underlying mantle. The denser, more primitive cumulates may have been removed via foundering into the asthenospheric mantle.

Keywords: delamination, arc geochemistry, arc crustal section

Japan Geoscience Union Meeting 2012
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SCG04-05 Room:302 Time:May 21 10:15-10:30

Three primary magma types from Pagan volcano in the Mariana arc and implications for arc magma genesis

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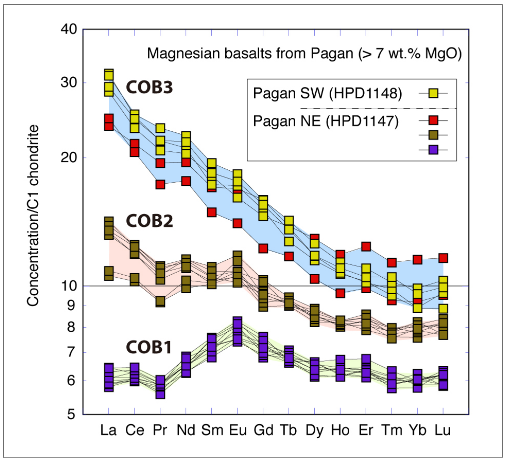
Pagan is an active volcano located in the volcanic front of the central Island Province of the Mariana arc and is one of the largest volcanoes in the Mariana arc; its main edifice rises from a base ~3,000 m below sea level and has a volume of 2,160 km3. Tamura et al. (2011) demonstrate the existence of near-primitive, phenocryst-poor lavas at NW Rota-1 volcano in the Mariana arc, which is located about 40 km west of the volcanic front. These magnesiana basalts are petrographically distinct cpx-olivine basalt (COB) and plagioclase-olivine basalts (POB).

The active Pagan volcano has erupted near-primitive lavas on its submarine flanks. The least fractionated compositions recovered from the NE flank (HPD1147) extend to higher MgO (7-11 wt %) and Mg# (60-70), than have ever been sampled from Pagan island lavas.

The Fo contents of olivine (up to Fo94) and Cr-number of spinels (up to 0.8) suggest that these magmas formed from high degrees of mantle melting. There are three geochemical groups of cpx-olivine basalt (COB1, COB2 and COB3) (Fig. 1). TiO2, Na2O, K2O, Rb, Nb are lowest in COB1 and highest in COB3. COB3 have steeper LREE-enriched patterns but the REE patterns of COB1 show contrasting LREE-depleted patterns, suggesting that COB1 formed from higher degrees of mantle melting. On the other hand, COB1 have the highest Ba/Th ratios and COB3 have the lowest, suggesting that a shallow subduction component is more important for COB1 than COB3, with COB2 intermediate. COB1, COB2 and COB3 show a negative trend on the Ba/Nb-Nb/Yb diagram. The higher Ba/Nb of the COB1 indicate that the COB1 contain greater abundances of slab-derived subduction components than the COB2 and COB3. Nb/Yb suggests that the degree of melting of the COB1 source is higher than for the COB2 and COB3.

Keywords: magma, arc volcano, basalt, primary magma, Mariana arc, subduction zone



Japan Geoscience Union Meeting 2012
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SCG04-06 Room:302 Time:May 21 10:45-11:15

Ultra-deep drilling to the middle crust of the Izu-Bonin-Mariana arc: Why is this planet to be the Earth?

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One characteristic feature of the planet Earth is the bimodal height distribution at the surface. This is caused by the difference both in density and thickness of the oceanic and continental crusts. These two types of crust on the Earth are created at convergent and divergent plate boundaries, respectively. The bulk composition of continental crust is andesitic (60 wt.% SiO2), in marked contrast with the basaltic oceanic crust with ˜50 wt.% SiO2. This raises the question of how intra-oceanic arcs produce continental crust if the dominant product of mantle wedge melting and a major proportion of intra-oceanic arc lava is basaltic. The ultra-deep drilling in the Izu-Bonin Mariana (IBM) arc aims at comprehensive understanding of arc evolution and continental crust formation. We propose to drill a deep hole that penetrates through a complete sequence of intra-oceanic arc upper crust and into the in situ arc middle crust, which may be the birthplace of continental crust. There is no pre-existing continental crust in the IBM arc, yet recent seismic studies of this arc reveal a thick layer in the middle crust (Vp=6.0-6.5 km/s) that is hypothesized to be intermediate/felsic in composition. The primary goals of sampling the in situ arc crust through drilling are: (1) to identify the structure and lithologies present in the upper and middle arc crust, (2) to constrain the petrologic and chronological relationship of mid-crustal rocks to the overlying upper crust, (3) to establish the temporal evolution of arc crust by relating this site with other regional drill sites and exposed sections of arc and continental crust, and (4) to test competing hypotheses of how the upper and middle crust forms and evolves in an intra-oceanic arc setting. These objectives address questions of global significance, but we have specifically identified the IBM arc system as an ideal locale to conduct this experiment. The composition of the pre-subduction upper plate was normal oceanic crust, and the tectonic and temporal evolution of this arc system is well-constrained. Moreover, the IBM system is perhaps the best-studied intra-oceanic arc on Earth, thanks to extensive sampling of the slab inputs and arc outputs through field studies and drilling, and to a series of recent, focused geophysical surveys. We propose returning to the region of ODP Site 792 to drill, via. Eo-Oligocene upper crust, to the middle crust at the proposed site. The mid-crustal layer in this area is shallow enough (˜4000 mbsf) to be reached by drilling, and heat flow is low enough for drilling to proceed at mid-crustal temperatures. Samples recovered from the proposed site will complement the drilling objectives at other proposed sites in temporally distinct Eocene and Neogene arc crust, which are proposed separately.

Keywords: continental crust formation, IBM arc, ultra-deep drilling

Japan Geoscience Union Meeting 2012
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SCG04-07 Room:302 Time:May 21 11:15-11:30

Active seismic studies in the Izu-Bonin arc and ultra-deep drilling

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JAMSTEC has been conducting intensive active-source seismic surveys in the Izu-Bonin arc since the last decade. Those studies found many new observations to examine a formation process of an arc crust, and also provide fundamental information toward future IODP drilling in this arc. For examples, a large volume of felsic-to-intermediate component crust having Vp of 6.0 - 6.8 km/s is predominantly observed beneath basaltic volcanic centers along the current volcanic front. A recent high resolution seismic study at a site where an ultra-deep drilling to the middle crust is proposed near the volcanic front found that a layer having seismic velocity of ~6 km/s is situated at 3-4 km below seafloor. We also discovered a similar along-arc-variation of the felsic-to-intermediate component crust in the rear-arc where another IODP drilling site is proposed. These findings suggest that the main part of the arc crust consisting of the felsic-to-intermediate component was created before the rear-arc has been separated from the volcanic front. Additional IODP drilling in this arc is proposed at a fore-arc close to the trench. A main objective of this proposal is to reveal a crustal formation process of an initial stage of crustal accretion in this arc. From seismic data obtained in the fore-arc, we found that the structure of the fore-arc region represents significantly different characters from that of the volcanic front; i.e., the seismic image along the Bonin ridge shows a remarkably thin crust which is seismologically identical to a typical oceanic crust as well as ophiolite. Petrological studies in the fore-arc region proposed a formation of oceanic crust associated with boninitic volcanism during an initial stage of subduction. The obtained seismic structures in the fore-arc strongly support this idea, which can be proved by the IODP drilling at the fore-arc area of the Bonin ridge.

Keywords: Izu-Bonin, Island arc, crust, seismic image

Japan Geoscience Union Meeting 2012
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SCG04-08 Room:302 Time:May 21 11:30-11:45

Evidence for Mesozoic basement in the Izu-Bonin-Mariana arc system

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The ca. 51-52 Ma age of subduction nucleation in the Izu-Bonin-Mariana (IBM) arc system (Ishizuka et al., 2011a) places it before most of the West Philippine Basin (WPB) formed (e.g., Deschamps and Lallemand, 2002). This implies that the potential location of subduction nucleation along the Mesozoic-aged arc crust that is now found along the northern and southern WPB (e.g., Amami Plateau (112-117 Ma): Hickey-Vargas, 2005; Daito Ridge (118 Ma): Ishizuka et al., 2011b; Huatung Basin (119-131 Ma): Deschamps et al., 2000). Recent investigation of Bonin Ridge forearc discovered Jurassic basaltic pillow lavas (159.4+-0.9 Ma: Ishizuka et al., 2011a). This age is consistent with the stratigraphic position of these basalts beneath and trenchward of Eocene gabbro. These Jurassic lavas are MORB-like basalt with Indian Ocean-MORB like isotopic characteristics, which strongly implies that these basalts are in situ and not accreted from the subducting Pacific plate. The presence of Jurassic basalts with an Indian Ocean MORB-type isotopic signature suggests that a sliver of this Mesozoic crust might be found in the Bonin Ridge forearc, and constitute basement of the Izu-Bonin arc. Similarly, Mesozoic sediments have been found from the central Mariana forearc with associated andesitic volcanic clasts at DSDP Sites 460 and 461 (Hussong, Uyeda et al., 1981) and dredge sites (Johnson et al., 1991) suggest that a similar Mesozoic sliver of crust might be present in the Mariana forearc.

Another piece of information about pre-Eocene crust in the IBM arc system was obtained by dredging from southernmost part of the Kyushu-Palau Ridge (KPR). We recovered mafic schists of amphibolite to greenschist facies from a ridge between the Palau trench and the KPR. Age and origin of these rocks are under investigation. These schists may have similar age and origin to those from the Cretaceous Daito Ridge.

These evidences indicate that at least some part of the IBM arc system was built on or adjacent to Mesozoic terranes composed of arcs and ocean basins. Subduction could have begun spontaneously, facilitated by the density contrast between the arc-bearing Mesozoic Asian crust and the old oceanic Pacific crust.

While Mesozoic basement exists beneath part of the IBM arc, other parts might lack pre-Eocene basement. The present geographic relationship between the KPR and the WPB, including the Central Basin Fault (extinct spreading center of the WPB), truncated by the KPR, implies that adjacent parts of the KPR formed on the very young oceanic crust of the WPB, which was still spreading until ~30Ma. The lack of Eocene ages for the central part of the KPR (11-20^{o}N) is consistent with this implication (Ishizuka et al., 2011b).

Petrographic and geochemical variation observed along the KPR may be linked to the variability of the basement crust and lithospheric mantle. For example, high-K andesite only occurs in the northern KPR, especially near the intersection between the KPR and the Daito Ridge, while the KPR south of 20^{o}N is characterized by dominance of basalt and lack of hornblende andesite relative to the northern KPR. However, to test this hypothesis, better tectonic reconstructions of the early Philippine Sea plate history is required, particularly to identify and sample where the various pre-Eocene crustal blocks were relative to each other when subduction began, and where are the segments of IBM and KPR crust where older crust is unlikely to exist, for example at the join between Bonin and Mariana arcs, ~23^{o}N.

Understanding the tectonic setting of subduction initiation is crucial for the understanding of present variability along-arc geochemical variation and seismic velocity structure of the arc crust. Tamura et al. (2010) pointed out the importance of contribution of Oligocene arc crust to silicic magmatism in the Izu-Bonin arc. Mesozoic crust and mantle lithosphere is likely to have significant control on arc crustal structure and composition.

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SCG04-09 Room:302 Time:May 21 11:45-12:00

Evidence for wehrlite and dunite xenoliths from West Zealandia Seamount, Mariana Arc, originating in the middle crust

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West Zealandia Seamount (~16^o 53' N) lies behind the magmatic front of the Mariana Arc. Sampling of the northwestern slopes from 1390-1135 mbsl with the ROV Hyper-Dolphin during NT09-08 in June 2009 recovered primitive porphyritic basalts containing dunite and wehrlite crystalline aggregates. Olivines within the aggregates contain glassy silicate melt inclusions. Firstly, major elements in the crystals forming the aggregates were analyzed by electron microprobe (EPMA) to determine whether the aggregates are mantle xenoliths. Crystals forming the phenocryst and groundmass population were also analyzed.

On the basis of olivine-spinel compositional relationships, spinels in aggregate olivines may have crystallized in the mantle. High Mg# (>91) and Na_2O/TiO_2 (>2.05) in aggregate clinopyroxenes suggest the wehrlites formed at high pressure, with clinopyroxene phenocrysts and groundmass crystals forming at successively lower pressures from increasingly evolved melts. Aggregate olivines (Fo_{85-90}, NiO 0.10 to 0.17 wt.%, CaO >0.15 wt.%) are distinct from those of the mantle (NiO 0.28 to 0.36 wt.%, CaO <0.10 wt.% at these Fo contents), but the high Fo contents suggest crystallization from a primitive melt. The olivine phenocryst population include a number of crystals that share geochemical characteristics with the aggregates, suggesting that these are fragments of aggregates. Furthermore, spinels hosted in these olivine phenocrysts have much higher Cr# (76) than spinels in other phenocrysts (Cr# <5), and together with the high host phenocryst Fo content (91) this results in them falling in the olivine-spinel mantle array along with those from the aggregates.

In order to better constrain crystallization depths we have estimated the entrapment pressures and compositional evolution of the glassy silicate melt inclusions found in the olivines. Dissolved volatile contents have been measured by micro-Fourier-transform infrared spectroscopy (FTIR) and the major element contents of the inclusions and the their hosts have been measured by EPMA. The olivine hosts range from Fo_{80-89}, NiO 0.06 to 0.30 wt.% and CaO 0.13 to 0.22 wt.%. The compositional range suggests that inclusions hosted by crystals from both the aggregate and phenocryst populations have been sampled. After correction for post-entrapment crystallization, the inclusions contain 46.08 to 50.65 wt.% SiO_2, 4.16 to 8.46 wt.% MgO, 0.59 to 1.14 wt.% TiO_2 and 0.17 to 0.42 wt.% K_2O. At these SiO_2 contents, the K_2O contents are low for the magmatic front of the Mariana Arc. In addition SiO_2 contents do not correlate strongly with MgO contents, with a group of inclusions largely from the wehrlite olivines characterized by high MgO (7.26 to 8.46 wt.%) and high SiO_2 (49.02 to 50.65 wt.%). Corrected inclusion H_2O contents range from 2.91 to 4.27 wt.%, with the exception of one inclusion containing 1.74 wt.%, while CO_2 contents range from below detection (59 ppm) to 764 ppm. Overall the H_2O-CO_2 systematics are consistent with open system degassing, with entrapment pressures estimated to range from 33 to 298 MPa. Entrapment pressures correlate with melt inclusion MgO content and host Fo content and indicate that inclusions in the wehrlite olivines were trapped from the most primitive melts at the deepest pressures. These are equivalent to depths of ~11 km, which approximate to the lower-middle crust boundary beneath West Zealandia, suggesting that the wehrlite aggregates may sample cumulates that formed in a magma chamber developed at this boundary in the crust. Inclusions in the dunite aggregates and phenocrysts were trapped later, after the melt had evolved, at pressures equivalent to ~6 km bsl, suggesting that a shallower magma chamber also exists at the middle-upper crust boundary.

Keywords: olivine, melt inclusions, major elements, water, carbon dioxide