Four-D Investigation of Subduction Initiation (SI) Magmatism as Revealed in Tethyan Forearc Ophiolites

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Introduction and Scope

Oceanic crust preserved in intra-oceanic forearc settings develops during subduction initiation and may preserve a complete igneous and geochemical record of melt evolution during the first 5-8 million years of subduction-induced magmatism (Reagan et al. 2010). Dredging, diving, and drilling provide but limited samples from modern forearc environments, making a systematic, age-constrained 4-D study of SI igneous stratigraphy and structure difficult and expensive. The results of the earlier studies of forearc crustal architecture and its magmatic record, based on DSDP Leg 60 and ODP Legs 125 and 126 expeditions to the Izu-Bonin-Mariana (IBM) system in the 1970's and 1980's, played a fundamental role in understanding oceanic crust formation in the upper plates of intra-oceanic subduction zones, and led to the development of the suprasubduction zone (SSZ) ophiolite concept (Pearce et al. 1984; Dilek 2003). Recent submersible (Shinkai 6500) studies of the IBM forearc indicate seafloor spreading formed forearc oceanic crust during the first 7 million years of SI magmatism (Reagan et al. 2010; Stern et al. 2010). The geological record of the IBM forerac shows a time-progressive evolution from 51-52 Ma forearc basalts (FAB), to 48 Ma boninitic lavas, and 44-45 Ma arc lavas prior to the construction of a mature magmatic arc with discrete volcanic centers. This geochemical trend of the SI-related IBM forearc crust is analogous to that of many well-preserved Tethyan SSZ ophiolites in the eastern Mediterranean region (Dilek & Furnes 2009). We, therefore, propose the designation of a Tethyan ophiolite as a focus site for the GeoPRISMS Subduction Cycles and Deformation (SCD) initiative.

Our study of some of the best-preserved Phanerozoic SSZ ophiolites in different orogenic belts demonstrate that their internal structure-stratigraphy and geochemical signatures indicate a seafloor spreading origin in forearc-incipient arc settings during subduction initiation (Dilek & Furnes 2009, 2010). In general, there is a well-developed magmatic stratigraphy in the extrusive sequences of these ophiolites from older MORB-like lavas at the bottom towards younger island arc tholeiite (IAT) and boninitic lavas in the upper parts (Shervais 2000; Ishikawa et al. 2002; Dilek et al. 2008). A similar progression of the lava chemistry also occurs in crosscutting dike swarms ad sheeted dikes, indicating increased subduction influence in the evolution of ophiolitic magmas through time. Lherzolitic peridotites in structurally lower parts of the upper mantle sequences of these ophiolites represent the residue after MORB melt extraction. Harzburgite and harzburgite-dunite associations higher up in the mantle sequences and below the mafic-ultramafic cumulates (transitional Moho) are crosscut by networks of orthopyroxenite (opxt) veins, which include hydrous minerals (amphibole). These orthopyroxenite veins represent reaction between host harzburgite (depleted, residual peridotite) and infiltrating Si-rich (boninitic) melt (Dilek & Morishita 2009). The lateral and vertical progression of melt evolution in the crustal and upper mantle units of these ophiolites traces different stages of SI-related magmatism, providing an opportunity to investigate the 4-D structure, stratigraphy, and time-progressive evolution of oceanic lithosphere formation in forearc settings of the Mesozoic Tethyan subduction zone systems. The geochemical evolution of these Tethyan ophiolites was governed by slab dehydration and accompanying metasomatism of the mantle, melting of the subducting slab and sediments and repeated episodes of partial melting of metasomatized peridotites.

Primary Site and Proposal

We propose to designate the Jurassic Mirdita ophiolite in Albania in the Mediterranean region as a GeoPRISMS Subduction Cycles and Deformation (SCD) initiative Primary Site for further investigations for SI magmatism. The Mirdita ophiolite occurs in a nearly 40-kmwide belt bounded by the conjugate passive margin sequences of the Apulia (west) and Pelagonia (east) microcontinents (**Fig. 1**). The

ophiolite and its gently-dipping sedimentary cover shows very little post-emplacement deformation, indicating that the igneous stratigraphy of the Jurassic oceanic lithosphere has not been affected by the Alpine orogenic events (Dilek & Furnes 2009).

The ~10-km-thick Eastern Mirdita Ophiolite (EMO) includes tectonized harzburgite and dunite with extensive chromite deposits, as well as ultramafic cumulates including olivine clinopyroxenite, wehrlite, olivine websterite, and dunite forming a transitional Moho with the overlying lower crustal section. The plutonic rocks are made of pyroxenite, gabbronorite, gabbro, amphibole gabbro, diorite, quartz diorite, and plagiogranite. A well-developed sheeted dike complex has mutually intrusive relations with the underlying isotropic gabbros and plagiogranites and fed the overlying pillow lavas. Dike compositions change from older basalt to basaltic andesite, andesite, dacite, quartz diorite, to late-stage andesitic and boninitic dikes as constrained by crosscutting relations. The ~1.1-km-thick extrusive sequence comprises basaltic and basaltic andesitic pillow lavas in the lower 700 m, an andesitic, dacitic and rhyodacitic massive sheet flows in the upper 400 m. Boninitic dikes and lavas occur as the youngest igneous products within the EMO (**Fig. 1b**). Cpx porphyroclast-bearing harzburgites occur in the lower parts of the upper mantle units, whereas harzburgites and dunites are more abundant in structurally higher parts of the peridotites. Dunite is commonly associated with chromitite layers (Morishita et al. 2010). Opxenite veins and dikes crosscut the peridotite foliations and the lithological boundaries between dunites (chromitite) and harzburgites, indicating its late-stage formation.

Major and trace element compositions of minerals in the Cpx-harzburgites indicate that they were formed as the residue of less-fluxed partial melting, and are similar to those in abyssal peridotites from mid-ocean ridges. Harzburgites have more depleted major element compositions than the Cpx-harzburgites. Light rare earth element (LREE)-enrichment in clinopyroxene coupled with hydrous silicate mineral inclusions in harzburgit spinels indicate these were produced as a result of enhanced partial melting of depleted peridotites due to infiltration of hydrous LREE-enriched fluids/melts. Refractory harzburgite, high-Cr# spinel-bearing dunite, and orthopyroxenite are genetically related to the late stage boninitic magmas in the crustal section of the EMO. In contrast, the Cpx-harzburgite is a residue related to mid-ocean ridge basalts (MORBs) or the "MORB-like" forearc basalt (FAB), as proposed by Reagan et al. (2010) from the IBM forearc system. Thus, we think that in the Jurassic Mirdita ophiolite we have an exceptionally well-preserved and exposed forearc oceanic lithosphere, which we can investigate through systematic mapping, sampling and drilling to put together a coherent story of the geochemical products of SI magmatism from its mantle geochemical reservoirs to the forearc-embryonic arc crust construction, and the effects of mantle metasomatism via melt and fluid flux and migration through the Tethyan mantle. We can accomplish these goals by systematic sampling of the crustal and upper mantle units of the EMO for whole-rock major oxide and trace-element analyses, electron microprobe and laser ICP-MS mineral analyses, and isotopic analyses (Rb/Sr, Sm/Nd, and Pb/Pb). We will better understand the crustal properties and geochemical features of magmas generated from melting of H_2O-rich mantle beneath a forearc setting in SSZ environments. The results of this investigation should provide new insights about forearc lithosphere evolution during SI (temporal constraints on changes in magmatic outputs), better characterization of boninite P-T-H_2O variations (links models to melts), and along-strike changes in the age, volume, and production rates of SI magmas. It is an excellent and accessible on-land site for 'groundtruthing' for studying forearc magmatic and tectonic evolution. This project also complements and brings synergy to the proposed activities by Stern et al. in their White Paper submitted for the GeoPRISMS Implementation Workshop (Stern et al., 2010).

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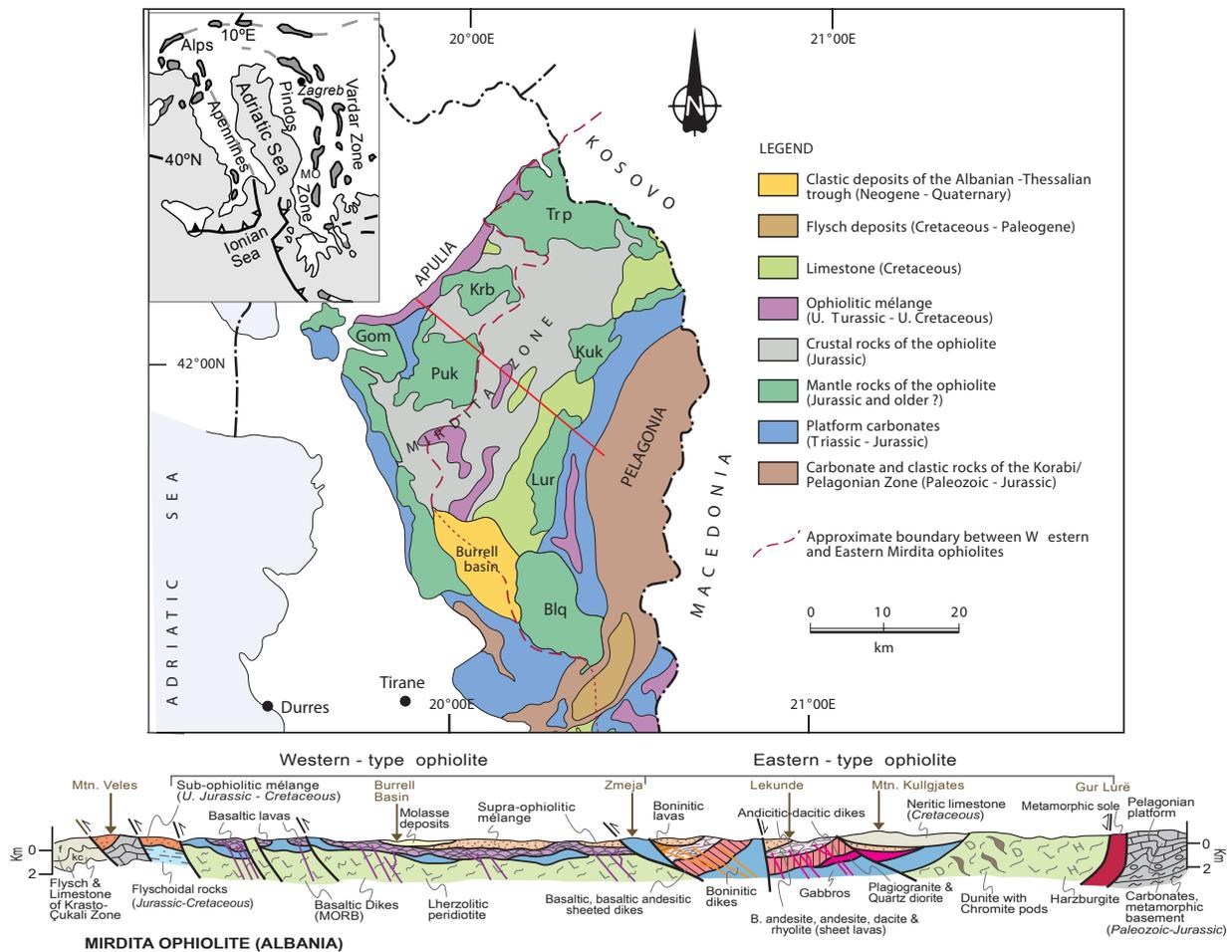
Figure-1: Simplified lithological map and a structural cross-section of the Jurassic Mirdita ophiolite in Albania (modified after Dilek et al. 2008; Dilek & Furnes 2009). The profile location is marked by the red-line on the map. Inset map shows the distribution of the Tethyan ophiolites in the Balkan Peninsula, with the Mirdita ophiolite labeled as MO.