News and Highlights

Probing the Troodos Ophiolite: IGCP-649 Workshop and Field Excursion Held in Agros-Cyprus

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The second IGCP-649 Workshop, held in Agros-Cyprus during 14-20 May 2016, brought together nearly fifty international scientists from around the world, and included a 5-day field excursion on the classic Troodos ophiolite. Organized by the IGCP-649 Project Leadership and the Geological Survey Department of Cyprus, the workshop provided a forum for discussions on the latest views and interpretations on the petrogenesis of crustal and upper mantle peridotites in ophiolites, and introduced many young researchers and students to the internal structure of the classical Troodos ophiolite. This was particularly the case for a large group of Chinese scholars and students, who visited Cyprus and the Troodos ophiolite for the first time. A 4-day profile across the complete ophiolite sequence gave these scientists a first-hand opportunity to examine the lithological and compositional variations within the Cretaceous oceanic crust and to study the igneous and tectonic contacts between them. Lively discussions by the experts and students in front of some of the best 3-dimensional outcrops were most fruitful and allowed all participants to compare the Troodos structure, geochemistry and tectonics with some of the other well-documented ophiolites elsewhere.

The workshop participants came from ten countries, including the USA, England, Russia, Czech Republic, Turkey, Morocco, Cuba, Egypt, Cyprus and China. There were 15 invited oral presentations and poster displays. The extended abstracts of the oral and poster presentations are collated for publication in a special issue of *Acta Geologica Sinica* later in 2106. Prof. Yildirim Dilek, Vice President of the IUGS (International Union of Geological Sciences) and Dr. Costas Constantinou, Director of the Geological Survey Department of Cyprus, delivered the welcome speeches for the opening of the workshop on the first day. Professor Jingsui Yang, the principal leader of the IGCP-649 project, gave an introduction to and a progress report for the project and its future activities. Professor Julian Pearce of Cardiff University (UK), a well-known ophiolite specialist in the world, ran the excursion on the Troodos ophiolite.

Cyprus is the third largest Mediterranean island with a surface area of 9251 sq. km. It lies in the NE corner of the Mediterranean Sea, located on the latitude 35° N and the longitude 33° E. The Troodos ophiolite occurs in the central part of Cyprus and is a well-developed and preserved, 92 million years old oceanic crust. The Troodos Massif has a unique combination of stratigraphic completeness and easy accessibility, and is hence one of the best-studied ophiolites in the world. It was created by seafloor spreading within the southernmost of Neotethys, and was emplaced in its present position through complicated tectonic processes associated with the collision of Eurasia to the north with Afro-Arabia to the south. Its stratigraphy formed the basis for the formal definition of a fully-formed ophiolite complex published by Penrose Conference Participants in the early 1970s. The various components of its stratigraphy are described below (Pearce, 2016).

The main part of the Troodos Ophiolite consists of the following stratigraphic units. From top to bottom (the order in which we saw on the excursion): hydrothermal and deep-water sedimentary units, a volcanic sequence, sheeted dykes, a plutonic sequence, and the upper mantle units (Fig.1). On the geological map of Troodos, this stratigraphy shows a topographic inversion, with the lower suites of rocks outcropping in the highest points of the range, while the stratigraphically uppermost crust rocks appear on the flanks of the ophiolite at lower elevations. This apparent inversion is related to the more recent uplift of the ophiolite and to its differential erosion. The diapiric rise of its serpentinized core took place mainly with episodes of abrupt uplift up to the Pleistocene (2 Ma).

The hydrothermal and deep-water sediments make up the Perapedhi Formation, which comprises brown umber (ferromanganoan sediment) and the often-pink radiolarites and radiolarian shales. These mainly result from

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hydrothermal activity and biogenic sedimentation respectively on the sea floor. They often form very small outcrops, but in places they are large enough to include on the map.

The volcanic sequence has been mapped as three series labelled from top to bottom: the Upper Pillow Lavas, the Lower Pillow Lavas and the Basal Group. Because of the domal structure, these dip away from the centre with the UPL furthest out. Although named after the best-known form of deepsea eruption, the pillow lava series do also contain other types of flows, notably the columnar jointed sheet-flows and the glassy and fragmentary hyaloclastites. At the base of the volcanic sequence, the lavas are intruded by progressively larger numbers of dykes. These dyke-lava transition zones have been mapped separately as the Basal Group. The volcanic sequence contains all members of the basalt-andesite-dacite-rhyolite (BADR) fractionation sequence, with basaltic andesites being the most abundant extrusive rock types.

The intrusive sequence occupies some 50% of the main ophiolite outcrop. It comprises the sheeted dyke complex in which dykes cut other dykes to produce a sequence made up of >90% dykes. This sequence is well-known for its pivotal role in the early stages of plate tectonic research, providing the evidence that oceanic lithosphere in general, and the Troodos Massif in particular, formed by sea-floor spreading. Many of the sheeted dykes were the feeders from the underlying magma chamber to the overlying volcanic sequence, though a significant proportion of the dykes may not have reached the seafloor.

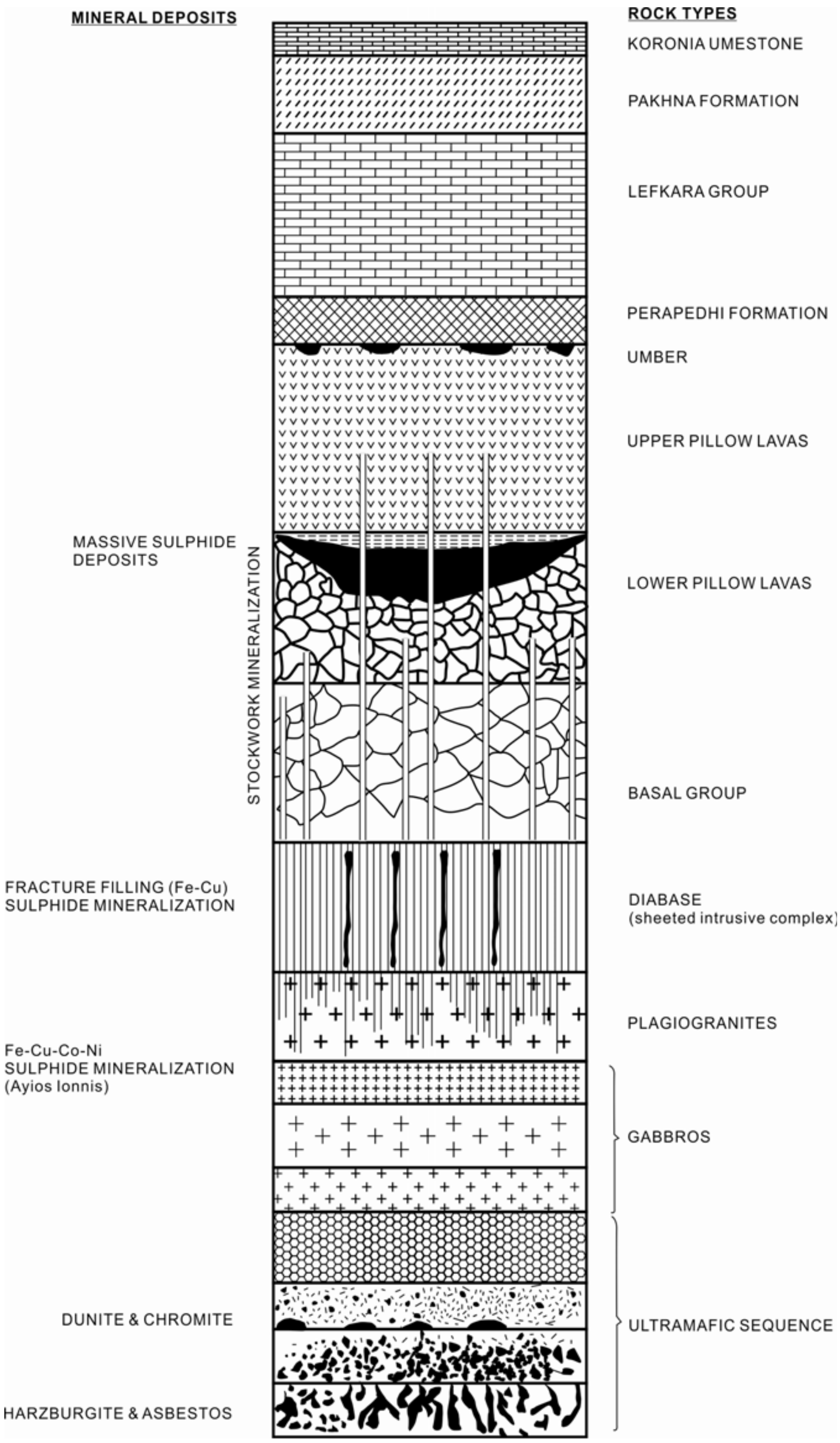

Fig. 1. Generalized lithological column of the Troodos ophiolite (after Constantinou 1980).

The plutonic sequence comprises a wide range of intrusive rocks, and is subdivided into several units. At the top is the plagiogranite unit mostly comprising quartz-bearing intrusive rocks from quartz diorites to plagiogranites. These rocks form discontinuous outcrops around the margin of the plutonic sequence, and are underlain by gabbros, both non-layered (isotropic) and layered. Gabbros make up most of the plutonic sequence. Small masses of ultramafic cumulates classified according to their relative proportions of olivine, clinopyroxene and

Fig. 2. Prof. Julian Pearce of Cardiff University, UK, introducing the Troodos ophiolite.

Fig. 3. World famous Troodos ophiolite has become a geological park and textbook.

Fig. 4. A vertical dike acted as magma channel cutting the horizontal sheeted flows with joint column and pillow lavas.

orthopyroxene (e.g. websterites, wehrlites and dunites) constitute small, locally mappable units at the base of the plutonic sequence.

Early models for the formation of the plutonic sequence had all these units forming within a single, c. 4-km thick magma chamber that extended from the sheeted dykes above to the upper mantle units below. However, there is

Fig. 5. Ultramafic pillow lava, which is very rare seen in ophiolite and on modern sea floor.

now definitive evidence from thermal modeling, geochemistry and oceanic seismic studies that any magma chamber must have been thin, and that the rock sequence originated from a complex process of magma ponding and migration within a crystal melt 'mush' and from the crystallization and reactions that resulted from this melt lens. Discussions in the field made it clear that the precise process of lower crustal accretion is inherently highly complex, and that it involves a series of distinctive magmatic events.

The mantle sequence is so termed because the rocks that form this suite are considered to be the residues after the partial melting of the upper mantle and the formation of the basic magma from which the remaining rocks of the ophiolite have been derived. It is typically highly tectonized with strong foliations and lineations resulting from deformation during and following accretion to the lithosphere while still at high temperatures. The upper mantle peridotites make up the highest mountain (Mount Olympos) of the Troodos Massif and, because of doming and erosion, occupies the center of the outcrop (the 'bullseye'). The main part of the mantle sequence is composed of harzburgite and dunite with 50-80% of the original minerals altered to serpentine. These rocks are mapped with a blue-green (teal) color and outcrop mainly on the west, north and south sides of the mantle sequence. To the east, and in the center, is a sub-circular body in which the original mantle rock has been pervasively altered to serpentinite.

Geological and geochemical studies have shown that the Troodos ophiolite underwent seafloor spreading and related multiple magmatic events. The tectonic setting of the formation of the Troodos Massif was the subject of intense debate during the 1970s. Originally, it was believed to have formed at a mid-ocean ridge spreading centre similar to the Mid-Atlantic Ridge. However, the proposal by Miyashiro (1973) suggesting that it formed in an island arc environment prompted more detailed investigations during the next two decades. The current and widely accepted models argue that the Troodos ophiolite formed at a spreading axis above a subduction zone, i.e. that it is Supra-subduction Zone (SSZ) ophiolite. More recent studies linked the spreading event to a period of slab rollback, following the initiation of subduction of the African Plate beneath the Eurasian Plate. This mechanism was the subject of a detailed study by Dilek & Flower (2003).

IGCP-649 Project is a global research project, which mainly aims to study the distribution and nature of peridotites, associated with chromitites and related mineral phases, such as diamond and other ultra-high pressure minerals, in different orogenic ophiolites around the world. This project is led by an international team of researchers, including Prof. Yang Jingsui of Institute of Geology of CAGS (China), Prof. Yildirim Dilek of Miami University (USA), Prof. William L Griffin of Macquarie University (Australia), Prof. Paul T. Robinson of Dalhousie University (Canada), Prof. Ibrahim Milushi of Polytechnic University of Tirana (Albania), and Prof. Mohamed Metwaly Abu Anbar of Tanta University (Egypt). IGCP-649 probes into the formation of ultra-high pressure minerals in oceanic lithospheric mantle and the evolution of mantle as well as the dynamic processes of ophiolite emplacement. The project was approved by UNESCO and IUGS in 2015 for a period of 5 years (2015-2020) (Yang et al., 2015). The first IGCP-649 Workshop was successfully held in Xining, Qinghai Province, China, in August, 2015. A field trip on an early Paleozoic ophiolite and high-pressure metamorphic zone was carried out after the Xining conference. More than 100 people from 10 countries participated in the Xining workshop and its field trip. The project plans to hold the third IGCP-649 Workshop in Cuba in April 2017, in order to investigate the Cuban ophiolites and the related chromitite deposits along a complex suture between the South America and North America plates.

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