High- and ultrahigh-pressure metamorphism: Past results and future prospects

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ABSTRACT

Fifty years ago, geologic conditions attending the formation of blueschists, eclogites, and garnet lherzolites were not known. But, with the advent of high-pressure phase-synthesis equipment and precise calorimetry, minerals like jadeite, aragonite, pyrope, and the dense polymorphs of SiO$_2$ and C were shown to be stable at elevated pressures and relatively low temperatures. Metamorphic conditions required by $P$-$T$ stabilities of these minerals reflect the operation of plate tectonics, lithospheric subduction, and inferred mantle convection. Integration of phase equilibria with dynamic tectonic processes has illuminated the petrogenesis of the crust. Combined with geochemical, geophysical, and isotopic data, high-pressure phase equilibria are also providing new constraints on the constitution and evolution of the mantle.

Circumpacific blueschists and eclogites occur in penetratively sheared nappes that are overturned seaward, indicating 30–50 km descent of an oceanic plate during metamorphism before partial exhumation of mainly low-density crustal material. Neoblastic coesite and microdiamond inclusions in tough, rigid host minerals show that continental collision involves fragmentary recovery of subducted rocks from depths of 100–130 km, far deeper than traditionally thought. Even more surprising, garnet peridottites from the central Alps, western Norway, Bohemia, and China display intergrowths and exsolution lamellae reflecting the former existence of majoritic garnet, stishovite, and other phases requiring depths of origin >300 km. Exsolved nanominerals attest to the decompression of precursor phases that had formed at profound depths preceding mantle upwelling. Times of deep-seated storage and rates of exhumation remain as major problems. Fluid-rock and lithosphere-asthenosphere interactions have recycled volatiles to the deep Earth through subduction of both hydrous and nominally anhydrous minerals. Mantle petrochemistry and plume-plate dynamics control the evolving architecture of the Earth’s crust and the interdependent biosphere. Applications of advanced technologies to condensed materials are leading to a fuller understanding of the planetary interior in time and space.

Keywords: Metamorphic petrology, high-pressure belts, phase equilibria, subduction-zone belts, high-pressure studies, convergent plate junctions, thermobarometry, ultrahigh-pressure rocks

INTRODUCTION

A technical session was held in Denver at the 2007 Geological Society of America national meeting to recognize and celebrate the accumulating scientific accomplishments of Gordon E. Brown Jr., recipient of the Mineralogical Society of America Roebling Medal for that year. Speakers were tasked by organizers Mike Hochella and Jerry Gibbs to provide a retrospective summary of the past 50 years and a prospective view for the next 50, and to offer “personal insights into how their fields of specialty, and the discoveries that come from them, will impact science, society, and/or the world of the future.” Our paper deals with high- and ultrahigh-pressure (HP and UHP, respectively) metamorphism, and is a product of that technical session. But chronicling past scientific developments is far easier than predicting future progress. Fifty years from now, mineralogists will probably agree with Yogi Berra, “The future ain’t what it used to be.”

Before proceeding to retrospective and prospective views, we need to be clear about use of the terms HP and UHP. Metamorphic petrologists conventionally regard HP conditions as the $P$-$T$ field in which lithostatic pressures exceed those defined by the aragonite–calcite polymorphic transition curve; thus, jadeite-rich clinopyroxene solid solution is stable in the HP field. Beyond the high-pressure realm, UHP conditions occupy the $P$-$T$ field at pressures greater than the coesite–quartz phase boundary; except at very low temperatures, this definition places diamond stability well within the ultrahigh-pressure field. A composite petrogenetic grid for some common crustal bulk-rock compositions is presented as Figure 1.

HP-UHP METAMORPHISM OF CRUSTAL ROCKS

Fifty years ago many workers regarded glaucophane schists (blueschists) as metasomatic products of typical Barrovian metamorphism, rather than examples of a relatively HP metamorphic facies (e.g., Turner and Verhoogen 1951, p. 473–474). However, bulk-rock chemical analyses demonstrated that most mafic blueschists have compositions indistinguishable from many unaltered basalts and metabasalts of the more common metamorphic facies (Ernst 1963). Documentation of neoblastic jadeitic clinopyroxene ± aragonite in associated quartzofeldspathic metasedimentary