Metamorphic rocks can form at shallow depths

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There is much experimental evidence demonstrating metamorphic rocks can form at various pressures and temperatures (figure 1). Metamorphic rocks commonly crop out at contacts near and with igneous rocks (contact metamorphism and migmatites, respectively) and over broad regions (regional metamorphism). Using standard laboratory measurements, the metamorphic grade of the minerals provides an estimate of the depth of formation.

The discovery of ultrahigh-pressure minerals

About 30 years ago, ultrahigh-pressure minerals (UHPm) were discovered.[1] They are usually inclusions in garnets, zircons, and other hard minerals believed to have formed at depths of over 100 km. UHPm include two rare high-pressure polymorphs of quartz, coesite (figure 2)and stishovite, and microdiamonds. They are found in isolated slices of presumed mantle rock and in more than 20 larger regions of the Earth called UHP terrains.[2] Scientists simply translate the metamorphic grade of UHPm to depth of burial.

It has been very challenging for scientists to explain why UHPm are found on the surface of the earth.[3] Most challenging is that nearly all of the UHPm are in what are believed to be continental rocks. This would require continental rocks to be forced downward to depths greater than 100 km, where it is believed high-pressure metamorphism takes place, and then 'rapidly' exhumed to the surface. Their idea of rapid, of course, means

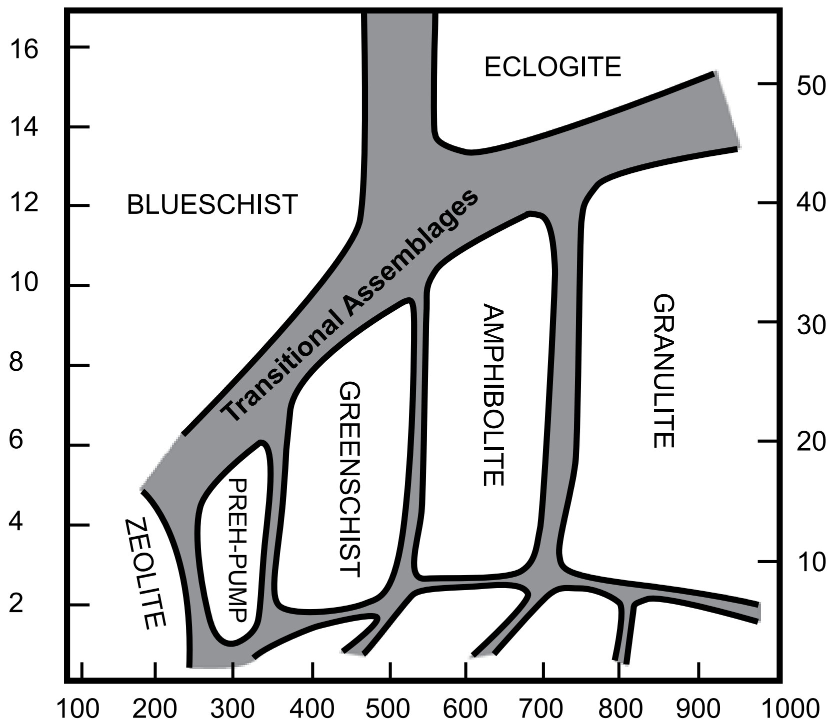

Figure 1. Temperature-pressure diagram for various metamorphic facies. The pressure is considered the lithostatic pressure caused by burial depth.

at subduction velocities of 5 to 10 cm/yr within secular geological time.

Scientists have suggested that UHPm form in continental crust due to 'continental collision', or when a sliver of crust is dragged downward in a subduction zone and then somehow returns rapidly to the surface before the UHPm can undergo retrograde metamorphism back to low-pressure mineral phases. However, continental crust is less dense than oceanic crust and also less dense than the mantle below. How could less dense rock be forced down into more dense rock? This is where subduction has come to the 'rescue'. At one time scientists firmly believed the continental crust was too light to subduct. Consequently, a paradigm shift resulted that now allows some continental crust to subduct. Many computer simulations have shown this process can occur *in theory*.[4] Despite the lack of empirical data, some scientists have now come to believe that their models demonstrate a physical reality.[5] Others see these model results as premature conclusions:

> "More-detailed and systematic field investigations are warranted to assess the predictions of numerical models, and more-sophisticated and realistic numerical models are required to replicate and explain the petrological, structural, and chronological data obtained from UHP terranes."[6]

Cracks in the paradigm change

Some scientists have suggested there are better possibilities than UHPm forming in subduction zones because they realized how difficult it would be for subduction zones to force continental rocks downward over broad areas of the Earth. Moulas *et al.* state: "However, there are well known cases where subduction has been excluded as a mechanism to explain the exhumation of such rocks …".[7] They continue:

> "We conclude, based on these considerations, that geodynamic scenarios involving very deep subduction processes with subsequent very rapid exhumation from a great depth must be viewed with due caution when one seeks to explain the presence of microscopic ultrahigh-pressure mineralogical indicators in rocks."[8]

However, there may be a somewhat easier solution. Experimental evidence shows coesite can form in high-stress environments at lower pressures.[9] Because metamorphism and deformation often occur together and the suggested depths of UHPm often seem too deep, Schmalholz, Podladchikov, and others suggested 'tectonic overpressure'.[10,11] Tectonic overpressure is added stress caused by tectonic movement or convergent forces within the rock. That would allow UHPm formation at depths less than half of those expected—less than 50 km deep as a possibility.[12]

Many scientists reject the idea of tectonic overpressure because they think the amount of tectonic pressure is too large to be realistic.[13] They also concluded stress in the earth is generally the same in all directions (isotropic).[14] Consequently, they do not include tectonic overpressure to their models. Isotropy can also be a poor assumption, since differential stress is rather common in Earth's crust and upper mantle due to tectonic forces and/or differences between fluid and rock pressures in porous rocks.[15]

Scientific implications

A number of implications follow from the discovery that coesite can form at lower pressures in high-stress environments. First, if tectonic overpressure is a possibility, deductions that were based on the metamorphic grade and depth of burial may need to be re-evaluated:

"If this is true, then Wheeler's result has considerable consequences for geological applications, because it is commonly assumed that the metamorphic reactions are controlled by the lithostatic pressure (the weight of the overlying rock) which can be directly related to depth. … If minerals might not be reliable indicators of maximum burial, then one might fear that metamorphic petrology could lose one of its main applications. However, if tectonic pressure and differential stress could indeed considerably influence metamorphic reactions, then this could also create new applications."[11]

Second, the discovery of low-pressure coesite demonstrates that we still do not understand many aspects of geology and geophysics, and what we thought we knew, may not be correct.

Third, this example shows that when a new variable is added to a concept, it can change the results as well as the applications.[16] We should therefore be aware that uniformitarian interpretations of the past based on rocks, fossils, and geophysics are tentative.

Fourth, we need to be skeptical of models claiming to demonstrate a past event. Models are marginally useful for many reasons and are only as good as their input parameters and assumptions.[17] Often there is a lack of knowledge about the variables and their interactions, which are often non-linear. Furthermore, even if all of the information about all of the variables were known, the lack of complexity of the software would still be a major limiting factor. Because of these difficulties, many variables are estimated. This increases the likelihood of error. The many models used to explain UHPm mask the underlying uncertainties.

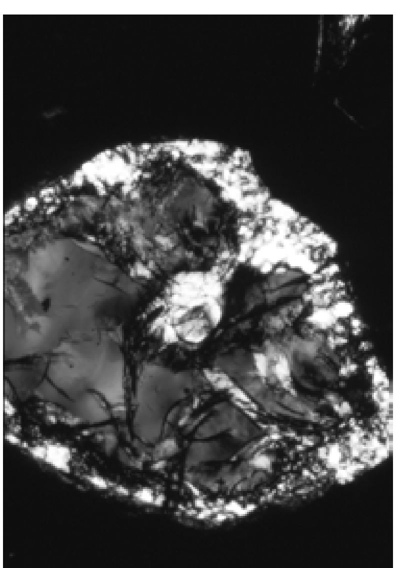

Figure 2. Coesite grain, 1 mm across, with a small inclusion of pyroxene in the center, surrounded by eclogite.

Creationist implications

Tectonic overpressure is couched in a uniformitarian context of non-catastrophic tectonic forces. The catastrophic Flood models have the potential to develop much greater tectonic overpressure because they are not limited to slow uniformitarian rates that are observed today. In the CPT model, plate movements of metres per second have the capability to create greater tectonic pressure at shallow depths and provide a better explanation of zones of UHPm. Meteorite impacts, powerful volcanism, catastrophic plate tectonics, and rapid differential vertical tectonics would add more stress to the earth than uniformitarian science assumes. As a result we are in a better position to explain how UHPm formed, possibly at depths shallower than 50 km. Meteorite impacts are well known to produce coesite, shistovite, and microdiamonds.[18] Further investigation will improve our understanding of UHPm and our Flood models. It is important to remember that Flood models are still in their infancy and are also limited by software capability and unknown variables.

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