Petrotectonic indicators for distinctive modern-style subduction zone

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Understanding how and when plate tectonics began on Earth and what came before is paramount for understanding the evolution of the solid Earth as well as its climate and biology. These questions are unresolved, with estimated beginnings that range from >4 Gya to <1 Gya. We were thus very interested to read a recent paper by Palin & White (2016) [Nature Geosciences] who argued that blueschist –metamorphic rocks formed during subduction– did not form on Earth until about 0.8 Gya because oceanic basalts were too Mg-rich prior to that time. We agree with their foundation assessment that the oldest blueschists are of Neoproterozoic age. We further agree: 1) presence of blueschists (or glaucophane-bearing rocks) indicate formation by modern-style subduction-driven plate tectonics; 2) importance of understand why these are missing from the first ~3.8 Gyr of Earth history; 3) absence is not a preservation artifact; and 4) that the thermal structure of subduction zones has not changed greatly since plate tectonics began. We question their conclusion that a change in oceanic crust composition was primarily responsible. Our refutation is based on the global inventory of other subduction-related indicators unlikely to be controlled by oceanic crust compositions. These include coesite- or diamond-bearing regional ultrahigh-pressure (UHP) metamorphic rocks, lawsonite-bearing rocks, jadeitites, and specific HP mineral (or mineral assemblage) in aluminous metasediments and metachert/quartzite, such as carpholite all of which first appear in the geologic record about the same time that blueschists occur. UHPs require subduction of continental crust to depths of at least 100 km and return to the surface. The initiation of UHP metamorphism near the Precambrian-Cambrian boundary could attest to an abrupt change in the subduction zone geothermal gradient due to large amounts of heat loss from the Earth's interior (Maruyama & Liou 1998), but like the slightly earlier appearance of blueschists could indicate the beginning of subduction and plate tectonics in Neoproterozoic time. Lawsonite formation requires high-P/T metamorphic conditions, typically blueschist and low-T eclogite facies; lawsonite can also be found in very-low-grade pumpellyite–actinolite facies metabasalts but not in the prehnite–pumpellyite facies metamorphic rocks that dominate Archean greenstone belts. The oldest lawsonite-bearing rocks are latest Neoproterozoic in age, implying that sufficiently cold subduction-zone thermal structures for lawsonite formation had to wait until Late Neoproterozoic time to exist (Tsujimori & Ernst 2014); lawsonite is stable even in a MgO-rich basaltic composition. Jadeitite formation requires the direct hydrous fluid precipitation or the interaction of such fluid and subduction zone metamorphic rocks at a high-P/T condition within forearc mantle wedge. There are no know occurrences of the historically important and economically valuable rock jadeitite for the first ~4 Gyr of Earth history (Harlow et al. 2015), which is easily explained if subduction did not begin until Neoproterozoic time. The oldest aluminous metasediments and metachert/quartzite are Archean in age. However, the oldest Fe–Mg carpholite and/or talc+phengite, as indicative of blueschist-facies condition, in those rocks are Late Paleozoic in age. In addition to the aforementioned metamorphic assemblages, we also point out the ophiolite record; ophiolites are indirect indicators of subduction because many of these form during the formation of new subduction zones; the rest are backarc basins and normal oceanic crust (Stern et al. 2012). Although a few ophiolites are ~1.9 Gya, nearly all ophiolites are Neoproterozoic or younger. Taken together, the absence of blueschists and the other subduction indicators compels the conclusion that subduction –and modern-style plate tectonics– did not occur until Neoproterozoic time.

