How do supercontinents form?

J. Brendan Murphy[1] and R. Damian Nance[2]
1. Department of Earth Sciences, St. Francis Xavier University, Antigonish, NS, B2G 1CO ❡ 2. Department of Geological Sciences, Ohio University, Athens, Ohio, 45701, USA.

Repeated amalgamation and dispersal of supercontinents have profoundly affected Earth's evolution since the Archean. The formation of Pangea in the Late Paleozoic and Gondwana in the late Neoproterozoic are cornerstones in our understanding of tectonics. Although their configurations are controversial, there is general acceptance of the existence of older supercontinents, Rodinia from about 1.0 to 0.75 Ga, and Columbia from 2.0–1.75 Ga. Each period of supercontinent assembly is succeeded by fragmentation and creation of oceanic lithosphere between the dispersing continental fragments, followed by subduction and re-assembly of the next supercontinent. However, we do not understand the geodynamic forces that drive these global-scale events.

When supercontinents rift, fragment and disperse, there are two contrasting types of ocean lithosphere, (i) an exterior ocean which surrounded the supercontinent with oceanic lithosphere that is older than the rifting event, and (ii) interior oceans formed between the dispersing blocks, with oceanic lithosphere that is younger than the rifting event. Although subduction of oceanic lithosphere during continental convergence generally destroys much of the primary evidence that would identify the vestiges of these contrasting oceans, remnants are preserved in ophiolite complexes and terranes accreted to the continental margins prior to terminal collision. As some of these terranes are generated by the subduction process itself, their crust-formation ages, rather than crystallization ages, are the key to distinguishing between remnants of interior and exterior oceans. This information can be derived from Sm-Nd isotope systematics.

Using Pangea and Gondwana as examples, we propose that Sm-Nd isotopic systematics can distinguish between two end-member models of supercontinent amalgamation. The first model is the classical Wilson cycle, in which terminal collision is produced by the destruction of the oceanic lithosphere that was generated since the separation of the previous supercontinent. These supercontinents turns "inside in" or "introvert". An example is the Appalachian-Caledonian-Variscan orogen of eastern North America and Europe in which the rifting events that opened the Iapetus and Rheic oceans gave way to subduction, terrane accretion and continent collision associated with the amalgamation of Pangea. Such an origin is indicated by Sm-Nd crustal formation ages of accreted mafic complexes that are younger than the onset of Iapetan rifting.

The second model, in which the supercontinent is driven towards areas of mantle downwelling, the supercontinent is turned "outside in" or "extroverts", that is, the exterior continental margins of the supercontinent at the dispersal stage become the interior orogenic belts of the next supercontinent. Since the oceanic lithosphere consumed is from the exterior ocean, its lithosphere pre-dates the breakup of the previous supercontinent so that Sm-Nd crustal formation ages of mafic complexes generated in that ocean are older than the age of rifting. These complexes are preserved as terranes in collisional belts. For example, crustal formation ages of mafic complexes accreted during the amalgamation of Gondwana are older than 750 Ma, i.e. their proto-crust pre-dates the breakup of Rodinia and therefore must have been part of the exterior ocean.

The data indicate that Pangea and Gondwana formed in different geodynamic regimes, suggesting that traditional views of a "supercontinent cycle" may well be flawed.