Oman ophiolite suggests subduction started with a shove

Plate tectonics is a fundamental control on how Earth operates and is important for the planet's habitability, but how this crustal recycling process got started has long been a mystery. A new study examining some uniquely coupled metamorphic and volcanic rocks in Oman is adding some needed clarity about the initiation of subduction zones, a critical component in plate tectonics.

"The driving force of plate tectonics is the lithosphere sinking into subduction zones and pulling other plates at the surface. The million-dollar question is: If subduction zones are what powers plate tectonics, how do you start a subduction zone?" says Robert Stern, a geophysicist at the University of Texas at Dallas.

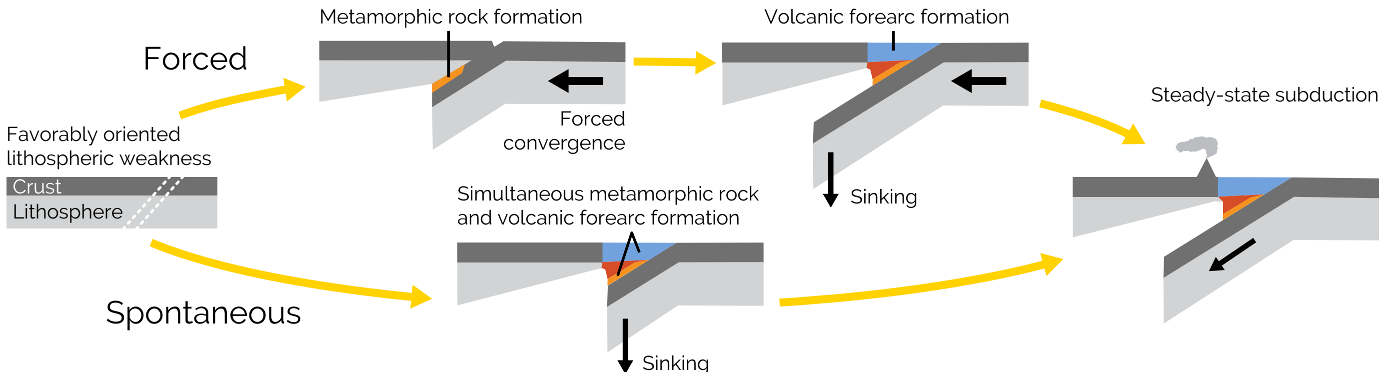
Subduction zone initiation is thought to occur by one of two mechanisms: spontaneous or forced. In spontaneous subduction, weaknesses and density contrasts in a plate encourage the denser part of the plate to start sinking under the force of gravity. As the downgoing slab sinks, cold rock and sediments formerly on the seafloor are metamorphosed when they encounter hot mantle. At the same time, extensional forces pull on the leading edge of the upper plate, triggering volcanism that creates an area of new crust above the subduction zone called a forearc. "When dated, these metamorphic and volcanic materials will be synchronous," says Carl Guilmette, a geological engineer at Laval University in Quebec and lead author of the new study in Nature Geoscience.

By contrast, in forced subduction, lateral movement of part of the lithosphere leads to compression, eventually forcing a dense slab downward under an adjacent plate. This convergence takes time to develop, however, such that new metamorphic rock in the downgoing plate will form a few million years before extension and forearc volcanism in the upper plate begins, creating a lag between the ages of the metamorphic and volcanic rocks.

Computer models suggest that Earth's first subduction zone may have been triggered by spontaneous subduction. "It makes sense that, at some point, a denser zone [of lithosphere] developed in one place that [then] started sinking under its own weight," Guilmette says. But no clear examples of the early phases of subduction exist on Earth today — although evolving transform boundaries south of New Zealand and west of Gibraltar may offer some tantalizing clues — so geoscientists look for evidence in the rock record of how slabs might begin sinking. Guilmette and his colleagues focused on the Semail Ophiolite of Oman in the southeast corner of the Arabian Peninsula. Here, pieces of both the overlying and underlying plates of a fossil subduction zone are exposed at the surface, enabling scientists to study how the system evolved.

"In Oman, we have the ultimate archetype of a subduction zone that has been very well studied and documented," Guilmette says. He and his colleagues are the first to date the burial of the lower plate in a fossilized subduction zone, and the results offer some clues about the timing of the events surrounding subduction initiation. They found that the metamorphic rocks in the downgoing slab started subducting 104 million years ago, whereas previous studies determined that the volcanic rocks in the upper slab dated to 96 million years ago.

"The new contribution by this study is this clear understanding of the magnitude of this lag time," Stern says. "The geochronology seems robust, with the lower metamorphism clearly predating the upper igneous activity." A study published last April in Geoscience Frontiers reported similar geochronological evidence of forced subduction initiation in Turkey, in an area that would have been geographically connected to the subduction zone forming in Oman. "It looks like



Past research has suggested two mechanisms by which subduction zones may form along an area of lithospheric weakness: spontaneous sinking of denser crust and lithosphere, and forced convergence driven by lateral movement of a plate. A new study suggests that the latter was responsible for the formation of a fossil subduction zone off the Arabian Peninsula beginning about 104 million years ago.

Credit: K. Cantner, AGI

a 3,000-kilometer-long convergent plate margin was forming about this time that stretched along the southwest margin of Eurasia from Oman to the island of Cyprus," Stern says.

Fossil subduction zones that preserve materials from both the upper and lower plates have also been identified in Newfoundland, California and the Himalayas. "I'd like to see more studies using this methodology to determine the absolute timing of subduction initiation settings around the Mediterranean and elsewhere," Stern says.

Mary Caperton Morton

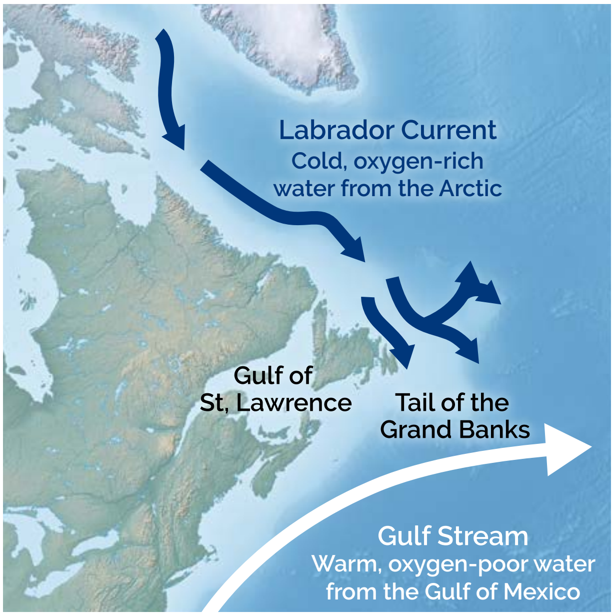
Ocean circulation change suffocating Gulf of St. Lawrence

Estuaries are among the most nutrient-rich and biologically productive areas of the ocean, and the Gulf of St. Lawrence, where freshwater from the Great Lakes and the St. Lawrence River meets the salty Atlantic Ocean in eastern Canada, is the largest estuary in the world. But the biodiversity and long-thriving fisheries of the Gulf of St. Lawrence could be threatened by declines in oxygen levels over the last half century. A new study suggests that a large-scale shift in Atlantic Ocean circulation is dumping warmer, oxygen-poor water into the gulf.

To protect the gulf, Canada's Department of Fisheries and Oceans (DFO) has been monitoring its health since the 1930s. "It's quite rare in oceanography to have such long records," says Mariona Claret, an oceanographer at the University of Washington, who led a new study of the gulf, published in Nature Climate Change. "We combined these records with centennial-scale time series of temperature and salinity collected at the Tail [southern extremity] of the Grand Banks of Newfoundland, where the Labrador Current and the Gulf Stream meet, which is one of the best-sampled areas in the entire ocean."

In 2005, a study published in the journal Limnology and Oceanography and led by DFO's Denis Gilbert, also a co-author of the new study, found a 72-year record of declining oxygen levels in the Gulf of St. Lawrence. "This deoxygenation trend was very alarming, but we didn't know what was driving it," Claret says. "Was it due to a local change in the gulf itself or a more remote change in the open ocean?"

In the new study, Claret, who was at McGill University in Montreal at the time of the work, and her colleagues combined the long-term datasets with a high-resolution Geophysical Fluid Dynamics Laboratory (GFDL) climate model developed by NOAA. This climate model simulates large-scale global ocean circulation as well as the coastal circulation that influences the Gulf of St. Lawrence. The researchers found that the gulf's declining oxygen is due in part to a northward shift of the Gulf Stream over the last century.



Research suggests that the Gulf Stream is shifting to the north, such that it's impinging on the flow of the Labrador Current near the Tail of the Grand Banks and reducing the supply of well-oxygenated water to the Gulf of St. Lawrence. Credit: K. Cantner, AGI

The Gulf Stream originates in the Gulf of Mexico, bringing warm, oxygen-poor water from the south up the Eastern Seaboard to the North Atlantic. Meanwhile the Labrador Current flows down from the Arctic Ocean, delivering cold, oxygen-rich water to the Gulf of St. Lawrence. The GFDL climate model showed that warming has triggered a shift in ocean dynamics such that the Gulf Stream is impinging on the Tail of the Grand Banks, reducing the supply of well-oxygenated Labrador Current waters to the Gulf of St. Lawrence. Moreover, based on the model, the researchers traced this shift in large-scale currents to the slowdown of the Atlantic Meridional Overturning Circulation, which is the Atlantic branch of the global thermohaline ocean circulation. Linking these global and local systems with the model is an important step forward, Claret says.

Since 1960, oxygen levels in the global ocean have dropped about 2 percent, while oxygen in the deeper parts of the interior of the Gulf of St. Lawrence have declined by as much as 50 percent. "This trend of declining oxygen in the world's oceans has the potential to affect biodiversity, fisheries and the cycling of nutrients and other elements that are important to the way the oceans function," says Denise Breitburg, a marine and estuary ecologist at the Smithsonian Environmental Research Center in Edgewater, Md., who was not involved in the new study. "As the American Lung Association's catchphrase used to say, 'If you can't breathe, nothing else matters.'" Breitburg says she'd "like to see modeling approaches like the one used in this study applied in more places. That will help us piece together the changes we're seeing, and can expect to see in the future, in the ocean as a whole."

Mary Caperton Morton