A forward geodynamic modelling approach to understand the history of subduction along the east Asian margin

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ABSTRACT

Plate reconstructions and island arc geochemistry in the northwest Pacific predict the intersection of a mid-ocean ridge with the east Asian subduction zone sometime from the Cretaceous to the Eocene. However, the absence of large swaths of ocean floor of the Pacific and now-subducted Izanagi plate, as well as a fragmented geochemical, volcanic and heat-flow dataset from east Asia, results in alternative models for when and where the mid-ocean ridge arrived at the subduction zone. Two competing models exist: sub-parallel intersection of the Izanagi-Pacific ridge between 60-50 Ma or trench-perpendicular intersection between 110-80 Ma. We use updated plate reconstructions of Panthalassa (proto-Pacific ocean) since the Mesozoic and a reanalysis of geological data from east Asia, coupled with a new generation of forward mantle flow models using the 3D finite element code, CitcomS, to differentiate between competing models. Our geodynamic models, which assimilate plate kinematics, the thermal structure of the oceanic lithosphere and the shallow portion of slabs (at one million year increments) predict the opening of a margin-wide slab window and slab detachment associated with the intersection of the Pacific-Izanagi ridge at the east Asia margin at 55-50 Ma. Our modelled present-day temperature field reveals a good first-order match seismic tomography (Figure 1), which is used as a proxy for present day mantle structure. The sub-parallel ridge-trench intersection and resultant margin-wide slab detachment event may have caused a change in the absolute motion of the Pacific plate at the time of a major global plate reorganization.

Figure 1: Forward geodynamic model output showing present day mantle temperature field (top left) for a profile perpendicular to the margin along 50°N. Slab contours for three alternative geodynamic model output defining material colder than the ambient mantle overlain on GYPSUM P-wave (bottom left) and CGRAND S-wave (bottom right) seismic tomography models. The good correlation between slab contours and present day mantle structure suggests that slab detachment due to ridge-trench intersection likely occurred around 50-55 Ma.
ABOUT THE AUTHORS

Maria Seton is an Australian Postdoctoral Fellow at the University of Sydney. She completed her PhD on the mechanisms of back-arc basin formation at the University of Sydney in 2005. She has a keen interest in marine geophysics and geodynamics and global plate motions and in particular, the dynamics of subduction and back-arc basin formation. She chairs an Interridge working group on island arc and back-arc basins and is a member of the American Geophysical Union, European Geosciences Union and the Geological Society of Australia. She will be Chief Scientist on an upcoming Southern Surveyor cruise to the eastern Coral Sea.

Nicolas Flament received a B.Sc. degree in Earth Sciences from the Ecole Normale Supérieure de Lyon (ENS), France, in 2004 and a Masters degree in Earth Sciences ENS in 2006. His PhD thesis on the emergence of the continents in relation with the secular cooling of the solid Earth, with Prof. Nicolas Coltice and Assoc. Prof. Patrice Rey as advisors, was awarded in 2009 by both ENS and the University of Sydney, Australia (cotutelle agreement). He joined the School of Geosciences of the University of Sydney as Postdoctoral Fellow in 2010. His research is presently focused on the effects of mantle convection on the topography of the Earth and sea level.

Jo Whittaker is a postdoctoral fellow in the School of Geosciences investigating Indian Ocean plate reconstructions and continental breakup as part of the “Gondwanaland extension, breakup and continental margin evolution” via a Statoil funded research project. Jo’s research interests are in the field of plate tectonics, geophysics and geology specifically looking at the formation and evolution of continental margins and oceanic crust. She completed her PhD from the University of Sydney in 2008 on the tectonic consequences of mid-ocean ridge formation, evolution and subduction.

Dietmar Müller is Professor of Geophysics at the University of Sydney, Australia. He obtained his PhD in Earth Science from the Scripps Institution of Oceanography in 1993 and his undergraduate degree at the University of Kiel, Germany. After joining the University of Sydney in 1993, he established the University of Sydney Institute for Marine Science and the EarthByte e-research group (www.earthbyte.org), pursuing collaborative development of open-source software and community digital data sets. One of the fundamental aims of his research is geodata and model synthesis through space and time, assimilating the wealth of disparate geological and geophysical data into a four-dimensional Earth model. His achievements have been acknowledged by winning the year 2000 Fresh Science Prize, awarded by the British Council and ‘ScienceNow!’, followed by the Carey Medal in 2004 for his contributions to the understanding of global tectonics. In 2009 he was awarded a 5-year Australian Laureate Fellowship to build a Virtual Geological Observatory.

Dan Bower obtained his PhD in geophysics at the Seismological Laboratory, California Institute of Technology in 2012. He completed his undergraduate degree at the University of Durham and his masters from University of Cambridge. His primary research focus is the development and application of numerical models to understand processes occurring in the Deep Earth. In addition he incorporates insights from high pressure-temperature mineral physics and observational constraints from seismology.

Michael Gurnis received a B.S. degree from the University of Arizona in 1982 and a Ph.D. from the Australian National University in 1987, both in geophysics. Following a postdoctoral research at Caltech, he was a faculty member at the University of Michigan. In 1994, he returned to Caltech where he is currently a John E. and Hazel E. Smits Professor of geophysics and Director of the seismological laboratory. His effort is divided between linking geodynamics and the rock record (especially stratigraphy), the basic physics of geophysical phenomena, studies of the deep interior of the Earth, and the development of new computational methods, including the GPlates package for plate tectonic modeling.