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Origin and time evolution of subduction polarity reversal from plate kinematics of Southeast Asia

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Materials and Methods:

In this study we propose a regional-scale tectonic reconstruction that fits into the global geodynamic frame, including all known plates. We reconstruct the movements of plates through time, instead of showing selected snapshots. To achieve this goal we use GPlates (www.gplates.org). This software allows both computation and real-time visualization of global plate-tectonic reconstructions (Boyden et al. 2011, Gurnis et al., 2012). GPlates is based on data from spreading activity. It allows to create rotations, and create a mid ocean ridge that moves with a half stage rotation. It is not possible to impose or measure stable mid-ocean ridges. Moreover, currently GPlates does not include intraplate deformation. Consequently absolute plate velocities reconstructed based on opening of oceans may be prone to errors. However, with closed circuit plate reconstructions it is possible to trace subduction polarity reversals through time, which will yield insights on the underlying processes. Our reconstruction southeast Asia is based on the plate motion model by Seton et al. (2012), from which we adopt the absolute reference frame, the plate circuit (linking the relative motions of the tectonic plates), and the geomagnetic polarity timescale. We take into account recent improvements of the model for the (Proto) South China Sea (Zahirovic et a. 2014). In order to track the subduction zones polarity, we modify and adapt locally the geometry of the plate boundaries, which are used to define continuously (temporally and spatially) closed plate polygon (Gurnis et al. 2012). We start our reconstructions in the late Cretaceous, a time when oceanic crust of the now extinct Izanagi Plate (a conjugate to the Pacific Plate) was subducting westward underneath Eurasia, i.e. opposite to present day subduction direction in south of Taiwan. Evidence for westward subduction during that time is evident from rhyolite-basalt assemblages, diabase/lamprophyre dikes and mostly peraluminous granitoids exposed in the South China fold belt.

Several plate reconstructions focused on the Neogene plate kinematics in southeast Asia as well as on the Taiwan area (e.g. Hall, 2002; Malavieille et al., 2002; Sibuet and Hsu, 2004). Figure S1 shows a compilation of existing models. A key player in SE Asian tectonics may be the now extinct Proto South China Sea. Extinct oceans have been shown to play a crucial role in mountain building phases. For instance in the European Alps, existence of the Meliata Ocean, of which only very limited remnants have been suggested is key ingredient for understanding the present day mountain belt. It was only in the continuation of the Alps into the Dinarides, where remnants of this ocean and its associated orogenic events are exposed. Despite extensive research on the Alps since more than 250 years, this ocean and its importance was not discovered until recently (Schmid 2004). In our reconstructions we can show the importance of the Proto South China Sea on evolution of Taiwan (see movie of reconstructions).

Due to large scale extension the pre-collisional Eurasian passive margin in the Taiwan area is characterized by thick Paleo- to Mesozoic and mostly Cenozoic sediments, overlying a wide zone of transitional lithosphere, which is either thinned, volcanically intruded continental (Nissen et al., 1995), or volcanically thickened oceanic crust (Hsüehshan Range et al., 2004), and potentially includes continental fragments (Shyu et al., 2005), or continental margin promontories that reflect the inherited rift-transform configuration (Lee et al., 2015; Mirakian et al., 2013). Our reconstructions show the north-westward movement of the Luzon Arc starting as late as 6.5 Ma. At this time, rifting ceased and foreland strata witness initiation of collision (Lin et al., 2003). This coincides with fast rollback of the Ryukyu Trench (Yamaji, 2003).

When collision occurred for the first time remains a matter of debate, and arguments have been put forward for a comparably old (i.e. mid to late Miocene) to close to recent (i.e. mid to latest Pliocene) collision. For instance the transition between pre- and syn-collisional strata in the Taiwan Strait at ~6.5 Ma supports a Miocene collision (Lin et al., 2003). On the other hand, at 4 and 3 Ma the sedimentary suite of the passive margin sediments overlying oceanic crust is incorporated into the wedge, which is witnessed by massive deposition of sediments into the surrounding basins thereafter (Chen et al., 2001; Chi et al., 1981; Nagel et al., 2013), and consequently was interpreted as young onset of collision. Recent thermochronological evidence supports a predominantly young, late Pleistocene exhumation pulse, with first onset of cooling occurring in the late Miocene (Fox et al., 2014; Kirstein et al., 2010; Mesalles et al., 2014).

Figure S1: Compilation of different reconstructions suggested for southeast Asia. Reconstructions focused on evolution of the Philippine Sea Plate, South China Sea, Taiwan, or on the entire region. Regional models often cannot account for details within particular areas, whereas mor local studies often are not put in the global plate tectonic framework. Our model refines existing global models with a special focus on evolution of the Taiwan area. Figure based on Seno & Maruyama (1984), Letouzey & Kimura (1985), Kong et al. (2000), Deschamps & Lallemand (2002), Sdrolinas et al. (2004), for Okinawa Trough and Philippine Sea Plate; Mahoney et al. (2011), Barckhausen et al. (2014) and Yeh et al. (2010) for the South China Sea; Sibuet & Hsu (2004), Malavieille et al. 2002, and Teng and Lin (2004) for the Taiwan area; Hall et al. (2008), Richards et al. (2007), Replumaz & Tapponier (2003), Morley (2002), Hall (2002), Yin (2010), Hall (2012), Xu et al. (2014), and Zahirovic et al. (2014) for the Proto South China Sea and regional models.

References:

Barckhausen, U., Engels, M., Franke, D., Ladage, S., and Pubellier, M., 2014, Evolution of the South China Sea: Revised ages for breakup and seafloor spreading: Marine and Petroleum Geology, v. 58, Part B, no. 0, p. 599-611.

Boyden, J. A., R. D. Müller, M. Gurnis, T. H. Torsvik, J. Clark, M. Turner, H. Ivey-Law, R. J. Watson, and J. S. Cannon (2011), Next generation plate-tectonic reconstructions using GPlates, in Geoinformatics, Cyberinfrastructures for the Solid Earth Sciences, edited by G. R. Keller and C. Baru, Cambridge University Press, Cambridge.

Chemenda, A. I., R. K. Yang, C. H. Hsieh, and A. L. Groholsky (1997), Evolutionary model for the Taiwan collision based on physical modelling, Tectonophysics, 274(1–3), 253-274.

Clift, P. D., H. Schouten, and A. E. Draut (2003), A general model of arc-continent collision and subduction polarity reversal from Taiwan and the Irish Caledonides, Geological Society, London, Special Publications, 219(1), 81-98.

Deschamps, A., and Lallemand, S., 2002, The West Philippine Basin: An Eocene to early Oligocene back arc basin opened between two opposed subduction zones: Journal of Geophysical Research: Solid Earth (1978–2012), v. 107, no. B12, p. EPM 1-1-EPM 1-24.

Gurnis, M., M. Turner, S. Zahirovic, L. DiCaprio, S. Spasojevic, R. D. Müller, J. Boyden, M. Seton, V. C. Manea, and D. J. Bower (2012), Plate tectonic reconstructions with continuously closing plates, Computers & Geosciences, 38(1), 35-42.

Hall, R. (2002), Cenozoic geological and plate tectonic evolution of SE Asia and the SW Pacific: computer-based reconstructions, model and animations, Journal of Asian Earth Sciences, 20(4), 353-431.

Hall, R., 2012, Late Jurassic–Cenozoic reconstructions of the Indonesian region and the Indian Ocean: Tectonophysics, v. 570, p. 1-41.

Hall, R., van Hattum, M. W., and Spakman, W., 2008, Impact of India–Asia collision on SE Asia: the record in Borneo: Tectonophysics, v. 451, no. 1, p. 366-389.

Hsu, S.-K., Y.-c. Yeh, W.-B. Doo, and C.-H. Tsai (2004), New Bathymetry and Magnetic Lineations Identifications in the Northernmost South China Sea and their Tectonic Implications, Marine Geophysical Researches, 25(1-2), 29-44.

Kong, F., Lawver, L. A., and Lee, T.-Y., 2000, Evolution of the southern Taiwan–Sinzi folded zone and opening of the southern Okinawa trough: Journal of Asian Earth Sciences, v. 18, no. 3, p. 325-341.

Kuo-Chen, H., F. T. Wu, and S. W. Roecker (2012), Three-dimensional P velocity structures of the lithosphere beneath Taiwan from the analysis of TAIGER and related seismic data sets, Journal of Geophysical Research: Solid Earth, 117(B6), B06306.

Lee, Y.-H., T. Byrne, W.-H. Wang, W. Lo, R.-J. Rau, and H.-Y. Lu (2015), Simultaneous mountain building in the Taiwan orogenic belt, Geology, 43(5), 451-454.

Letouzey, J., and Kimura, M., 1985, Okinawa Trough genesis: structure and evolution of a backarc basin developed in a continent: Marine and Petroleum Geology, v. 2, no. 2, p. 111-130.

Lin, A. T., A. B. Watts, and S. P. Hesselbo (2003), Cenozoic stratigraphy and subsidence history of the South China Sea margin in the Taiwan region, Basin Res, 15(4), 453-478.

Magni, V., C. Faccenna, J. van Hunen, and F. Funiciello (2014), How collision triggers backarc extension: Insight into Mediterranean style of extension from 3-D numerical models, Geology, 42(6), 511-514.

Mahony, S., Wallace, L., Miyoshi, M., Villamor, P., Sparks, R., and Hasenaka, T., 2011, Volcano-tectonic interactions during rapid plate-boundary evolution in the Kyushu region, SW Japan: Geological Society of America Bulletin, v. 123, no. 11-12, p. 2201-2223.

Malavieille, J., S. E. Lallemand, S. Dominguez, and A. Deschamps (2002), Arc-Continent collision in Taiwan: New marine observations and tectonic evolution, Geological Society of America Special Paper, 358, 189-213.

Mirakian, D. C., J. M. Crespi, T. B. Byrne, C. Huang, W. B. Ouimet, and J. C. Lewis (2013), Tectonic implications of nonparallel topographic and structural curvature in the higher elevations of an active collision zone, Taiwan, Lithosphere, 5(1), 49-66.

Morley, C. K., 2002, A tectonic model for the Tertiary evolution of strike–slip faults and rift basins in SE Asia: Tectonophysics, v. 347, no. 4, p. 189-215.

Nissen, S. S., D. E. Hayes, P. Buhl, J. Diebold, Y. Bochu, W. Zeng, and Y. Chen (1995), Deep penetration seismic soundings across the northern margin of the South China Sea, Journal of Geophysical Research: Solid Earth, 100(B11), 22407-22433.

Replumaz, A., and Tapponnier, P., 2003, Reconstruction of the deformed collision zone between India and Asia by backward motion of lithospheric blocks: Journal of Geophysical Research: Solid Earth, v. 108, no. B6.

Richards, S., Lister, G., and Kennett, B., 2007, A slab in depth: Three-dimensional geometry and evolution of the Indo-Australian plate: Geochemistry, Geophysics, Geosystems, v. 8, no. 12.

Sdrolias, M., W. R. Roest, and R. D. Müller (2004), An expression of Philippine Sea plate rotation: the Parece Vela and Shikoku basins, Tectonophysics, 394(1), 69-86.

Seno, T., and Maruyama, S., 1984, Paleogeographic reconstruction and origin of the Philippine Sea: Tectonophysics, v. 102, no. 1, p. 53-84.

Seton, M., et al. (2012), Global continental and ocean basin reconstructions since 200 Ma, Earth-Sci Rev, 113(3–4), 212-270.

Shyu, J. B. H., K. Sieh, and Y.-G. Chen (2005), Tandem suturing and disarticulation of the Taiwan orogen revealed by its neotectonic elements, Earth Planet Sc Lett, 233(1–2), 167-177.

Sibuet, J.-C., and S.-K. Hsu (2004), How was Taiwan created?, Tectonophysics, 379(1–4), 159-181.

Suppe, J. (1984), Kinematics of arc-continent collision, flipping of subduction, and back-arc spreading near Taiwan, Mem. Geol. Soc. China, 6, 21-33.

Teng, L. S., C. T. Lee, Y.-B. Tsai, and L.-Y. Hsiao (2000), Slab breakoff as a mechanism for flipping of subduction polarity in Taiwan, Geology, 28(2), 155-158.

Teng, L. S., and Lin, A. T., 2004, Cenozoic tectonics of the China continental margin: Insights from Taiwan: Geological Society, London, Special Publications, v. 226, no. 1, p. 313-332.

Ustaszewski, K., Y.-M. Wu, J. Suppe, H.-H. Huang, C.-H. Chang, and S. Carena (2012), Crust–mantle boundaries in the Taiwan–Luzon arc-continent collision system determined from local earthquake tomography and 1D models: Implications for the mode of subduction polarity reversal, Tectonophysics, 578(0), 31-49.

Xu, J., Ben-Avraham, Z., Kelty, T., and Yu, H.-S., 2014, Origin of marginal basins of the NW Pacific and their plate tectonic reconstructions: Earth-Science Reviews, v. 130, no. 0, p. 154-196.

Yamaji, A. (2003), Slab rollback suggested by latest Miocene to Pliocene forearc stress and migration of volcanic front in southern Kyushu, northern Ryukyu Arc, Tectonophysics, 364, 9-24.

Yeh, Y. C., Sibuet, J. C., Hsu, S. K., and Liu, C. S., 2010, Tectonic evolution of the Northeastern South China Sea from seismic interpretation: Journal of Geophysical Research: Solid Earth, v. 115, no. B6.

Yin, A., 2010, Cenozoic tectonic evolution of Asia: A preliminary synthesis: Tectonophysics, v. 488, no. 1, p. 293-325.

Zahirovic, S., M. Seton, and R. D. Mueller (2014), The Cretaceous and Cenozoic tectonic evolution of Southeast Asia, Solid Earth Discussions, 5, 1335-1422.

Zhou, X. M., and Li, W. X., 2000, Origin of Late Mesozoic igneous rocks in Southeastern China: implications for lithosphere subduction and underplating of mafic magmas: Tectonophysics, v. 326, no. 3–4, p. 269-287.

Figure DR1


Plates
Pacific
Eurasia
Philippine
Australia
India
Luzon Arc
Carolina
Basin/Ocean
South China Sea
Proto South China Sea
Celebes sea
Molucca Sea
Coastline
Subduction zone
Spreading center
Normal fault
Transform
Seno and Maruyama1984
Letouzey and Kimura 1985
Kong et al., 2000
Deschamps and Lallemand 2002
Sdrolias et al., 2004
Mahony et al., 2011
Barckhausen et al., 2014
Yeh et al., 2010
Teng and Lin 2004
Pelletier and Stephan, 1986
Sibuet and Hsu 2004
Hall et al., 2008
Richards et al., 2007
Replumaz and Taponnier, 2003
Morley 2002
Hall 2002
Yin et al., 2010
Hall 2012
Xu et al., 2014
Seton et al., 2012
Zahirovic et al., 2014
THIS STUDY
Philippine sea plate
S. China Sea
Taiwan
SE Asia