# Two decades of progress in the understanding of the Indo-Burmese Arc plate circuit

The drifting of the Indian plate in the northward direction was initiated ~100 million years ago, until it collided with the Eurasian plate in the early Cenozoic period, i.e. 50–45 million years ago[1]. During this continental–continental collision, the eastern boundary of the Indian plate slid past against the western boundary of the Sunda land[2], leading to the formation of the complex Indo-Burmese Arc (IBA) as a consequence of oblique convergence. With subsequent collisions, the Burma Terrane became predominantly north–south trending due to clockwise rotation[1,3]. This significant clockwise rotation forced the subduction–collisional boundary to become a hyper-oblique plate boundary of the present day[3]. However, whether the subduction which occurred in the geologic past is still active in the IBA is a topic of debate.

IBA comprises the Indo-Burmese Wedge in the forearc and Sagaing Fault in the backarc. It joins the Eastern Himalayan Syntaxis in the north and the Andaman–Sumatra subduction zone in the south[4,5]. Several distinct fault systems have been mapped across the Indo-Burmese Wedge from west to east, which separate different litho units, namely the Blind Thrust Plate Interface (BTPI), Chittagong Coastal Fault, Kaladan Fault, Churachandpur–Mao Fault (CMF) and Kabaw Fault[4,5]. Various geologic[6,7], geodetic[8–11] and seismotectonic[12,13] investigations provide diverse opinions regarding the status of present-day subduction activity, long-term plate motion, its distribution amongst the mapped/inferred faults and associated earthquake hazard in this highly populated region, particularly near the western and updip edge of the arc. The status of the present-day active subduction across the IBA plate boundary region is still debated. Characterizing the long-term slip distribution between the Indian and Sunda plates, and the status and quantification of the present-day subduction along this complex plate boundary is of prime importance, since these issues have a direct impact on earthquake nucleation and associated seismic hazard along the densely populated regions of North East India, Bangladesh and Myanmar, i.e. the IBA region.

In the past few decades, the advancement of several space-based geodetic techniques (e.g. GNSS, VLBI, InSAR, DORIS and SLR) has allowed us to characterize lithospheric deformation, evidence of strain accumulation, decipher different deformation phases in an earthquake cycle, deformation caused by non-tectonic forcings, etc.[14,15]. Exploiting the high precision and ease of data access of the GNSS measurements, several researchers have invested their efforts in understanding the geodynamic complexity, lithospheric deformation, seismic hazard, and earthquake occurrence process across the IBA[8–11]. This complex plate boundary has not drawn much attention of geoscientists as other plate boundaries such as continental transform fault systems, e.g. the Alpine fault[16] and San Andreas fault[17], or subduction/collisional boundaries associated with the Himalayas[18], Alaska[19], and Japan[20]. However, in the past two decades, scientific knowledge of IBA plate-boundary region has progressed well in the field of tectonic geodesy. In this context, here we present a progressive evolution of our understanding of the plate-motion representation (or plate circuit) across IBA region in the past two decades.

By considering geological/geophysical datasets, collected from the offshore region of Burma during a marine survey (Andaman Cruise), Nielsen *et al.*[21] proposed a plate kinematic model to characterize the nature of slip distribution and strain partitioning in the western part of the IBA (Figure 1). Combining the above observations with geodetic measurements, they proposed that in the southern part of the Arc, half of the 35 mm/yr India–Sunda plate motion is accommodated at the Arakan trench itself (i.e. the frontal arc in the northern Andaman), and the other half is accommodated along the Sagaing Fault in Myanmar[21]. However, in the northern part of the Arc, where the Bangladesh fold-and-thrust system had developed, predominantly dextral strike–slip faults are active within the accretionary prism. In fact, this observation converged with the GNSS measurements reported by other researchers[22,23]. By analysing

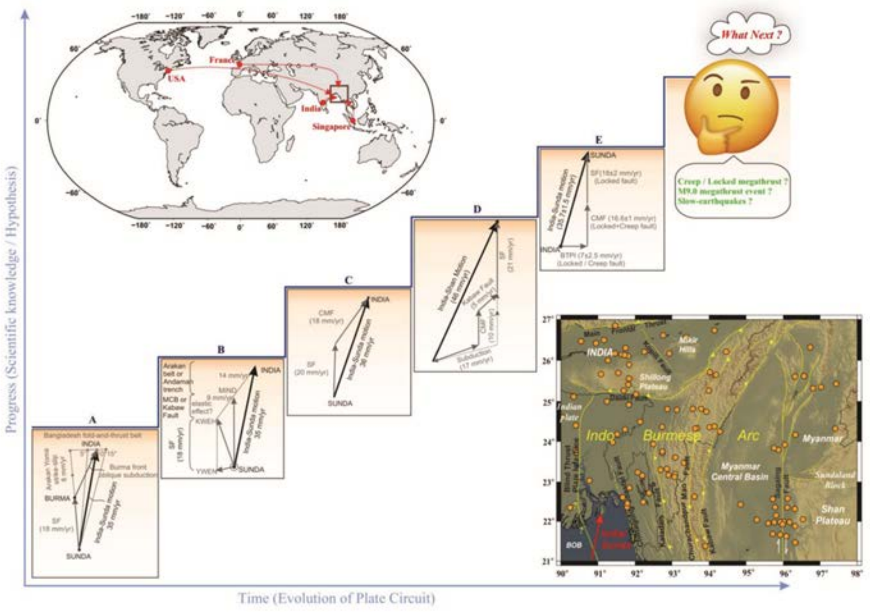


**Figure 1.** Progressive evolution of the India–Sunda relative plate motion and plate motion representation across IBA, proposed by several researchers in the last two decades by constraining geodetic observations (A, Nielsen *et al.*[21]; B, Socquet *et al.*[23]; C, Gahalaut *et al.*[8]; D, Steckler *et al.*[9]; E, Panda *et al.*[11]). Global footprints and scientific interest are presented in the top. The GNSS networks are marked by circles (in the bottom). BTPI is represented by a series of question marks. Major fault systems are indicated by thin lines with the respective dip directions. Bold arrow marks the India–Sunda long-term relative plate motion. Top (inset) shows spatial location of the region of interest and global scientific organizations associated with this region. CMF, Churachandpur-Mao Fault; KLF, Kaladan Fault; BTPI, Blind Thrust Plate Interface; CCF, Chittagong Coastal Fault; SF, Sagaing Fault; KBF, Kabaw Fault.

well-distributed geodetic data from the Indian and Sunda plates[22,23], and adopting a modelling approach in which rigid blocks are separated by faults, it has been proposed that the major portion of the India–Sunda relative plate motion is absorbed as an east–west compression along the IBA. This implies that the subduction along the IBA is still active, which may host an earthquake of *M* 8.5 (ref. 23) (Figure 1). Taking constraints from new GNSS measurements from Myanmar and India, Gahalaut *et al.*[8] suggested that the relative plate motion between India and Sunda (~36 mm/yr) is mainly taken up by the Sagaing Fault in the back-arc (18 ± 2 mm/yr) and dextral slip along CMF (~18 mm/yr). They suggested that the CMF could act as the plate boundary between the Indian and Burmese plates (Figure 2). Steckler *et al.*[9] considered new GNSS data from Bangladesh, in addition to the existing GNSS observations from India[8] and Myanmar[22], to assess the crustal deformation process and associated strain accumulation between the Indian Plate and Shan plateau. They reported that subduction along this plate boundary is still active at a significant rate of ~17 mm/yr. The large extent of the locked plate interface with thrust motion inferred from the GNSS measurements may produce a giant megathrust rupture of ~*M* 8.2–9.0 (ref. 9) (Figure 1). Complementing the above observations and implementing a block-modelling approach by considering new GNSS site velocities from the Myanmar–India–Bangladesh–Bhutan (MIBB) network, Mallick *et al.*[10] characterized the slip rates and geometry of the three major active fault systems across the IBA region. They also arrived at a similar conclusion as that of Steckler *et al.*[9]; however, their study did not characterize the long-term relative plate motion between the Indian and Sunda plates. A recent study reanalysed all available geodetic datasets from NE India, Bangladesh, Myanmar and the surrounding regions. It redefined the India–Sunda long-term plate motion as ~37–40 mm/yr, by separately estimating the Euler poles of the Indian and Sunda plates[11] (Figure 1). This study[11] concluded that the magnitude of convergence across the BTPI is significantly less than the previous estimates[9,10]. The large uncertainty in GNSS site velocities near the updip region of the blind thrust plate interface does not conclusively imply that the entire detachment is slipping in a stick–slip manner. In previous analysis, Steckler *et al.*[9] had overestimated the relative plate motion between the Indian and Sunda plates by incorporating GNSS sites from the Shan plateau region that are deformed by the toroidal flow around the eastern Himalayan syntaxis[22].

From this evolutionary journey of geodetic observations during the past two decades from the IBA region (Figure 1), we note diverse and contrasting opinions regarding plate motion representation, present-day subduction activity and a large-magnitude thrust earthquake threat to this densely populated region[8–11,21–23]. Although we have progressed significantly (Figure 1), the IBA still deserves more in-depth scientific study by deploying dense GNSS and seismometer networks spanning the entire plate boundary zone, irrespective of political boundaries. We are optimistic that advanced modelling efforts in this complex geodynamic unit will lead to a better seismic hazard assessment.


1. Hall, R., *J. Asian Earth Sci*., 2002, **20**(4), 353–431.
2. Bertrand, G. and Rangin, C., *J. Asian Earth Sci*., 2003, **21**(10), 1139–1157.
3. Westerweel, J. *et al.*, *Nature Geosci*., 2019, **12**(10), 863–868.
4. Kundu, B. and Gahalaut, V. K., *Tectonophysics*, 2012, **524**, 135–146.
5. Kundu, B. and Gahalaut, V. K., *Curr. Sci.*, 2013, **104**, 920–933.
6. Aung, T. T. *et al.*, *J. Earthq. Tsunami*, 2008, **2**(4), 259–265.
7. Betka, P. M., Seeber, L., Thomson, S. N., Steckler, M. S., Sincavage, R. and Zoramthara, C., *Earth Planet. Sci. Lett.*, 2018, **503**, 17–28.
8. Gahalaut, V. K. *et al.*, *Geology*, 2013, **41**(2), 235–238.
9. Steckler, M. S. *et al.*, *Nature Geosci*., 2016, **9**(8), 615–618.
10. Mallick, R., Lindsey, E. O., Feng, L., Hubbard, J., Banerjee, P. and Hill, E. M., *J. Geophys. Res*., 2019, **124**(3), 3155–3171.
11. Panda, D., Kundu, B., Gahalaut, V. K. and Rangin, C., *Tectonics*, 2020, **39**(8), e2019-TC006034.
12. Le Dain, A. Y., Tapponnier, P. and Molnar, P., *J. Geophys. Res.*, 1984, **89**(B1), 453–472.
13. Rao, N. P. and Kalpna, *Geophys. Res. Lett*., 2005, **32**(5), L05301.
14. Coulot, D., Berio, P., Biancale, R., Loyer, S., Soudarin, L. and Gontier, A. M., *J. Geophys. Res*., 2007, **112**(B5), B05410.
15. Burgmann, R., Thatcher, W. and Bickford, M. E., *Geol. Soc. Am. Spec. Pap*., 2013, **500**, 397–430.
16. Beavan, J. *et al.*, *N.Z. J. Geol. Geophys*., 2016, **59**(1), 5–14.
17. Lisowski, M., Savage, J. C. and Prescott, W. H., *J. Geophys. Res*., 1991, **96**(B5), 8369–8389.
18. Bilham, R., *Geol. Soc. Spec. Publ*., 2019, **483**(1), 423–482.
19. Freymueller, J. T. *et al.*, *Active Tectonics and Seismic Potential of Alaska*, 2008, **179**, 1–42.
20. Miyazaki, S. I. and Heki, K., *J. Geophys. Res*., 2001, **106**(B3), 4305–4326.
21. Nielsen, C., Chamot-Rooke, N. and Rangin, C., *Mar. Geol*., 2004, **209**(1–4), 303–327.
22. Vigny, C. *et al.*, *J. Geophys. Res*., 2003, **108**(B11), 2533.
23. Socquet, A., Vigny, C., Chamot-Rooke, N., Simons, W., Rangin, C. and Ambrosius, B., *J. Geophys. Res*., 2006, **111**(B5), B05406.



ACKNOWLEDGEMENTS. We thank the Saibal Gupta (Subject Editor) and two anonymous reviewers for their constructive comments that helped improve the manuscript. We also thank our colleagues for their contributions during fieldwork and research during the past two decades in the Indian part of IBA and the adjacent region. Michael S. Steckler, Leonardo Seeber, Christophe Vigny, A. Socquet, Claude Rangin, Judith Hubbard, Paramesh Banerjee, Eric O. Lindsey, R. Mallick and Emma M. Hill contributed in improving our understanding of this region. We thank Roland Bürgmann of UC Berkeley, USA for his valuable comments and discussions on the earlier version of this manuscript. Some figures have been generated using Generic Mapping Tools (version 5.2.1; URL: https://www.generic-mapping-tools.org/).

Received 6 January 2022; revised accepted 22 June 2022



BHASKAR KUNDU[1,*]
VINEET K. GAHALAUT[2]
DIBYASHAKTI PANDA[1]

[1]*Department of Earth and Atmospheric Sciences,*
*National Institute of Technology,*
*Rourkela 769 008, India*
[2]*CSIR-National Geophysical Research Institute,*
*Hyderabad 500 007, India*
**For correspondence.*
*e-mail: rilbhaskar@gmail.com*