Although providing a causal mechanism is beyond the scope of the present study, the occurrence of periods of enhanced monsoonal precipitation slightly after the termination of the Wolf, Sporer and Maunder minima periods (less sun activity) and concomitant temperature changes could be a matter of further intense research. A number of similar studies need to be carried out at geographically distinct localities supported by many ^{14}C dates to arrive at comprehensive conclusions and better understanding of the causal linkages between solar activities and climatic changes. Such relationship, if confirmed by further measurements, may also assist in modelling studies of the Little Ice Age climate changes.

1. Schone, B. R. *et al.*, Climate records from a bivalved Methuselah (*Arctica islandica*, Mollusca; Iceland). *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 2005, **228**, 130–148.
2. Williams, D. F., Be', A. W. H. and Fairbanks, R. G., Seasonal oxygen isotope variations in living planktonic foraminifera in the northwestern Sargasso Sea off Bermuda. *Science*, 1979, **206**, 447–449.
3. Fairbanks, R. G. and Wiebe, P. H., Foraminifera and chlorophyll maximum; vertical distribution, seasonal succession and palaeoceanographic significance. *Science*, 1980, **209**, 1524–1526.
4. Jiang, H., Seidenkrantz, M. S., Knudsen, K. L. and Eiriksson, J., Diatom surface sediment assemblages around Iceland and their relationship to oceanic environmental variables. *Mar. Micropaleontol.*, 2001, **41**, 73–96.
5. Jones, P. D., Osborn, T. J. and Briffa, K. R., The evolution of climate over the last millennium. *Science*, 2001, **292**, 662–667.
6. Grudd, H., Briffa, K. R., Karlen, W., Bartholin, T. S., Jones, P. D. and Kromer, B., A 7400-year tree-ring chronology in northern Swedish Lapland: natural climatic variability expressed on annual to millennial timescales. *Holocene*, 2002, **12**, 657–665.
7. Niggemann, S., Mangini, A., Richter, D. K. and Wurth, G., A palaeoclimate record of the last 17,600 years in stalagmites from the B7 cave, Sauerland, Germany. *Quat. Sci. Rev.*, 2003, **22**, 555–567.
8. Cioccale, M. A., Climatic fluctuations in the Central Region of Argentina in the last 1000 years. *Quat. Int.*, 1999, **62**, 35–47.
9. Qian, W. and Zhu, Y., Little ice age climate near Beijing, China, inferred from historical and stalagmite records. *Quat. Res.*, 2002, **57**, 109–119.
10. Mackay, A. W., Ryves, D. B., Battarbee, R. W., Flower, R. J., Jewson, D., Rioual, P. and Sturm, M., 1000 years of climate variability in central Asia: assessing the evidence using Lake Baikal (Russia) diatom assemblages and the application of a diatom-inferred model of snow cover on the lake. *Global Planet. Change*, 2005, **46**, 281–297.
11. Stine, S., Late Holocene fluctuations of Mono Lake, eastern California. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1990, **78**, 333–381.
12. Maley, J., Mecanisme des changements climatiques aux basses latitudes. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1973, **14**, 193–227.
13. Till, C. and Guiot, J., Reconstruction of precipitation in Morocco since 1100 AD based on *Cedrus atlantica* tree ring widths. *Quat. Res.*, 1990, **33**, 337–351.
14. Zheng, S. Z. *et al.*, The changes of moisture during the last 2000 years in south China. Proceedings of Climatic Changes and Prediction, Science Press, Beijing, 1977, pp. 29–32.
15. Nigam, R. and Khare, N., Significance of correspondence between river discharge and MPS in paleomonsoon studies. *Geomar. Lett.*, 1995, **15**, 45–50.
16. Funnel, B. M., Foraminifera and radiolaria as depth indicators in the marine environment. *Mar. Geol.*, 1967, **5**, 333–347.
17. Boltovskoy, E. and Wright, R., *Recent Foraminifera*, Dr W. Junk b. V. Publishers, The Hague, 1976, p. 515.
18. Lipps, J. H., Foraminiferal ecology and paleoecology. SEM Short Course, Houston, 1979, 6, pp. 62–104.
19. Gibson, T. G., Planktonic benthonic foraminiferal ratios: Modern patterns and tertiary applicability. *Mar. Micropalaentol.*, 1989, **15**, 29–52.
20. Nigam, R., Khare, N. and Borole, D. V., Can benthic foraminiferal morphogroups be used as indicators of paleomonsoonal precipitation. *Estuarine Coastal Shelf Sci.*, 1992, **34**, 533–542.
21. Nigam, R. and Khare, N., Signals of the change in monsoonal precipitation at around 2,000 years BP in a sediment core off central west coast of India. *Curr. Sci.*, 1994, **66**, 226–228.
22. Nigam, R. and Khare, N., Effect of river discharge on the morphology of benthic foraminiferal test. *J. Geol. Soc. India*, 1994, **43**, 457–463.
23. Caratini, C., Fontugne, M., Pascal, J. P., Tissot, C. and Bentaleb, I., A major change at ca. 3500 years BP in the vegetation of the western ghats in North Kanara, Karnataka. *Curr. Sci.*, 1991, **61**, 669–672.
24. Caratini, C., Bentaleb, I., Fontugne, M., Morzadec-Kerfourn, M. T., Pascal, J. P. and Tissot, C., A less humid climate since ca. 3500 years BP from marine cores off Karwar, Western India. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 1994, **109**, 371–384.
25. Stuiver, M. and Polach, H. A., Discussion: Reporting of ^{14}C data. *Radiocarbon*, 1977, **19**, 355–363.
26. Eddy, J. A., The Maunder minimum. *Science*, 1976, **192**, 1189.
27. Eddy, J. A., Climate and the changing sun. *Climatic Change*, 1977, **1**, 173–190.
28. Bell, B., The oldest records of the Nile floods. *Geogr. J.*, 1970, **136**, 569–573.

ACKNOWLEDGEMENTS. We thank the Director, NCAOR and the Director, NIO for their encouragement and support. We also thank Rajeev Saraswat and S. K. Yadav for help.

Received 29 December 2005; revised accepted 28 February 2006

Crustal deformation in the Indo-Burmese arc region: implications from the Myanmar and Southeast Asia GPS measurements

Vipul K. Sahu[1], Vineet K. Gahalaut[1,*], Shikha Rajput[1], R. K. Chadha[1], Sunil Singh Laishram[2] and Arun Kumar[2]

[1]National Geophysical Research Institute, Uppal Road, Hyderabad 500 007, India
[2]Department of Earth Sciences, Manipur University, Imphal, India

Several models of plate boundary and convergence between the Indian and South China plate across the Indo-Burmese arc (IBA) region have been proposed, which include active subduction, transform, oblique and no plate boundary. We theoretically compute the dis-

*For correspondence. (e-mail: vkgahalaut@yahoo.com)

placement fields corresponding to each model and compare them with the results of GPS measurements in Myanmar and Southeast Asia. Available GPS observations are consistent with the model in which relative plate motion of about 36 mm/yr between India and Sundaland is partitioned almost equally between the Sagaing fault and the IBA through episodic dextral motion. Eastward motion of the Indian plate is generally compensated by eastward motion of the South China plate. Thus almost no subduction occurs along the Indo-Burmese arc. The GPS data are consistent with strain accumulation in both regions.

Keywords: Crustal deformation, GPS measurements, Indo-Burmese arc, Mynamar, Southeast Asia.

THE northeastern part of the Indian subcontinent is one of most active regions of the world. It consists of mainly three units, approximately east-west extending eastern Himalaya, which marks the collisional boundary between the underthursting Indian plate beneath the Eurasia plate; approximately N–S extending Indo-Burmese Arc (IBA), which extends further southward to join the Andaman Arc, and the Eastern Himalayan Syntaxis (EHS), which lies at the junction of the above two. Subduction occurs along the Andaman arc, but whether it is still active in the IBA is debated[1–5]. EHS consists of several NW–SE trending thrust faults, e.g. Mishmi thrust, which acts as a buttress, resisting the motion of Indian plate. The zone is marked by high seismicity, high erosion, high uplift and exhumation rates[6]. Due to the complex nature, geodynamic setting, plate motion and other geodynamic processes in the region are largely unknown. Here we focus attention on the IBA and try to infer the plate motion and earthquake occurrence process from the available Global Positioning System (GPS) measurements.

The region consists of Indo-Burman ranges (IBR; Arakan Yoma, Chin Hills and Naga Hills, from south to north), the Myanmar Central Basin (MCB) and the eastern highlands of Shan plateau. IBR is an arcuate sedimentary belt with N–S trend of folded mountain chain, formed by Cenozoic rocks with Triassic metamorphic basement. It is considered as an active accretionary wedge linked to eastward subduction of the Bengal basin oceanic crust[7–10]. This wedge is composed of Cretaceous ophiolite, Cretaceous to Eocene pelagic sediments and a section of Eocene to Oligocene flysch overlain by Neogene shallow water sediments[11–14]. MCB is separated from the IBR by the Eastern Boundary Thrust[15,16], which is also known as the Kabaw fault. The basin is actually a series of Cenozoic basins presently affected by an active tectonic inversion[17]. Sagaing fault separates the MCB from the Shan plateau and joins into the Andaman sea rift system. Shan plateau, with an elevation of 1000 m, is considered as the western edge of the rigid Sundaland block. Estimates of magnitude of dextral movement across the Sagaing fault vary from 250 to 460 km since Miocene[8,18].

Seismotectonic studies of the Indo-Burma region have been attempted by several investigators[1–5,19–25]. An eastward-dipping zone of seismicity, consistent with the Benioff zone in a typical subduction zone, has been inferred[1]. Chen and Molnar[24] found that the earthquakes beneath the northern IBR define a gently-dipping east-southeast zone with a depth of 30–45 km beneath the Bengal basin and 40–90 km beneath the IBR. They inferred that earthquakes might have occurred within the subducting Indian lithosphere and not at the interface between the subducting and overriding plates, as the *P*-axis of these earthquakes is parallel to the north-south trending seismic zone and the folds of the IBR. They concluded that the orientation of maximum compression may have changed dramatically in the recent past, or more likely, deformation in the IBR is decoupled from that in the underlying Indian plate, while the northward movement of the ranges must be accommodated along the Sagaing fault and other faults further east. Rao and Kumar[2] identified a distinct segregation of strike slip and thrust-type focal mechanisms along the slab. They reported that the *P*-axis of focal mechanisms of these earthquakes is oriented in NNE direction, same as that of the Indian plate motion. It prompted them to suggest that the two plates shear past each other at this boundary. On the contrary, using the earthquake data Satyabala[4,5] opined that subduction is currently active as the *T*-axis of the focal mechanisms of earthquakes is aligned with the subducting slab. She suggested that all aspects of seismicity, including the paucity of shallow underthrusting earthquakes and orientation of *P*-axes are consistent with oblique convergence. Guzman-Speziale and Ni[1] studied the focal mechanisms, focal depth distributions and geometry of Wadati–Benioff zone in this region and suggested that there are no interplate earthquakes in this region. This can be interpreted in several ways, namely (i) the stress build-up is released in infrequent events, too few to be detected by the time window for which the data are available, (ii) the overriding plate is totally decoupled from the subducting plate, and (iii) the overriding plate is strongly coupled to the subducted Indian plate. They favoured the last interpretation because deformation in southwest China, a region under simple shear, is a consequence of transmitted stress from the north to northeastward moving Indian plate, which would be an impossible situation if the overriding plate were totally decoupled from the subducting plate. Thus they suggested that the relative motion between the Indian and Burmese plate has thus been transferred from subduction along the arc to right lateral motion along the Sagaing fault to the east. Radha Krishna and Sanu[3] estimated the crustal deformation rates from the moment tensor summation derived from the focal mechanisms of the earthquakes and supported the inferences of Guzman-Speziale and Ni[1]. Recently, Rao and Kalpna[25] inverted the focal mechanism data in the Burmese arc region and suggested that while the shallower part (<90 km) of the lithosphere is governed by the NNE-oriented horizontal plate tectonic forces, the lower part is governed entirely by tensile forces due to gravitational loading on the subducted slab. They also argued against the active subduction of the Indian plate under IBR.

The region has experienced a few great earthquakes. The great Assam earthquake of 1897 (*M* 8.7) occurred in the Shillong plateau region. Another great earthquake (*Mw* 8.6) occurred in the Indian Tibet region, close to the EHS[26]. The Arakan earthquake of 1762 was accompanied by changes in elevation of the coast of Burma and 1878 earthquake was associated with uplift in excess of 6 m on the western coast of Ramree Island[27]. The 23 May 1912 earthquake in eastern Burma is presumed to have accompanied normal fault[28]. Large earthquakes in the Bengal basin have occurred in 1885, 1918, 1923 and 1930. To the east of the ranges several large earthquakes, namely 1908, 1929, 1931, 1946 were associated with the Sagaing fault[28].

The above review suggests that there are conflicting views about the ongoing plate motion and geodynamic processes in the IBA region as no direct measurements of crustal deformation have been made in the region. GPS measurements have been made in campaign mode[29] in southeast China, SE Asia covering Brunei, Indonesia, Malaysia, the Philippines, Singapore, Thailand and Vietnam under the Geodynamics of South and South-East Asia (GEODYSSEA) project. Similar measurements have been made in Myanmar to infer the present-day crustal deformation around the Sagaing fault system (Figure 1) in central

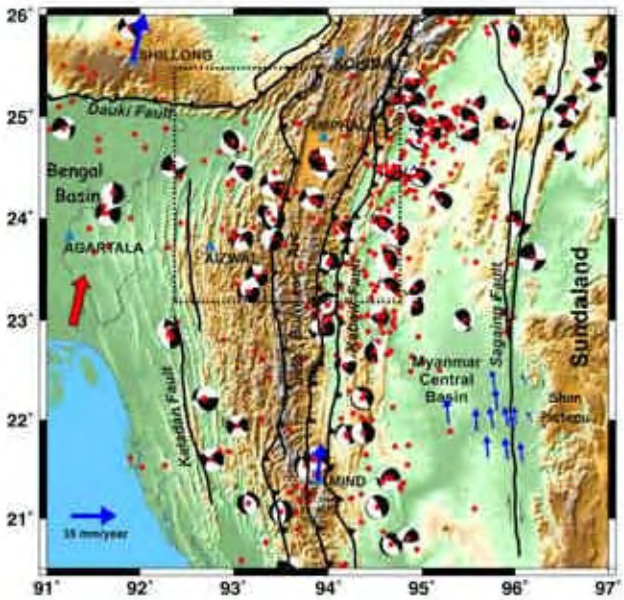

Figure 1. Simplified tectonic map of the region over the topography. Earthquake epicentres (red filled circles) for the period 1964–2004 and CMT focal mechanisms of some of the earthquakes for the period from 1977 to 2004 are also shown. All displacement vectors are in Sundaland reference frame. Vectors around the Sagaing fault and at station MIND are after Vigny *et al.*[30]. Red bold arrow indicates predicted motion of Indian plate in the NE region in Sundaland reference frame. Box in the IBA region is the location of GPS network operated by us.

Myanmar[30]. There are no results of GPS observations from NE India in the IBA region and EHS. The results of these campaigns and their implications for the IBA may resolve some of the basic issues that were discussed earlier. First, we briefly review the results of the above measurements and then use them to constrain the plate motion in the IBA.

Chen *et al.*[29] reported results of GPS measurements from eastern Tibet. These measurements suggest that relative to Eurasia, South China moves 6–10 mm/yr east-southeast, indicating that the eastward movement within the plateau is part of the broader eastward movement that involves the plateau and its eastern and northern foreland. Another important conclusion drawn from these measurements is that the IGS site at the Indian Institute of Science (IISc), Bangalore moves at a rate of 37 ± 3 mm/yr towards N22°E with reference to Eurasia, which is consistent with the revised plate reconstruction model[31]. GPS measurements further south of Eurasia have been reported by several authors under the GEODYSSEA project[32–35]. Major findings of the measurements include definition of the Sundaland block, i.e. Indo-China as well as the western and central parts of Indonesia, together with South China, that is decoupled from Eurasia and behaves differently from the Eurasian plate. This block moves to the east about an Euler pole approximately that of Eurasia, but with a higher velocity. With respect to India and Australia, the Sundaland–South China block is moving due south. It implies that the eastward motion of India is to a large extent compensated by the eastward-directed motion of SE India. To further understand the crustal deformation across the Sagaing fault and in the MCB, additional GPS measurements were undertaken[30]. The results of these measurements broadly support those obtained through GEODYSSEA campaigns. The results suggest that the relative southward motion of Sundaland with respect to the Indian plate is distributed over distinct fault systems. About 18 mm/yr of dextral motion occurs on the N–S trending Sagaing fault, which is presently locked and accumulating elastic strain[30]. Rest of the motion is assumed to be absorbed either seismically or aseismically across MCB or IBA.

We adopted the Euler pole of Sundaland–India deduced from GPS measurements in SE Asia, including Myanmar. In NE India, the Indian plate moves at a velocity of about 36 mm/yr in N13°E direction with respect to MCB and Sundaland along the IBA. The velocity is largely parallel to the strike of IBA, and other predominant faults, e.g. Kaladan fault, Kabaw fault and Sagaing fault. Hence we suggest that motion across IBA is largely of strike slip-type. However, a small component of subduction may not be ruled out[32–35] due to error in such analyses. According to the debated models of plate motion across the IBA, three hypothetical end-member models may exist. First is the case where the boundary between the two plates lies in the IBA region. The slip in this case can occur either aseismically or seismically. Aseismic slip will not cause

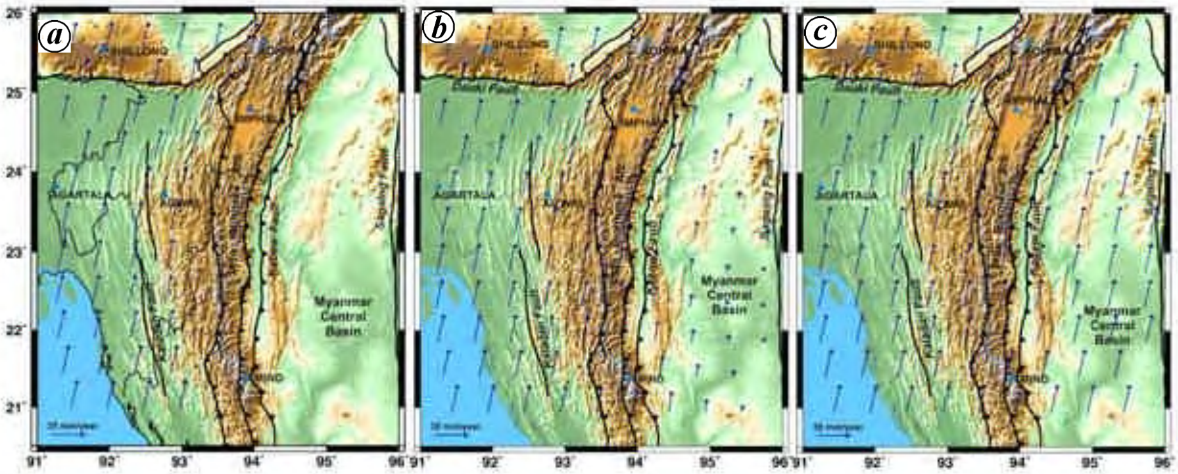

Figure 2. Predicted horizontal surface displacement rates V_H in Sundaland reference frame, corresponding to various end-member models considered by us. ***a***, V_H due to the model in which aseismic slip occurs on the IBA. ***b***, V_H due to the model in which seismic slip occurs on the IBA, both models imply that IBA represents a plate boundary. ***c***, V_H due to the model in which no slip occurs on the IBA, implying that IBA is not a plate boundary.

any strain accumulation and hence will not lead to interplate earthquakes. Thus, in this model the Indian plate moves at a constant rate of 36 mm/yr in the N13°E direction with respect to MCB and Sundaland along the IBA (Figure 2 *a*). However, if slip occurs seismically, the episodic slip along the boundary will lead to elastic strain accumulation and earthquake occurrence. We assumed that the great and large earthquakes occur in the updip part of the plate boundary fault through dextral slip, which is consistent with the focal mechanism of shallow earthquakes in the region. The width of the seismogenic zone is assumed as 80–100 km, with its downdip edge at 50 km depth dipping in the east direction at angle of 30°. These estimates are based on inferences drawn by several investigators on the basis of earthquake hypocentres and their focal mechanisms[1,5]. We assumed full coupling between the two plates and predicted annual surface displacements due to a slip deficit equivalent of relative plate motion of 36 mm/yr in N13°E direction (Figure 2 *b*). The second model is the case where there is no plate boundary in the IBA region and hence no differential movement occurs across the IBA and MCB (Figure 2 *c*). Finally, there could be a case where the motion of 36 mm/yr is distributed across the various faults in the region. In this case, we partition the motion of 36 mm/yr between IBA and Sagaing fault region. Vigny *et al.*[30] reported a dextral motion of about 18 mm/yr on the Sagaing fault. They also reported velocity of about 24 mm/yr towards N5°E at MIND, a station in Myanmar located on the eastern edge of the IBR. We derived velocity of 34 ± 6 mm/yr at Shillong in Sundaland reference frame, from that given by Jade[36] in ITRF 1997. The predicted plate motion of the Indian plate of about 36 mm/yr with respect to Sundaland in the NE region is consistent with the derived velocity at Shillong. We assumed that geometry of the locked fault is the same as that used above, but the slip deficit on the locked fault is now estimated as 18 mm/yr, which occurs in dextral sense on the approximately N–S striking fault. We show an E–W profile of northward motion across the IBA, CMB and Sagaing fault (Figure 3). It can be seen that the predicted plate motion along the profile corresponding to this model is consistent with observed motion at Shillong, MIND and at several sites located across the Sagaing fault. We also show responses of the above two cases, i.e. cases in which the plate boundary is aseismic and there is no plate boundary. It can be seen that both these cases are inconsistent with the GPS observations at MIND and at sites across Sagaing fault. Moreover, the case of aseismic plate boundary at IBA is not consistent with the observed deformation in southwest China, a region under simple shear[23].

GPS measurements in SE Indo-China, across the Sagaing fault in Myanmar, and at Shillong in India imply that the relative plate motion of India with respect to Sundaland is predominantly northward at a rate of about 36 mm/yr in the NE region. The relative plate motion is shared almost equally through distributed slip across the IBA and Sagaing fault in predominantly dextral slip manner. Thus the view that the IBA region does not represent the plate boundary between Indian and Sundaland plates and entire relative plate motion occurs through slip on the Sagaing fault, is not consistent with the available GPS data. The eastward motion of the Indian plate is to a large extent compensated by the eastward-directed motion of SE Asia. Thus no or insignificant subduction occurs across the IBA. This is consistent with the earthquake focal mechanisms, which show predominant N–S oriented *P*-axes. Their occurrence can be ascribed to the northward movement of the sub-

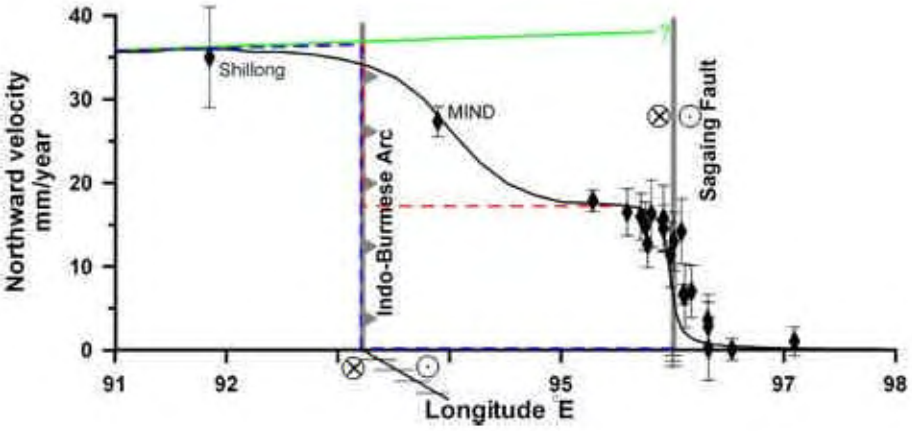

Figure 3. Northward horizontal velocity in Sundaland reference frame along an east-west profile. Green line denotes the predicted displacements across IBA when no plate boundary across the IBA is assumed. Red and blue dashed lines show predicted displacements when the boundary at IBA is assumed to be aseismic, i.e. total decoupling is assumed between the Indian plate and Burmese platelet. Red line represents the case when plate motion is shared between the aseismic IBA and seismically active Sagaing fault, while blue line represents the case when entire plate motion is accommodated at IBA through aseismic motion. Bold curve corresponds to the case when the relative plate motion between the Indian plate and Sundaland is shared equally through seismic motion across the IBA and Sagaing fault. Locking across the IBA and Sagaing fault is indicated by parallel lines across the seismogenic fault.

ducted Indian slab under the IBA. Slip deficit of about 18 mm/yr in the IBA suggests that strain accumulation is underway in the region.

To further test the inferences drawn here, we have set up a 15-stations campaign mode GPS network in the region which includes Manipur, Mizoram and southern Assam (Figure 1). We hope that in a couple of years, estimates of the plate motion in the NE region will be well constrained.

1. Guzman-Speziale, M. and Ni, J. F., Seismicity and active tectonics of the western Sunda Arc. In *The Tectonic Evolution of Asia* (eds Yin, A. and Harrison, T. M.), Cambridge Univ. Press, New York, 1996, pp. 63–84.
2. Rao, N. P. and Kumar, M. R., Evidences for cessation of Indian plate subduction in the Burmese arc region. *Geophys. Res. Lett.*, 1999, **26**, 3149–3152.
3. Radha Krishna, M. and Sanu, T. D., Seismotectonics and rates of active crustal deformation in the Burmese arc and adjacent regions. *J. Geodyn.*, 2000, **30**, 401–421.
4. Satyabala, S. P., Subduction in the Indo-Burma Region: Is it still active?. *Geophys. Res. Lett.*, 1998, **25**, 3189–3192.
5. Satyabala, S., Oblique plate convergence in the Indo-Burma (Myanmar) subduction region. *Pure Appl. Geophys*., 2003, **160**, 1611–1650.
6. Zeitler, P. K. *et al.*, Erosion, Himalayan geodynamics, and the geomorphology of metamorphism. *GSA Today*, 2001, **11**, 4–9.
7. Acharya, S. K., Ray, K. K. and Sengupta, S., Tectonics of the ophiolite belt from Naga Hills and Andaman Islands, India. *Proc. Indian Acad. Sci.* (*Earth Planet. Sci.*), 1990, **99**, 187–199.
8. Curray, J. R., Moore, D. G., Lawver, L., Emmel, E., Raith, R., Henry, M. and Kieckhefer, R., Tectonics of the Andaman Sea and Burma, geological and geophysical investigations. *Am. Assoc. Pet. Geol. Mem.*, 1979, 189–198.
9. Bender, F., *Geology of Burma*, Beiträge zur regionalen geologie der erde, Borntraeger, Stuttgart, 1983, vol. 16.
10. Nandy, D. R., Geology and tectonics of the Arakan Yoma, a reappraisal. *Bull. Geol. Soc. Malays*., 1986, **20**, 137–148.
11. Brunnschweiler, R. O., On the geology of Indo-Burman Range, (Arakan coast and Yoma, China Hills, Naga Hills). *J. Geol. Soc. Aust*., 1966, **13**, 137–194.
12. Brunnschweiler, R. O., Indo-Burman ranges, mesozoic-cenozoic orogenic belts. In *Data for Orogenic Studies* (ed. Spencer, A. M.), Geologic Society of London Special Publication, 1974, vol. 4, pp. 279–299.
13. Roldolfo, K. S., Bathymetry and marine geology of the Andaman Basin, and tectonic implications for southeast Asia. *Geol. Soc. Am. Bull.*, 1969, **180**, 1203–1230.
14. Mitchell, A. H. G., Phanerozoic Plate Boundaries in Mainland SE Asia, the Himalayas and Tibet. *J. Geol. Soc. London*, 1981, **138**, 109–122.
15. Nandy, D. R., Tectonic patterns in northeastern India. *Indian J. Earth Sci*., 1980, **7**, 103–107.
16. GSI, *Seismotectonics Atlas of India*, Geological Survey of India, Kolkata, 2000, p. 87.
17. Pivnik, D. A. *et al.*, Polyphase deformation in a fore-arc/back-arc basin, Salin subbasin, Myanmar (Burma). *AAPG Bull.*, 1998, **82**, 1837–1856.
18. Khin Zaw, Geological, petrological and geochemical characteristics of granitoid rocks in Burma: With special reference to the associated W-Sn mineralization and their tectonic setting. *J. Southeast Asian Earth Sci.*, 1990, **4**, 293–335.
19. Fitch, T. J., Plate convergence, transcurrent faults, and internal deformation adjacent to Southeast Asia and western Pacific. *J. Geophys. Res*., 1972, **77**, 4432–4460.
20. Molnar, P., Fitch, T. J. and Wu, F. T., Fault plane solutions of shallow earthquakes and contemporary tectonics in Asia. *Earth Planet. Sci. Lett.*, 1973, **19**, 101–112.
21. Chandra, U., Seismicity, earthquake mechanisms and tectonics of Burma, 20N–28N. *Geophys. J. R. Astron. Soc.*, 1975, **40**, 367–381.
22. Saikia, M. M., Seismic activity in northeastern region of India. In *Earthquake Prediction – Present Status*, 1986, pp. 223–233.
23. Ni, J. F., Guzman-Speziale, M., Bevis, M., Holt, W. E., Wallace, T. C. and Seager, W. R., Accretionary tectonics of Burma and three-dimensional geometry of the Burma subduction zone. *Geology*, 1989, **17**, 68–71.

24. Chen, W. P. and Molnar, P., Source parameters of earthquakes and intraplate deformation beneath the Shillong plateau and the northern Indo-Burman range. *J. Geophys. Res.*, 1990, **95**, 12527–12552.
25. Rao, N. P. and Kalpna, Deformation of the subducted Indian lithospheric slab in the Burmese arc. *Geophys. Res. Lett.*, 2005, **32**.
26. Chen, W. P. and Molnar, P., Seismic moment of major earthquakes and the average rate of slip in Central Asia. *J. Geophys. Res.*, 1977, **82**, 2945–2969.
27. Richter, C. F., *Elementary Seismology*, W.H. Freeman, San Francisco, 1958, p. 768.
28. Molnar, P. and Deng, Q., Faulting associated with large earthquakes and the average rate of deformation in central and eastern Asia. *J. Geophys. Res.*, 1984, **89**, 6203–6227.
29. Chen, Z. *et al.*, GPS measurements from eastern Tibet and their implications for India/Eurasia intercontinental deformation. *J. Geophys. Res.*, 2000, **105**, 16,215–16,227.
30. Vigny, C. *et al.*, Present-day crustal deformation around Sagaing fault, Myanmar. *J. Geophys. Res. Solid Earth*, 2003, **108**, 2533.
31. Gorden, R. G., Argus, D. F. and Heflin, M. B., Revised estimate of the angular velocity of India relative to Eurasia, Supplement to the EOS Transactions. *AGU*, 1999, **80**, F273.
32. Michel, G. W., Becker, M., Angermann, D., Reigber, Ch. and Reinhart, E., Crustal motion in E- and SE-Asia from GPS measurements. *Earth Planets Space*, 2000, **52**, 713–720.
33. Michel, G. W. *et al.*, Crustal motion and block behaviour in SE Asia from GPS measurements. *Earth Planet. Sci. Lett.*, 2001, **187**, 239–244.
34. Becker, M., Reinhart, E., Nordin, S. B., Angermann, D., Michel, G. and Reigber, C., Improving the velocity field in South and South-East Asia: The third round of GEODYSSEA. *Earth Planets Space*, 2000, **52**, 721–726.
35. Nielsen, C. *et al.*, From partial to full strain partitioning along the Indo-Burmese hyper-oblique subduction. *Mar. Geol.*, 2004, **209**, 303–327.
36. Jade, S., Estimates of plate velocity and crustal deformation in the Indian subcontinent using GPS geodesy. *Curr. Sci.*, 2004, **86**, 1443–1448.

ACKNOWLEDGEMENTS. We thank two anonymous reviewers for their comments. We also thank the Director, NGRI, Hyderabad for support. The GPS project in the NE region is financially supported by the Department of Science and Technology, New Delhi. We thank Mr B. K. Bansal and Mr M. Mohanty for support.

Received 23 November 2004; revised accepted 29 April 2006