Chapter 4

Pre-seismic deformational constraints

4.1 Spatio-temporal analysis of pre-seismic earthquakes

The spatial distribution of instrumentally recorded earthquakes (January 1, 1973 to December 25, 2004) coincides with the major tectonic segments of the Andaman-Nicobar arc (Figures 4.1.A, 2.1 and 2.3). Inner side of the arc shows considerable and distinct seismicity along the West Andaman Fault (WAF), Andaman Spreading Ridge (ASR) and the volcanic arc (See, Figure 2.1 for locations).

Loci of earthquakes mostly follow a NNE trend, the western arm representing the fore-arc setting as well as the volcanic arc consisting of Barren and Narcondam Islands. The eastern arm that branches off at about 11°N is characterized by shallow seismicity associated with the back-arc extension in the ASR as discussed later. The reduced level of seismicity and formation of a gap north of the archipelago is evident and has been reported (Sinvhal et al., 1978; Rajendran and Gupta, 1989). Similarly there is a lack of any significant cluster of near trench earthquakes in the Sumatra-Andaman boundary during this period. If ASR earthquakes are not taken into account, this can be assumed due to a pre-seismically locked trench-ward plate interface and a seismogenic plate interface away from the trench. Such pre-seismic quiescence is not uncommon for subduction zones. For example, inter-plate earthquakes are not usually observed along the shallowest (<10 km) portions of the subduction megathrust pre-seismically (Byrne et al., 1988; Scholz, 1998; Pacheco et
Figure 4.1: A) Spatial distribution of Andaman-Nicobar seismicity, M≥4.0, for a period of January 1, 1973 to December 25, 2004, Data Source: USGS, NEIC database. B-D) zones marked for depth analysis.
Figure 4.2: Depth wise distribution of earthquakes at 12 degree north (zone marked B in Fig. 4.1). Note the trend of dipping slab. Shallow earthquakes east of 94°E are due to the Andaman spreading ridge (ASR) events.

Figure 4.3: Depth wise distribution of earthquakes at zone marked C in Fig. 4.1
A better way to validate this assumption is to analyze the spatial distribution of earthquakes depth wise. For this, specific segments of Andaman-Nicobar arc are selected (see Fig. 4.1, zones are marked B, C and D), and depth-wise distribution of the events are plotted. The hypocentral distribution of earthquakes are located at the plate interface as well as within the plate, showing the trend of the dipping subducting slab. This dipping interface (Wadatti-Benioff zone), has a characteristic dip angle which varies along the strike. Depth section along 12°N (by projecting the events between 11.5 - 12.5°N on a plane), clearly shows an eastward dipping subducting slab, with no significant events on the trench-ward side, dipping at about 30-35° (Fig. 4.2). Towards the back-arc regions intermediate/deeper events associated with the volcanic arc are found, followed by shallow spreading
ridge earthquakes from the Andaman Spreading Ridge (ASR). Transverse section of hypocenters within the selected block shows that the Benioff zone is about 85-130 km deep along this part of the trench.

Similar depth-wise distribution of the events were studied at 6°N (Fig. 4.3) and 3°N (Fig. 4.4). At 6°N the subduction is more steeper and deeper than at 12°N. At 3°N the setting is even more complicated with dipping interface earthquakes and events associated with the Sumatran Fault system. Thus it can be inferred that the dipping interface, dip angle and thus the geometry of the subduction setting of the Andaman-Nicobar changes along strike. From north to south its dip angle becomes more steep and penetration of the downgoing slab becomes more deep. The maximum hypocentral depth is at 260 km, near the southern segment of the study area. The youthfulness of the subduction zone along this part is evident also from the presence of large and great earthquakes in this area (See, Figure 4.8).

A comparison made on the bathymetry and hypocentral depths along the same profile defines the above discussed trend of downgoing slab beneath the archipelago. To map the trend of the dipping plate interface and better 3-D visualization of the trench geometry along the arc (Fig. 4.5) cross-section of the gridded data sets of bathymetry and hypocentral distribution are made use. Gridded topography data is from ETOPO-5 (National Ocean and Atmospheric Administration (NOAA), 1988) and the epicentral data is from USGS, NEIC database of events M\geq4.0. A wire-frame surface map of the gridded hypocentral data created shows the spatial variation of the hypocentral depths on a surface.

A wire-frame plot of the gridded bathymetry data set along the 12°N (Fig. 4.5),
Figure 4.5: Upper panel shows the wire-frame surface topographic section along 12°N, showing the trench, accretionary prism (Andaman Islands), volcano (Barren island), and the Andaman spreading center. Lower panel corresponds to the gridded wire-frame surface map of the hypocentral data along the same profile, showing the trend of the dipping Benioff zone, volcanic earthquakes, and shallow spreading ridge earthquakes. Gridded topography data is from ETOPO-5 from National Ocean and Atmospheric Administration (NOAA) and the epicentral data is from USGS, NEIC database of events $M \geq 4.0$. 
Figure 4.6: Gridded wire-frame surface map of the hypocentral data distribution of Andaman-Nicobar earthquakes along the island arc. It shows the trend of the dipping plate interface along the arc which is representative of the subduction geometry. Black line shows trench location from Bird (2003). Black patches are location of Andaman-Nicobar Islands. Colour scale gives hypocentral depth information.

shows the bathymetric highs and lows viz., Sunda-Andaman trench, the accretionary prism (whose sub-aerial expression are the islands) and a very deep back-arc basin where the Andaman Spreading Ridge (ASR) exists. Comparing with a gridded wire-frame plot of the hypocentral distribution along the same section shows the spatial extent of the earthquakes and the trend of the dipping slab beneath the accretionary wedge. Also seen are the presence of very shallow volcanic arc earthquakes beneath the Barren Island and the spreading ridge earthquakes beneath ASR.

Similar wire-frame surface map along the arc was made with the gridded hypocen-
tral data. All earthquakes below 40 km depth were removed from the ASR and the volcanic arc. This was to avoid any shallow spreading ridge and volcanic earthquakes being included in the analysis and to exclusively obtain the trend of the dipping interface (Fig 4.6). It shows a complicated and very deep subduction in the southeastern end of the study area. It may be possibly due to the deep penetration of the downgoing slab in this segment. The western part of the subduction front is shallower as expected. South to north subducting slab occurs at a shallower depth, as inferred from scanty earthquake data (Srivastava and Chaudary, 1979) as well as seismic reflection data (Curray, 2005 and references therein).

Temporal evolution of seismicity is analyzed using the earthquakes $M \geq 4.9$ from the NEIC database mentioned above, for the region within 0-14°N and 92-100°E, which defines the area of interest of this study. Annual frequency of earthquakes during this period consist of ~700 events of $M \geq 4.9$ among which 43 events are of $M \geq 6.0$ (Fig. 4.7). Among these events twelve are of $M \geq 6.5$ and three are of $M \geq 7.0$ (Fig. 4.8). Maximum event magnitude reported during this period was $M 7.6$, an event occurred near the trench-ward side of the north western Sumatra.

The temporal pattern of seismicity does not suggest any particular pattern. It has been suggested based on some of the worlds better studied subduction zones that a period of quiescence follows major earthquakes (Ohtake et. al., 1981). The spatial distribution of $M \geq 6.0$ events along arc generally suggests that most parts of the subduction front have been generating earthquakes (Fig. 4.8). Some earthquakes in the southern (1861) as well as the northern part of the subduction zone (1881, 1941 and 1679) have caused larger ruptures. Admittedly, the sampled data
Figure 4.7: Temporal pattern of Andaman-Nicobar seismicity from 1973-2004 for the events $M \geq 4.9$. Maximum magnitude of earthquake reported is marked above for the particular year. Data Source: USGS, NEIC database.
time span window is very small, compared with the time scales of continental deformation. However, based on the available data one may note that no part of this subduction zone (except in the northern portions) has remained free of earthquakes.

4.2 Tectonic segmentation based on focal mechanism data and the major stress regimes.

A subduction zone is expected to feature near trench shallow thrust faulting earthquakes, shallow strike-slip earthquakes at the back-arc transforms, shallow normal earthquakes around the spreading ridge and deep normal fault earthquakes in the down-dip side of the downgoing plate (Spence, 1987). Analysis of the available focal mechanisms around the Andaman-Nicobar arc shows the variations in tectonic activity along the arc. Here, data sets from Harvard centroid moment tensors were analyzed for a period from 1973-2004 of magnitude 4.9 and above. Mechanisms within the study area are only discussed herewith, although for the sake of completeness, data from surroundings are also used for plotting. Mechanisms are scaled for magnitude and depth by size and colour respectively (Fig. 4.9).

Focal mechanisms of the major earthquakes along the Sumatra-Andaman trench are consistent with the under-thrusting along the megathrust fault. As already discussed, there is a lack of significant trench-ward earthquakes during this period of analysis (1973-2004). During this period only one event is located on the trench line east of Nicobar with a thrust faulting mechanism. Trench-ward earthquakes
Figure 4.8: Significant pre-seismic earthquakes of M ≥ 6.0 along the Andaman-Nicobar arc.
east of Andamans and Nias Island (See Figure 4.8 for locations) shows consistent thrust mechanism, striking parallel to the trench. Many events at or immediately adjacent to the trench are characterized by both normal and strike slip faulting. These near-trench shallow normal fault earthquakes may be due to the intra-slab bending stress (Spence, 1987). The near-trench strike-slip mechanisms may be associated with many features on the incoming Indian plate.

Further south, the orientation of the fore-arc gradually changes from NNE to NW-SE in South Nicobar - Sumatra Islands. This part of the subduction zone belongs to two tectonic regimes. The northern segment corresponds to the Great Nicobar and Sumatra Islands, where Indian and the southeast Asian plates are interacting. Present day tectonic processes are controlled by three major fault systems, the most prominent being the subduction thrust, which outcrops in the Sunda trench. Inland, the trench-parallel Sumatra Fault that runs through the entire length of the island from Banda Aceh to Sunda Strait accommodates oblique convergence through strike-slip faulting. The Mentawai Fault at the outer margin of the fore-arc basin is another important fault system in the Sumatra region (Sieh and Natawidajaja, 2000). The Benioff zone is about 170-190 km deep in this section and not much of back-arc activity is observed here. Some minor along-arc variations have been noted, the general pattern is that of active subduction dominated by shallow thrust events in the southern part. Further south, the subduction geometry is more complicated, where the plate convergence is partitioned as dip-slip and right lateral strike-slip components, respectively along the Sunda trench and the Sumatran Fault.
Away from the trench to the east, thrust earthquakes of <40 km, with its striking parallel to the arc can be seen. It is followed to east towards back-arc by 40-80 km deep thrusting events (coloured green in Fig. 4.9) primarily associated with the series of the thrust faults in the Andaman subduction zone. Among these, the West Andaman Fault (WAF) is the most prominent. This fault appears to be continuous from the west of Sumatra to east of Nicobars and Andamans. Along the WAF earthquakes with normal mechanisms appear forming another plane of seismicity.

Deeper events of varying mechanisms (coloured blue in Fig. 4.9) are seen among which most may be associated with the Sunda-Andaman volcanic arc. Along the Sumatran Fault (SF), strike-slip events of <40 km can be seen which extends towards north to the Andaman Spreading Ridge (ASR). The ASR earthquakes show typical shallow strike-slip and normal mechanisms. Earthquakes in the 7 to 15°N show distinct characteristics of the back-arc spreading. The orientation of the normal faulting earthquakes are consistent with the small ocean spreading features in Andaman marginal sea. The Andaman Sea basin is considered to be complex back-arc spreading center, categorized as a pull apart or rip off basin rather than a typical back-arc extensional setting (Curray, 2005).

The transition region between north of SF and south of ASR shows a cluster of shallow and intermediate predominant strike-slip and normal mechanisms and deeper normal mechanisms. This part of the arc exhibits more complex pattern and segregation into clusters of thrust, normal and strike-slip earthquakes (Dasgupta et al., 2003). These mechanisms represent the tectonic features accommodating the right lateral oblique convergence along the WAF and SF and the slip partitioning
happening there due to the obliqueness in subduction. Along the Sumatra Subduction zone, plate convergence is partitioned into dip-slip and right lateral strike-slip components, the former being accommodated by the slip on the subduction interface and the latter by the Sumatran Fault (Fitch, 1972; Curray, 2005).

The P- and T-axes inferred from earthquake focal mechanisms provide a first order approximation of the stress. The maximum horizontal stresses inferred from the focal mechanisms in the segments discussed above were analyzed as a function of depth. The average P-axis orientation from the focal mechanisms was assumed to be the direction of maximum horizontal stress ($S_H$ in regions of strike-slip and thrust faulting). In regions of normal faulting, the direction perpendicular to the T-axis was assumed to the direction of $S_H$. The figures 4.10 and 4.11 show the P- and T-axes inferred from the focal mechanism solutions available for the area. The rose diagram showing the orientations of mean $S_H$ and $S_h$ within 40 km depth are shown in Fig. 4.10. The same parameters for the earthquakes deeper than 40 km are shown in Fig. 4.11.

Around the Andaman Islands (Fig. 4.10.a), the direction of $S_H$ is N-S to NE-SW. Two shallow normal faulting earthquakes are reported from this area, which may be representative of deformation within the upper plate structures or volcano deformation. In the zone of shallow seismicity at the northern segment of ASR (Fig. 4.10.b), the mean stress direction is in the NNE-SSW direction, whereas below this segment (Fig. 4.10.c) the trend is in NNW-SSE direction, which is also reported by Rajendran and Gupta (1989). These are associated with the ocean floor spreading and the right lateral motion, and is consistent with the reported opening up of the
Figure 4.9: Centroid moment tensor solution mechanisms of M>4.9 earthquakes (1973-2004) from Harvard CMT catalogue. Events are size wise scaled for magnitude and colour wise scaled for depth. Red - 0 to 40 km, green - 40 to 80 km and blue - 80 to 300 km deep. Plate boundary locations are from Bird(2003). Inverted yellow triangles are volcanoes.
Figure 4.10: The directions of P- and T-axes and type of faulting derived from focal mechanisms of the earthquakes with hypocentral depth less than 40 km. The direction of the lines indicates the orientation of P-axis for strike slip and thrust faulting and T-axis for normal faulting. Rose diagrams show $S_H$ and $S_h$ (maximum and minimum horizontal stresses) for different tectonic regimes (marked by dashed areas).
Figure 4.11: The directions of P- and T-axes and type of faulting derived from focal mechanisms of the earthquakes with hypocentral depth greater than 40 km. The direction of the lines indicates the orientation of P-axis for strike slip and thrust faulting and T-axis for normal faulting. Rose diagrams show $S_H$ and $S_h$ (maximum and minimum horizontal stresses) for different tectonic regimes (marked by dashed areas).
Figure 4.12: Generalized stress map of the Sumatra-Andaman region within 40 km depth. Converging arrows indicate compressions and diverging arrows indicate extension.
Figure 4.13: Generalized stress map of the Sumatra-Andaman region of >40 km depth. Converging arrows indicate compressions and diverging arrows indicate extension.
Andaman sea region by Curray, (2005) and Raju, (2004). Figures 4.10.d and 4.10.e show similar stress orientations but they are oriented towards N-E to NWW-SEE direction.

A segment very near to the trench shows $S_H$ oriented towards NNE-SSW (Fig.4.10.f), consistent with the plate velocity vector azimuth there (DeMets et al., 1994a). North western segment of Sumatra (Fig. 4.10.g) shows typical trench-ward under-thrusting with a stress orientation of NNW-SSW. It is a typical signature (Lu et al., 1997) of the near trench extensional stress in the bent plate due to the earthquakes that occur below the plane of the bending subducting lithosphere. East of this zone the stress orientations are mainly controlled by the right lateral SF and its northern extension. The major $S_H$ orientation is towards NNE-SSW.

At a greater depth (>40 km) (Fig. 4.11.a), the major stress orientation changes to E-W compression. Fewer number of earthquake mechanisms in ASR shows consistent stress orientations like the shallower portions there. Segment - b, shows a NW-SE trend of stress, consistent with the deeper WAF right lateral motion. Segment - c, shows the trend of near trench compression in the deeper portions of North Western Sumatra.

Spatial distribution of the stress field and their variations with depth are summarized in Fig. 4.12 and Fig. 4.13. Trench-ward, the Sumatra-Andaman region shows a general sense of compression in NE-SW to N-S direction at the shallower portions. In the ASR region, the general trend of stress ($S_N$) is in NNW-SSE. In a transition zone between the ASR and SF, the stress orientations ($S_N$) change to E-W direction. In intermediate depths, the trend of ($S_H$), east of Sunda-Andaman trench
is NE-SW to N-S (Fig. 4.13).

4.3 Geodetic constraints on the pre-seismic convergence along the arc

4.3.1 Pre-earthquake velocities

Pre-earthquake GPS surveys were carried out in the Andaman-Nicobar Islands as part of this study and were part of a broader study of geomorphic features in the islands, and a total of 8 sites were surveyed prior to the earthquake in measurement campaigns in 2002, 2003, and 2004 (Earnest et al., 2005). The final pre-earthquake campaign was carried out in August 2004 over a period of about 4 weeks, and was 4-5 months before the December 26th mainshock. A site in Port Blair was surveyed in each campaign, and sites in Diglipur (North Andaman) and Car Nicobar were surveyed in both 2003 and 2004. The other 5 sites were surveyed only once prior to the earthquake. Each GPS survey at a site involved the collection of 2 or more days of data, with each days data generally covering a full 24-hour span. The Port Blair site, PBLR was surveyed continuously for the duration of each survey.

Pre-earthquake velocities were estimated using daily GPS solutions spanning between 4th May, 2001 and 11th September, 2004. Coordinate repeatability were tested (See figs. 4.14 to 4.16), and station velocity is measured in the ITRF00 frame (Fig. 4.17 and Table 4.1 for details). Convergence between India is computed by fixing the IISC point (Fig. 4.18 and Table 4.2 for details).
Figure 4.14: Time series plot of PBLR, Port Blair GPS point from 2002-2004 in ITRF00 reference frame.
DGLP North Offset 1464988.389 m
rate(mm/yr) = 28.09 ± 1.14 nrms = 0.77 wrms = 2.8 mm

DGLP East Offset 10077441.630 m
rate(mm/yr) = 32.45 ± 1.40 nrms = 0.43 wrms = 4.1 mm

DGLP Up Offset 146.440 m
rate(mm/yr) = 1.75 ± 1.49 nrms = 0.92 wrms = 22.8 mm

Figure 4.15: Time series plot of DGLP, Diglipur, North Andamans GPS point from 2003-2004 in ITRF00 reference frame.
Figure 4.16: Time series plot of CARN, Car Nicobar GPS point from 2003-2004 in ITRF00 reference frame.
Table 4.1: Computed absolute velocity (mm/yr) of the control points in ITRF00 reference frame.

<table>
<thead>
<tr>
<th>Station Code</th>
<th>East</th>
<th>E-sigma±</th>
<th>North</th>
<th>N-sigma±</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBLR</td>
<td>40.43</td>
<td>0.08</td>
<td>33.36</td>
<td>0.05</td>
</tr>
<tr>
<td>DGLP</td>
<td>32.45</td>
<td>0.21</td>
<td>28.09</td>
<td>0.12</td>
</tr>
<tr>
<td>CARN</td>
<td>29.72</td>
<td>0.41</td>
<td>36.34</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Figure 4.17: Absolute velocity vectors of the campaign and IGS stations used in this study. The frame of reference is ITRF00.
Table 4.2: Computed relative velocity (mm/yr) of the control points with respect to IISC, Bangalore.

<table>
<thead>
<tr>
<th>Station Code</th>
<th>East</th>
<th>E-sigma</th>
<th>North</th>
<th>N-sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBLR</td>
<td>-4.99</td>
<td>1.38</td>
<td>-1.91</td>
<td>0.03</td>
</tr>
<tr>
<td>DGLP</td>
<td>-12.97</td>
<td>2.21</td>
<td>-7.18</td>
<td>0.12</td>
</tr>
<tr>
<td>CARN</td>
<td>-15.70</td>
<td>2.87</td>
<td>1.07</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Figure 4.18: Relative velocity vectors of the campaign and IGS stations used in this study. The frame of reference is ITRF00. Velocity vectors are computed with respect to IISC, Bangalore.
4.4 Discussion

Temporal analysis of pre-seismic earthquakes shows that there is an ambient and consistent seismicity level with occasional M>6.0 earthquakes. But it does not show any precursory signal towards the 2004 megathrust occurrence. But spatial spread of earthquakes shows that the trenchward side is devoid of seismic activity and is representative of a locked pre-seismic plate interface. Also the back-arc side do have plenty of earthquakes, including some significant ones, pointing towards an active down-dip extension of the pre-seismic plate boundary. Three dimensional Benioff zone distribution shows the along the strike variation in the dip angle of the subduction zone. From north it becomes steeper towards the south and is more deeper towards the southern part of the study area. It shows that south of Great Nicobar the depth of penetration of the subducting plate is more than 200kms.

Along the arc the mechanism of the earthquakes are generally thrusting in nature. It basically shows the reverse slippage of the overriding plate over the subducting Indian plate. Off the arc there are shallow strike-slip events, and is representative of the spreading ridge extensional earthquakes. Also some characteristic normal faulting events are seen along the volcanic arc, representative of the stress direction there. These are the present day major tectonic regimes of the Andaman-Nicobar subducting environment. The Sumatra-Andaman trench region shows general sense of compression in NE-SW to N-S direction at the shallower portions. In the ASR region, the general trend of stress is in NNW-SSE. In a transition zone
between the ASR and SF, the stress orientations change to E-W direction. In intermediate depths, the orientation of stress, east of Sunda-Andaman trench is NE-SW to N-S. The trend of P-axis is generally N-S, suggesting that the entire area is subjected to compression in relation to the nearby Himalayan syntaxis consistent with the observations of Le Dain et al., (1984) and Guzman Speziale and Ni, (1993).

GPS observations prior to the earthquake show nearly pure convergence across the Andaman Trench, consistent with the previous and independent GPS results of Paul et al., (2001). The sites in the Andaman Islands move westward relative to India. Only one site, Port Blair (PBLR), has a velocity significantly different from zero, because the other sites have only two pre-earthquake surveys one year apart and have large uncertainties. However, the estimated velocities of Diglipur (DGLP) and Car Nicobar (CARN) are consistent with that of PBLR. Port Blair converges with India at a rate of $5.34 \pm 1.38$ mm/yr oriented almost due west. This estimate is slower than the $14$ mm/yr estimate of Paul et al., (2001). Diglipur (DGLP) shows a velocity of $14.82 \pm 2.21$ mm/yr and Car Nicobar (CARN) shows $15.73 \pm$
2.87 mm/yr. This suggests that the Andaman Trench is part of a purely slip partitioned plate boundary, with the strike-slip component of India-Sunda relative plate motion being taken up on the transform fault in the Andaman Sea or on the West Andaman Fault, and the convergent component on the Andaman Trench. In this respect the Andaman Trench is similar to Sumatra, which also exhibits almost full strain partitioning between the subduction zone and Sumatra Fault (McCaffrey et al., 2000). Thus there is no reason to expect a significant strike-slip component to the co-seismic displacements along the Andaman segment, except in the northernmost Andaman Islands where there is a significant bend in the trench.

Some of the differences may be due to reference frame, as Paul et al., (2001) defined an India-fixed frame by subtracting the motion of India from the NNR-NUVEL1A plate motion model (DeMets et al., 1994b) from their ITRF96 velocities. This assumes that the ITRF96 velocities are in the same frame as NNR-NUVEL1A (DeMets et al., 1994b), which is not true, although the ITRF is approximately aligned with the NNR frame. In addition, the motion of India in NUVEL1A is now known to be biased, due to the diffuse plate boundaries in the Indian Ocean (Gordon et al., 1998). Thus their reference frame is different from this study and direct comparison of velocities may be misleading. Unfortunately, the analysis strategy of Paul et al., (2001) (fixing several sites to their ITRF96 coordinates) makes it difficult to place their velocities into the latest ITRF without a re-analysis.

The azimuths of convergence of Port Blair (PBLR), Diglipur (DGLP) and Car Nicobar (CARN), with respect to India (IISC) are probably representative of the motion of the Burmese sliver along the arc. These velocities are not representative
of the full Andaman-Nicobar velocity, due to the unknown degree of seismic coupling there. The predicted NUVEL-1A convergence rate of Indian plate along this margin is 54 mm/yr along N22°E (DeMets et al., 1994a). Locally, due to the back-arc rifting process opening up of the Andaman sea in the ASR occurs in a direction of 327° (Fig. 4.10.c) from present day north with a magnitude of 37.2 mm/yr (Raju et al., 2004 and Curray, 2005). Assuming, uniform subduction without any locking along the various segments of the arc, yields an Indo/Andaman convergence vector of ~40 mm/yr almost due west. A vector closure model (Fig. 5.12) based on these assumptions and arc-normal convergence predicts that in the pre-earthquake period PBLR should move toward India at 85% of the Burma-India convergence rate. Elastic deformation from the locked shallow megathrust causes eastward motion of only 15% of the total convergence rate. Similarly, DGLP and CARN samples only 37% and 37.5% respectively of the India/Andaman convergence.