"Physics of earthquakes and delineation of Himalayan Thrust Faults in Jammu and Kashmir"

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Final Report

Submitted by

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ANNEXURE- I

Detailed report of the work done under the UGC MRP No. 43-538/2014(SR) dated 03/12/2015

Project title: **"Physics of earthquakes and delineation of Himalayan Thrust Faults in Jammu and Kashmir"**

<u>Introduction:</u>

Researchers have recognised the significance of seismic studies in the Himalaya, the youngest and presently an active orogen, which under the ongoing continent-continent collision has been converging. This convergence has developed many seismic sources and has led to rupturing in the region. Himalayan earthquakes pose great seismic hazard and they need to be studied keeping in mind the increasing population of the region. The past and ongoing recorded activity has provided and continues to provide plenty of opportunities to study the region.

Over the past 200 years, various major-to-great earthquakes have ruptured nearly half of the Himalayan arc due to strain accumulation. However, certain regions have succeeded in avoiding any rupture, despite being under stress in the past 500 years (Kashmir being one of these regions). Kashmir Himalaya houses the significant "Kashmir seismic gap" and is one of the least understood regions in the Himalaya. With the advent/development of broadband seismology and interest of scientific community towards the understanding of Himalayan earthquakes, it has become possible to study the Himalayan belt in greater detail.

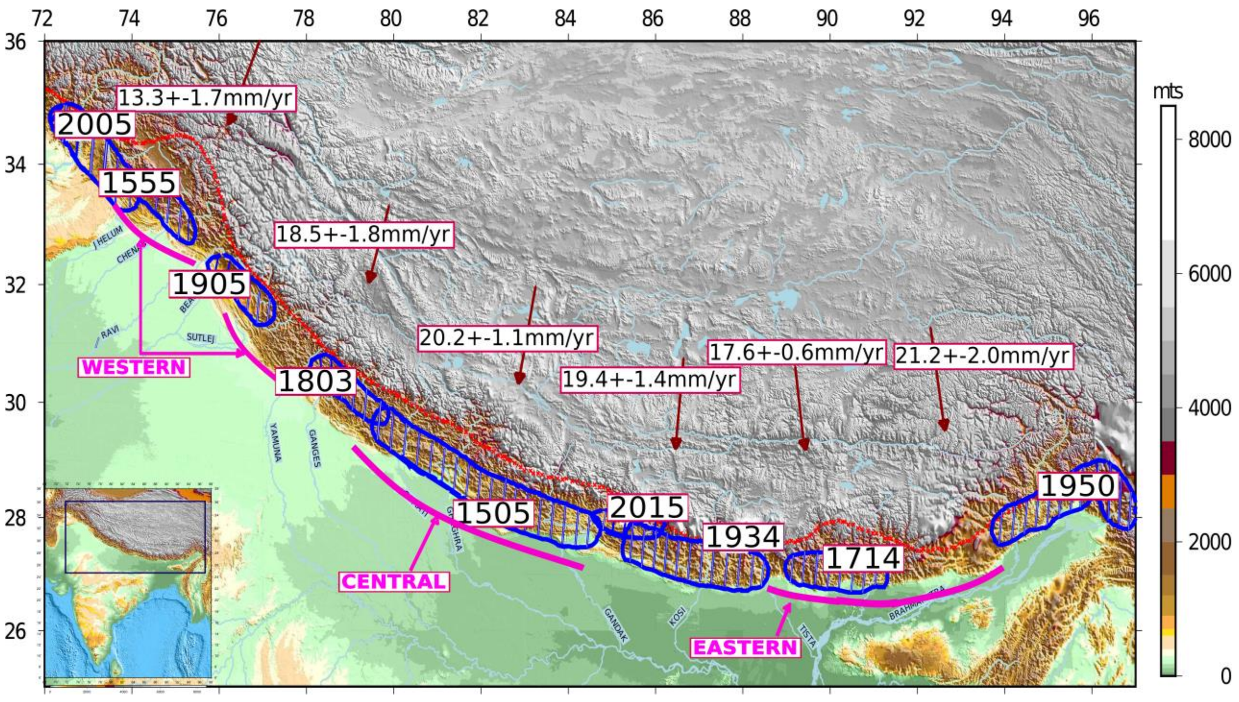


Figure 1*: Past earthquakes in the Himalayan region. Map compares the different rates at which the parts of arc are converging focusing existing seismic gaps, namely Western, Central and Eastern.*

The present study has focussed on Kashmir seismic gap which straddles the northwest India comprising of the states of Jammu and Kashmir and Himachal Pradesh. The region is bound in between 2005, Muzaffarabad earthquake and 1905 Kangra earthquake and coincides with 1555, ~M_w 7.6 Kashmir earthquake meisoseismal zone.

The study proposed in this project is meant to develop basic scientific understanding so far as the source of earthquakes and crustal structure is concerned. This is expected to work as a prerequisite and basic building block towards the assessment of the seismic hazard in the J&K Himalaya and the surrounding Western Himalaya. This study is also important as Kishtwar and Badherwah areas of the J&K Himalayas have shown heightened seismic activity since 2013 which prompted us to initiate work in J&K Himalaya since then. Accordingly this project had been submitted in 2014 and as envisaged therein, we conducted reconnaissance surveys before and after submitting it to UGC. Subsequently this led to the establishment of a broadband seismograph experiment in the region with capital costs being provided for through other projects/ grants. The current UGC MRP has helped us to operate and service some of the seismographs and broaden the scope of study by attempting to look into the seismotectonics of the Jammu and Kashmir Himalaya.

We have attempted to study seismicity in the region of experiment/ interest by extending the reach of the network further towards north-eastward direction (Kishtwar window zone), reportedly active as concluded from our previous studies of Kishtwar earthquake (Mitra et. al., 2014, BSSA). Unfortunately the receipt of the grant under this project from UGC got significantly delayed and was received finally on 04.04.2016 as the project had been submitted in the year 2014. However, we had continued our work with respect to setting up of the seismograph sites in the region. This was done by carrying out detailed discussions and field reconnaissance surveys from time to time leading to finalization of the sketch of the experimental layout in the NW Himalaya.

Objectives:

Scientific component

- to deploy 5-10 additional broadband seismograph systems in the state of Jammu and Kashmir (Himalaya), in the region extending from Basohli at the southeastern end to Poonch at the northwestern end of state, along the Himalayan arc; and from fronts to north in Paddar, across the arc in the state.
- to undertake studies to understand the geometry and motion on the Main Himalayan Thrust.
- to undertake earthquake source studies to understand the nature of earthquake source and pattern in region.
- to create our own local catalogue for events recorded at our network sites for all the earthquake events of magnitude greater than 2.

Community outreach component

- to train the manpower in seismic data analysis and community outreach programmes to through activities so as to increase the awareness amongst common public about the earthquakes and to enhance their engagement in risk management.
- proposed additional public service component, with main focus on the engagement of locals in network deployment.

Work accomplished under the project

The studies proposed under this project have components involving both scientific and social aspect. The work carried out has contributed towards the development of (first of its scale) better understanding of lithospheric structure and earthquake processes beneath the Jammu and Kashmir Himalaya and nearby region. We also have been able to increase awareness among the stakeholders about the potential earthquakes for the region, with prime focus on Jammu and Kashmir Himalaya forming a major part of the Kashmir seismic gap.

The main contributions of the work carried out under this project are

- Develop structural understanding and more precisely, 3-dimensional imaging of the Moho and Main Himalayan Thrust (MHT) beneath the Jammu and Kashmir Himalaya. We have emphasized on the ramp structure of the active thrusts/faults in the region, considerably the most preferred porters of mega-earthquakes in the Himalayas.
- Develop understanding of earthquake processes through study of seismicity distribution or microseismicity, earthquake location and relocation, source mechanisms, seismic moment, energy release, fault geometry, magnitude and direction of motion, rupture area and duration and stress drop.
- Human resource development in seismological instrument deployment, operation, data analysis and interpretation.
- Public awareness towards earthquakes in the Himalaya.

In this regard, we have had divided our work into three sections

1) **Field work**: This majorly included new deployment, maintaining and servicing of already deployed stations. We have generated a huge set of data, to be further used for various seismic studies in the region which ultimately may lead to the development of hazard maps of the region which has not seen much studies so far at a scale at which work has been done in other similarly placed regions in the Himalaya.
2) **Structural studies**: The first half of data analysis has focussed on the structural studies, specifically on lithospheric structure (mainly Moho, MHT and other trailing boundaries) beneath the region of study. The work has been carried out with the help of receiver function studies, H-K stacking and joint inversion techniques.
3) **Source studies**: This covers other part of data analysis. The work consists of seismicity and source mechanism studies and lateral structure of the MHT modelled from the source studies beneath the region.

The intended work was initiated with existing students (PhD students from SMVDU and IISERK) and soon after the release of funds the hiring of Project fellow was done.

Appointment of Project Fellow and procurement of equipment:

After receipt of the funds we initiated the work towards procurement of equipment and recruitment of project fellow through open advertisement issued vide no. No. SMVDU/A&R/R&D/2016/88 dated 27th June, 2016. A total of 13 applications from 8 different states were received. 12 applicants were shortlisted for the interview process. The interview was conducted on 28th August, 2016 and a total of 4 candidates appeared for the selection process. A panel of 3 candidates was recommended by the committee and accordingly candidate placed at S.No. 1 in merit by the selection committee was offered the post of Project Fellow after due approval by the Competent Authority, who after asking for multiple extensions finally joined the post on 07/11/2016. Simultaneously we had initiated the process of procurement of equipment for setting up of the computational facility with data archiving facility (2+2 TB at present). The same has been established and has been helpful for performing the computational work in our lab in addition to the resources available with our collaborators. The project fellow had left the project on 30th June 2017 for better opportunity elsewhere. Accordingly the process of recruitment of Project Fellow was again initiated by way of an open advertisement issued vide no. No. SMVDU/A&R/R&D/2017/144 dated 11th August, 2017. The interview was held on 6th November 2017 and a candidate placed at s.no. 1 in merit by the selection committee after approval was offered the post of Project Fellow on 8th December, 2017. However after waiting for the requisite period she declined to join for better opportunity available to her elsewhere. As the project was ending on 30th June, 2018 we did not attempt to appoint the project fellow after that as period was insufficient to undertake such an exercise. However the Ph.D. students continued to work on the project simultaneously.

Field stations-Experiment layout:

We aimed at understanding the structure and source mechanisms of the seismic activities encompassing the lithosphere beneath the Jammu and Kashmir Himalaya. Our interest was to develop an understanding of the nature of deformation and the pattern followed by the seismic activities which ultimately would help us to assess seismic hazard for the region; Kashmir seismic gap. The deployments have been purely based on the region of our interest, known as Kashmir Himalaya. We have set up our network to cover the front of Kashmir valley, with major thrust system lying beneath the region (Figure 1, 2).

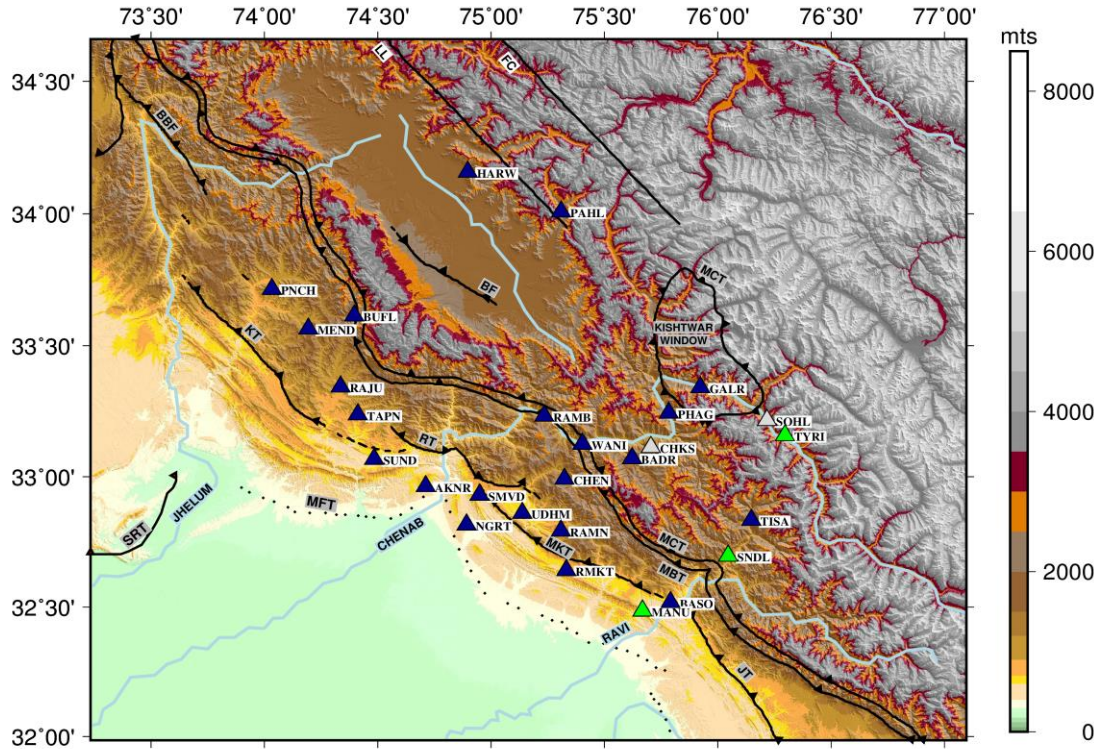


Figure 2: *Seismograph sites in the Jammu and Kashmir Himalaya denoted by triangles. Blue triangles indicate stations used for the current analysis; grey indicate insufficient data; green indicate ready for deployment. The lines parallel to the Himalayan arc plotted in black are fault lines in the existing thrust system in the region with small triangles on it highlighting the direction of thrust dip. Dotted black line at the front of this thrust system marks the expected MFT for the region (blind in north-western Himalaya). Grey lines indicate directories of the rivers flowing in the region.*

The above network (Figure-2) has been set in a non-linear fashion, along and across the Himalaya arc, in the region. The present picture and layout of the network is a result of hard work and mid-course corrections that have gone in over a period of several years.

The studies demanded availability of continuous data (24x7) which was accomplished with the deployment, maintenance and servicing of the seismographs (instruments deployed under various other projects/ grants used for the purpose) in the area of interest. The instruments were loaned by our collaborator at IISERK on long-term basis who also happens to be the Co-PI of the project.

This seismological experiment was initiated back in 2013 and presently we are operating 24 stations in the region. The network of stations have been setup over these years. We have used data from 22 of these sites for analysis against a projected number of 10. Figure 2 (above) shows the locations of each of these seismographs.

Work for vault building was already initiated and completed at some of the sites (vault building is not part of this MRP). We have carried out field work from time to time as per requirement under this MRP, for servicing of these stations and other stations from which the data is utilised for carrying out computational work as per mandate of this project.

<u>Servicing and Data Archiving:</u>

Our requirements for deploying Seismograph stations, demanded setting up of these instruments mainly in the remote and inaccessible areas, often away from cultural noise. We also required exposed bedrock, a solid cement base otherwise, for housing the instrument inside a vault.

As the instruments tick on continuous mode basis, these sites needed to be serviced regularly after a site is set-up and commissioned. These required periodic and need based servicing-cum-surveillance (in absence of real-time remote monitoring) to ensure the good health of the instrument and uninterrupted recording of high quality data. These also require periodic servicing, so as to retrieve high quality data from each site and to archive the same for processing and further analysis. Thus deployments were followed by continuous monitoring of their proper functioning. These sites have been deployed with Gurälp CMG-3TD/ ESPCD instruments. Data archiving was done at IISER Kolkata (Co-PI/ Collaborator) in the initial phase of our project, since we did not have any data archiving and processing/ analysis facility in our lab at that time. However we later on could establish archiving and storage facility and are using the same as parallel archiving and data processing facility here at SMVDU, Katra. Such a facility is essential as this data shall be useful for various types of studies in future as well. We shall continue to conduct the servicing of instruments (Table 1) as per requirement of work in future as well. Servicing of the instruments is one of the most important activities in such experiments. We are maintaining these stations and are servicing them even today while we finalize and submit this report.

Table 1: Seismographs used for data analysis

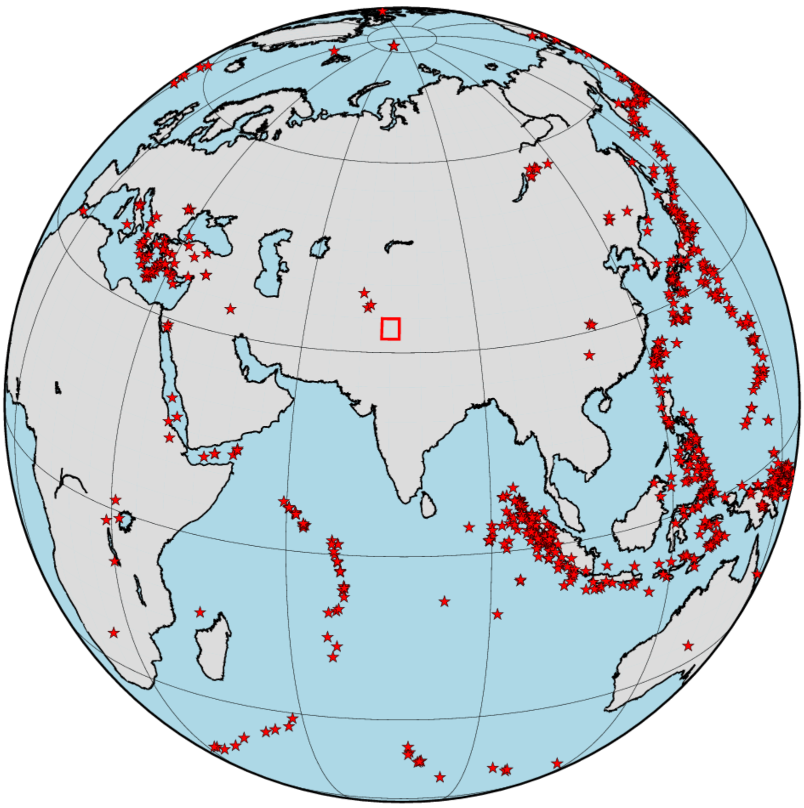
S.No	STATION	LOCATION (LONG., LAT., LEV) (in deg, m)
1	Akhnoor (AKNR)	32.963072 74.711436 550
2	Bhaderwah (BADR)	33.070688 75.622045 1521
3	Nagrota (NGRT)	32.816663 74.891973 392
4	Phagumarh (PHAG)	33.243887 75.78374 1141
5	Udhampur (UDHM)	32.860758 75.137445 704

6	Tattapani (TAPN)	33.237498	74.412398	762
7	Sunderbani (SUND)	33.067785	74.48437	590
8	Smvdu (SMVD)	32.930201	74.94861	643
9	Ramnagar (RAMN)	32.792593	75.30802	860
10	Doda (WANI)	33.12545	75.40282	1221
11	Chennani (CHEN)	32.99153	75.32370	1465
12	Rajauri (RAJU)	33.34381	74.33628	918
13	Bufliaz (BUFL)	33.6139	74.3964	1866
14	Galhar (GALH)	33.34122	75.92287	1788
15	Pahalgam (MAML)	34.00853	75.3089	2216
16	Srinagar (HRWN)	34.15835	74.8971	1641
17	Basohli (BASO)	32.518606	75.79152	628
18	Mendhar (MEND)	33.56413	74.19395	1458
19	Ramban (RAMB)	33.22986	75.23916	1065
20	Poonch (PNCH)	33.71506	74.0331	1360
21	Tissa (TISSA)	32.834187	76.147790	1711
22	Ramkote (RMKT)	32.641372	75.331724	685
23	Sohal (SOHL)	33.216259	76.217072	1932
24	Chaksoo (CHAK)	33.112908	75.704696	1500

Data Analysis:

Structural studies:

The Jammu and Kashmir Himalaya, lying in the seismic gap, between the 1905 Kangra earthquake and the 2005 Kashmir earthquake, has accumulated ~5-7 m of potential slip (as indicated by studies by various groups worldwide), since the last major earthquake in 1555. Till date, very limited knowledge, exists about the crustal structure and seismotectonics of this segment of the Himalaya. Out of the seismological experiment of 24 broadband seismograph stations, we have acquired and used data from 22 of these stations to study the crust and upper mantle velocity structure for the present study against originally projected number of 10 sites.



These stations are situated along (a) SW- NE and (b) SE-NW profiles spanning the Himalayan foothills, the Lesser and the Higher Himalaya.

Teleseismic earthquake data from 22 of these stations have been used to compute P-wave receiver functions (P-RFs). We have used a total of ~999 teleseismic events of magnitude ≥ 5.0, for the structural analysis, calculation of P-RFs (Figure 3).

Figure 3: *Event map, shows the distribution of events recorded at the deployed sites used for the present study. Red stars shows the event location and red square denotes the region of network deployment. The specific region of densification of events, states and corners our studies in particular directions bounding our results to certain zones and directions.*

A total of ~4400 P-RFs were calculated from the data recorded at these sites in the past 5 to 6 years. The calculated P-RFs were stacked and analysed for local structures in the area beneath each station. Forward modelling of the P-RFs reveals a NE dipping Main Himalayan Thrust (MHT), first observed at a depth of 4-6 km beneath Shivalik and close to 8 km beneath the Lesser Himalaya, and deepening to 14 km beneath the Higher Himalaya. The MHT marks the top of the under-thrusting Indian crust and has a ramp-flat-ramp geometry.

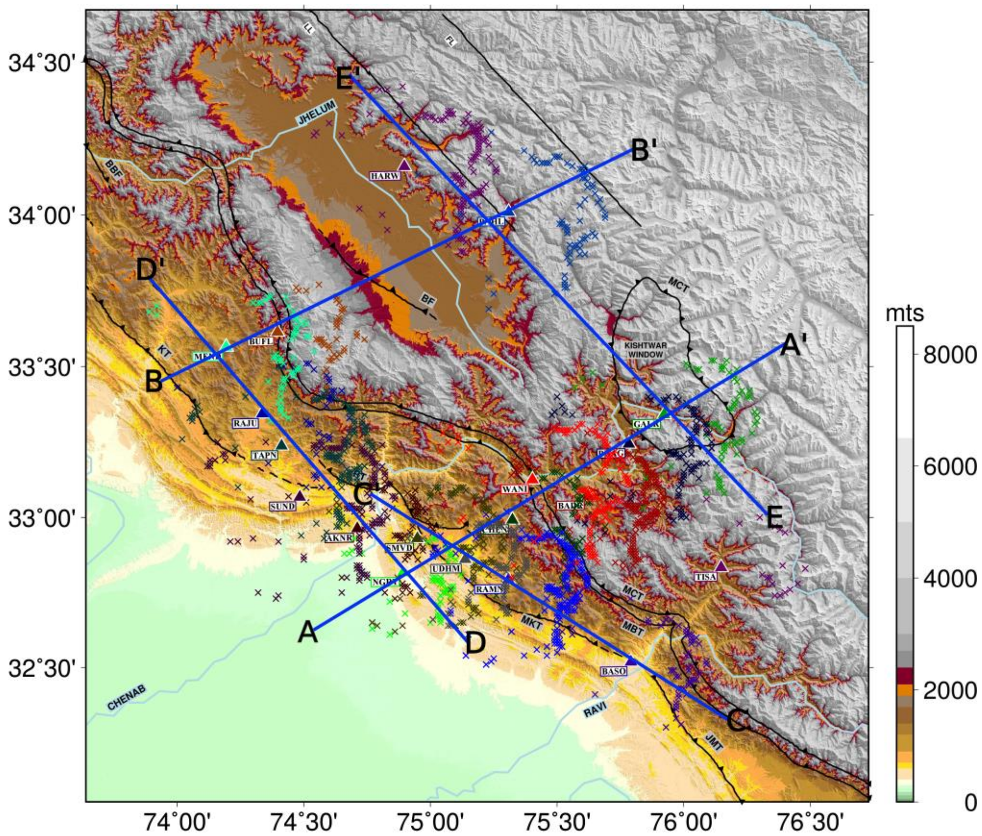
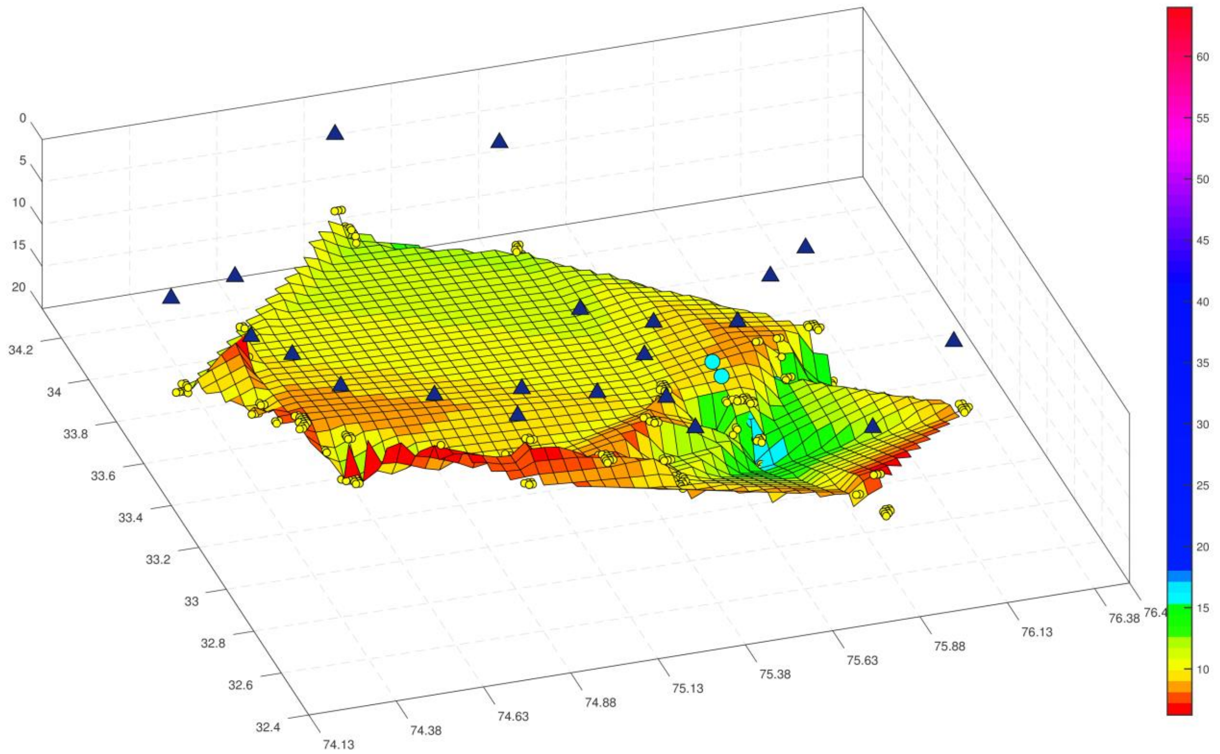


Figure 4: *Figure shows the profiles (marked in blue thick lines) selected for structural studies in the region. The coloured cross marks are the piercing points of the data (best) used for present study, with each colour recorded at each individual site.*

From Common Conversion Point (CCP) stack of P-RFs we observe that the ramps are associated with splay faults which align with the surface trace of the MBT and MCT (profiles used for the study are shown in Figure 4). The structure has been mapped along various profiles in the region, (shown in Figure 4) for 2-D map, visualising the lateral variation of MHT and other major crustal layers of the structure.

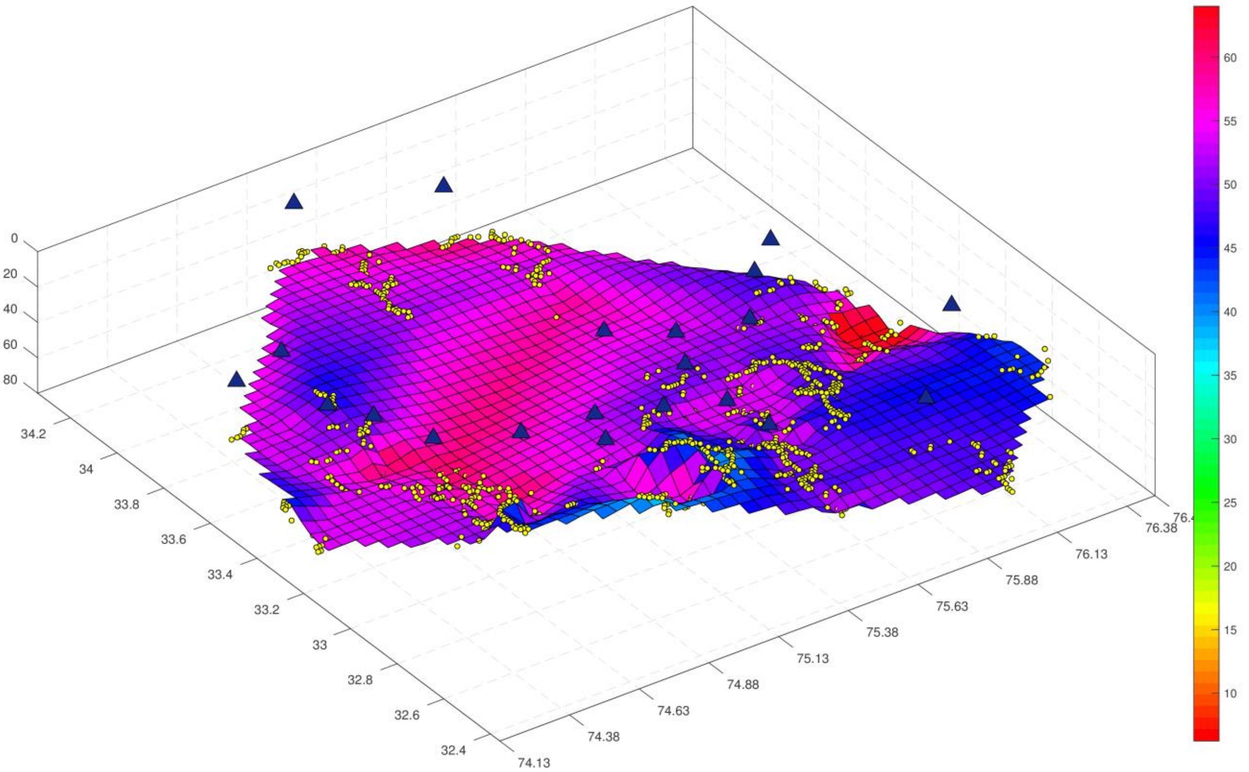
We have employed H-K stacking for estimating depth and V_p/V_s for crustal and upper mantle structure beneath the Jammu and Kashmir Himalaya. From H-K stacks we model the total crustal thickness beneath the Lesser Himalaya to be ∼44 km, increasing gradually in the NE direction to ∼54 km beneath the Higher Himalaya. The average crustal V_p/V_s varies between 1.71 and 1.83. The P-RFs from each station were stacked in narrow bins of back-azimuth and distance and were inverted jointly with Rayleigh Wave Group Velocity dispersion data. Jointly inverted models show, crust separated from upper mantle by Moho at ~ 38 – 40 km with ~ 4 – 8 km thick Himalayan wedge on top of it, in the front of the Himalaya in the region. The Moho deepens to ~further north to ~ 60 – 64 km with ~12 – 16 km thick top wedge, beneath the higher Himalaya, to just south of Zanskar ranges. The top Himalayan wedge is separated from Indian crust by MHT. The top of the Indian crust is highlighted by the negative arrival on the P-RFs, which marks the MHT and the base (Moho) is highlighted by the large positive impedance contrast boundary on all P-RFs. The S-wave velocity models obtained through the joint inversion reveal a two layer Indian crust under-thrusting the Himalayan wedge. (Copy of the posters through which results have been presented is annexed herewith)

We have calculated and plotted 3-D map of the Moho and MHT (shown in Figure 5, 6) beneath the Jammu and Kashmir Himalaya and incorporated the depth knowledge obtained from these models for the source studies enumerated in the next section.
Both the MHT and the Moho dip gently to the NE at $\sim 7^\circ$ with significant second order dip variations, both across and along the Himalayan arc.



Figure, 5: *3-D structure plotted for MHT beneath the Jammu and Kashmir Himalaya (depth colour coded as per bar). The light blue coloured circles are event locations in the region and yellow circles are piercing points (plotted at MHT depths) shows the region pierced by RFs which are used in calculating MHT depths, beneath the region. MHT depths indicate the northward dip in along and across strike directions, validating the common understanding of deepening and dipping Indian crust, skidding under the Eurasian plate.*

Recent seismicity in this segment of the Himalaya is marked by the sequence of earthquakes in the Kishtwar region in 2013, the largest one being the m_b 5.7 event which occurred beneath Kishtwar. Source mechanism of this earthquake shows it be a thrust event that occurred at the junction of the MHT and the upward splay of the MBT. This event marks the unlocking zone on the MHT and we conjecture that the occurrence of these sequence of earthquakes marks an important stage in the earthquake cycle of mega-thrust events in the Himalaya.



Figure, 6: *3-D depth structure plot for Moho beneath Jammu and Kashmir Himalaya (depths colour coded as per bar). Yellow circles are piercing points calculated for RFs, at Moho depths beneath each station in the region. Figure shows the dip in Moho along and across the strike directions, validating the common understanding of deepening and dipping of the Indian crust, skidding under the Eurasian plate. The structure has local up-warping in the Moho beneath Pir-Panjal and equivalent Higher Himalaya in the NE as well as NW directions.*

Seismicity studies:

The seismicity studies are a prerequisite for accurately locating earthquakes together with the structure of existing faults, finding the extent of stressed zone and active faults in a given region of interest. This is one of the most important as well as significant steps towards understanding of the seismotectonics of a given region and are critical in arriving at the hazard maps. So far we have analysed more than 1300 micro-earthquakes and relocated these using data from our local network. The continuous broadband data was subjected to Coalescence Microseismic Mapping (CMM) (program of Drew et al., 2013) for detection of local earthquakes between 1.0 and 5.0 with manual refining which later were relocated using NLLoc (Lomax et al., 2000) and HYPODD (Waldhauser and Ellsworth, 2000) algorithms. All the methods used velocity models (Sharma et al., 2018) or initial gridding for calculation of travel time. Our studies concluded from the initial study and analysis **(a)** seismicity clustering in two significant regions shown by location profiles **(b)** active nucleation occurring at the zone of splaying of MBT-MCT from MHT shown in depth profiles.

Both the regions of interest are reported to accommodate significant local faults and have been reportedly active in past earthquakes. One of these lies in the Pir-Panjal region between the Reasi Fault and the ~ 3.5 km elevation contour and other is in the adjoining region of western syntaxes and IKSZ. The location profile in the Pir-Panjal region shows two active clusters, one at the depth of 3 - 12 kms and the other at 14 - 20 kms. The micro-earthquakes almost become non-existent and could easily be identified with the MHT locking line. The MHT is seen to be dipping to the north. The cluster on the north is found to be at a similar depth (10 - 18 kms) but the dip on the MHT is not evident and would require more studies/ analysis. From this study we observe that the seismicity dies out at the depth of 20 kms and beyond ~ 33.3^o which possibly could be a sign of brittle to ductile profile transition. The shallower seismicity in the splay fault has the dominance in the NE region. This could be due to the relative motion in the Karakoram fault caused by strike slip process. We also observe that the seismicity in the region 2 is peaking periodically while it is constant in the region 1. The study highlights the active region within J&K (Paul et al 2018) and provides scope for further study.

<u>Relocation:</u>

These events obtained from NLL are relocated for the catalogues, with accurate relative timings obtained by cross-correlation of the waveforms, for enhanced location precision. The seismicity was clearly segregated into two prominent clusters with significant distance separation between events clustered as NE and SW clusters). The diffused seismicity was cleared into these two sharp clusters with NLL relocation. For further testing HypoDD was repeated for these events.

The seismicity is apparently divided into two distinctive zones of different depth ranges, however, the seismicity pattern is in parallel to the normal deformation front. The events are clustered at a distance of ~22kms. The NE cluster, near Kishtwar Window (KW) shows activity with depth range of 13-18 km whereas the SW cluster has shallow activity, at the depth range of 7-15 km. The deeper activity in the NE cluster in indicative of the activity in the vicinity of the depth of locked MHT in the region (Sharma et al., 2018). For the SW cluster the shallow depths point towards the activity culminating in vicinity of the MHT-MBT splays in the region (Sharma et al., 2018).

However in both the clusters the seismicity deepens towards (from) NW to SE and is not vertically up. This indicates to some shallow local structures in NW direction. The observed strikes and dips of the fault planes for all the earthquakes have been used in these studies. (A copy of the paper in which results have been published is annexed herewith)

<u>Seismotectonics of the region:</u>

The focal mechanism of 2013, M_b 5.7 Kishtwar earthquake and hypocentral location of 24 well located events of magnitude > 3 within ±50 km of profile, overlay was plotted with CCP. The hypocentre of local events collides with the depth of splay thrusting zone. Earthquake cluster at the MBT-MHT splay thrusting. The Kishtwar earthquake (Mitra et al 2014) occurred on a very shallow (~29^o) NE dipping plane, which occurred close to the unlocking zone, in the region accumulating strain. This plane aligns with MHT-MBT splay in the region.

This hints at the region which is ~150 kms wide, locked all the way to the front from this region of unlocking. The local activity in the region clusters at the depth of MHT in the region. The convergence rates for the region have normal component of ~11 mm/yr in the Kashmir Himalaya. This hints at the accumulated strain in this region.

The different scenarios of rupture on the MHT, either through the splay faults or through rupture of the entire detachment, estimates to an earthquake of magnitude Mw 7.8 – 8.5. The geometry of the detachment surface (MHT) and the presence of asperities will influence the initiation, termination and lateral limit of the faulting, and therefore, the size of the earthquake.

Training of Manpower/ Human Resource Development:

Training of human resource is one of the important objectives of this project. We have trained two students (JRF of this project had joined in November 2016 is included in the two) from SMVDU and one from IISER Kolkata in deployment of seismograph stations in J&K Himalaya in past couple of years. Two of these are already registered for Ph.D. programme in SMVDU and IISERK respectively and have been working in this area since 2013. One of these students Ms. Swati Sharma has submitted her thesis at SMVD University based on the work carried out under this project and the other Mr. Debarchan is about to submit his thesis at IISERK. Apart from these we have many other students from IISERK and SMVDU who have got hands-on training and practise so far as the commissioning and servicing of Gurälp seismometers in the field of Jammu and Kashmir are concerned, and have been trained to handle the instruments in the field from time to time. These students has been involved in other experiments in other parts of Himalaya as well. Besides this we have conducted several hands-on sessions for students both in laboratory as well as at the seismograph sites from time to time.

Outreach:

The PI and Co-I of the project have conducted many outreach activities to sensitize the society towards the hazards posed by earthquakes some of which include the popular lectures at various platforms both within and outside the State of J&K. A national level training programme in this subject area was organized and was attended by over 30 young scientists from all over India and a couple of them from Cambridge in November, 2015 (just before this grant was released). This activity was supported by SERB, DST, GoI. We shall continue to engage ourselves in such activities in future as well. This is one of the objectives of this project. We have also organized several sessions in INSPIRE Science Internship Camps at our University and Leh. Through this activity we have reached over 3000 students directly.

Outcomes:

Accomplishments under this project are following:

- Have put in joint efforts towards the dissemination of relevance of earthquake sciences and laid emphasis on introducing, initiating and delivering the importance of geophysical studies in the state of Jammu and Kashmir at this scale in the University.
- Have developed capable human resource in this field of study.
- Have extended seismic network in the state, initiated in 2013 (under various projects) and maintained this network over the period of project. Continuous servicing and maintenance conducted under this project has helped to operate the instruments for as long as possible without interruptions (in terms of power and other instrumental or atmospheric problems). We have continued to acquire and add continuous data for a longer period, sufficient enough to contribute towards seismological studies in the region of NW Himalaya for next 15 to 20 years.
- Have performed analysis for studying lithospheric structure beneath Jammu and Kashmir Himalaya and seismicity in the region. The data acquired during 2013-2019 has helped us to quantify the velocity structure for the region which is a prerequisite to progress towards the quantification of probabilistic Seismic Hazard in the region.
- Developed and enriched the human resources in the area of seismology in Jammu and Kashmir which is in great need of such and other earthquake studies.
- Another aspect of this project has led us to organise various programmes which are expected to motivate the young generation to pursue these studies in the state and prepare the next

generation of Indian scientists. We have recently recruited three more students to work on this problem with grants from other projects.

- Have initiated many interactions and have highlighted the prevailing natural hazards in the state in those interactions. With these interactions we have tried to spread awareness at various occasions at school level towards the persisting geophysical problems and their societal impact among the young generation urging them to pursue and maintain the growth of seismological studies in the state. We have also engaged ourselves in very basic interactions with local society, mostly at places of deployments.
- The work carried out under this project has been presented at the prestigious European Geosciences Union general assembly and American Geophysical Union meeting.
- The work done from the data acquired under the grant of this project has been presented (listed in publications). This has paved our way to enter into the international research community working on Himalaya. We have successfully attracted the interest of multiple researchers internationally who are keen to collaborate with us. The Project has helped students and PIs to develop a strong collaboration for interdisciplinary studies at an International level.
- The PI of this project also got Cambridge-Hamied visiting Lecture Scheme fellowship during the period of this project in 2018.

We have conducted and set-up our experiment in one of the most difficult places under this and other projects. The difficulty was propagated from difficult terrains and challenging locations both geographically as well as socio-politically. We have faced many difficult situations since the beginning in executing the mandate of this project. The conducted studies on lithospheric structure with main emphasis on Moho and MHT, on seismic source and on seismicity, may even be useful for initiating many other studies to be carried out with added data in next couple of decades for various scientific studies.

We are in the process of expansion of this network to Himachal Pradesh and will continue to include more sites in Kashmir valley as well. We will continue processing of data for better understanding of the region and many other studies required in the region.

We are thankful to UGC for supporting our work. We are also grateful to IISERK (part of UGC project) and Department of Earth Sciences, University of Cambridge, UK for extending excellent support to the team towards successful execution of the project. Through this research support, Indian scientific community is expected to benefit by being able to generate improved knowledge of earthquake hazard in the Himalaya and the Indo-Gangetic plains, which are some of the most densely-populated regions of the country. We will also be able to better understand the earth processes taking place within the active outer layer beneath the North Western end of Himalaya.

Continuing Work:

We are in the final leg of generating an earthquake catalogue of local events for all events greater than magnitude of 2, w.e.f. 2013. This component will be accomplished soon.

Publications: Following papers/ posters have been published/ presented in journals/ conferences.

Journal papers:

- Himangshu Paul, Keith Priestley, Debarchan Powali, Swati Sharma, Supriyo Mitra and Sunil Wanchoo, “Signatures of the existence of frontal and lateral ramp structures near the Kishtwar Window of the Jammu and Kashmir Himalaya: Evidence from microseismicity and

source mechanisms” Geochemistry, Geophysics, Geosystems, Volume 19, Issue 9, pp. 3097-3114, 2018. https://doi.org/10.1029/2018GC007597

Conference papers:

- Swati Sharma, Debarchan Powali, Supriyo Mitra, S. K. Wanchoo and K. Priestley, Lithospheric Structure and Earthquakes beneath Jammu and Kashmir Himalaya, Geophysical Research Abstracts, Vol. 20, EGU2018-11932, 2018, EGU General Assembly 2018, European Geosciences Union General Assembly, Vienna, 8-13 April, 2018 (poster). https://meetingorganizer.copernicus.org/EGU2018/EGU2018-11932.pdf
- Himangshu Paul, Keith F. Priestley, Supriyo Mitra, Sunil K. Wanchoo, “The extent of locked zone in the Jammu and Kashmir Himalaya as observed from Micro earthquake study”, T23B-2918, AGU, Fall Meeting-2016.
- Swati Sharma, Debarchan Powali, Supriyo Mitra, S. K. Wanchoo and K. Priestley, Crustal Structure of Jammu and Kashmir Himalaya, Eos Trans. AGU, Fall Meet. Suppl., Abs. T23B-2919, American Geo-physical Union meeting, San Fransisco, 11-15 Dec., 2016 (poster). http://abstractsearch.agu.org/meetings/2016/FM/T23B-2919/author1.html

Collaborations:

This work enumerates from an excellent and robust trilateral collaboration between University of Cambridge, SMVDU and IISER Kolkata. Part of the scientific analysis was performed at Bullard Labs, University of Cambridge as a pilot study and we shall continue the work in SMVDU and IISER Kolkata beyond the completion of this project as well.

MOU:

We have also signed a Memorandum of Understanding (MoU) under the trilateral collaboration between Shri Mata Vaishno Devi University, Indian Institute of Science and Education and Research, Kolkata (IISERK) and University of Cambridge (CU). We will continue working with the two institutions to further strengthen our collaboration to undertake other projects in the region and in the nearby region. As a part of this effort and work carried out in the past we have recently received a collaborative mega project from Royal Society London which is expected to give impetus to our efforts in Himalaya.

Future Work:

We plan to continue supporting the smooth operation of the network for another few years (deployed through various projects) and to support reconnaissance surveying towards the expansion of the network as well. We plan to retrieve data from the deployed stations and in future servicing use the data for seismicity studies and to complete the catalogue of local earthquakes. The data collected from this project will be utilised for further studies of source mechanisms and attenuation structure in the region (This work is projected to be undertaken in the next 4 to 5 years).

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