Introduction to Engineering Seismology
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Lecture – 56
Seismotectonics of India - 3

Welcome. So we will continue our lecture on engineering seismology. So we have been discussing about the seismotectonics of India. We detailed discussed about the northern seismotectonic and northwestern seismotectonic and then we have been end up with the eastern seismotectonic in the last class. So we have been emphasizing the seismotectonics because the seismotectonic details are arrived based on the recorded earthquake in the region.

That is one of the very important aspect where there are several seismotectonic parameters VP velocity, VS velocity, the density of the rocks in the region, types of the rocks in the region and also people make a trench and drill a borehole and confirm a different geological materials associated in each location and depth of earthquake, the source mechanism, beach ball what type of beach ball it is occurring, what type of magnitude is occurred. So all those information are provided in the seismotectonic studies.

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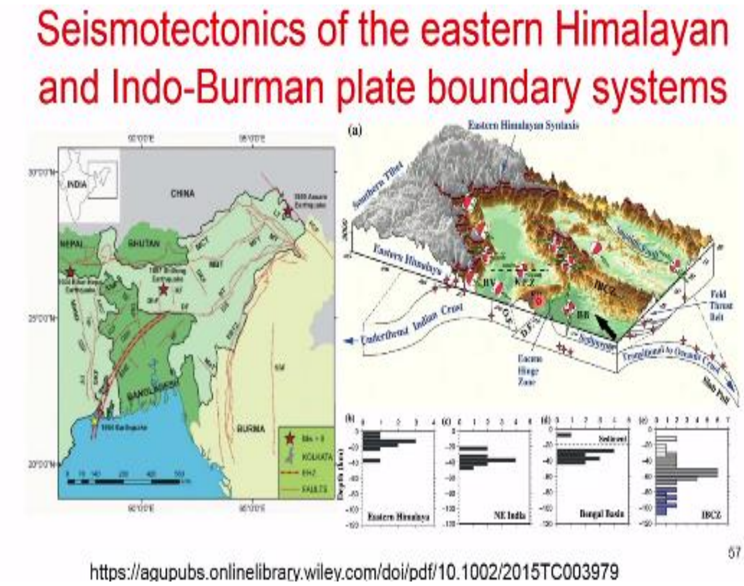

If we look at the eastern part of seismotectonic which we are discussing that so we have seen the Eastern Himalaya majority of the earthquakes are occurring basically up to 25 kilometer. When you move to the northeastern part the earthquakes occurring from 20 to 50 kilometer depth. So the Bengal basin so the earthquakes are occurring in between 25 to 45 kilometer and also there is a shallow earthquakes between 5 to 10 kilometer that also we can see.

So if we go to IBCZ area so where you can see that the earthquakes are occurring so almost up to 110 kilometer depth. So which indicates that when you want to consider hazard analysis at particular location as a source and then what type of depth you should take so that is the information you provided. You can see this is the three dimensional figure where the starts are indicating the different earthquake and then the source mechanism.

And then the fold thrust belt and geological formations all those information you will get from the seismotectonics. So this is you can understand from our discussion that so basically the east and then the west and north we have the very complex geological seismotectonical formation which has to be accounted whenever you do any earthquake hazard parameter prediction for any development. So let us come back to the southern part of India as we discussed well in the eastern and western and western particularly we even discussed about the Gujarat region, western part of India.

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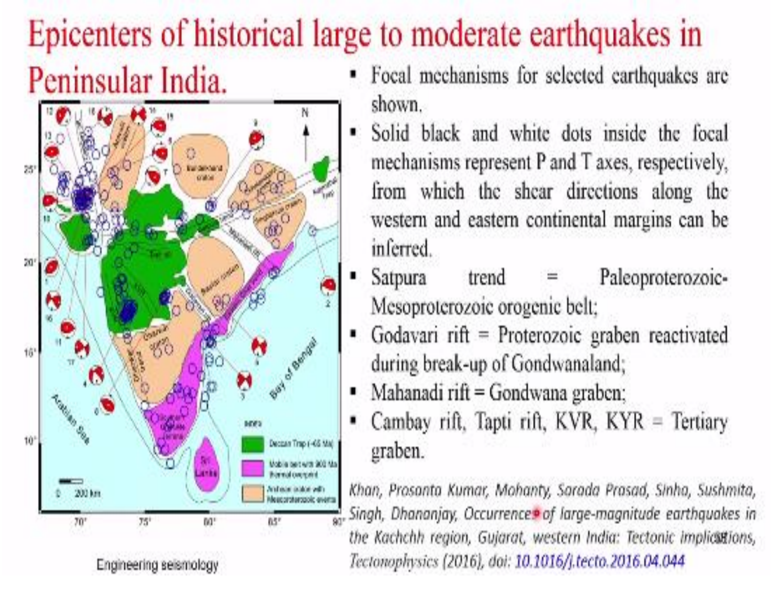

So the peninsular India also has a complex geological formation you can see here so the Aravalli Craton in the orange color this is actually Aravalli Craton so then there is Bundelkhand Craton and then the Chhotanagpur Craton and then the Mahanadi fault, the Bastar Craton and then Godavari rift, Dharwar Craton. So Dharwar trend, Southern Granulite Terrain then again this is basically another like Koyna region.

So this is actually a very complex geological formation. You can also see the minor earthquake recorded in this region whatever derived here source mechanism you can also see the different type of source mechanism. You can see the source mechanisms are not uniform throughout the peninsular India. So the focal mechanism for the selected earthquakes are shown like beach balls are shown there.

Solid blacks and white dots inside the focal mechanism represent the P and T axes representatively from the shear direction along the western, eastern continental margin can be inferred from that where the shear taking place. So the Satpura trend so that is what you have seen the different geological formation. You can see that wherever there is a joins you can see there is a earthquake in this joins you can see.

So the geological material basically when it forms with the different geological edge the joins together and this has a potential to fracture when there is a moment and other things are taking place. So this particular data was actually obtained from this publication which is from the Technophysics 2016 where I was telling that as and much data are available this interpretation and then the understanding of siesmotectonic are refined so that is what we can see here.

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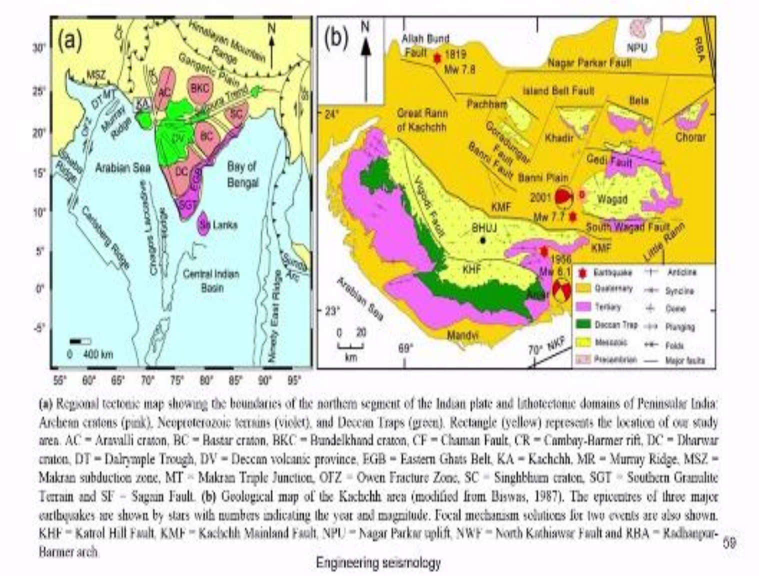

So this is again further to a similar kind of this one here they have given so the DV is actually Deccan Volcanic Province this one DV the green one so DC is actually Deccan Craton so the BC is actually Bastar Craton so like that these are all actually geological name which indicates the different formation of the geological material there. So this is the geology complex geology we have seen in the basically in our Gujarat region where you can see the different geological material moment this is actually the beach ball for 2001 earthquake. So this kind of studies one has to go through before doing any analysis seismic hazard analysis in the region.

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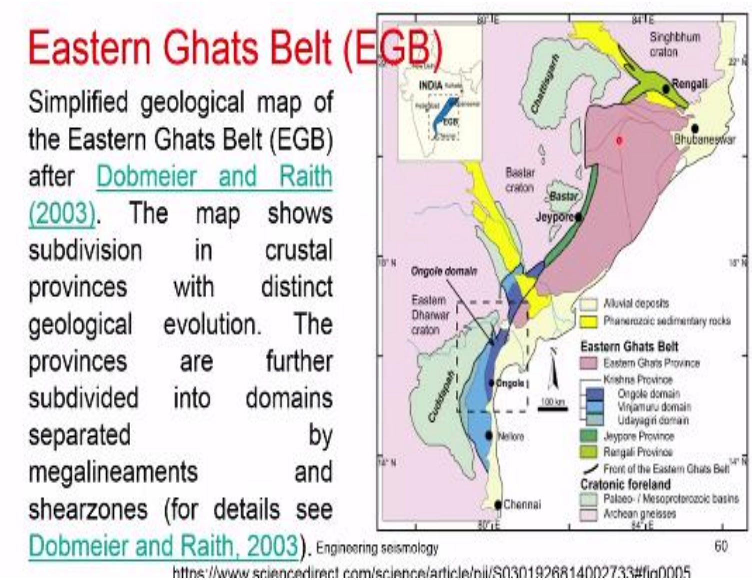

So this is again the Eastern Ghat Belt where the Cuddapah and other regions are investigated here also we can see so there are several geological material formation particularly Warangal and nearby the area. So if you see this kind of geological material formation you can see basically this region and then this region or this region. Three regions we can take into account and then if you look at a seismic activity there you can see.

So wherever there is a geological complex you will have the more earthquakes that is what it indicates. So those kinds of information will be easily understood from this kind of previous earthquake data on analyzing the microearthquake data will help to understand this kind of geological formations and how the crustal evolution is taking place, what is the crustal velocity there, what is the crustal density there.

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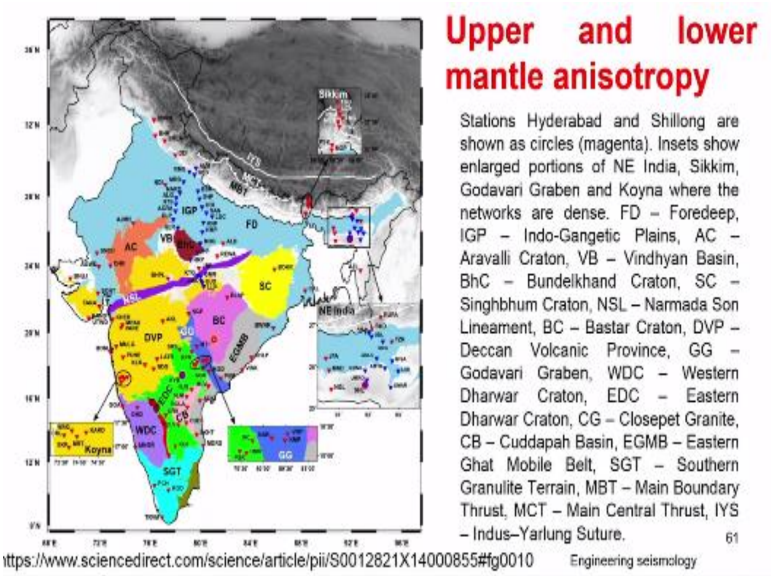

So this is again the upper and lower mantle anisotropy in India. So this particular article actually gives the details about the different seismic station so run a different part of India and what are the information they collected from the entire India they tried to map a different geology complex phenomena I can see here. So this is actually the KGF is one of the station so basically here the so northeast portion shown here what are the seismic station they used.

Then the GG basically the GG is actually Godavari Craton so the Koyna where the network are dense so where they tried to map all this information and try to understand how the seismotectonics are varies in this region using this kind of data. So these stations some of them are done purposefully to map a seismotectonic. So what they do basically they deploy a station for a year or 2 year, 3 years, 5 years part of research project.

And then they tried to collect a data that data they analyze. Some of them maybe the permanent station, some of them maybe the installed station to understand. Based on their observation and way it changes how the seismic wave changes from this kind of (()) (08:07) and then try to mark a boundary this plates with respect to special variation as well as depth variation that is what they tried to do that which is very useful to interpret several geology and seismotectonic behavior of this one.

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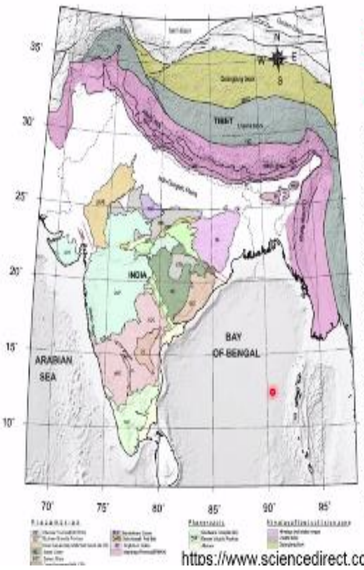

Simplified geological map of India and Tibet

SGT, Southern Granulite Terrain; CG, Closepet Granite; WDC, Western Dharwar craton; EDC, Eastern Dharwar craton; CB, Cuddapah Basin; DVP, Deccan volcanic province; NSL, Narmada–Son Lineament; GG, Godavari Graben; BC, Bastar craton; CTB, Chattishgarh Basin; SC, Singhbhum craton; VNB, Vindhyan Basin; BUC, Bundelkhand craton; DAFB, Delhi–Aravalli Fold Belt; SP, Shillong Plateau; MKH, Mikir Hills; MHR, Mahanadi Rift; CBR, Cambay Rift; MFT, Main Frontal Thrust; MBT, Main Boundary Thrust; MCT, Main Central Thrust; ITSZ, Indus–Tsangpo Suture Zone; BNSZ, Bangong–Nujiang Suture Zone; JSZ, Jinsa Suture Zone.

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So you can see the simplified model of map of Indian and Tibet where you can see that the Southern Granulite Terrain basically this one so this one and then the Western Dharwar Craton so this one so then the Cuddapah basin this one again in that Dharwar Craton there is a complex geological formation I can see here. So then here this part so where these are all the places where you can even got some kind of earthquakes reported on this Jabalpur earthquake, Warangal earthquake those are all the earthquakes are wherever this kind of complex setting geological formations are available.

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- Singh et al (2015) review presents an account of the variations in crustal and upper mantle structure beneath the Indian subcontinent and its environs, with emphasis on passive seismic results supplemented by results using controlled seismic sources.
- Receiver function results from more than 600 seismic stations, and over 10,000 km of deep seismic profiles have been exploited to produce maps of average crustal velocities and thickness across the region.
- The crustal thickness varies from 29 km at the southern tip of India to 88 km under the Himalayan collision zone, and the patterns of variation show significant deviations from the predictions of global models.
- The shear-wave splitting results clearly show the dominance of absolute-plate-motion related strain of a highly anisotropic Indian lithospheric mantle with delay times between the split S phases close to 1 s.
- Further installations of permanent and temporary stations will fill these gaps and improve understanding of the geodynamic environment of the Indian subcontinent.

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So this analysis of data so basically done by the Singh on 2015 so review the present and account of the variation of the crustal upper mantle structure beneath the Indian subcontinent at each environment with emphasis on passive seismic result supplemented by the result using the controlled seismic source. So the people they recorded the passive seismic waves which comes from the Earth as well as any minor earthquake anywhere else or major earthquake all around the world and that data.

And they also used a controlled seismic source like blasting or some kind of seismic source so where they try to estimate a receiver function from the 600 seismic stations over 10,000 kilometer deep seismic profiles have been exploited to produce a map of average crustal velocity and thickness across the this southern part. The crustal thickness varies from 29 to southern tip of India and 88 to the upper of the Himalayan Collision zone.

So now from this study you can get the crust thickness varies from 29 to the almost 88 kilometer Himalayan. The pattern of variations shows the significant deviation from the prediction of global models. So they here emphasize that the pattern is not consistent with any of the global similar kind of tectonic pattern. The shear wave splitting results earlier shows that the dominance of absolute plate motion related to the strain highly anisotropic Indian lithosphere mantle with delay times between the split phases to the one second.

So that means however the plate movement and the thickness are very complex when compared to the similar kind of geological formation in the world. So obviously because earlier as I told you that it was a Island which is called as a Kumari Kandam about 70 million years ago then it was moving towards the Eurasian plate and heating Eurasian plate all this made a very complex geological formation which happens due to the nature there is nothing we can do.

But if you want to predict hazard reliably we need to basically understand how this things are varies, how can we can relatively take a suitable model to understand all this seismic wave propagation in this kind of crust. The further installation of permanent and temporary station will fulfill these gaps so he suggested actually whatever data he collected and analyzed even though that is a very extensive study.

But he said that there is a need to improve our seismic station which I also highlighted that as of now the number of stations inside India is insufficient when compared to the seismic activity what we are having or seismic glass what we have experienced.

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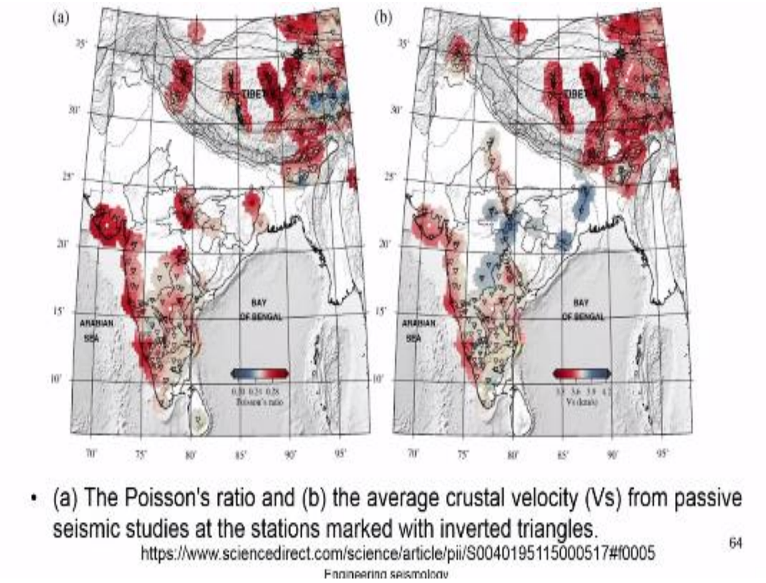

So this is basically the distribution of the Poisson ratio of the region you can see how this varies from the data recorder. So the average crustal velocity you can see the VS velocity this from the different network the passive seismic studies of station marked the inverted triangle. So where the triangles are the station from there the recorded data was processed and they tried to estimate what is the VS velocity.

You can see that we do not have uniform VS velocity throughout the India that means if somebody want to calculate location of the earthquake they cannot take a uniform velocity throughout India. So some places where you have the 4.2 kilometers, some places where you have the 3.3, some place 3.6, some place 3.9. So this has to be accounted in the estimation of the earthquake epicenter and in depth of earthquake. So this article details we can found in this websites where you can get more information about this earthquake.

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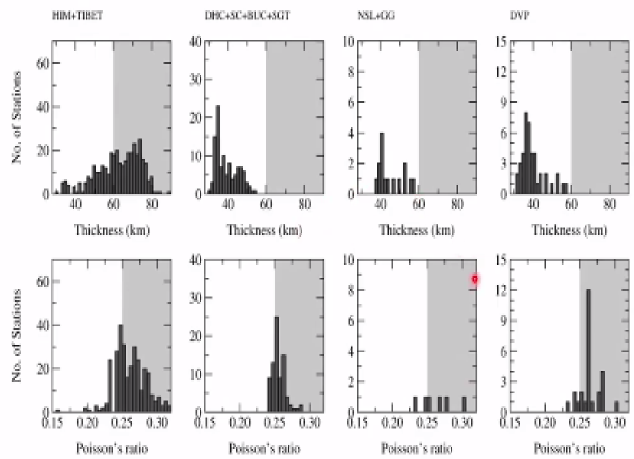

Histograms for crustal parameters and crustal thickness, Each box is divided with distinct background colours to ease comparisons.

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So this is how the thickness varies from the different part of India from the recorded data they analyze. So this is the Himalayan and Tibetan plate you can see the thickness varies from about 40 to 80 kilometer basically here a crust thickness this is the crust thickness that is what we are discussing. So then the DHC SC and BU and SGT this we have seen like Southern Granulite Terrain and all you can see here this has become again shallow.

Then NLC and GG where you can see this was around this range and this. So this is actually the dark and light was given to understand how the values are varies half and more than half kind of things it is there. So you can see the Poisson ratio the Poisson ratio of the rock present in the region. You can see here this was Poisson ratio from 0.2 to 0.3 so this is the 0.25 to 3 and then Poisson ratio of 0.25 and 3 Poisson ratio of 0.25.

So you can see like whenever there is a soil associated the fracturing more fracturing the Poisson ratios are slightly on the higher side where the rock Poisson ratio lowers. So histogram the crustal parameter and crustal thickness each box divide the distinct background color to ease comparison of the results so were higher side and lower side comparison of the results is possible that is why they have given. So this was kind of studies will help you to understand.

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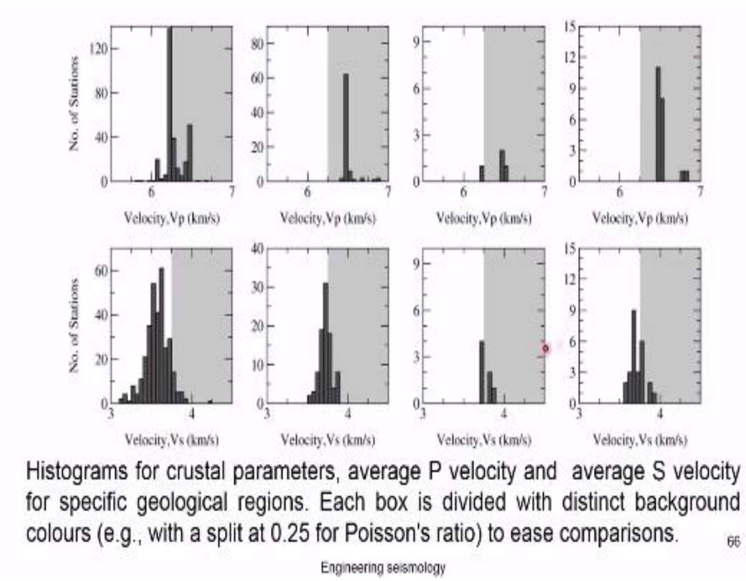

If you know the thickness of the crust then obviously the depth of earthquake and then the velocity of crust are useful. So this is the histogram again given the VP and VS velocity on the region. So even though we have seen that the VS has a velocity range of about 60 kilometer per second to the 80 kilometer per second, but you can see the regions like this the Himalayan region the VS Himalaya and Tibet.

So this is the VS was actually this range so around 6.2 and 6.3 so where in the other regions where the DHC and SC and Southern Granulite Terrain, the VS values we can see here so which is slightly larger than this. Here again so this one the other regions so which is again the NSL and GG and then the DVP this you can see. Similarly the VS you can see the VS variation.

So it is not throughout the country the VS and VP values are not similar that is the message we have got from the analyzing large number of seismic data passive and active data recorded in the region.

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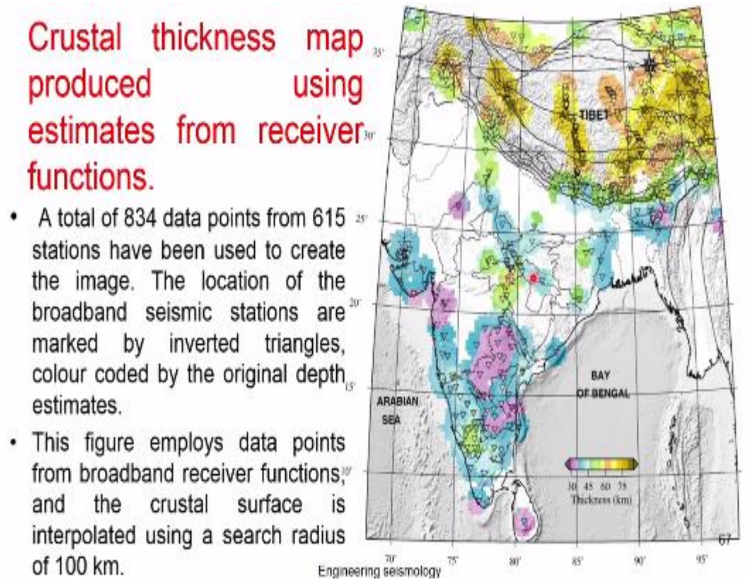

So the crustal thickness map produced using this kind of data and analysis so where using the estimated from the receiver function. So you can see the thickness of the crust so the pink one is actually very shallow you can see here then slightly the blue and then the green then followed by the other color like yellow and darker. So this also maps on Himalayan not only peninsular India this map was prepared throughout the India.

And wherever the white gap actually there is no such study has been done that is what it indicates because this people generally they deploy station soon after some earthquake from funding the places and tried to understand how it varies. This people used totally 834 data points from 61 stations have been used to create image. The location of the broadband seismic stations are marked in the inverted triangle where they used.

The figure employ points of broadband receiver functions the crustal surface interpolated using each radius of 100 kilometer. So the accuracy of this is actually they consider each 100 kilometer so the segment and then tried to interpolate and extrapolate the data of the using that so that is why you can see that there are places where there is no data means there is no station installed there, there is no study has been carried out.

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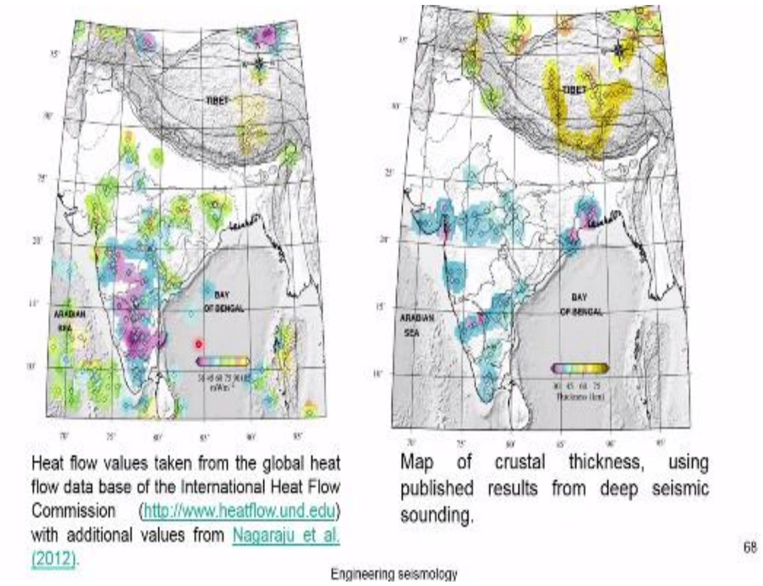

So this is again the heat flows value taken from the global heat flow of map published by the International Heat Flow Commission where you can see the heat flow values. So this heat flow this is the map of crustal thickness using the published result of the deep seismic sounding by the elsewhere. So the other basically results he try to validate and compare by the other results by looking at all this one.

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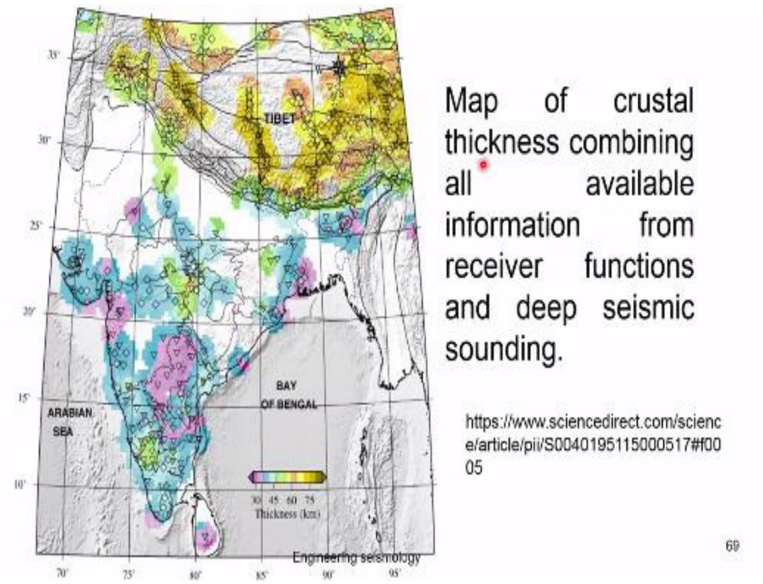

And try to give a map of crustal thickness combining all the available results we can see now the since the old publication, new publication he tried to improve where you can see the crustal thickness at many places you can get, but still there are white patches where there is no any seismic activities are taken place.

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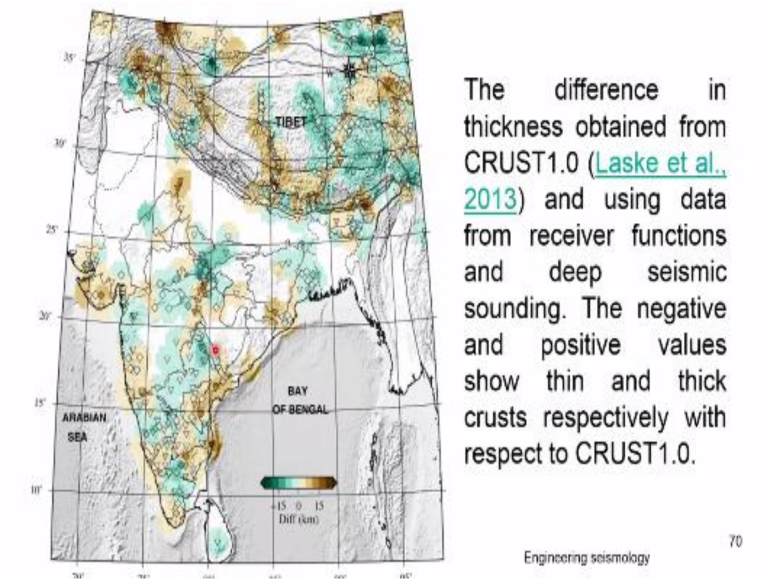

So this is the difference in the crustal thickness what he estimated with respect to the model the crust 01 data (()) (17:56). You can see the so the negative value, positive value shows thin and thick crust respectively with respect to the crust 1. Crust 1 is actually maybe the global program where the crustal thickness they might have estimated how these values are comparable and where it deviates.

So you can see that the more or less most of the places the values are variations are very small not too much, but however since he has done specific to India we should give actually basically more importance to each studies the crust is on a global scale it is not on the local scale. So there maybe variation you always expect that because the crust talks about the global scale and how that program what model they use.

And he has done his own receiver function data which will be more authenticated, but since when you talk about in the international community you have to validate and compare with the global level comparison.

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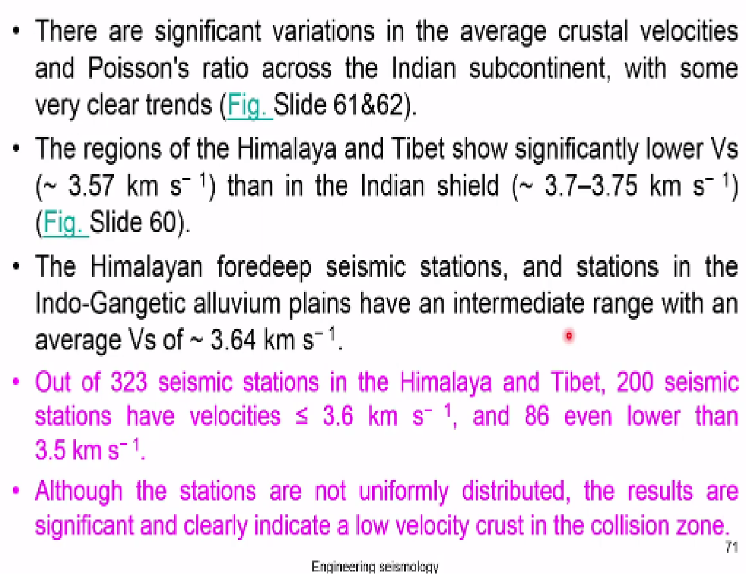

So there are significant variations in the average crust velocity and Poisson ratio across Indian subcontinent. So with some very clear trend okay what we discussed in the slide previously. The regions of Himalaya and Tibet show the significantly lower VS like 3.57 kilometer per second. So if you want to consider, estimate a epicenter, hypocenter on this region you should consider this velocity.

Then the Indian shield like the southern India were 3.5 to 3.75, 3.7 to 3.75 kilometer per second. You can see the difference so a second actually causes a kilometer difference so much you can find if it is 100 kilometer travels accordingly the time difference will cause a huge amount of error in the estimation of epicenter. So the Himalayan foredeep seismic stations in the Indo-Gangetic alluvium plane have the intermediate range of velocity from 3.65 kilometer per second.

So out of 322 seismic station in the Himalaya and Tibet the 200 seismic station have been velocity is less than 3.6 kilometer and 86 even a lower value of 3.5 this was about the Himalayan and Tibet stations which is run by our Indian this one. Although stations are not uniformly distributed the results are significant, clear indicate a low velocity crust in the collision zone.

So the shear wave velocity lower and lower will indicate that the regions are more and more complex in nature and the density and the velocity of the rocks are basically low. Lower shear wave velocity or shear properties are changed the S wave propagation drastically that is what the message you have to understand from this discussion.

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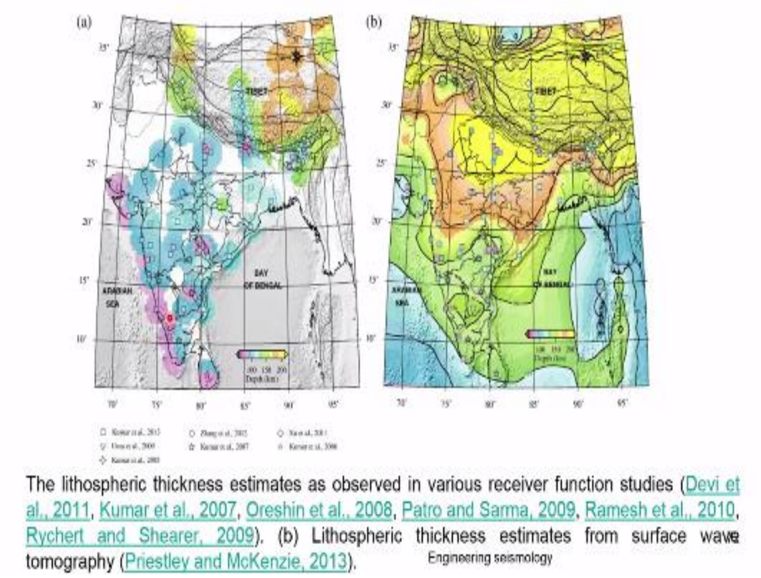

So this is basically the lithosphere thickness estimated, observed by various receiver function studies. So you can see here and then lithosphere thickness estimated from surface wave topography. So this variation like here the color scales are given based on the topography. Here you can see that the minor level variations are mapped well in this study on the regional based study mapped well that.

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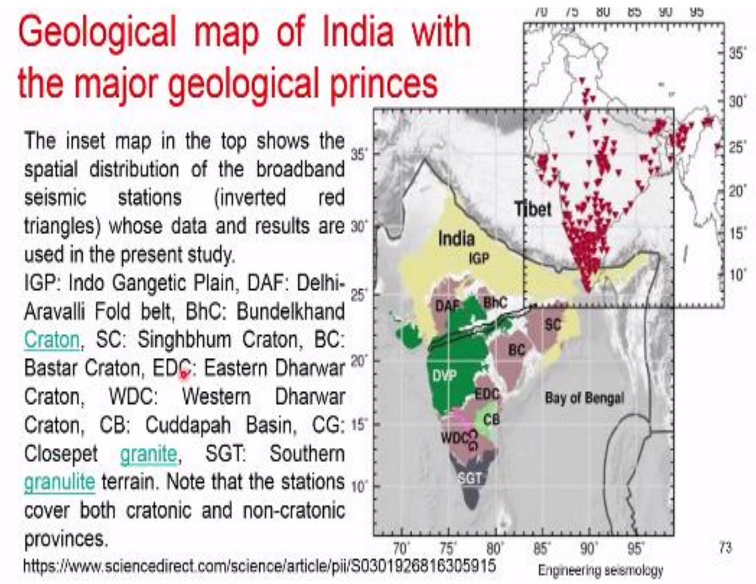

So this is again the geology map with major geological princes India with seismic data what they use. The inset map of top shows a spatial distribution of the broadband seismic station inverted red triangle whose data and results are used to study and understand the different seismotectonic of the southern part of this one India. So what they have studied actually.

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- Haldar et al (2017) use converted wave data to extract the bulk crustal properties of the Indian cartons.
- In order to estimate the bulk crustal properties in diverse cratons of the Indian shield, we use the teleseismic waveforms recorded at 82 stations being operated by the CSIR- National Geophysical Research Institute and the National Center for Seismology, India.
- India. Further, a large number of crustal parameters from 217 stations, published by other workers in the Indian shield have also been used to complement our observations.
- The converted wave techniques (called as P-receiver function analysis, PRF) to a large amount of seismological data from the Indian stations and investigated the crustal parameters.

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So it is actually Haldar was carried out this study it was very recent paper 2017 it published use converted wave data to extract a bulk crustal properties in the Indian Craton. In order to estimate the bulk crustal properties in diverse craton of the Indian shield we use teleseismic wave recorded at 82 stations being operated by the CSIR then NGRI National Geophysical Research Institute and the National Center of Seismology.

The India further large number of crustal parameters from 217 stations published by other workers in India also been complemented our observation. The converted wave technique called P wave receiver function analysis PFR to the large amount of the seismological data. Indian station and investigated the crust thickness.

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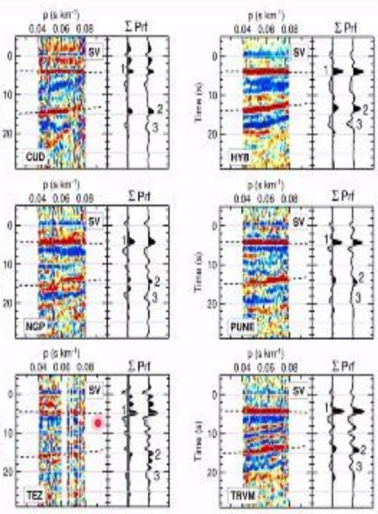
- Haldar et al (2017) have performed bootstrap analysis to show that the interpreted phases are well above the 2SE. All the images in Fig. 2 clearly show P-to-s conversions from the Moho, at about 4–5 s delay time.
- Fig. 2 Station-wise Receiver function images. The dashed lines are the predicted travel times for a simple one layer model with Moho and half-space. The thin double black lines on the stack trace are ± 2SE bound.



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So you can see that the wave form basically they have taken a seismic record at different places and try to understand how this wave indicate a different geological parameters in the region seismotectonic parameters in region. So Haldar it allows for bootstrap analysis to show the interpret phase are well above the 2 second you can see here the phase. Moho depth you can see the Moho depth this is basically the Moho depth,

And then the second layer here so this is the wave form only they do. So these are all the studies where the seismologist will do, seismologist we focus on seismic record and try to interpret this kind of depth which will give you the depth of earthquake at a particular location. So the figure 2 basically so the station wise receiver function image. Dashed line predict travel time of the simple one layer Moho depth and then thin double black lines of the stack trace plus 2 second bound. So these are all the Moho depth the interpreter from this kind of data.

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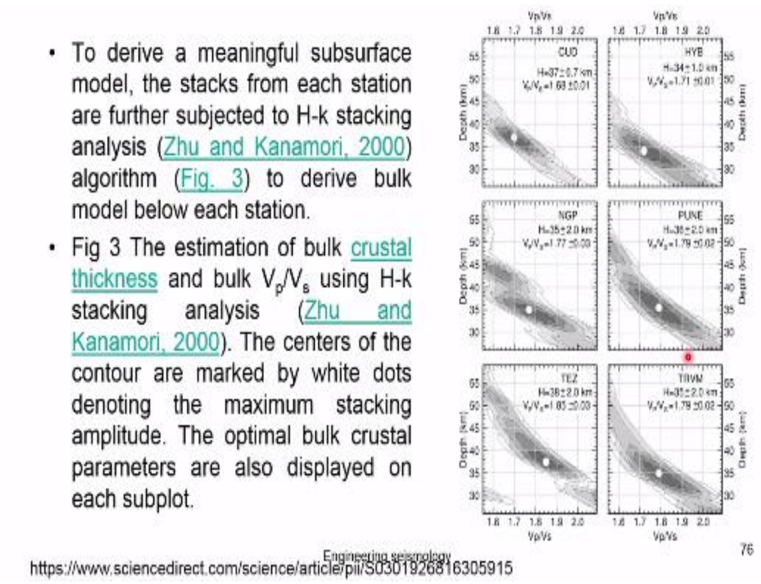

So further they used this data to derive a subsurface model at each station subjected to H-K stacking analysis to derive a bulk model of the station. You can see the Vp Vs ratio and thickness of the breakage where it happens crust thickness Moho depth you can see this one. So this is the earthquake data what they consider so this is the place how it is distributed. So the estimation of bulk crustal thickness the bulk Vp / Vs using H-K stacking analysis. The center of the counter are marked white dots denoting the maximum stacking amplitude is expected. The optional bulk crustal parameters are displayed on each subplot.

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- Bulk crustal parameters have been estimated, a comprehensive crustal parameter images have been prepared (Fig. 4). The results reveal that the crustal structure of the Indian Shield is variable, with the thickness varying from ~30 to 50 km in most of the region, except for the Himalayan region where it reaches up to ~70 km.
- The crustal thickness below the DVP is ~30–50 km with an average of ~38 km (Fig. 4a). The crust in EDC is thinner i.e. from ~32–44 km with an average of ~35 km compared to WDC where the crustal thickness varies from ~38–48 km with an average of ~45 km.
- Crustal thickness of the Aravalli Craton is ~30 km, whereas for Bundelkhand Craton it is ~43 km.
- All along the IGP, the thickness varies from ~30 to 45 km, with an average value of ~37 km.
- The average crustal thickness of Singhbhum Craton (SC) and Bastar Craton (BC) is ~44 km and ~42 km respectively.

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So the bulk crustal parameters have been estimated comprehensive crustal parameters image have been prepared. The result reveal that the crustal structure of Indian shield is variable with the thickness varying from 30 to 50 kilometer that is what we have also seen the previous author also told the similar kind of variation of the thin crust in the southern part and then the Himalayan region thick, but there is a slight difference.

So about 10 kilometer or 5 kilometer thickness difference that is okay this is not a very big amount when you consider the geological studies. The crust thickness below the DVP was about 30 to 40 kilometer an average of 38 kilometer the crust DCE thinner 30 to 40 kilometer the average of 35 kilometer. So the Western Dharwar Craton, Eastern Dharwar Craton the crust thickness vary 30 to 48 average of 45.

The crust thickness of Aravalli Craton 30 kilometer whereas the Bundelkhand Craton is 43. All along the IGP Indo Gangetic Basin varies from 30 to 45 kilometer with a average of 37. The average crustal thickness of the Singhbhum Craton and Bastar Craton 44 and 42 respectively.

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- The crustal thicknesses derived from receiver functions are quite consistent with the estimations by different workers using deep seismic sounding and passive seismological studies (Kaila et al., 1979, Kaila and Krishna, 1992; Sarkar et al., 2001; Krishna, 2004, Reddy and Rao, 2013; Saul et al., 2000; Kumar et al., 2004, Kumar et al., 2001; Sarkar et. al. 2003; Singh et al., 2015).
- Fig. 4b depicts the average V_p/V_s ratio map of the Indian shield derived from our analysis and supplemented by previously published results derived from receiver function analysis by various workers (Borah et al., 2014; Das et al., 2015; Gupta et al., 2003; Jagadeesh and Rai, 2008; Julia et al., 2009; Kayal et al., 2011; Kumar and Mohan, 2014; Kumar et al., 2004, Kumar et al., 2001; Kumar et al., 2013; Mitra et al., 2005; Rai et al., 2005; Rai et al., 2006; Saikia et al., 2016; Singh et al., 2012).

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https://www.sciencedirect.com/science/article/pii/S0301926816305915

The crustal thickness derived from the receiver function are quite consistent with the estimation made by the different workers in the previous studies. The deposit of 4b depicts the average Vp and Vs ratio map of Indian shield derived from our analysis and supplemented by the previous published work.

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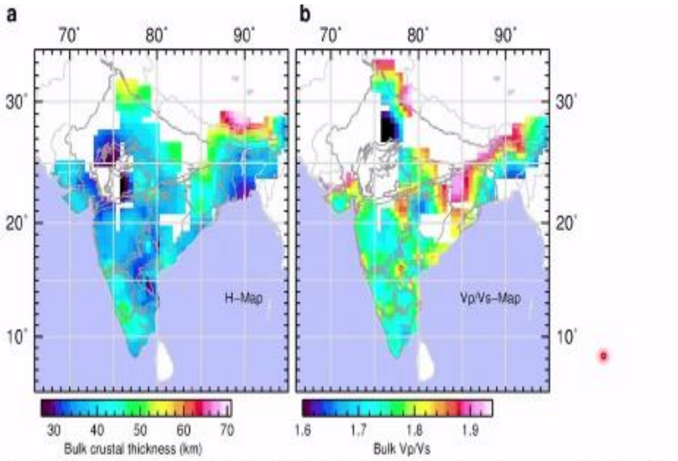

Fig. 4. Crustal parameters (bulk crustal thickness and bulk crustal Vp/Vs) for the Indian shield superimposed on the tectonic map. The boundaries of the various cratons are shown and labeled in Fig. 1. 79

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So they have given what is the bulk crustal thickness and the bulk Vp and Vs ratio. You can see there is a considerable variation in the geological scale basically geological scale India is very thin it is very small size when compared to other part particularly southern India, but you can see the variation within the small portion like 5 degree portion you can see how the thickness varies and the bulk Vp and Vs ratio varies.

So these are all indicates that the geologically and seismotectonically this regions are more and more complex which has to be accounted when you do any hazard parameter prediction for the future earthquake.

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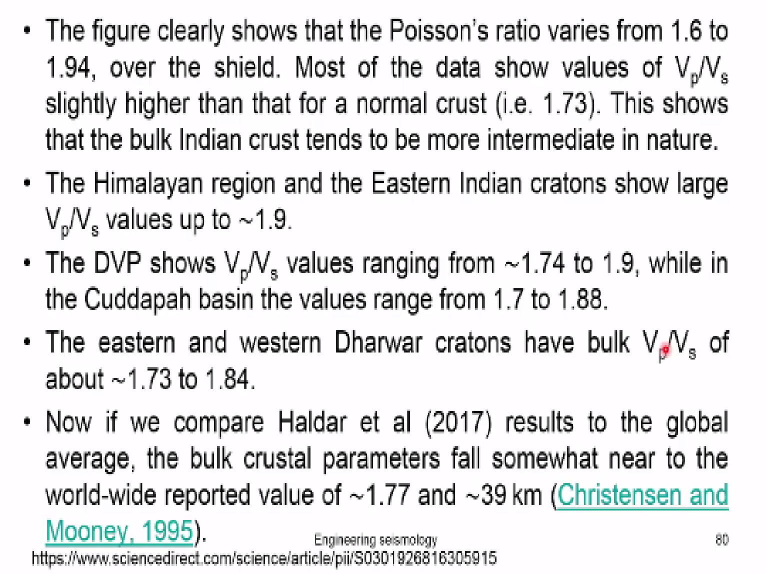

So the figure clearly shows that the Poisson ratio varies from 1.6 to 1.94 over the shield. Most of the data shows Vp / Vs slightly higher than the normal crust. So the normal crust is actually 1.73, but each shows a higher trend. So the bulk Indian crust tend to more intermediate in nature. The Himalayan region Eastern India Craton shows large Vp Vs value that is 1.9.

So DVP shows Vs Vp value ranging from 1.7 to 1.9 while the Cuddapah basin value ranges from 1.7 to 1.88. The eastern and western Dharwar Craton bulk Vp / Vs of about 1.7 to 1.84. Now if we compare Haldar et al result with the global average the bulk crustal parameters are fall somewhat near to the worldwide reported 1.7 to 39 kilometer published by Christensen and Mooney in 1995, but that is the world data based on the global scale values.

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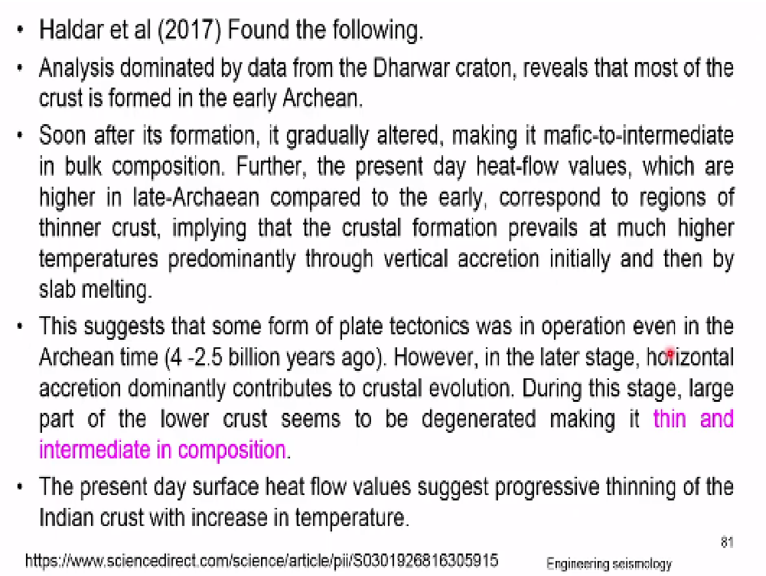

So Haldar found the following conclusion he has given actually. The analysis dominated by the data from the Dharwar Craton reveals that most of the crust formed in the earlier archean period. So the archean period is basically 4 to 2.5 million years ago so that was one of his finding. Soon after its information it is gradually altered making mafic to intermediate bulk composition.

Further present day heat flow values which was higher late archean compared to the earlier correspond to the regions of thinner crust implying that the crust formation prevails at a much higher temperature predominantly although the vertical accretion initially and then slab melting. So how the plate was formed, how the heat flow was there golden time and now they tried to compare.

So overall his finding say that the Indian plate stable continent region as a thin plate when compared to any other intraplate crust thickness because of its thin it is moving very fast because of its moving very fast it getting to fracture locally highly than compared to any other region that is why you have the many frequent so the damaging earthquake in the region starting from Killari, Jabalpur, Bhuj, Koyna.

These are all the some of the earthquake which happened in the last 50 to 60 years and caused the extensive damage than the any other well known earthquake in India. The Indian seismicity if we divide as a two pattern before 1950 after 1950 before 1950 we do not have much record and data except very few earthquake where they have only written data are available.

But if we take the instrumented data and no knowledge data in the last 70 years. So the southern India suffered more damage than the north India so that was one of the main concern that the scientist start working on the stable continent region results.

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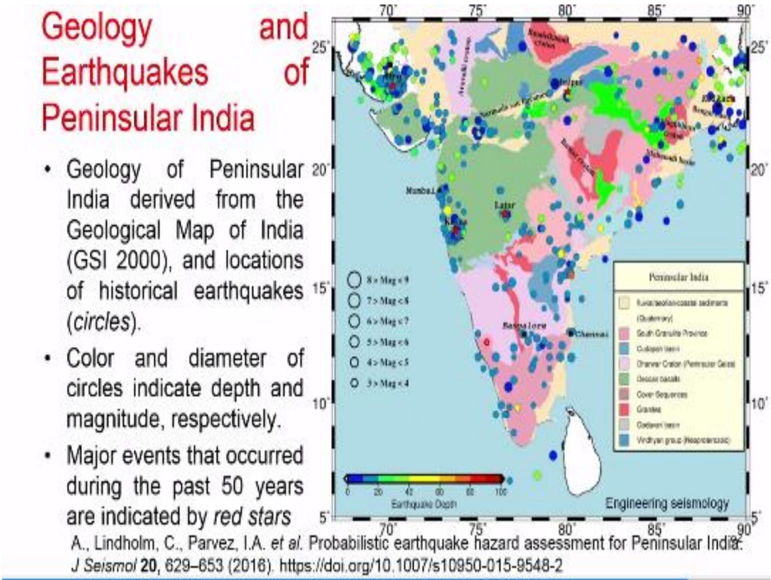

So this is basically again the geology and earthquake of peninsular India you can see a several earthquake which is plotted okay the geology peninsular India derived from the geological map of GSI 2000. Location of historical earthquake circles the color diameter of circle indicate depth and magnitude respectively. So basically the geological terrain is given here and the size indicate the size of earthquake the color indicate this.

So you can see that most of the earthquake except this one. So most of the earthquake in southern India are the shallow in nature. So this basically this kind of shallow earthquake may cause a devastating so the damage than the deeper earthquake. You can see if you go slightly higher part you can see here the earthquakes are around like 40 kilometer depth so here these are all shallow earthquakes are there.

So the major event occurred during the 50 years indicated by the red stars. So this is like the Koyna earthquake, Latur earthquake, Jabalpur earthquake, Bhuj earthquake you can see how this are. So this data are available and published in the 2016 by the Cmax scientist group of Cmax scientist. If we get more information we can visit that page.

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Earthquake Catalogues of PI

1. The ISC reviewed bulletin since 1960 (www.isc.ac.uk),
2. The PDE catalogue since 1973 (USGS National Earthquake Information Center http://earthquake.usgs.gov/~regional/neic/)
3. The IMD (India Meteorological Department) cataloguesince 1898 (http://www.imd.gov.in),
4. The catalogue prepared by the NDMA from varioussources for their report (between −2474 to2008) (http://www.ndma.gov.in),
5. The National Oceanic and Atmospheric Administration(NOAA) catalogue (www.noaa.gov)
6. Events listed by Oldham (1883), Tondon andChaudhury (1968), and Guha et al. (1970). Forhistoric events, Ramalingeswara Rao and SitapathiRao (1984) provide a magnitude scale basedon intensities.

A., Lindholm, C., Parvez, I.A. *et al.* Probabilistic earthquake hazard assessment for Peninsular India. *J Seismol* **20,** 629–653 (2016). https://doi.org/10.1007/s10950-015-9548-2 83

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So this people how they use a catalogue for compiling this actually they used a catalogue from IS reviewed bulletin since 1960 and PDE catalogue 1973 USGS National Earthquake Information Center IMD Indian Meteorological Department from 1898. Catalogue prepared by the NDMA from various resources their report from 2474 to 2008 NDMA report, National Oceanic and Atmospheric Administration NOAA catalogue.

And then the event listed by the Oldham and the Tondon and Chaudhury and then the (()) (32:09) all those people Ramalingeswara Rao and Sitapathi Rao so all those people data are these people considered to prepare a previous map. So these data if you study these data how individually varies.

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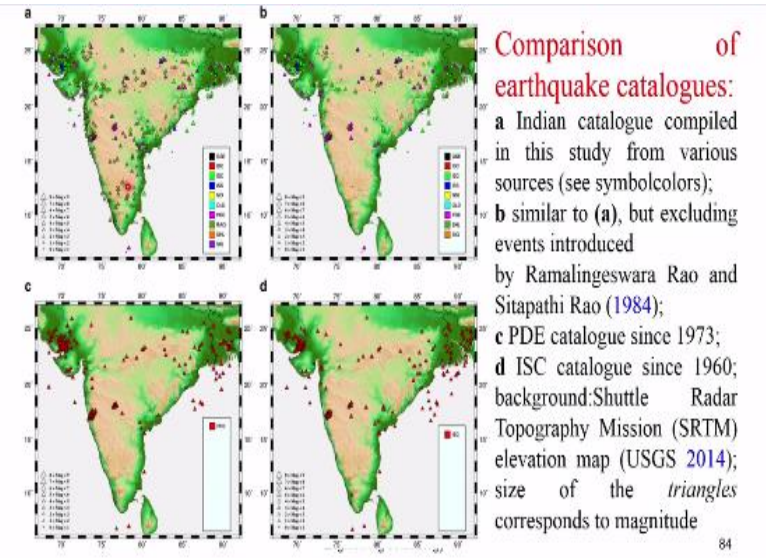

So you can see this plot. So basically the plot a this one here so indicates the Indian catalogue complied in this study from various resource so where the data descriptions are given here. So the data b is this plot is basically similar to a, but excluding the introduced by the Ramalingeswara Rao and Sitapathi Rao where that book yesterday was (()) (32:48) so that data was excluded.

Then the c is PDE catalogue since 1973 so this is the catalogue from there and then the d this one the IS catalogue since 1960. So Shuttle Radar Topography Mission also they used USGS kind of catalogue you can see the distribution. So this is a compiled all the data so now you can understand that the data where from we are obtaining how the data are reliable also gives the indicate how your interpretations are accurate enough to get some analysis.

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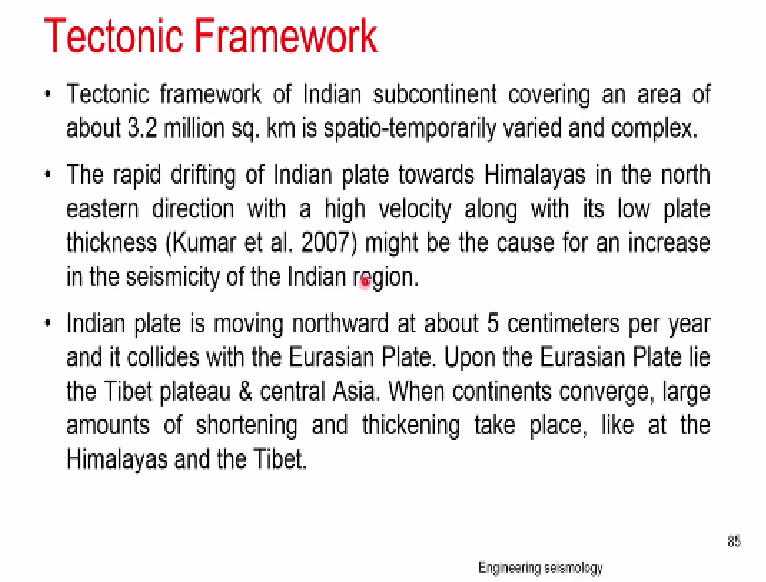

So overall what we discussed so far I am going to summarize in the next three slides. We have been talking about the seismotectonic of Indian region. So we have talked about India as actually a major two group you can divide the North India and South India. North India has actually the complex geological formation of northern side where there is a subduction and continent active crust region in that.

And the western part and eastern part has a transformed boundary where the trust falls are forming due to the transformation action between the Eurasian and Indian plate. So if you come the eastern part little down Sumatra region you have the complete subduction activity there which is below the sea so then if you come back to South. South there is no any kind of major plate boundary exist.

But there was formation the land formation has a different geological region, so different craton different like the magma emission and formation, melting. So all those created a different geological units that geology unit they joins and associated the fracture in that region causes a earthquake. So those earthquakes we need to broadly account in the hazard analysis.

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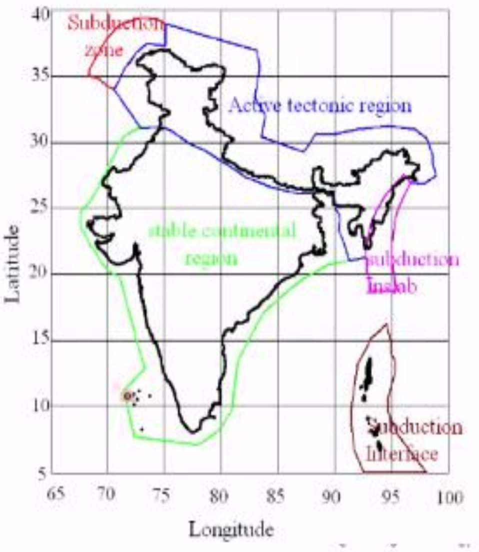

As I told you that this is a subduction zone active tectonic, subduction inslab, subduction intra slab and stable continent. So this earthquake occurring here most of them are localized activity because of the geological formation and the activity seismic activity or seismic force created by the movement of the plate of Indian plate while heating the Eurasian plate whatever is happened folding and fracturing so that causes this one.

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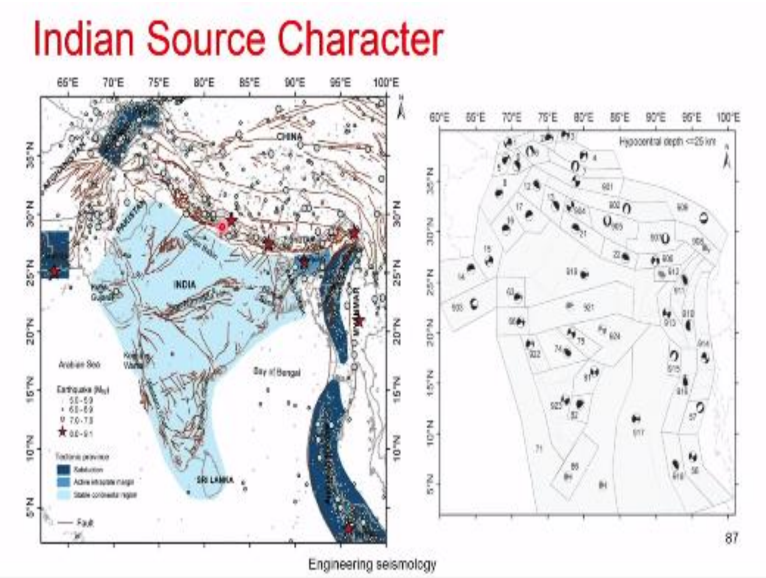

So this is how you can make this is a model which he was actually consider for the global earthquake model (()) (35:35) what they used this is the model they consider, they made it everything as a three major category and then they try to account the respective their model and equations for the estimation of hazard which we will be discussing in the last class. This is the source and beach ball what they use you can see.

Based on the different earthquake they consider this as a model to estimate a global seismic hazard. So which we need to they have taken and the macroscale which we will be in detail we will be discussing and the earthquake hazard analysis which will be from the next class on this. So the seismotectonic the understanding of geology is very important to decide your earthquake hazard input parameters.

So what are the input parameters, what magnitude you should consider, what focal depth you should consider, what source mechanism beach ball you should consider for the simulation kind of things, what is the crust thickness you should consider, what is the VP velocity, VS velocity you should consider to interpret a seismic data to locate earthquake. So those are all the information are essential which has to be derived from the regions specific data.

At least we have the subsequent studies and considerable amount of data is there. When I was doing seismic hazard analysis of Bangalore in 2004 no such study data was available so I made lot of assumption actually, but now this data are being available this also consider in the recent seismic hazard analysis of south India by my student Ketan Bajaj and also the site specific hazard analysis.

And rupture based analysis by the Shailesh Abraham another PhD student who is working on the dam seismic hazard analysis and all where we try to account these information whatever I studied we tried to account in the hazard analysis, tried to estimate a reliable hazard parameters for the design and other activity. So that we are going to discuss in the next class. So thank you much for watching this video I will meet you in the next class.