

Aseismic Layer Detected in the Mid-Crust of Nubra-Siachen Region, India Using Local Seismic Data

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Abstract

The local seismicity observed by seismic network in siachen-nubra region during January 2010-December 2012 shows that the middle part of the crust (17 - 40 km) is aseismic. This aseismic layer (17 - 40 km) is sandwiched between two seismically active layers and depicts a good spatial correlation with the observations of low resistivity reported from magnetotelluric studies for the same region. The local seismicity shows a trend along the Karakoram fault and clustering of events in Shyok Suture zone and Karakoram shear zone. The moment magnitude of these events lies between 1.3 and 4.3. Most of these events have been originated in upper crust.

Keywords

Shear Zone, Karakorum, Local Events, Aseismic, Nubra-Siachen

1. Introduction

The Himalayas, spanning length of 2500 km is a consequence of continent collision [1]-[3]. The Himalayan region is known for its high seismicity for small to large magnitude earthquakes. Five large magnitude earthquakes have visited Himalayan region (mag. > 8.4) and nine earthquakes of magnitude > 7.0 since 1897. Beside these large magnitude earthquakes, numerous small magnitude (Magnitude < 3.0) earthquakes have visited the Himalaya.

Nubra valley locates in the eastern Karakorum region of northern Ladakh and extends from Siachen glacier

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system in North-West to Shyok-Nubra confluence in South East. It covers 4381.23 sq km area and amassed of various litho units such as Karakorum plutonic complex, Ladakh Plutonic Complex, etc. Siachen Glacier is more than a valley glacier; it is a system of glaciers, consisting of Northern, Central and Southern glaciers [4]. Siachen glacier along with its tributaries covers more than 1500 sq kms. This is the largest glacier in the Himalaya and second largest among the known glacier outside the polar and sub-polar regions. Siachen lies between the Saltoro Range immediately to the west and the main Karakoram Range to the east. The melting waters of the glacier are the main source of the Nubra River, which meets the Shyok River near Khalasr forming Nubra-Shyok confluence (Figure 1). The Shyok in its onward journey joins Indus River; thus the glacier is a major source of water for the Indus.

A network of digital broadband seismograph equipped with 3-component digital seismometer (Trillium 120P) is operational in Nubra-Valley, since 2008. The seismic data recorded (Jan'10-Dec'12) at these stations have been used for this study. The hypocentral depth of the local events recorded at seismic stations is in the upper crust depth range 0 - 17 km and 40 - 75 km but few events are observed at the depth greater than 100 km in the mantle along the Karakorum fault.



Figure 1. The earthquake events (Table 2) used in this study is shown on the Geological map [16] of the area.

2. Tectonic Set up of the Area

The collision between the Eurasian plate and the Indian plate started about 55 Ma ago [5], and is still continuing at the present time [6]. This successive collision forms the Himalaya and the Earth's largest and highest plateau with anomalously thick crust. Different models have been proposed by various research workers to explain the origin of the Himalaya [2] [3] [7]. The collision has also resulted into large scale thrusting and the same is progressed southward forming the Main Central Thrust (MCT) and Main Boundary Thrust (MBT). The Indus-Tsangpo Suture (ITSZ) located about 250 km. North of MCT marks the pre-collision boundary along which the Indian plate subducted below the Eurasian plate and the subduction ended in Eocene times [7]. Along the MCT, the Higher Himalaya overthrusted the Lesser Himalaya along MBT, the Lesser Himalaya thrusted over the Siwaliks.

The crustal thickness using, 15 - 60 s Rayleigh wave group velocities with receiver functions from teleseismic arrivals was mapped up to 75 km at Taksha station in Nubra region [8]. Nubra region is tectonically highly disturbed [9] and this region is bisected by Karakoram fault [10]-[13]. Approximately 800 km, dextral strike slip Karakoram fault is the prominent tectonic feature in the region [14] [15], this fault runs almost parallel to the main body of Siachen glacier. The other major tectonic features of this region are Karakoram shear zone, Shyok Suture zone, Khalsar thrust, etc. Karakoram Shear Zone (KSZ) is intensely mylonitized granite gneiss, volcanic, conglomerate, slate-phyllite-limestone intercalations, amphibolites and serpentinite intervene the Shyok Suture Zone and the frontal Asian Plate margin along the Nubra-Shyok Valleys for nearly 200 km to form the 1 - 5 km wide KSZ [16].

This region falls in the zone IV of the seismic zoning map of India [17], and seismotectonic atlas of India and its enviors [18]. Geographical position of study region is shown in **Figure 2**, and this region is tectonically active due to the presence of Karakoram fault and various structural features like Shyok Suture Zone (SSZ), Karakorum Shear Zone (KSZ). This region is almost virgin as far as local seismological observations are concerned, prior to the installation of this network. This region is remote and accessible through world highest motor able





pass Khardung La (18,380 feet) for a very limited period in the year. Owing to remoteness and harsh climatic condition throughout the year, maintenance and operation of seismic network is a big challenge in nubra-siachen region. However four, broadband seismometers has been installed during 2008 in this region. This region did not experience any major earthquake till date (as per the literature/record available). However micro, small & large earthquakes frequently experienced by local residing in this region [19] [20]. The local seismicity observed by this seismic network is mainly mapped along the Karakoram Fault, Karakoram Shear zone & Shyok Suture zone.

3. Data Used and Methodology

The local seismological network comprising of four broad band recording station has been installed in Nubra Valley region, Jammu & Kashmir. The layout of the network is shown in **Figure 3** and the details of recording stations are given in **Table 1**. The four recording stations used the same type of instrumentation *i.e.* the Trillium 120P broadband seismometer and Taurus 24 bit data acquisition system, manufactured by M/s Nanometrics, these instruments are operational in continuous mode. The seismic data recorded at Nubra valley seismological network and used for present analysis is given in **Table 2**. The 3-C seismogram of one of the recorded event are shown in **Figure 4**. Data were recorded with a sampling rate of 100samples per second. For computation of hypocentral parameters of Local earthquakes three types of data is required such as phase data of local earthquake, accurate geographical co-ordinates along with elevation of recording stations and the local velocity model of the region covered by the recording stations. Additionally a computinally efficient and stable computer program is a major requirement to allow conversion of travel time data to estimate hypocentral parameters [21] [22]. The seismic velocity model determined by [23] at Taksha seismic station (TKS) has been used for estimation of hypocentral parameters of local earthquakes. The "HYPCENTER 3.2" given by [24] and incorporated in SEISAN environment has been used for the estimation of hypocentral parameters of local earthquakes. The "HYPCENTER 3.2" given by [24] and incorporated in SEISAN environment has been estimated using [25] given as below.



Figure 3. Layout plan of local seismic stations of Nubra-Siachen region shown on Google earth image.



Figure 4. 3-C Seismogram of Local earthquake recorded at seismic network in Nubra-Siachen region (Z, N-S, E-W from top to bottom).

Table 1. De	tans of seismic station	i instance in area	a of study.		
Sr.No.	Station Code	Latitude (Degree)	Longitude (Degree)	Elevation w.r.t. Mean Sea Level (Meters)	Mode of Operation
1	Stn 1	77.49 E	34.92 N	3430	Digital
2	Stn 2	77.41 E	34.61 N	3180	Digital
3	Stn 3	77.2 E	35.18 N	3455	Digital
4	Stn 4	77.12 E	34.82 N	3180	Digital

logM

$$Mw = \frac{N_{\rm gmax}}{1.5} - 10.7\tag{1}$$

4. Result and Discussions

Table 1 Details of saismic station installed in area of study

The hypocentral parameters of local earthquake are estimated with the help of "HYPOCENTER 3.2" [24] from the phase data recorded at seismic stations. The standard error in the estimation of hypocentral parameters for these events are <0.5 seconds in origin time, <5.0 Km in epicenter (ERH) and <6.0 in focal depth (ERZ).

The local seismicity is mainly oriented with the Karakoram Fault and clustered in Shyok Suture Zone and Karakoram shear zone. The depth trend of earthquake events (**Figure 5**) shows that the seismicity in the Siachen region is mainly occurring at upper crustal depth. However few events are occurred at a depth of 40 km and more but no local event is reported in a depth range from 17 - 40 km below the surface of the earth. This seismically inert layer (17 - 40 km) shows that no stress get accumulated in this layer. This layer shows good spatial correlation with the low resistivity layer in the mid crust of NW Himalaya determined from the magnetotelluric studies of NW Himalaya [26] & Partially melted upper middle crust revealed by Rayleigh wave dispersion [23]. Due to the partially melted nature of mid-crust (depth range 17 - 40 km) no stress is accumulated in the midlle-crust, so no earthquake is reported in mid-crustal depth range in Siachen region. This infers the presence of aseismic layer in the mid-crust part. This aseismic layer is sandwiched between seismically active layers in Siachen

Table 2. List of Local events recorded at Nubra-Siachen seismic Network.										
	Origin	Time	Нуросе	entral Param	neters					
Sr No.	DD-MM-YYYY	HR:MIN:SEC	Longitude	Latitude	Depth (km)	MW	RMS	ERH (Km)	ERZ (Km)	
1	01-01-2010	10:19:57	77.37	35.828	10	2.5	0.4	4.7	3.7	
2	03-01-2010	04:06:09	77.466	34.923	53.2	3.2	0.21	5	1.9	
3	08-01-2010	05:45:42	77.16	35.12	10	3.7	0.36	3.2	2.7	
4	14-01-2010	08:32:09	77.419	34.866	0.1	2.5	0.47	4.3	1.2	
5	14-01-2010	17:24:54	77.425	34.791	10	3.1	0.58	2.4	3.9	
6	17-01-2010	07:09:52	78.832	34.831	10.3	2	0.21	5	1.9	
7	22-01-2010	02:51:40	77.466	34.923	3.2	3	0.39	4.6	3.8	
8	25-01-2010	22:12:18	77.582	35.237	15.8	2.8	0.89	1.7	3.4	
9	08-02-2010	03:21:12	77.477	34.92	10	4.2	0.76	3.4	2.6	
10	09-02-2010	11:26:00	76.951	35.136	10	3	0.63	5	1.7	
11	10-02-2010	03:19:00	77.109	35.062	7.3	2.9	0.42	1.2	3.6	
12	11-02-2010	01:42:00	77.507	35.323	10	2.4	0.53	4.3	4.9	
13	11-02-2010	11:51:03	77.59	34.878	10.4	2.6	0.56	5	3.7	
14	14-02-2010	06:09:44	77.651	34.838	0	2.8	0.39	4.8	1.7	
15	18-02-2010	01:20:07	77.37	34.795	16.2	2.6	0.57	5.2	3.5	
16	25-02-2010	12:19:50	77.751	34.683	98.7	3.6	0.17	3.7	2.9	
17	26-02-2010	03:07:23	77.656	34.836	10	2.9	0.34	4.9	2.6	
18	06-03-2010	20:01:56	77.182	34.939	8.6	1.9	0.12	4.3	3.8	
19	12-03-2010	07:05:18	77.379	34.718	10	2.1	0.26	2.9	3.1	
20	21-03-2010	01:42:18	76.725	34.717	96	2.4	0.69	1.3	4.9	
21	28-03-2010	12:55:00	76.905	34.83	52.8	2.2	0.34	3.7	1.9	
22	16-04-2010	12:19:50	77.044	35.519	51.2	2.9	0.43	2.6	2.1	
23	23-04-2010	00:28:45	78.735	33.297	10	1.8	0.56	1.8	2.6	
24	25-04-2010	20:01:56	77.153	35.326	54	3.2	0.71	2.8	1.9	
25	29-04-2010	06:43:12	77.654	33.04	2.7	2.6	0.63	4.3	3.2	
26	02-05-2010	13:32:13	77.464	34.918	56.7	4.1	0.59	3.1	2.7	
27	06-05-2010	21:51:17	77.383	34.647	68	2.7	0.89	1.7	3.9	
28	07-05-2010	13:26:00	77.248	35.1	14	4.4	0.63	2.6	3.2	
29	14-05-2010	02:27:26	76.644	35.721	56.2	3.7	0.72	1.7	2.8	
30	17-05-2010	03:06:03	77.328	35.023	92	3.2	0.45	3.2	1.7	
31	19-05-2010	07:41:00	77.21	35.238	63.7	2.7	0.26	1.6	2.8	
32	20-05-2010	04:06:09	77.387	34 954	2.7	2.6	0.12	1.9	2.9	
33	28-05-2010	05.45.42	77.248	35.1	11.1	3.1	0.47	11	36	
34	29-05-2010	08.32.09	77 308	35.018	6.5	2.8	0.38	2.5	5	
25	30-05 2010	17.24.54	77 425	35.045	57	2.0	0.58	3.8	13	
)) 26	02 06 2010	02.51.40	77.0	24.90	J.1	3.7 2.7	0.76	J.0	1.0	
30 27	03-00-2010	02:31:40	11.2	25.15	4.5	4.2	0.24	4./	1.9	
37	04-06-2010	22:12:18	77.258	35.15	2.1	4.2	0.26	1.6	1.9	

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38	06-06-2010	03:21:12	77.024	35.27	8.1	3.9	0.53	3.4	2.7	
39	08-06-2010	05:45:42	77.226	35.34	9	3.8	0.45	4.3	3.6	
40	09-06-2010	08:32:09	77.119	35.147	45	4.2	0.47	2.8	3.4	
41	10-06-2010	17:24:54	77.333	35.159	43	3.6	0.59	0.9	4.1	
42	23-06-2010	02:51:40	76.8	35.5	1.4	3.7	0.32	1	3.7	
43	24-06-2010	22:12:18	77.795	35.4	12.3	2.5	0.26	2.7	1.8	
44	11-07-2010	03:21:12	77.2	35.4	12.8	3.7	0.89	0.5	4.9	
45	12-07-2010	13:32:13	76.793	35.102	9.5	3.1	0.67	1.1	0.9	
46	16-07-2010	21:51:17	77.336	35.024	9.8	1.8	0.58	1.2	1.8	
47	21-07-2010	13:26:00	77.466	35.016	0.1	3	0.12	3.4	4.6	
48	26-07-2010	01:42:00	76.872	35.622	72	3.2	0.45	1.2	4.3	
49	28-07-2010	11:51:03	76.917	35.582	9.7	4.3	0.38	4.7	2.6	
50	01-08-2010	06:09:44	76.988	35.523	7.4	3	0.36	1.7	1.6	
51	03-08-2010	01:20:07	77.141	35.335	10	2.8	0.16	1.5	2.7	
52	06-08-2010	12:19:50	77.18	35.287	1.7	4	0.23	0.8	1.9	
53	12-08-2010	03:06:03	78.594	34.19	6.7	2.5	0.39	3.7	4.3	
54	16-08-2010	00:30:59	78.331	33.974	10	3.2	0.48	2.6	4.3	
55	18-08-2010	17:24:54	77.298	35.177	12	3	0.59	1.2	4.9	
56	19-08-2010	14:11:29	77.219	35.177	16.8	2.3	0.66	3.6	1.2	
57	24-08-2010	16:25:32	71.282	36.49	10	3.15	0.38	1.8	3.2	
58	31-08-2010	20:17:10	77.355	35.068	13.7	3.6	0.12	1.6	3.4	
59	02-09-2010	00:21:12	77.044	35.519	14.5	2.6	0.49	4.3	4.9	
60	05-09-2010	04:15:47	77.591	34.969	71.2	2.2	0.27	1.7	3.7	
61	06-09-2010	23:30:15	77.334	34.787	87.2	3.6	0.72	1.7	2.8	
62	07-09-2010	14:36:54	77.431	34.75	15.4	2.4	0.45	3.2	1.7	
63	09-09-2010	16:13:12	77.345	34.84	63.6	4.5	0.26	1.6	2.8	
64	10-09-2010	13:18:15	77.412	35.004	11.1	2.7	0.12	1.9	2.9	
65	15-09-2010	21:21:32	77.452	34.76	26	2.8	0.47	1.1	3.6	
66	17-09-2010	14:11:16	77.661	35.926	13.2	4.1	0.38	2.5	5	
67	19-09-2010	12:43:17	71.478	36.931	0.1	3.5	0.36	3.2	2.7	
68	01-10-2010	02:00:27	77.158	34.652	10	3	0.78	3.8	1.3	
69	03-10-2010	10:19:57	77.081	35.48	12	2.6	0.24	4.7	1.9	
70	09-10-2010	04:06:09	77.401	34.495	10	3.3	0.26	1.6	1.9	
71	11-10-2010	05:45:42	77.59	34.7	9	4	0.53	3.4	2.7	
72	13-10-2010	08:32:09	77.085	35.495	6	2.8	0.45	4.3	3.6	
73	14-10-2010	17:24:54	77.156	35.366	10	2.1	0.47	2.8	3.4	
74	15-10-2010	01:34:12	77.887	34.69	10	3	0.59	0.9	4.1	
75	18-10-2010	11:47:21	77.309	35.19	10	2.8	0.32	1	3.7	
76	22-10-2010	12:39:42	76.725	35.44	10.3	3.3	0.26	2.7	1.8	
77	26-10-2010	15:33:18	76.786	35.334	37.7	2.8	0.89	0.5	4.9	
78	28-10-2010	01:16:29	77.21	35.24	3.2	2.8	0.67	1.1	0.9	

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79	01-11-2010	04:03:11	77.125	35.427	5.9	3.2	0.58	1.2	1.8
80	02-11-2010	10:01:16	77.58	34.671	4.9	2.3	0.12	3.4	4.6
81	07-11-2010	07:15:18	77.552	34.805	6.2	3.9	0.45	1.2	4.3
82	09-11-2010	01:42:18	70.746	35.732	10	3.6	0.38	4.7	2.6
83	10-11-2010	12:55:42	77.556	34.721	83	2.6	0.36	1.7	1.6
84	13-11-2010	19:49:00	77.537	35.362	4.6	3.4	0.16	1.5	2.7
85	14-11-2010	20:01:56	77.367	35.042	8.2	3.7	0.23	0.8	1.9
86	15-11-2010	07:05:18	77.619	34.586	10	3.9	0.39	3.7	4.3
87	02-12-2010	01:42:18	74.246	35.249	10	3	0.48	2.6	4.3
88	03-12-2010	12:55:00	76.802	34.023	2	2.54	0.59	1.2	4.9
89	06-12-2010	02:55:03	77.54	35.011	0.1	3.5	0.66	3.6	1.2
90	09-12-2010	07:29:27	77.412	35.1	9.8	3.8	0.38	1.8	3.2
91	18-12-2010	20:01:20	77.153	35.326	10	2.6	0.12	1.6	3.4
92	19-12-2010	04:18:17	76.692	35.109	10	3.3	0.49	4.3	4.9
93	01-01-2011	10:15:47	77.29	34.795	9.4	2.2	0.27	1.7	3.7
94	20-01-2011	22:43:56	77.552	34.853	10	4.2	0.4	4.7	3.7
95	08-02-2011	16:52:59	77.43	35.398	132.4	3.2	0.21	5	1.9
96	13-02-2011	11:52:19	77.195	35.408	10	2	0.36	3.2	2.7
97	18-05-2011	10:19:57	77.177	35.224		71.2	0.47	4.3	1.2
98	05-07-2011	04:06:09	77.29	35.14	9.8	2.2	0.58	2.4	3.9
99	05-07-2011	05:45:42	77.517	34.892	10	3.7	0.39	4.6	3.8
100	10-07-2011	08:32:09	77.11	35.4	12	3	0.89	1.7	3.4
101	24-07-2011	17:24:54	77.09	35.21	11	4.2	0.76	3.4	2.6
102	04-09-2011	14:11:29	77.049	34.843	10	2.2	0.63	5	1.7
103	05-09-2011	16:25:32	77.208	34.911	15	1.7	0.42	1.2	3.6
104	06-09-2011	20:17:10	77.071	34.815	10	2.2	0.53	4.3	4.9
105	25-09-2011	06:47:49	76.679	35.39	10	3.1	0.56	5	3.7
106	16-10-2011	00:31:18	77.937	34.702	14	2.3	0.39	4.8	1.7
107	24-10-2011	10:17:10	77.24	35.12	57	2.6	0.57	5.2	3.5
108	29-10-2011	20:53:29	76.598	35.298	45	1.7	0.17	3.7	2.9
109	01-11-2011	18:37:00	77.863	34.563	10	3.5	0.34	4.9	2.6
110	02-11-2011	15:18:44	76.761	35.135	16.8	1.7	0.12	4.3	3.8
111	02-11-2011	03:21:12	77.211	35.132	4.3	2.8	0.26	2.9	3.1
112	06-11-2011	11:26:54	77.244	35.247	55.9	3	0.69	1.3	4.9
113	11-11-2011	03:19:39	77.228	35.133	1.2	4.2	0.34	3.7	1.9
114	12-11-2011	01:42:51	76.779	35.405	47	2	0.43	2.6	2.1
115	12-11-2011	11:51:03	77.412	35.332	42	3.6	0.56	1.8	2.6
116	17-11-2011	20:17:10	77.082	35.038	2.9	2.6	0.71	2.8	1.9
117	21-11-2011	00:03:00	76.621	35.303	45	1.8	0.63	4.3	3.2
118	27-11-2011	05:27:00	77.433	34.83	110	2.1	0.59	3.1	2.7

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119	30-11-2011	00:34:00	77.997	34.862	10	1.9	0.89	1.7	3
120	02-12-2011	10:19:37	77.007	35.12	9.5	3.8	0.63	2.6	3
121	08-12-2011	14:06:09	77.82	35.18	4.3	2.7	0.39	3.7	4
122	09-12-2011	11:45:42	77.955	35.58	97.8	3.2	0.48	2.6	4
123	12-12-2011	08:32:09	77.173	35.259	10	3.2	0.59	1.2	4
124	14-12-2011	17:24:54	77.167	35.412	49.5	3	0.66	3.6	1
125	29-12-2011	02:51:40	77.15	35.36	63.7	2.4	0.38	1.8	3
126	30-12-2011	22:12:18	77.183	35.252	1.9	4.3	0.12	1.6	3
127	18-02-2012	03:21:12	77.233	35.14	10	2.6	0.49	4.3	2
128	23-02-2012	11:26:00	77.345	35.084	10	3.9	0.27	1.7	3
129	02-03-2012	03:19:00	77.424	34.935	100.7	3	0.4	4.7	3
130	29-03-2012	01:42:00	77.558	34.711	125	2.1	0.21	5	1
131	09-04-2012	11:51:03	77.581	34.681	10	2.8	0.36	3.2	2
132	18-04-2012	06:09:44	76.95	35.481	2.7	3.9	0.47	4.3	1
133	19-04-2012	01:20:07	77.088	35.382	10	2.7	0.58	2.4	3
134	20-04-2012	12:19:50	77.166	35.196	12	2	0.39	4.6	:
135	21-04-2012	03:07:23	77.257	35.048	13.7	3.8	0.89	1.7	1
136	27-04-2012	20:01:56	77.34	34.899	3.2	4	0.76	3.4	-
137	28-04-2012	07:05:18	77.261	35,153	10	3.8	0.63	5	-
138	01-05-2012	01:42:18	77.286	35.114	7.8	2.6	0.42	1.2	
139	07-05-2012	12:55:00	77.23	35.161	3.8	4.4	0.53	4.3	2
140	11-05-2012	10:38:12	77.257	35.121	10	2.5	0.56	5	1
141	13-05-2012	22:36:41	77.317	35.099	8.7	3.4	0.39	4.8	-
142	15-05-2012	12:21:44	76.891	35.621	9.4	3.8	0.57	5.2	1
143	16-05-2012	09:43:07	77.016	35.564	49.8	3.7	0.17	3.7	2
144	16-05-2012	00:57:09	77.054	35.472	43.7	4.1	0.34	4.9	2
145	17-05-2012	18:22:54	77.122	35.402	90.2	2.9	0.12	4.3	
146	18-05-2012	03:40:40	77.163	35.292	48.4	3	0.26	2.9	-
147	20-05-2012	11:18:39	77.19	35.212	10	4.2	0.69	1.3	2
148	21-05-2012	17:26:41	77.209	35.317	53.8	2	0.34	3.7	
149	27-05-2012	01:08:29	77.252	35.236	9.4	2.3	0.43	2.6	2
150	27-05-2012	17:46:41	77.344	35.101	8.4	3	0.56	1.8	2
151	28-05-2012	00:38:12	77.123	35.378	59.2	3	0.71	2.8	
152	29-05-2012	12:36:41	77.218	35.118	4	3.6	0.63	4.3	3
153	30-05-2012	10:19:57	76.927	35.653	12.1	4.3	0.59	3.1	
154	04-06-2012	04:06:09	77.318	35.131	10	3.4	0.12	1.9	4
155	05-06-2012	05:45:42	76.887	35.635	61.7	3.7	0.47	1.1	:
156	08-06-2012	08:32:09	77.407	35.021	67.9	3.2	0.38	2.5	
157	11-06-2012	17:24:54	77.186	35.139	10	3.9	0.78	3.8	1
158	12-06-2012	02:51:40	77.322	35.102	71.3	2.9	0.24	4.7	1

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Continued	I								
159	14-06-2012	22:12:18	77.325	34.986	7.4	2.4	0.26	1.6	1.9
160	15-06-2012	03:21:12	77.226	35.282	5.2	3.6	0.53	3.4	2.7
161	20-06-2012	11:26:00	77.282	34.744	12.8	3.8	0.45	4.3	3.6
162	22-06-2012	03:19:00	77.611	34.577	45.8	3.2	0.47	2.8	3.4
163	24-06-2012	01:42:00	77.419	34.641	94.3	3.5	0.59	0.9	4.1
164	29-06-2012	11:51:03	77.557	34.776	68.5	2.3	0.32	1	3.7
165	11-07-2012	06:09:44	77.481	34.86	10	2.8	0.26	2.7	1.8
166	14-07-2012	01:20:07	77.545	34.703	74.9	4.2	0.89	0.5	4.9
167	17-07-2012	12:19:50	77.007	35.494	6.8	3.7	0.67	1.1	0.9
168	18-07-2012	03:07:23	77.134	35.388	0.9	2.1	0.58	1.2	1.8
169	23-07-2012	20:01:56	77.361	35	10	2.3	0.12	3.4	4.6
170	31-07-2012	07:05:18	77.634	34.637	47.9	3.8	0.45	1.2	4.3
171	01-08-2012	01:42:18	77.509	34.748	110.1	3.5	0.38	4.7	2.6
172	06-08-2012	12:55:00	77.47	34.691	320.1	2.9	0.36	1.7	1.6
173	12-08-2012	07:31:12	77.204	34.847	10	3.7	0.16	1.5	2.7
174	17-08-2012	10:38:12	77.504	35.149	10.7	3.6	0.23	0.8	1.9
175	26-08-2012	22:36:41	76.954	35.243	8.4	2.3	0.39	3.7	4.3
176	28-08-2012	12:21:44	77.072	35.458	10.2	3.4	0.48	2.6	4.3
177	01-09-2012	09:43:07	77.388	34.966	12	3.6	0.59	1.2	4.9
178	02-09-2012	00:57:09	77.01	35.256	74	3.2	0.66	3.6	1.2
179	05-09-2012	18:22:54	77.146	35.255	86	2.8	0.38	1.8	3.2
180	05-09-2012	03:40:40	77.254	35.193	73.7	3.9	0.12	1.6	3.4
181	09-09-2012	11:18:39	77.255	35.245	98.7	4.1	0.69	1.3	4.9
182	10-09-2012	17:26:41	77.633	34.654	12	4	0.34	3.7	1.9
183	07-10-2012	01:08:29	77.477	34.911	10	2.6	0.43	2.6	2.1
184	08-10-2012	17:46:41	76.629	35.46	10	1.9	0.56	1.8	2.6
185	09-10-2012	00:38:12	77.241	35.402	10	1.3	0.71	2.8	1.9
186	15-10-2012	12:36:41	77.121	35.12		12	0.63	4.3	3.2
187	15-10-2012	02:49:39	77.464	34.918	10	6.9	0.59	3.1	2.7
188	20-10-2012	07:31:12	77.429	34.893	10	2.6	0.89	1.7	3.9
189	25-10-2012	10:38:12	77.53	35.14	47.9	3.5	0.63	2.6	3.2
190	26-10-2012	22:36:41	77.21	35.12	12.9	3.2	0.39	3.7	4.3
191	06-11-2012	12:21:44	77.198	34.916	432.8	2.9	0.48	2.6	4.3
192	09-11-2012	09:43:07	77.483	34.922	134	2.8	0.59	1.2	4.9
193	16-11-2012	00:57:09	76.914	34.975	10	2.7	0.66	3.6	1.2
194	23-11-2012	18:22:54	77.406	34.9	10	2.1	0.38	1.8	3.2
195	28-11-2012	03:40:40	77.222	34.912	172	2.2	0.12	1.6	3.4
196	05-12-2012	19:43:07	76.917	35.12	218.9	3.9	0.49	4.3	4.9
197	24-12-2012	22:49:18	77.945	34.93	115.6	3	0.27	1.7	3.7
198	25-12-2012	10:49:38	77.684	35.238	126.7	2.8	0.4	4.7	3.7

region, India and consistent with the geological section of the area prepared by [24] (Figure 6(a)).

Considerable amount of broken ice chunks were observed near the snout of siachen glacier during field visit in Aug'2011 (Figure 7). The field personnel deployed at field stations reported that the cracking mainly observed contemporaneous to the shacking. The close association of log book maintained at field sites for keeping



Figure 5. Plot of number of earthquakes versus focal depth.



Figure 6. (a) Geological cross-section through the Northern parts of NW Himalaya and Karakorum, after [16]; (b) Aseismic layer in the mid-crust.



Figure 7. Field Photographs showing cracking in the snout region.

record of shaking and seismic data recorded at field seismic stations indicates that these cracking mainly associated with tremors occurring near the snout of the siachen glacier. Moreover few earthquake events are located in the snout region of glacier it is evident that these earthquake events are responsible for cracking in the snout of glacier. As the Karakoram fault passes through the main body of siachen glacier as well as through snout region of siachen glacier (**Figure 1**) such tremors will keep occurring due to the presence of this active fault and theses tremors may have very serious implication on the snout of the siachen glacier.

5. Conclusion

Aseismic layer (17 - 40 Km) is detected in the mid-crust of Nubra-Siachen region of NW, Himalaya with the help of locally observed seismic data. This layer is sandwiched between two seismically active layers. This aseismic layer shows the good spatial correlation with the low resistivity layer [26]. Results of this study support the proposed "partially melted crust for this region" by [24]. The observed local seismicity for the period Jan' 2010-Dec' 2012 in Siachen-Nubra region of Jammu & Kashmir is mainly oriented along the Karakoram Fault and clustered in Shyok suture zone & Karakoram Shear zone. The moment magnitudes of these events lie between 1.3 and 4.3. The depth distribution of earthquake events shows that most of the local earthquakes in this region have been occurred at upper part of the crust. Such shallow seismic activity in the glacier region may affect the glaciers. These aspects need to be studied in more detail.

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