RESEARCH

THE BALOCHISTAN EARTHQUAKE 2013: EMERGENCE OF A NEW ISLAND IN THE ARABIAN SEA

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CONFLICTS OF INTEREST
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ABSTRACT:
A massive earthquake of 7.7 magnitude struck south-central Pakistan on September 24, 2013. The epicenter of the earthquake was 63 km north-north-east (NNE) of Awaran in Baluchistan. The earthquake caused the death of 386 people, leaving thousands homeless. The earthquake also affected different cities in Iran, India and Afghanistan. The fundamental cause of the earthquake was displacement along oblique-strike-slip fault at a depth of only 15 km (9.3 miles). The quake has created an island in the Arabian Sea which is an unusual in case of strike-slip faulting and it raises the question of the nature and original mechanism of the earthquake. The formation of the island indicates that there is a significant push of the northward moving Indo-Pakistani plate along with oblique-strike-slip faulting which was the original motion of the earthquake. These facts were discussed and explained in this paper.

Keywords: Arabian Sea, Awaran, Baluchistan earthquake, Island, Strike-slip fault

INTRODUCTION

Earthquakes or seismic tremor are a natural hazard caused by environmental factors, killing an increasing number of people. The increase in casualties may be due to the growth in population, towns growing into urban centres [1]. Major population centres are often located along mountain ranges, with cities lying next to faults. Significant damage occurs when they rupture due to the proximity of vulnerable buildings [2]. The degree of damage varies according to the intensity of the quake and local geological conditions. Close to the epicenter, the damage is direct, resulting in immediate destruction, such as collapsed buildings and destroyed infrastructure, broken installation, and indirect or secondary, resulting in fires, landslides, floods, etc.

The 2013 Balochistan earthquake struck along one of the most hazardous yet poorly studied tectonic plate boundaries in the world. The earthquake of 7.7 magnitude was likely centered on a southern strand of the Chaman Fault. The Chaman Fault is a large, active fault around 860 kilometers long, stretching along Pak-Afghan border region. It is one of the world's major terrestrial transform faults that cross back and forth between Afghanistan and Pakistan, ultimately merging with some other faults and going to the Arabian Sea [3]. One of the deadliest earthquakes ever in Southeast Asia occurred in 1935, on the northern Chaman Fault and destroyed the town of Quetta, killing more than 30,000 people.

Sometimes mountains are created and islands emerged when continents collide, causing tectonic faults to move. Most of these faults are locked in the upper crust, and sudden slipping in earthquakes mountain growth for example, in Nepal during 2015 Gorkha earthquake [4]. The Balochistan 2013 earthquake undergoes similar situation and resulted in the creation of an Island off Gwadar coast Figure 1. The earthquake occurred on September 24, 2013, in the south central region of Pakistan [5]. The earthquake was

measured at 7.7 magnitude, and lasted for a very short time, 8 seconds, but degree of damage caused was enormous. Over 300,000 people have been affected across six districts. Awaran district near the epicenter was the most affected area, homes which were made up of mud and stone were demolished. This paper addresses the September 2013 Balochistan Earthquake, creation of island and discusses history of earthquakes in this particular region.

Figure 1: Gwadar Island. Inset images show details of the island surface [5]

EARTHQUAKE SEPTEMBER 2013

At Pakistan standard time (PST) 16:29:48, (11:29:48 GMT), on September 24, 2013 a powerful earthquake struck the south-central part of Pakistan. The epicenter of the earthquake was 63 km NNE of Awaran district (26° 59' 58.92"N, 65° 30' 51.48"E). The location of the earthquake hit area is shown in Figure 2(a-b) [5].

The magnitude of the earthquake that lasted for 8 seconds was 7.7 on the Richter scale. The epicenter of the event is 69 km north of Awaran, Pakistan, and 276 km north-west of Karachi city, where over 11.6 million people resided [5].The earthquake shocks were also observed in neighbouring countries India, Iran and Afghanistan too. The earthquake was as a result of oblique-strike-slip type motion at shallow crustal depths. The location and mechanism of the earthquake are consistent with rupture within the Eurasian plate above the Makran subduction zone, Figure 3 [6]. The event occurred within the transition zone between northward subduction of the Arabian plate beneath the Eurasian plate and northward collision of the Indian plate with the Eurasian plate. The intensity of the event over the distance is shown in "Distance vs Intensity" curve in Figure 4 [5].

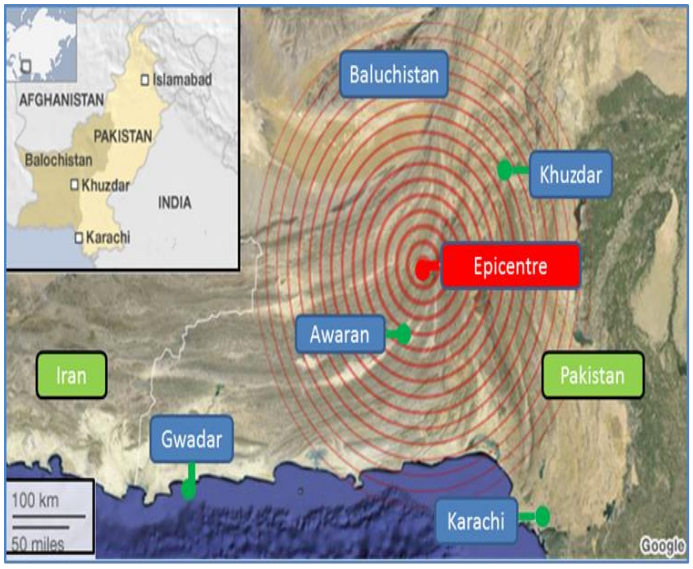


Figure 2(a-b): Location map of Gwadar Island created by September 24, earthquake [5]

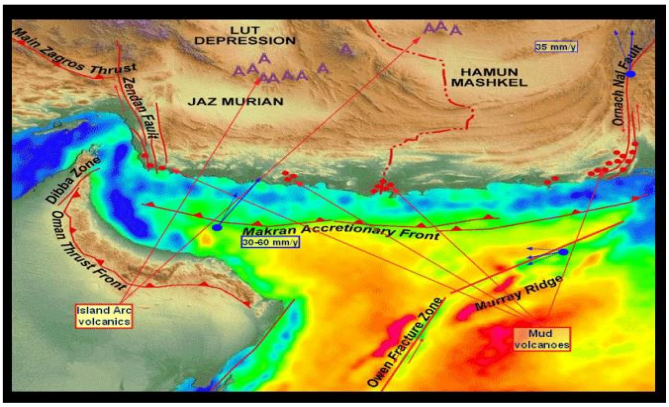


Figure 3: Makran Accretionary prism & zone of subduction in Arabian Sea (PMD)

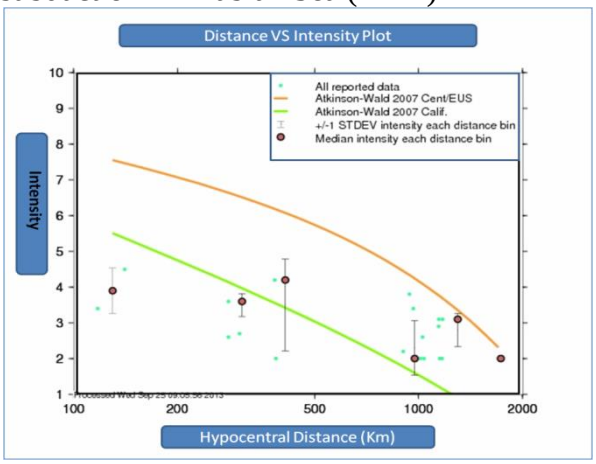


Figure 4: Distance vs Intensity of the September 24, 2013 Balochistan Earthquake (USGS)

The aftermath of the September 24, 2014 earthquake in Balochistan has been devastating. According to National Disaster Management Authority, Islamabad, the earthquake caused the death of about 386 people, injured 816 people, and made thousands of people homeless (totally damaged houses 32638, partially damaged houses 14118) [7] (Figure 5).

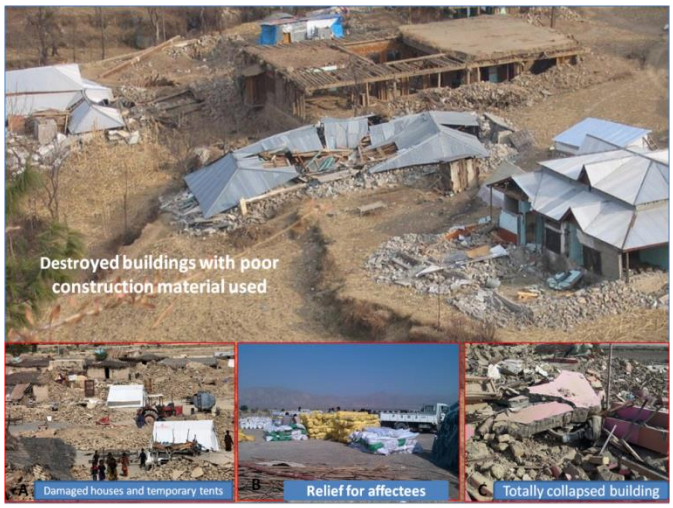


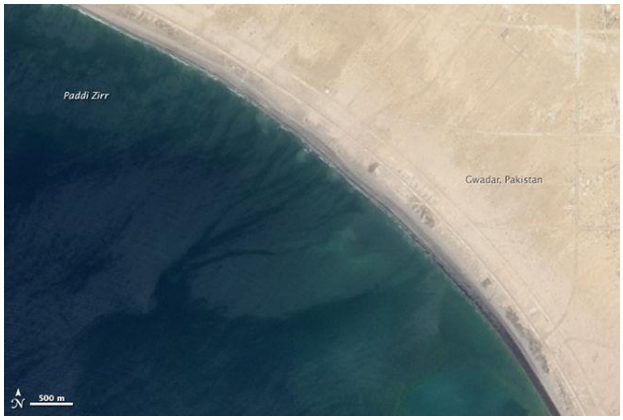
Figure 5: Photos of destroyed buildings and relief camp

A subduction zone along the Makran coast was first time proposed about four decades ago [8] and found to be consistent with seismic activities [9] followed by field investigations [10]. Several researchers assessed the tsunami hazard along the coast of Iran, Pakistan and Oman originating from the subduction process [11-13]. Heidarzadeh and his colleagues [14,15] performed deterministic analyses based on five magnitude 8.1 events and six magnitude 8.3 events, respectively, and Heidarzadeh and Kijko [16,17] carried out a probabilistic study based on three magnitude 8.1 sources associated with probabilities to propose what they labeled a "first generation" probabilistic tsunami hazard assessment (PTHA) for the region. There is a complex tectonics history of southern and central Pakistan at the regional scale, where Indian-Pakistani plate slides northward relative to the Eurasian plate in the east, and the Arabian plate subducts northward beneath the Eurasian plate in the Makran (earthquake epicenter region) [18-21]. These motions typically result in north-south to northeast-southwest strike-slip motion at the latitude of the September 24 earthquake that is primarily accommodated on the Chaman Fault, with the earthquake potentially occurring on one of the southern-most strands of this fault system [5]. The dramatic formation of an island in the Arabia Sea raises questions about the original trigger and mechanism of the event for which deep investigation is required - Figure 6(a-d). It is also noted that out of 23 strong earthquakes (over 6.0 Mw) in Pakistan, 14 occurred in Balochistan which makes it one of the most prone province to earthquakes. The earthquake of 27 November 1945 - off the Makran coast (Balochistan) Mw 7.9, [11] also formed an island which disappeared later.

Although it is not unusual for earthquakes of this magnitude to change the coastline, or even deform the shape of the planet, for example; in 2010, an earthquake of 8.8 magnitude in Chile [created new coastlines in that country and changed the shape of the Earth enough to shorten our days by a fraction of second [22]. However, in the case of strike-slip events like the current event, this is not usual. Only one strong earthquake occurred in the region during last few decades within 200 km of the current event; a magnitude 6.1 occurred in July 1990 [23] killing 6 persons.

Emerging Island

Balochistan earthquake 2013 was a powerful strike-slip earthquake leaving more than 100,000 homeless. Amidst the destruction, a new island was created offshore in the Paddi Zirr (West Bay) near Gwadar, Pakistan [24]. The images in Figure 6(a-d) illustrate the emergence of the new island over Gwadar offshore and its approximate size [24, 25]. There is no island visible in the image (Figure 6a) in the area, snapped by the Operational Land Imager on Landsat 8 satellite on April 17, 2013. On September 26, 2013, Advanced Land Imager on NASA's Earth Observing-1 satellite captured an image of the emerging island, as shown in Figure 6b [24,25]. The island sits roughly one kilometer (0.6 miles) offshore of the town of Gwadar. The French Pleiades satellite further mapped the muddy hill's dimensions, Figure 6c [25].



a. NASA Earth Observatory - April 17, 2013, No visible image

b. NASA Earth Observatory - September 26, 2013, Advanced Land Imager on NASA's Earth Observing-1 satellite Birth of an island:

c. Size of Island – French Astrium/Pleiades

d. Close up of the island – PNIO and NASA

Figure 6(a- d): Images of the emerging Island, named "Zalzal Koh" or Zalzala Jazira, or Gwadar Island

Description The Island

The aerial photograph of the new island named "Zalzala Koh" or Gwadar Island, in Figure 6d [25], released by Pakistan's National Institute of Oceanography (PNIO) [26], suggests the gray-colored mound. The surface is covered in sea creatures such as dead fish and solid enough for people to walk on.

The island is partially composed of rock fragments, mud and sand. It is about 330 miles (533 kilometers) from Pakistan's largest city of Karachi and 75 miles (120 kilometers) from Iran border (Figure 1, 2a). The island is about 60 feet (18 meters) high, 100 feet (30 meters) wide and 250 feet (76 meters) long (Figures 1 and 6d). The new island may have formed by surface deformation produced by the earthquake or by the release of gas trapped in surface sediments due to ground shaking. The in situ geological observations show that the second mechanism is the most adequate since the surface of the island presented fissures and cracks indicating the escape of gas, which was also observed bubbling along the shores of the island. The combustion produced by open fire suggests that the gas was mainly methane. The occurrence of methane is a good clue for hydrocarbon prospecting in the area. Due to its unconsolidated nature it is probable that the island will soon be destroyed by marine abrasion. It is very obvious that there is fossil fuel source underneath seabed, the indication of methane gas confirms this claim and it is suggested to carry out deep investigations for hydrocarbon prospective.

Table 1: History of earthquakes in Pakistan (over magnitude 6.0)

Year	Location	Coordi-nates	Magni-tude	Depth (km)	Damages
893 - 894 A.D.	Debal (Lower Sindh)		7.5 / 8.0		Nearly 1,50,000 people were killed and several towns were destroyed in the region
2 May 1668	Near Shahbundar (Lower Sindh)	24.00 N, 68.00 E	7.6		Nearly 50,000 people were killed and several towns were destroyed in the region
16 June 1819	Allahbund, Indo-Pak Border region	23.60 N, 69.60 E	7.5		About 3200 people were killed and dozens of towns and villages were destroyed in Kutchh and adjoining parts of southern Pakistan. The earthquake resulted in great surface deformation including a 90-kilometres stretch of land uplifted about 4 metres, called the Allahbund. The shock was felt throughout the Sub-continent as far as Kolkata.
26 September 1827	Near Lahore (Punjab)	31.00 N, 75.30 E	7.8		At least 1000 people killed in Lahore and the neighbouring parts of Punjab province. Some discrepancies in the exact location of the epicentre. Very few earthquake catalogs list this event.
24 January 1852	Near Kahan (Balochistan)	29.30 N, 68.80 E	8		250 - 350 people killed in the Kahan area, in the Muree Hills. Hundreds of heads of cattle also perished and buildings in the fort area were either badly damaged or destroyed.
January 1865	Near Kahan (Balochistan)				Several buildings destroyed.
1883	Jhalawan (Balochistan)				
1889	Jhalawan (Balochistan)		8		
20 December 1892	Near Chaman, Afghanistan-Pakistan border		6.8		This earthquake was triggered by a fault that caused surface displacement for nearly 200 kilometres off setting railway lines and other man-made structures. It was felt throughout Balochistan (Pakistan) and was centred in the Khojak range.
20 October 1909	Between Loralai and Sibi (Balochis tan)	30.00 N, 68.00 E	7.0	60	Several villages completely destroyed and more than 100 killed.
1 February 1929	Between Buner and Hazara (North West Frontier Province)	36.50 N, 70.50 E	7.1	180-220	Occurred just north of Abbotabad at around 10:45 pm local time. Reached a maximum RF intensity of 8.
25 August 1931	Sharigh (Balo chistan)	30.00 N, 67.00 E	7.2		This earthquake reached a maximum RF intensity of 8. It had a very shallow focal depth and destroyed most of the mud houses in the region.
27 August 1931	Mach (Baloch istan)	29.80 N, 67.30 E	7.4	35	This was the second earthquake within a span of two days to hit the same region. It was much stronger than the earthquake on August 25th, but did not reach a maximum RF value of more than 8. It was felt in much of Balochistan and Sindh. Several people were killed by falling masonry in Quetta.
30 May 1935	Quetta (Baloc histan)	27.39N, 88.75E	8.1	17	Close to 30,000 people were killed and the city of Quetta was devastated. The main shock was most intense in a small region surrounding the epicentre, its intensity dying off rapidly as one moved away from it.
27 November 1945	Off the Makran coast (Balochi stan)	24.50 N, 63.00 E	7.9 / 8.0	25	At least 4000 people killed in southern Pakistan and neighbouring Iran. Tsunamis with heights of 12 meters struck the Makran coast. Widespread damage. Damage also occurred at Ormara. Tsunamis were recorded at Kutchh (India) and Mumbai, India, with wave heights of 6 meters and 2 meters respectively. An Island was formed during the earthquake.
5 August 1947	Off the Makran coast (Balochi stan)	25.10 N, 63.40 E	7.2		

28 December 1974	NE of Malakhand, NWFP, (Indo-Pakistan Border region)	35.054N, 72.870E	6.2	22	Reports on this earthquake are very sketchy and apart from the 5300 fatalities caused by this quake nothing else conclusive can be stated.
27 February 1997	Near Harnai (Balochistan)	29.976 N, 68.208 E	7.3	33	One of the strongest earthquakes in Pakistan for several decades. At least 50 people were killed in the region in the cities of Quetta, Sibi and Harnai. Landslides blocked several roads and railway tracks in the region. Felt throughout central Balochistan
20 November 2002	Gilgit-Astore region (P.O.K.)	35.529 N, 74.531 E	6.3	33	23 killed in the Astore Valley and heavy damage in the area. Major landslides reported in the Astore and Gilgit areas. 15,000 people rendered homeless. Felt at Islamabad, Pakistan and at Srinagar, India.
8 October 2005	Parts of Khyber and Azad Kashmir	34.46 N, 73.58 E	7.8	19.1	87,000 Dead (According to World Bank Report) and 100,000 injured. 171,884 houses completely demolished and over 100,000 houses were partially damaged. Several entire villages were destroyed in Kashmir. 4 Million people homeless in 1,083 villages of Azad Kashmir. In Kashmir, the districts of Muzaffarabad, Bagh and Rawlakot were the most affected. Mansehra and Batagram districts were also affected very badly.
29 October 2008	Quetta (Balochistan)		6.4		216 and thousands homeless
January 18, 2011	Balochistan	28.78 N, 63.95 E	7.2	68	2 and hundreds homeless
September 24, 2013	Awaran (Balochistan)	27.09 N, 65.61 E	7.7	10	350 or more and thousands homeless

Note: *Data presented in Table 1 is mostly taken from Global Seismic Hazard Assessment Program (GSHAP) alongwith small aditional information for different parameters from various sources; for example USGS, PMD, web-sources*

Table 2: Earthquake record of Pakistan during 2013

S.No	Date	Origin Time H-Time (H:M:S)	Focal Depth (Km)	Epicenter	Magnitude	Location Coordinates	Province Name
1	Tuesday, 24 September, 2013	16:29:50 PST	10	120 km SW of Khuzdar, Balochistan	7.7	27.09N, 65.61E	Baluchistan
2	Saturday, 28 September, 2013	12:34:13 PST	47	150Km SW of Khuzdar,Pakistan	7.2	27.43N, 65.67E	Baluchistan
3	Wednesday, 17 April, 2013	08:15:54 PST	84	Pakistan-Iran Border Region	6	28.15N 62.42E	Border (Near Baluchistan)
4	Tuesday, 24 September, 2013	18:01:44 PST	30	80 km SW of Khuzdar	5.9	27.41N, 65.86E	Baluchistan
5	Tuesday, 24 September, 2013	17:07:01 PST	114	Mitthi, Sindh	5.7	24.51N, 69.69E	Sindh
6	Tuesday, 24 September, 2013	22:22:20 PST	10	105Km SW of Khuzdar,Pakistan	5.6	27.12N, 65.80E	Baluchistan
7	Friday, 18 October, 2013	18:18:24 PST	10	66 km North of Khuzdar	5.6	28.30N, 66.70E	Baluchistan
8	Tuesday, 24 September, 2013	19:08:35 PST	10	65 km SW of Khuzdar	5.5	27.65N, 65.78E	Baluchistan
9	Sunday, 21 July, 2013	03:13:20 PST	211	95Km NW of Chitral, Pakistan,	5.2	36.64N, 71.41E	Gigit Baldistan
10	Tuesday, 24 September, 2013	17:42:16 PST	26	66 km SW of Khuzdar	5.2	27.30N, 65.80E	Baluchistan
11	Wednesday, 17 April, 2013	09:53:30 PST	97	Pakistan-Iran Border Region	5.1	28.04N 62.56E	Border (Near Baluchistan)
12	Friday, 27 September, 2013	23:08:43 PST	10	160Km East of Panjgur, Balochistan, Pakistan	5.1	27.16N, 64.77E	Baluchistan
13	Saturday, 12 October, 2013	14:37:27 PST	10	80 km SW of Khuzdar, Blochistan	5.1	27.37N 65.97E	Baluchistan
14	Friday, 18	18:12:30 PST	10	122 km East of Turbat	5.1	26.01N, 64.60E	Baluchistan

	October, 2013						
15	Saturday, 13 April, 2013	14:09:41 PST	529	147km SE of Pasni Airport	5	24.35N 64.45E	Baluchistan
16	Tuesday, 24 September, 2013	20:12:27 PST	10	100 km SW of Khuzdar	5	27.11N, 65.90E	Baluchistan
17	Wednesday, 25 September, 2013	02:59:04 PST	10	65 km SW of Khuzdar, Pakistan	5	27.47N, 66.00E	Baluchistan
18	Tuesday, 24 September, 2013	23:51:59 PST	10	75 Km Sw of Khuzdar,Pakistan	4.9	27.32N, 66.29E	Baluchistan
19	Wednesday, 25 September, 2013	00:54:10 PST	53	60Km SW of Khuzdar,Pakistan	4.9	27.41N, 66.01E	Baluchistan
20	Wednesday, 25 September, 2013	03:38:19 PST	10	70Km SW of Khuzdar,Pakistan	4.9	27.14N, 65.87E	Baluchistan
21	Thursday, 14 February, 2013	08:43:21 PST	32	40 Km North of Sibi, Pakistan	4.8	29.78N, 68.17E	Baluchistan
22	Tuesday, 24 September, 2013	23:13:14 PST	146	165Km SE of Khuzdar,Pakistan	4.8	27.29N, 68.20E	Baluchistan
23	Thursday, 10 January, 2013	01:10:23 PST	10	130km south west of Lora Lai, Pakistan	4.7	27.20N, 63.97E	Baluchistan
24	Thursday, 7 March, 2013	20:56:40 PST	10	172km S.E of Karachi	4.7	24.23N 68.69E	Near Baluchistan
25	Friday, 9 August, 2013	06:32:25 PST	25	45Km southwest of Chaman,Balochistan,Pakistan	4.7	30.52N , 66.29E	Baluchistan
26	Tuesday, 26 November, 2013	06:04:29 PST	95	108km East of Skardu,KPK	4.7	35.03N,76.76E	Kyhber Pakhtun Khawa
27	Saturday, 5 January, 2013	10:58:27 PST	10	Pakistan Iran Border Region	4.6	25.28 N, 61.52 E	Baluchistan
28	Wednesday, 27 February, 2013	01:12:18 PST	10	45 km south of Sibbi, Pakistan	4.6	29.13 N, 67.97 E	Baluchistan
29	Wednesday, 25 September, 2013	06:37:21 PST	10	130Km SW of Khuzdar,Pakistan	4.6	26.91N, 65.73E	Baluchistan
30	Wednesday, 25 September, 2013	06:37:21 PST	10	130Km SW of Khuzdar,Pakistan	4.6	26.91N, 65.73E	Baluchistan
31	Wednesday, 25 September, 2013	04:41:59 PST	10	63Km SW of Khuzdar,Pakistan	4.6	27.29N, 66.23E	Baluchistan
32	Wednesday, 25 September, 2013	04:41:59 PST	10	63Km SW of Khuzdar,Pakistan	4.6	27.29N, 66.23E	Baluchistan
33	Wednesday, 25 September, 2013	04:41:59 PST	10	63Km SW of Khuzdar,Pakistan	4.6	27.29N, 66.23E	Baluchistan
34	Friday, 25 January, 2013	07:42:35 PST	45	ES of Karachi, Pakistan	4.4	24.30N 67.67E	Near Baluchistan
35	Friday, 28 June, 2013	08:16:54 PST	10	43km north of mangora, Paskistan	4.1	35.21, 72.45	Kyhber Pakhtun Khawa
36	Thursday, 1 August, 2013	10:11:07 PST	10	Near Pezu, D.I.Khan	4	32.29N 70.71E	Kyhber Pakhtun Khawa
37	Sunday, 3 November, 2013	13:18:43 PST	10	Hunza, Pakistan	3.8	36.41N, 74.18E	Gigit Baldistan
38	Friday, 6 December, 2013	18:29:54 PST	10	110 km NW of Gilgit	3.7	36.76N, 73.64E	Gigit Baldistan
39	Saturday, 9 February, 2013	04:02:45 PST	10	Near Chichawatni Pakistan	3.4	30.50N, 72.58E	Punjab
40	Wednesday, 20 March, 2013	04:56:42 PST	10	25km SW of Mianwali, Pakistan	3.4	32.40N 71.36E	Punjab
41	Thursday, 4 April, 2013	22:39:17 PST	10	35km East of Chakwal	3.4	32.93N 73.23E	Punjab
42	Tuesday, 24 September, 2013	23:34:29 PST	10	70Km SW of Khuzdar,Pakistan	3.3	27.38N, 66.07E	Baluchistan
43	Sunday, 19 May, 2013	12:14:58 PST	10	30Km NW of Mansehra	3.2	34.54N, 73.03E	Kyhber Pakhtun Khawa
44	Wednesday, 12 ‘’June, 2013	23:10:09 PST	10	Near Chitral, Pakistan	3.2	35.49N, 71.08E	Gigit Baldistan

45	Saturday, 6 July, 2013	04:36:30 PST	10	Eastern Kashmir, Pakistan	3.2	33.48N, 74.80	Pakistan Occupied Kashmir
46	Thursday, 21 November, 2013	16:05:41 PST	10	Layyah, Pakistan	3.2	30.84N, 70.90E	Punjab
47	Tuesday, 15 January, 2013	19:23:35 PST	10	35 km North of Sakardu	3.1	35.61N, 75.67E	Gigit Baldistan
48	Friday, 8 February, 2013	08:54:45 PST	10	68km NW of D.G Khan	3.1	30.46N 69.95E	Punjab
49	Monday, 12 August, 2013	20:03:44 PST	10	Mir Baz, 70 Km East of Zhob, Balochistan Pakistan	3.1	31.07N, 70.13E	Baluchistan
50	Tuesday, 17 September, 2013	11:14:48 PST	10	100km SE of Mianwali, Pakistan	3.1	31.79N 72.11E	Punjab
51	Tuesday, 15 January, 2013	08:15:56 PST	10	Near Barkhan, Pakistan	3	29.85N, 69.58E	Baluchistan
52	Monday, 2 December, 2013	21:59:24 PST	10	Quetta Pakistan	3	30.16N, 67.30E	Baluchistan
53	Monday, 14 January, 2013	01:45:25 PST	10	47km NW of Zhob	2.9	31.79 N 69.35 E	Baluchistan
54	Wednesday, 24 April, 2013	04:41:57 PST	10	14km South of Haripur	2.9	33.8N 72.9E	Kyhber Pakhtun Khawa
55	Friday, 21 June, 2013	18:56:56 PST	32	40 km NW of Gilgit	2.9	36.08N, 73.95E	Gigit Baldistan
56	Monday, 25 November, 2013	22:15:52 PST	10	50km NW of Mingora,KPK	2.9	35.19N,70.61E	Kyhber Pakhtun Khawa
57	Sunday, 19 May, 2013	15:23:46 PST	10	Near Karak Pakistan	2.7	33.13N, 71.04E	Kyhber Pakhtun Khawa
58	Wednesday, 3 July, 2013	22:46:26 PST	10	Near Zhob, Pakistan	2.7	31.46N, 69.80E	Baluchistan
59	Wednesday, 3 July, 2013	15:21:55 PST	10	40 km SE of Chitral	2.7	35.56N, 72.05E	Gigit Baldistan
60	Friday, 18 January, 2013	20:00:32 PST	10	70 km NE of Chitral	2.6	36.20N, 72.28E	Gigit Baldistan
61	Sunday, 3 February, 2013	16:38:27 PST	10	Gilgit Baltistan Region	2.6	35.87N 70.87E	Gigit Baldistan
62	Sunday, 3 February, 2013	16:38:27 PST	10	Gilgit Baltistan Region	2.6	35.87N 70.87E	Gigit Baldistan
63	Saturday, 19 October, 2013	20:34:36 PST	429	Gilgit	2.6	35.93N 74.92E	Gigit Baldistan
64	Monday, 18 November, 2013	22:25:43 PST	10	20 km West of Chillas, Pakistan	2.5	35.37N, 73.88E	Gigit Baldistan
65	Saturday, 13 April, 2013	18:06:07 PST	343	Pakistan, 227km NE of Kabul-Afghanistan	2.4	35.55N 71.27E	Border (Near Baluchistan)
66	Wednesday, 23 January, 2013	18:24:21 PST	258	105 km NW of Gilgit	2.3	36.42N, 73.34E	Gigit Baldistan
67	Saturday, 19 October, 2013	20:35:11 PST	10	Batgram, Pakistan	2.3	34.92N 73.62E	Kyhber Pakhtun Khawa
68	Saturday, 16 March, 2013	13:04:11 PST	10	40km NW of Manshera	2.2	34.70N 73.04E	Kyhber Pakhtun Khawa
69	Wednesday, 24 April, 2013	00:26:16 PST	10	21km NE of Muzaffarabad Airport	2.2	34.4N 73.7E	Pakistan Occupied Kashmir
70	Friday, 26 April, 2013	18:42:37 PST	10	50 km NW of Chitral	2.2	36.29N, 71.68E	Gigit Baldistan
71	Tuesday, 17 September, 2013	23:44:50 PST	10	87Km North East of Mingora,Pakistan	2.2	34.92N, 73.30E	Kyhber Pakhtun Khawa
72	Monday, 6 May, 2013	15:45:50 PST	10	12 km NE of Muzaffarabad	2.1	34.42N, 73.59E	Pakistan Occupied Kashmir
73	Tuesday, 17 September, 2013	19:39:58 PST	10	Kotli, Azad Kashmir	2	33.49N, 74.01E	Pakistan Occupied Kashmir
74	Wednesday, 10 July, 2013	16:13:21 PST	1	Near Dasu, KPK	1.9	34.90N, 72.87E	Kyhber Pakhtun Khawa
75	Wednesday, 16	00:09:57 PST	10	40km NW of Balakot, Pakistan	1.8	34.83 N, 73.08	Kyhber Pakhtun

	January, 2013					W	Khawa
76	Thursday, 2 May, 2013	17:55:48 PST	10	Mingora, Pakistan	1.7	34.76N, 72.41E	Kyhber Pakhtun Khawa
77	Thursday, 2 May, 2013	17:55:48 PST	10	Mingora, Pakistan	1.7	34.76N, 72.41E	Kyhber Pakhtun Khawa
78	Saturday, 19 October, 2013	12:15:07 PST	10	Allai Pakistan	1.3	34.92N, 72.92E	Kyhber Pakhtun Khawa
79	Saturday, 19 October, 2013	20:34:36 PST	429	Gilgit	2.6	35.93N 74.92E	Gigit Baldistan
80	Saturday, 19 October, 2013	20:35:11 PST	10	Batagram, Pakistan	2.3	34.92N 73.62E	Kyhber Pakhtun Khawa
81	Monday, 18 November, 2013	22:25:43 PST	10	20 km West of Chillas, Pakistan	2.5	35.37N, 73.88E	Gigit Baldistan
82	Wednesday, 20 November, 2013	21:38:37 PST	10	16km Ne of Shangla, Pakistan	1.9	35.02N, 72.85E	Kyhber Pakhtun Khawa
83	Thursday, 21 November, 2013	16:05:41 PST	10	Layyah, Pakistan	3.2	30.84N, 70.90E	Punjab
84	Tuesday, 26 November, 2013	06:04:29 PST	95	108km East of Skardu,KPK	4.7	35.03N,76.76E	Kyhber Pakhtun Khawa
85	Monday, 2 December, 2013	21:59:24 PST	10	Quetta Pakistan	3	30.16N, 67.30E	Baluchistan
86	Wednesday, 11 December, 2013	17:34:20 PST	10	Fort Manro, Pakistan	3.8	29.80N, 69.75E	Punjab
87	Friday, 13 December, 2013	06:55:45 PST	10	Near Wana Pakistan	3.6	32.42N, 69.93E	FATA (near, Kyhber Pakhtun Khawa)
88	Friday, 20 December, 2013	13:03:14 PST	43	70 km West of Sargodha, Pakistan	3.6	31.79N, 71.97E	Punjab

DISCUSSION: Tectonic History - Seismicity and Seismic Hazards

Earthquake history of Pakistan shows that Balochistan Province is one of the most earthquake prone regions in Pakistan (Table 1 and 2). According to a map created by the Pakistan Meteorological Department (PMD), the country is divided into 4 zones based on expected ground acceleration (Figures 7&8). The areas surrounding Quetta, along the Makran coast and parts of the Khyber Pakhtun Khawa (KPK) province, along the Afghan border fall in Zone 4. According to the Global Seismic Hazard Assessment Program (GSHAP), the most vulnerable areas of Pakistan are parts of Balochistan province in and around Quetta stretching to the Afghan border and western parts of Balochistan, which include the Makran coast upto the Iranian border (Figures 7&8). These regions may expect to have maximum peak ground accelerations (PGA) ranging from 0.24g to 0.4g.

The Arabian, Eurasian and Indo-Pakistani plates are the main contributors to active tectonics and seismicity in Pakistan. Mountain orogeny in Pakistan is the result of compressional tectonics associated with collision of the Indian plate moving northwards at a rate of 48 mm/yr with respect to the Eurasian plate [27,28]. Continental thickening of the northern and western edge of the India subcontinent has produced the highest mountains in the world, including the Himalayan, Karakoram, Pamir and Hindu Kush ranges. Almost all of the earthquake activity and related deformation found in this region,

as well as in adjacent parts of Afghanistan and India, are due to collisional plate tectonics.

In the western margin of the Tibetan Plateau, in the vicinity of southeastern Afghanistan and western Pakistan, the Indian plate translates obliquely relative to the Eurasian plate, resulting in a complex fold-and-thrust belt known as the Sulaiman Range. Faulting in this region includes strike-slip, reverse-slip and oblique-slip motion and often results in shallow, destructive earthquakes. The relatively fast moving left-lateral, strike-slip Chaman Fault system in southeastern Afghanistan accommodates translational motion between the Indian and Eurasian plates (Figure 9). In 1505, a segment of the Chaman Fault system near Kabul, Afghanistan ruptured causing widespread destruction of Kabul and surrounding villages. In the same region, the more recent 30 May 1935, M7.6 Quetta, Pakistan earthquake, occurred within the Sulaiman Range, killing between 30,000 and 60,000 people.

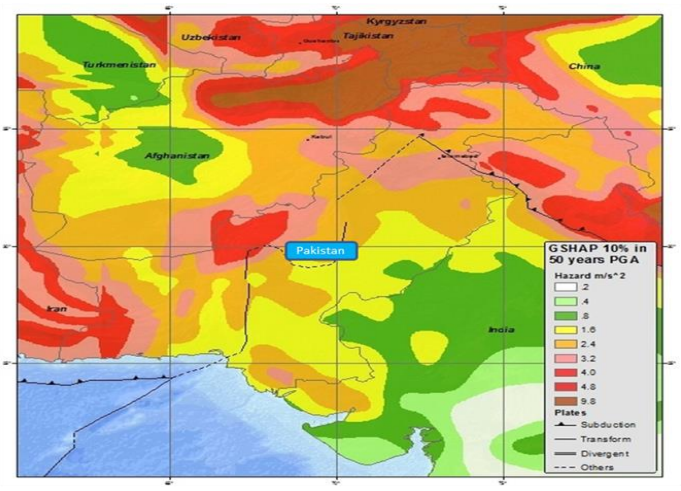


Figure 7: Seismic Hazards map of Pakistan (PMD)

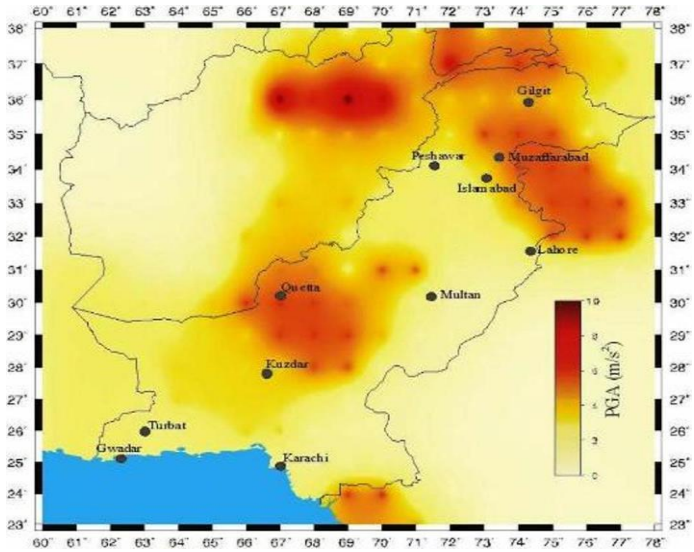


Figure 8: Peak Ground Acceleration (PGA) map of Pakistan (PMD)

Off the south coast of Pakistan and southeast coast of Iran, the Makran trench is the present-day surface expression of active subduction of the Arabian plate beneath the continental Eurasian plate, which converges at a rate of approximately 20 mm/yr. Although the Makran subduction zone (Figure 9) has a relatively slow convergence rate, it has produced large devastating earthquakes and tsunamis. For example, the November 27, 1945 M8.0 mega-thrust earthquake [22] produced a tsunami within the Gulf of Oman and Arabian Sea, killing over 4,000 people. Northwest of this active subduction zone, collision of the Arabian and Eurasian plates forms the approximately 1,500-km-long fold and thrust belt of the Zagros Mountains, which crosses the whole of western Iran and extends into northeastern Iraq. Collision of the Arabian and Eurasian plates also causes crustal shortening in the Alborz Mountains and Kopet Dag in northern Iran. Eastern Iran experiences destructive earthquakes that originate on both strike-slip and reverse faults. For example, the 16 September 1978 M7.8 earthquake [29], along the southwest edge of the Dasht-e-Lut Basin killed at least 15,000 people.

The September 24, 2013 earthquake led to the formation of an island [30] which indicates that there is a significance push of northward moving Indo-Pak plate along with oblique-strike-slip fault which was the original cause of the earthquake. Based on Modified Mercalli Intensity Scale, the earthquake is very strong earthquake (intensity-VII). The island is just a big pile of mud from the seafloor that got pushed up. This area of the world seems to see so many of these features because the geology is correct for their formation. The underground pressure in this case came from expanding natural gas. Similar islands have appeared offshore, 700-kilometer (450-mile) of Makran coast in the past century [31,32]. The Makran coast is where the Arabian tectonic plate is pushed northward and downward to go underneath the Eurasian continental plate. The thick layer of mud and rock on the Arabian Plate is scraped off and has formed the land in southwestern Pakistan, southeastern Iran, and the shallow underwater area offshore.

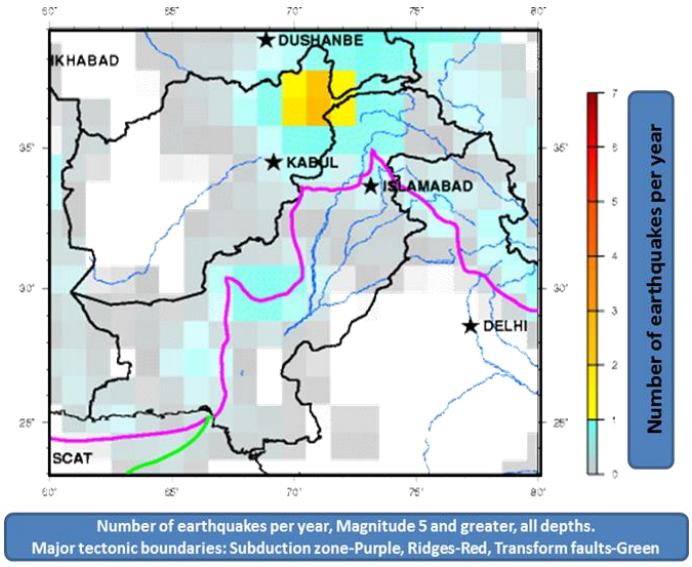


Figure 9: Earthquake density map of Pakistan (Source; USGS)

The life of such islands is usually short. Underground gas cools down or escapes, leaving the crust to collapse and settle back down. Waves and tides may wash away the loose sand, soft clay, and mud. However such mud volcanoes and islands are a natural hazard and threat to navigation.

CONCLUSIONS

The September 24, 2013 earthquake was a drastic earthquake but resulted in less human and property loss due to its epicenter in less populated area, which killed about 386 people, injured 816 people, and made thousands of people homeless (totally damaged houses 32638, partially damaged houses 14118). It is concluded that:

1. The study area lies along and near very seismically active zones, and seismic history interprets that more earthquakes of over 6.0 magnitudes are expected in near and far future.
2. Based on Modified Mercalli Intensity Scale, the earthquake is very strong earthquake (intensity-VII), whereas the magnitude of was 7.7 on Richter scale.
3. There are two main options to address the issue of earthquake damages; (i) Earthquake proof building should be constructed in the region following the proper construction codes and keeping in mind the earthquakes intensity in the region, (ii) the second option is “excavation”, because it is also very less populated and undeveloped region so it is not very difficult to do so.
4. The escape of methane, that produced the mud volcano, is the result of compressive waves due to the earthquake, which is independent of the focal mechanism. The occurrence of methane is a good clue for hydrocarbon prospecting in the area and it is suggested to carry out deep investigations for hydrocarbon prospective.

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