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Some Seismological Characteristics of Mw 6.5 Pishin-Ziarat October 29, 2008 Double Earthquake

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SOME SEISMOLOGICAL CHARACTERISTICS OF Mw 6.5 PISHIN-ZIARAT OCTOBER 29, 2008 DOUBLE EARTHQUAKE

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ABSTRACT

On October 29, 2008 two shallow focused earthquakes of Mw 6.5 struck the Pishin-Ziarat districts of Baluchistan in Pakistan. Both seismic events took place between 12 hours of each other with Intensity X and have been termed as Double Earthquake. The Earthquakes are located approximately 50 km northeast of the region of most intense damage from the Pakistan earthquake of May 30, 1935 (Mw 7.8), which is estimated to have killed 35,000 people. Field observations in the earthquake affected areas were undertaken field observations along previously mapped seismically active Gogai, Bibai and Kawas Tangi faults and study Seismological Characteristics such as surface rupture, displacements, rock falls, landslides, slumping and liquefactions. More than 1500 aftershocks of Mw 3.5 have been recorded up till April, 30, 2009 with many felt in an area of around 350 sq km, which left around 400 people killed, 70,000 homeless including 30,000 children. All the aftershocks were located in the Suleiman fold-and-thrust belt, a region where geologically young Tertiary sedimentary rocks have been folded and squeezed by forces associated with the India-Eurasia collision. The earthquakes are located approximately 80 km east of the 650-km-long Chaman fault, which is a major left-lateral strike-slip fault that accommodates a significant amount of the slip across the plate boundary. The occurrence of the earthquakes suggests that other strike-slip faults are present beneath the fold-and-thrust belt and that they accommodate some of the relative motion of the India and Eurasia plates.

INTRODUCTION

It is estimated that around 2000 people were killed and 4357 injured by the double earthquake (Figure-1). According to figures released by the local agency at least 12,000 buildings were destroyed and 20000 people were displaced by this earthquake. Most of the damages occurred in the districts of Pishin and Ziarat but casualties were also reported from Chaman, Dera Murad Jamali and Sani Shoorn. The villages of Ahmadoon, Gogi Kawas, Kan Depot, Lori, Sarkhizai, Wam and Warchun were almost completed destroyed. Damages were also reported from the Kalazai area in Ziarat district. Several people were also injured at Kalat while 50 were hurt at Quetta, most after jumping out of buildings in panic. Power supply was disrupted in the epicentral region. The villages of Killi Kant, Killi Shadi Khan and Warchum near Ziarat were struck by landslides. The road between Quetta and Ziarat was also damaged by "large cracks". Damage to mud-walled buildings has been reported from Chaman, Kalat, Killa Abdullah, Pishin, and Ziarat and from Quetta including at Nawakilli and Pashtunabad on the outskirts of the city. Many people spend the rest of the morning outdoors in fear of further tremors. Tremors were strongly felt at Bolan, Jaffarabad, Loralai, Mach, Mastung, Muslimbagh, Naseerabad, Qalat, Qila Saifullah and Quetta as well as parts of northern and central Baluchistan. This earthquake is the strongest in Baluchistan since a Mw=7.0 earthquake on 27 February 1997 near Harnai killing at least 170 people and causing widespread damages at Duki, Harnai, Mustang, Sibi and Quetta. Other significant earthquakes in this immediate region include an Mw=7.0 earthquake near Duki on 1 August 1966, an Mw=7.8 near Quetta earthquake on 30 May 1935, an Mw=7.3 near Mach on 27 August 1931 and an Mw=7.1 in the Kachhi Plain on 20 October 1909. The 27 August 1931 earthquake followed an Mw=6.8 earthquake near Sharigh on 24 August while the 1 August 1966 Duki earthquake was preceded by an Mw=6.6 earthquake near Barkhan on 7 February 1966. One of the earliest known earthquakes in this region was an Mw~6.6 earthquake that occurred on 24 January 1852 and resulted in at least 300 deaths.

Three most important earthquakes occurred within 4 years between the Bolan Pass and Quetta. The first of these near Sharigh Mw 6.8 24 August 1931, was followed by the Mach Mw 7.3 earthquake 27 August 1931. The third and biggest earthquake was the Mw 7.7 30 May 1935 event, which destroyed 90% of Quetta and caused 35,000 deaths. All three earthquakes lie within the 150-km-wide zone between the Asian and Indian plates, a region bounded to the west by the Chaman fault and the Indus plain to the east.

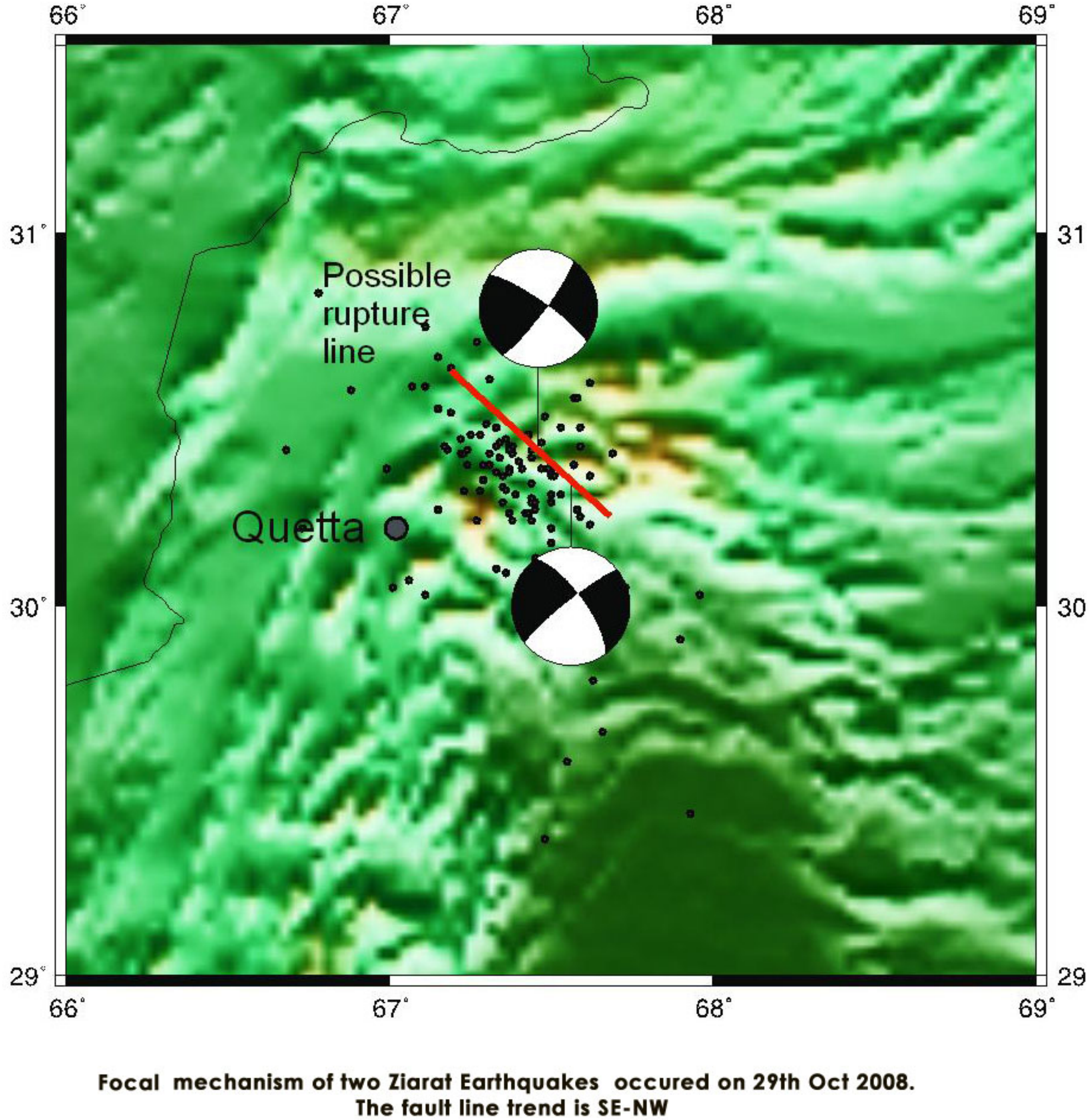


Figure - 1

The 1931 Sharigh earthquake was clearly responsible for triggering the Mach earthquake, but the geometrical relationship between these two events is obscure. The Mach earthquake reduced east-west stresses on the decollement/ramp system, and circumstantial evidence advocate that accelerated down-dip creep may have reduced fault-normal stresses that were eventually responsible for triggering the Quetta earthquake around 3.5 years later.

The installed continuous operating GPS receiver at Quetta reveals a SW motion of Quetta region relative to India Plate at approximately 7 mm/yr. The observed rate is puzzling in that Quetta lies in east of Chaman fault and its rate relative to India would therefore be anticipated to be much lower. For example, measurements of a point near Las Bela, less than 5 km east of the Ornach Nal fault to the south indicate that it moves less than 2±1 mm relative to India. This suggests that whereas the Ornach Nal system near the Makran coast may in part be creeping close to the surface, the shear component of plate boundary slip must be distributed far more broadly at the latitude of Quetta. Accordingly an array of GPS measurements has been planned to conclude the details of this distributed shear. Whereas we note that our observed signal in Quetta may in part be caused by after slip following the Quetta earthquake, the observed signal suggests that as much as 75% of the sinestral shear signal at the plate boundary remains west of Quetta suggesting that other prominent strike slip faults are vulnerable to future slip.

GENERAL GEOLOGY OF THE AREA

The Ziarat District is roughly rectangular piece of mountainous country comprising several scenic valleys. Principle valleys are

Kach, Kawas, Ziarat, Zandara, Mangi, Mana and Gogai-Ahmedudoon. The altitude ranges from 1800 to 3,488 m (Kilafat Peak). Most of the rocks in investigated area are sedimentary in origin ranging in age from Jurassic to Pleistocene with Sub- recent to recent deposits exposed in the area. As the region lies in the seismically active zone, the tectonic activities in the past have shaped and reshaped the geomorphology of the area. The happening of a regional unconformity pinpointing of a hiatus is marked by a laterite bed and is traceable in the eastern part of the earthquake affected area (Shah, S.H.A., 1965). Presence of Siwaliks, and ripple marks on the rocks in the study area propose varied depositional environments.

The Neogene molasses sediments form a loop like orographic feature called Zarghun knot. On either side of the Zarghoun range which bears the highest peak in Baluchistan (Loe Sar 3, 583 m), there are several parallel or en echelon, narrow ridges. The syntaxial bend of the Shin Ghar-Khanozai arc, changes from a westerly to southwesterly direction as it joins the Takatu Range near Quetta (Kazmi & Jan, 1997). In the present event the Peak of Takatu Mountain which can be seen even from Khanozai is reported to be peneplained.

The wide-ranging stratigraphic series from older to younger is Shrinab formation of Jurassic age (limestone with interbedded shale), Jurassic Chiltan Limestone, Cretaceous Parh group (shale, conglomerate, limestone and marl), late Cretaceous Mughal Kot formation (Volcanic lasts, sandstone and shale), Paleocene Dungan Limestone, Eocene Ghazij formation (shale with minor intercalation of thin beds of sandstones), Eocene Nasai formation (limestone with shale), Miocene Pliocene undivided Urak group, Quaternary Terrace Gravels, Alluvial Scree deposits and cultivated land.

SEISMOTECTONIC SET UP

Pakistan is subject to a number of natural hazards, of which flood earthquakes, cyclones and drought/heat waves are the mainly important Floods, droughts and landslides in Pakistan tend to be frequent, seasonal, and localized. The snowmelt from the high mountains coinciding with the monsoon season leads to very large discharges of the Indus River and its tributaries, resulting in annual floods. In February and March 2005, large areas of Pakistan were battered by rain, snowfall and flooding. The worst affected areas were NWFP, the Northern Areas, and Baluchistan (Figure-2). Water supply and sanitation systems, electricity, communication and road links were severely affected. In Baluchistan, nearly half a million people were affected, with more than 4,000 families left homeless. In NWFP more than 80,000 houses were destroyed and over 108,000 were damaged. A number of dams collapsed due to excessive flooding, causing severe destruction to crops and livestock.

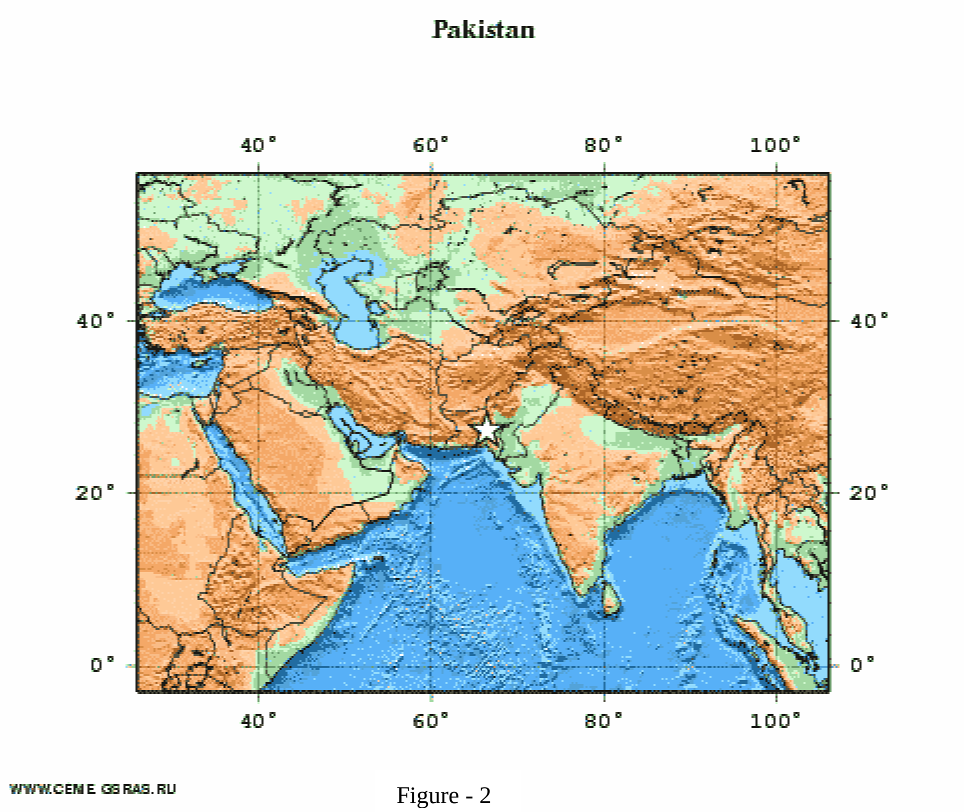


Figure - 2

The earthquake hazard in Pakistan is high and derives from Pakistan's location on the eastern margin of the collision of the Indian plate with the Eurasian plate. The result is the potential for major earthquakes in the north, where the Indian plate thrusts under the Himalayas, and along the western edge of the country, where transform motion of the Indian plate relative to the Iranian and Afghan micro-plates is expressed with the Chaman fault. The 1935 Quetta earthquake (60,000 killed) occurred on the Chaman fault.

The Arabian plate subducts underneath the Iranian plate along Makran coast, where the 1945 magnitude 7.9 earthquake resulted in a tsunami with 12 meter waves. Karachi, east of the Makran coast, has significant seismic risk due to quite a few nearby faults, including the Allah Bund fault (1819 earthquake), and the Pubb fault. Although it is prone to a variety of natural hazards, Pakistan has an unplanned approach to dealing with hazard risk management. Interventions are primarily focused on relief and response as opposed to previous ante mitigation measures.

The investigated area lies in seismic zone IV which has the most active regional Seismotectonic setting. The communication of various tectonic elements, that is, southward progressing Sulaiman Lobe, Chaman Transform Fault and resistant mass at Sibbi trough were responsible for structural styles and tectonics in the region (Naimatullah, 1992). The earthquake affected area is an integrated part of the syntaxial bend of Quetta region, the whole of it falls on an overthrust sheet which forms the high ground and well-known peaks of the region, the foreland coincides with the Shahrig-Harnai low land which lies south of the studied area and passes north of Kach.

In the vicinity of the devastated area two large thrust sheets i.e. the Bibai and Gogai nappes, were emplaced between middle Eocene and early Eocene epochs after the deposition of Ghazij shales but prior to the deposition of rocks of the Siwalik Group. The rocks of Gogai nappe are strongly deformed and complex folding is associated with Gogai nappe whereas an imbrication zone is associated with Bibai nappe. Strike slip faults are more widespread in association with Gogai nappe and at places such faults are mapped in Bibai nappe which is exposed from Kach to Ziarat area, 45 km NE of Quetta to 120 km. All the strike slip faults connected with Gogai and Bibai nappes are sinistral faults.

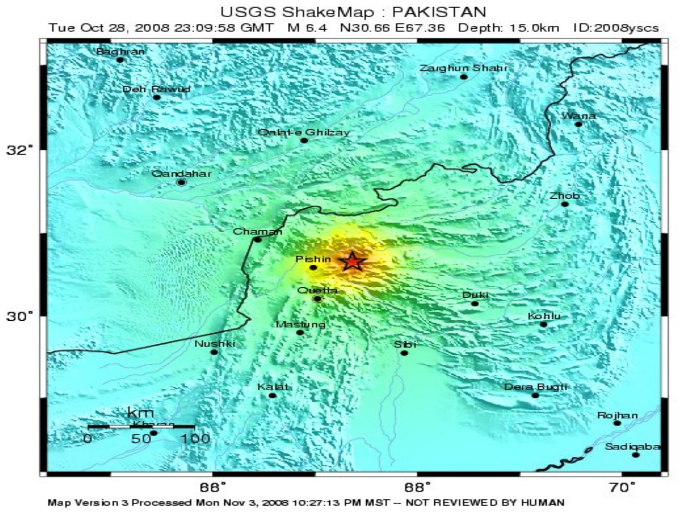
The Pishin-Ziarat double earthquake occurred in an area with previously mapped three major active thrusts namely EW trending Zhob valley thrust, Chinjan, Bibai and Gogai thrusts running parallel to each other in this region and splayed into several parallel fault planes, on which accumulation of strain is taking place as a result of the stresses applied by the tectonic forces which in turn stem from Chaman fault boundary. The rate of motion at this left lateral strike slip fault is reported to be 4 to 7 cm/yr. The Quetta Ziarat region lies 80 km east of 650 km long Chaman Fault that accommodates a significant amount of slip across the plate boundary. The occurrence of series of tremors suggests that other faults are present beneath the major thrust as their offshoots. Of special interest to the experts was the previously mapped Kawas Tangi fault which on one hand acted as a barrier to safeguard the Ziarat town itself and on the other hand caused much damage between Kawas and Kach areas. There is a possibility of a blind fault running more or less parallel to this strike slip fault beneath the surface near Kan and Wam which the authors believed to be the causative fault of the recent seismic event. During the recent research on this blind fault running parallel to the Kawas Tangi strike slip fault interpreted by various workers which trends NWSE and passes west of the Zindra village, has been identified along which most of the epicentral locations from Khanozai to Gogai and farther south lie. This is a younger fault which truncates most of the older thrusts and axis of folds. As majority of the epicenters of aftershocks > 3.5 M are located along this line so that is a clear indication of recently activated fault, which most probably is the causative fault of this event. The Ghazaband-Zhob and Gwal-Bagh Fault system in the NNW of the investigated areas are bounded by the faults from south east and west also and are in turn associated with the most active Chaman-Ornach- Nal Fault system.

FIELD OBSERVATIONS

Soon after the occurrence of the double event, data was collected from various sources. Field observations were undertaken around the affected areas from November 10, 2008 to November 17, 2008. Tables were filled in order to know the direction and model of ground cracks and seismic fissures. The epicentral location area was studied in detail to conclude the mode of formation of ground cracks. Recently generated ground shortening and ground displacement were recorded in the main towns. In order to determine the intensity of the earthquake the displacement measurements of ground and damaged engineering structures were carried out. Recorded field observations about fault plane, surface rupture, vertical & horizontal displacements, rock fall, landslides, slope failures and related geological phenomena's like liquefaction, subsidence and mass wasting were investigated.

It was observed that due to rock falling, mass wasting at certain places with dust clouds arose and remained suspended in the air due to cold climate for some time. In dry and cold climatic regions like Quetta, Ziarat and Pishin valleys, on steep rock slopes, if the rain water percolates deeply in the rocks, such type of weathering may continue to a considerable depth and dislodge the rock layers which are of interbedded hard and soft earth materials. The weathered material forms a mantle of rock waste and slides downwards due to gravity. It is possible that the dust/smoke and green lava reported by some locals to be coming out of the mountain top and emission of light rays may be dust cloud when the upper most layer of the rock moved down to the bottom and hit ground with a bang triggering cracks in the soft layers and rolling of boulders. This is another encouraging aspect of present event that no rain is forecast in the region and there is no distinguished danger of landslides in this region as was common after October 8, 2005 Kashmir-Hazara earthquake.

The field investigations were carried out starting from the reported epicenter at the junction of Surkhab and Jihad Nala at Shrun village, Khanozai (30. 653 N, 67.323 E), 60 km NNE of Quetta. The tremors did not cause major surface faulting or displacement, near the epicenter. Loose material at the bank of nalas slided due to strong vibration of energy release resulting in hairline cracks on the ground and collapse of mud houses built nearby on the main Kanozai-Pishin road. Ground cracks were observed to be formed at several places but none of these showed any feature peculiar to fault rupture. Close examination of the cracks in their geologic and geomorphic perspectives suggests that several severe shaking of unconsolidated material on the sloping ground may have given rise to hairline fissures as no major structural damage, no surface rupture or remarkable nearby on the main Kanozai-Pishin road. Ground cracks were observed to be formed at several places but none of these showed any feature peculiar to fault rupture.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure-3

Close examination of the cracks in their geologic and geomorphic perspectives suggests that several severe shaking of unconsolidated material on the sloping ground may have given rise to hairline fissures as no major structural damage, no surface rupture or remarkable major structural damage and ground failure was observed in a narrow belt 3X10 km in the E-W direction in Ziarat valley just after Kadi Kach. The worst affected area forms a narrow to broad valley which comprises a long and continuous belt of recent and sub recent deposits overlying Ghazij shale between Wam and Kawas. This zone of quaternary sedimentation is parallel to the structural trends of major thrusts in the region. Arcuate type of cracks and fractures were observed on the Kach-Wam road segment built on the dump filled, less compact strata along the causeways. Field observation of their geologic and geomorphic perspectives suggests that severe shaking of unconsolidated material over the bed rock along the stream banks and sloping ground gave rise to open cracks and fissures on the roads and bridges. A road bridge near Gogai gave way due to strong NS ground vibration and displacement of 10 to 15 cm was recorded in the middle abutment and ground shortening on the top of 3 cm. The pattern of destruction in five union councils of Ziarat district indicates a maximum acceleration of ground in the NW-SE direction between 2, 500 and 5, 000 g corresponding to an intensity of IX to X (Figure-3).

The characteristic effects noted in the epicentral area were destruction of mud houses, masonry buildings and ground cracks, landslides on steep slopes, critical damage to dams and bridges. Although the tremors were felt over an area of around 400 sq.km, but the intensity of X on Mercalli scale was felt more in two union councils, Kach and Kawas. People in Wam, Sera Khezi, Killi Pio Khan and Sahibzad, Verchum, Kan Depot & Kawas W & E reported an intensity of XI. Destruction was more severe on the left bank of the Ziarat Manda stream on the terraces composed of loose sediments of Ghazij shale (Eocene) as compared to the right bank where the settlements are built on solid bed rocks of Dungan limestone. It was also observed that certain houses were damaged due to ground failure. Wam village is the most horrible affected area in the region due to numerous reasons e.g., poor quality of construction and local geology. The ground cracks in the silty cover of hillocks opposite Wam Tangi were noted which comprise multiple parallel to sub-parallel slightly zigzag, cracks over a significant length up to solid bed rock of Dungan Limestone. The houses are totally collapsed as poorly constructed dwellings are built atop terraces composed of loose sediments along dangerous slopes.

The other reason of the destruction is the ground failure, as a bend (32 x 18 m) occurred at slope inclination 35° and composed of loose material bearing water saturation which totally destroyed the settlement. Ground Zero Gogai is the epicentral area as the second mega event was located near it and most of the 1500 aftershocks in 20 days after the main event were also reported to be originated from this area. This village is not as much damaged as Wam. Most of the veranda pillars, boundary walls and electric polls were found to be tilted southwards indicating that shock waves travelled from NW to SE in this part follow-on in displacement of 10-15 cm.

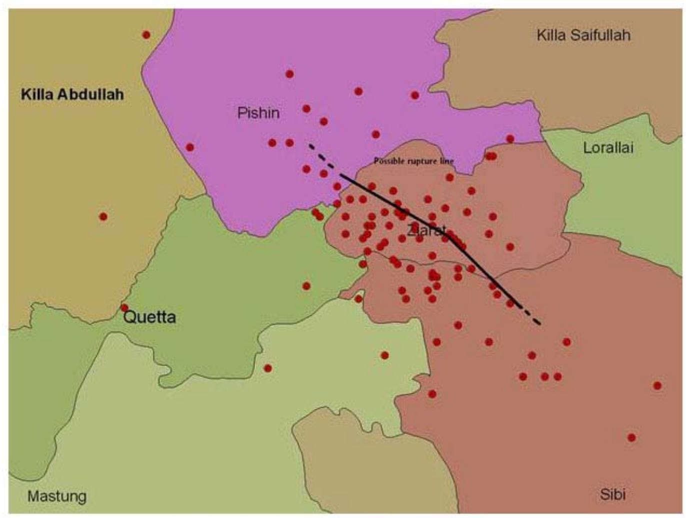
INTERPRETATIONS ON INVESTIGATION

After recording these preliminary field investigations, an attempt was made to take first hand explanation to ascertain the location of epicenters of major aftershocks above 4.5 to explain the causative faults. Evidences point out to the NW-SE trend of shifting epicenters from Khanozai towards Gogai and further southwards from Wam to Harnai area in configuration with a previously mapped strike slip fault at Kawas Tangi near Zandra. The cluster of most of the major aftershocks can be seen flanking alignment parallel to this localized fault plane on the published map of the area coinciding with the epicentral area (Geologic Map and Landsat image of parts of Loralai, Sibi, Quetta and Khuzdar Divisions, GSP-USGS, 1998). The published geologic maps do not mark surface traces of an active fault along this alignment but the present data supports our interpretation of the existence of a hybrid fault between Wam and Kan. From the field observations it is inferred that the causative fault is probably located between Gogai and Wam where evidence of strong ground shaking in the main events and most of the aftershocks were observed. The plotting of major aftershocks > 3 also point to a grouping with epicenters of the three major events along a hybrid fault parallel to Kawas Tangi fault. There is apparently no surface break of this hybrid fault and the team of experts found no sign of a continuous rupture except ground fissures due to energy release at Khanozai and Wam.

The permanent process of destruction of solid rocks by weathering and erosion through wind, water, ice and tectonic movement has been going on for millions of years, shaping and re-shaping the geomorphology of the area but no fresh fissures or cracks were seen in these rocks anywhere in the Ziarat valley. The chemical weathering over eons has contributed to the disintegration of rocks by the general weakening and formation of solution cavities which are widened over time and washed out by rain water. The parting of debris of obviously decayed rock is also witnessed in the area. Rock falls from the steep escarpment of the frontal hill composed of Mughal Kot formation and limestone of Paleocene age facing the valley occurred at Road Mulla Zai, Ahmedoon and Kach areas. Steepness of the escarpment, scissor faulting and joints in limestone bed rocks and triggering by strong earthquake vibrations might be the reason that facilitated rock falls at certain places in Ahmedoon and Kach. Another interesting feature indicative of strong ground shaking was the position of rock fragments on the ground surface. Boulders of various sizes embedded in unconsolidated material were loosened and moved slightly down slope over the hillocks during the aftershocks. The effect of ground vibrations ranged from just dislodging or loosening of the boulders from their former positions in the matrix to move down-slope due to gravity. The damage in the earthquake influenced area increased due to the orientation of seismic wave propagation in the NW-SE direction parallel to Kawas Tangi Fault. Due to displacement on this strike slip fault, the Kawas Tangi dam was also damaged and the water stored in the dam is reported to be seeped into ground fissures developed in the aftermath of this earthquake. The water channels are also damaged and water supply to orchids is no more available now. Wam village was the worst affected area in the region and almost all the small settlements between Wam and Kawas have completely being destroyed by this earthquake.

It is inferred from the present study of the location of epicenters and intensity of earthquake in this area that a blind fault may be running NW-SE between Gogai, Wam and Kawas and this is also the worst affected area due to the cause that most of the construction was concentrated along both sides of the Kach Ziarat road on the terraces composed of unconsolidated sub recent deposits upon Ghazij shale (Figure-4). Type of construction is an important factor in considering the intensity of an earthquake which was about IX to X in this area while it was between IV to V in Quetta Ziarat areas. Only a few buildings of schools and basic health units were constructed with cement masonry but without reinforcement. Almost all the settlements in the area were constructed by primitive methods using mud mortar and timber as construction material. Construction was on steep hill lopes prone to ground failure and slumping due to vibrations. The death toll was not large due to simple design of these mud houses which were only storey, line up of rooms with frontal open space and roofs were made up of timber, straw and mud plaster or light weight tin sheets. It may be said that bigger damage occurred in structures on unconsolidated material and least affected are those built on firm bedrock during this earthquake. As a rule, earthquake waves are influenced by the geological conditions of the ground. In GSP's published reports on post earthquake studies, it is mentioned very clearly that it is the type of foundation on which a particular civil engineering structures rest that determines the amount of damage caused by earth vibrations. The foundations of the boundary walls of these houses were only a few feet below ground surface. Loose saturated sediments may liquefy under earthquake shaking with disastrous consequences as witnessed in case of first settlement of Wam at the confluence of streams along Ziarat Manda. A remarkable feature noted in the affected area was that the walls oriented N-S sustained greater damage as a whole, no matter they were mud houses or cement masonry and all the collapsed structure showed destruction towards south.

There is no surface sign on published maps available pinpointing the hybrid fault along Wam but all indications point to this fact that a blind fault is hidden below the surface. Another fault on GSP published maps in the Upper and Lower Cretaceous and Upper Jurassic Mona Jhal Group near Soro Ghar (KJm) continues from Pil Ghar southwards but is hidden beneath the surface in the investigated area. Most of the villages which were raised to ground were located near the right and left bank of Ziarat Manda stream or on the thick terraces and hillocks of loose sediments. Most of the walls and electric polls were found to be tilted towards south indicating that shock waves traveled from north to the south (Khanozai to Gogai and Wam) in this part resulting in complete destruction. More than 1000 multiple aftershocks have been reported to continue after lapse of a fortnight followed by the major earthquake to rock the Ziarat valley, creating fresh fears that badly damaged buildings which already have developed major cracks might collapse in these aftershocks. However the intensity of aftershocks decreased after a week and intervals between these aftershocks is now increasing after passage of 150 days which is a good sign. Lithologic control plays an important role in the devastation and destruction of infrastructure. Arcuate type of



The analysis of aftershocks recorded by PMD Sesmic Monitoring Network.
There is a possible rupture due to Ziarat Earthquakes occured on 29th Oct 2008

Figure-4

cracks and fractures were observed on the Gogai-Kach Wam road segment built on the dump filled strata along the causeways. Uprooting of trees and electric poles were observed at Wam and all the pillars and most of the collapsed walls indicated that the tectonic forces were acting in N-S direction. Discharge from springs at Wam village was reported to be increased due to seepage from the ground. It was also observed that certain houses were damaged due to ground failure and quality of construction material used in these buildings.

RECOMMENDATIONS

Hazard is natural but disaster is not. As earthquakes occur without any forewarning, there should be all time preparedness on part of people and government machinery for quick response to mitigate the loss of lives and property. Little had been done to prepare and protect masses in Quetta, Chaman, Harnai, Kalat and Ziarat despite the fact that these areas are known to lie in an active seismic zone of severe damage intensity and are prone to such earthquakes. Even public awareness about what one can do in earthquakes should contribute to reducing death toll. Such criminal negligence is inexcusable. Investigations concerning various aspects of seismicity and inherent hazardous zones have been made by GSP after Oct 8, 2005 calamity. Paleoseismological trench excavation, geoslicing and geomorphological/geological hazard zonation mapping is strongly recommended before the reconstruction phase in Quetta, Ziarat, Harnai and Pishin valleys.

The damage to settlements on different types of soils and bed rocks were analyzed and it was inferred that un-reinforced masonry cement brick buildings behavior is just similar to mud houses, rather at certain places government buildings like schools and basic health care units behaved worse than that of mud dwellings. For reconstruction of the affected villages, proper town planning is the need of the hour based on geo hazard zonation mapping which should include the local geology, geomorphology, geohydrogeology, and geotechnical investigation as GSP has done after October 8, 2005 earthquake in Bagh and Muzaffarabad areas. The ERRA, NDMA, PDMA and other concerned agencies should draw up a rehabilitation strategy based on their experience of reconstruction and resettlement of the earthquake affectees of AJK earthquake. Lessons need to be learnt from the past mistakes. Firm, level ground should be selected for establishing new model villages, and preference should be given to ground composed of solid bed rock on both the sides of the Ziarat valley and loose sediment terraces should be avoided for this purpose. Water saturated alluvium along the Ziarat Manda may be considered to be high seismic risk. It is better to avoid old settlements on terraces made up of Ghazij shale. Reconstruction should be avoided on slopes, close to the margin of terraces, escarpments and on the contacts between solid bed rocks and loose sedimentary alluvium of shale due to the fact that the seismic waves amplify at these contacts.

A realistic and dependable estimate of earthquake risk factor may be adopted in revised building codes based upon studies of seismic events occurred in the vicinity of the area. For a more detailed investigation, Paleoseismological trench excavations between Gogai and Wam village along Gogai –Bibai thrusts are recommended. Historical record of past major earthquakes can give us a clue to recurrence of the next big event in this area. Glancing the past hundred year record of major earthquakes in Quetta, it is a wild guess that a mild to moderate earth tremor can be expected after a lapse of 10-12 years in the Quetta-Ziarat - Harnai region.

Earthquakes strike suddenly and destructively, causing deaths, injuries, and property damage. Yet, injuries and damage can be reduced or avoided to a certain extent if appropriate preparedness measures are taken. The GSP has already started an effective mass awareness program in Quetta for mitigation of the losses of lives and property for pre-empting the natural disasters. One must be prepared to cope with such natural calamity and pre-empt it from becoming disaster in Quetta valley. In order to mitigate the collateral loss, there are certain precautionary measures to be adopted in case of any eventuality. Here are some steps masses can take to prepare for earthquakes.

Organize and frequently update disaster plans. Address both response and recovery issues. Establish ongoing training programs in emergency measures first aid, evacuation, search and rescue, use of fire extinguishers, and damage assessment. Hold periodic drills and exercises. Consult local building codes to ensure that the building meets current structural safety principles. Conduct "hazard investigations" to find nonstructural hazards in offices, classrooms, storerooms, laboratories, warehouses, and manufacturing areas. Determine and post primary and alternate routes for emergency evacuation of the building, should that be essential after an earthquake. Establish procedures for that needing evacuation assistance. Educate staff, as applicable, on earthquake effects on high rise buildings. Lower floors will shake rapidly. Movement on upper floors will be slower, but the building will move farther from side to side. Secure and fix equipment and furniture, including bookshelves, cabinets, computers, typewriters, water heaters, other gas appliances, and laboratory equipment. Include articles on business and home earthquake safety in electronic and print media, newsletters, or provide people with posters, brochures or flyers. Develop an inventory of critical supplies and equipment. Assemble emergency kits with water, first aid supplies, radios, flashlights, batteries, heavy gloves, food, and sanitation supplies. Maintain in a secure, accessible location.

There is a multiplicity of housing related issues in the earthquake prone regions in Pakistan, mainly generated by population bang combined with difficulties in governance and corruption and against the law neglect to the minimum quality standards equal with the building codes. If one has to minimize the human losses in any future catastrophes like this, the building codes ought to be implemented in proper letter and spirit. Taking note of the building material behavior in Wam-Kawas area, it is felt that all brick or cement masonry work should be reinforced according to local building codes using non expensive indigenous material. For reconstruction of the affected villages, suitable town planning is the need of the hour based on geo hazard zonation mapping which should include the local geology, geomorphology, geohydrology, and geotechnical investigation as GSP has done after October 8 earthquake in Bagh and Muzaffarabad areas.

CONCLUSIONS

1. The area studied is highly susceptible to seismic hazards since it is bounded by numerous major thrusts and active faults from all sides. An earthquake like the Pishin-Ziarat double earthquake can occur without forewarning. There should be all time general awareness on the part of community and civil administration to cope with such calamities and pre-empt the natural hazards to become disasters.
2. All houses in decaying condition either damaged partially or completely in Pishin and Ziarat valleys should be demolished as those are bound to collapse in any event of even smaller magnitude.
3. Most of the settlements were strong along both sides of Ziarat Manda beside Kach Ziarat road. The ground shaking

during the earthquake caused remarkable damages in this area because these dwellings were built on terraces of unconsolidated sediments on dangerous escarpments and steep slopes.

4. Structural damages were highest in this region due to poor quality construction. All the brick or cement block masonry construction work should be reinforced according to the buildings codes particular for Zone-IV.

5. Ordinary un-reinforced cement buildings are as unsafe as mud houses in respect to seismic hazards. In all previous post earthquake investigations, un-reinforced brick cement masonry buildings were found to be more damaged than the adjacent mud and timber houses.

6. Firm, level ground should be chosen for rehabilitation of destroyed settlements. The solid bed rock on both sides of Ziarat valley is better choice than the central valley portions along Ziarat stream composed of unconsolidated sediments.

7. Water saturated alluvium along the banks of Ziarat Manda is considered to be at a higher seismic risk and may be avoided for reconstruction.

8. Reconstruction phase to be implemented after the harsh winter season is over.

9. The present study shows that there is a high potential for recurrence of such seismic events. Potential threat to the existing built up environment of Quetta has increased by tenfold increase in population since the 1935 earthquake both in Quetta and in surrounding villages. Despite the implementation of earthquake resistant design in post earthquake reconstruction, much recent construction is of very poor quality with an un-reinforced masonry workmanship built on alluvium, which is prone to local amplification of surface waves. The present study not only confirms that the region continues to be seismically active but that the region vulnerable to future earthquakes extends throughout the thrust and fold belt, and that interaction between thrust faults to the east and strike slip faulting to the west are coupled in ways that may potentially provide methods to forecast future seismicity near populations centers in the province.

10. All necessary safety measures should be taken into account in reconstruction of government buildings like schools, basic health care units, offices, mosques, police stations and hospitals from the public money that they can withstand future tremors to certain extent.

REFERENCES

A. A. Khawaja, Monalisa., S.A. Khan, M. C. Rafiq and A.T. Khan, Recent Seismic Activity along the western margin of the Nanga Parbat - Haramosh Massif, Pakistan. Islamabad Jour. Of Science Vol.13 (1).

Ali. H. Kazmi, and M.Q. Jan, Geology and Tectonics of Pakistan. Graphic Publishers Karachi – Pakistan, (1997).

Farah Abul & de Jong, 1979; Geodynamics of Pakistan, GSP Quetta.

Florian Maldonado, Shahid Hasan Khan and Jan Mengal, 1998; Geologic Map & Landsat image of parts of Loralai, Sibi, Quetta and Khuzdar Divisions, Baluchistan, USGS & GSP.

Hunting Survey Corp (HSC), 1960, Reconnaissance Geology of part of West Pakistan, a Columbo Plan Report, and Govt. of Pakistan-Govt of Canada.

Kazmi & Jan, 1997; Geology and Tectonics of Pakistan, Graphic Publishers.

Khan, Kanwar Sabir Ali, 1980; Pattan earthquake of December 28, 1974 & Reconstruction Program in the affected areas of Swat, Hazara and Kohistan District, NWFP, Pakistan; GSP Rec Vol 47.

Le Fort, Patrick and A. Pecher, An introduction to the geological map of the area between Hunza and Baltistan, Karakoram-Kohistan-Ladakh-Himalaya Region, Northern Pakistan (Scale 1: 150, 000). Geologica, Vol. 6, No.1, (2002).

L.L. Malinconico, 1989. Crustal thickness estimates for the western Himalaya. In Malinconico, L.L. & Lillie, R.J. (eds.). Tectonics of the western Himalayas. Geol. Soc. Ammer, Spec. paper.

L. Seeber, R.C. Quittmeyer and J.G. Armbruster, 1980, Seismotectonic of Pakistan: A review of results from network data and implications for the central Himalayas. Geol. Bull. Univ. Peshawar, Vol. 13

Mahdi, Syed Kazim, The Pir Panjal Earthquake & Aftershocks, Report on the October 08, 2005 Mega earthquake, Unpublished Office Files.

Mohsin, Anwar Kazim, Rana, Asif Nazeer, Younus, Muhammad, 2001, Geological Map of Quetta Valley.

Monalisa et al., Seismic Hazard Assessment of NW Himalayan fold and thrust belt, Pakistan, using probabilistic approach, Proc. Pakistan Acad. Sci 42 (4) 2005.

Niamatullah, M, et. Al, 1989, Emplacement of Bibai and Gogai Nappes, NW of Quetta. Geol. Bull., Univ. of Peshawar, Vol 22.

Rana, Asif Nazeer, Abdul Qadir, Hasan Shaheed et al; 2004 Preliminary Report on the investigations of the Sor Range Quetta earthquake of May 9, 2004 (Unpublished).

Shah, S.H.A, 1965, The structure of the area between Ziarat and Wani, Sibi and Loralai districts, W. Pakistan, GSP Record Vol. XIV Part II, Geol. Surv. Pak.

Thangani, G.Q., et. al., 2005, Water Resources Assessment in Ziarat sub basin of Nari river hydrogeologic basin (Unpublished).

W.J. Sercombe, D.A. Pivnik, W.P. Wilson, M.L. Albertin, R.A. Beck and M.A. Stratton, Wrench Faulting in the northern Pakistan foreland. AAPG Bulletin, v. 82, (1998).