CHAPTER – 12

CONCLUSIONS

The present study has utilised multiple line of evidences – geomorphological, geological field mapping, structural data, shallow subsurface geophysical studies using GPR, high resolution microscopy using SEM and empirical mathematical relationships to unravel the seismogenic characteristics of the KHF and provide important inputs for earthquake hazard in the region. A significant achievement of the present study, is determination of the length of surface faulting and related parameters along with estimates on the size of the paleo-earthquake events that have occurred along the KHF in the last ~ 30 ka B.P., using empirical relationships. The present study along the Katrol Hill Fault (KHF) has led to the following conclusions.

1. The Katrol Hill Fault (KHF) is a major range bounding fault in Central Mainland Kachchh. The fault strikes E-W and is structurally expressed as a high angle, south dipping reverse fault that marks the lithotectonic contact between the Bhuj Formation to the north and Jumara and Jhuran Formations to the south. The fault zone presents a largely erosional, rocky landscape with highly patchy and thin Late Quaternary sediment cover. The Quaternary sediments that intermittently cover the KHF faultline includes, aeolian and fluvial (reworked) miliolites, sandy alluvium and colluvio-fluvial deposits.
2. The KHF is marked by discontinuous and sparse occurrences of different varieties of Late Quaternary deposits, of which, the aeolian miliolites and valley-fill or fluvially reworked miliolites are the most common type found on both the windward and leeward slopes of the north facing scarps towards the southern side of the KHF and in the valleys and depressions respectively, present in the KHR. The thin section analysis of aeolian and fluvial miliolites under an optical microscope showed presence of the mineral grains such as quartz, pyroxene microcline and (augite – very rare) and, bioclasts of bryozoans, foraminifera, algae, shell fragments and pellets, which are held together by calcareous cement. The point contact relation between the constituent grains indicates minimal compaction and presence of alkali feldspar indicates weak diagenesis undergone by the rock. The higher amount of broken shell fragments in the fluvial miliolite sample indicates its reworked nature.

3. The quartz grains from fluvial and aeolian miliolites samples collected from the KHF zone are observed using the SEM to examine the microtextures on the grain surface. The fluvial grains showed many breakage microtectures such as uneven grain boundaries, unoriented fracturing, radial fractures, parallel fractures, step like fractures, straight and curved fractures, conchoidal fractures, fresh fractured grain surface, large breakage blocks, crescentic gouges and randomly oriented V-shaped percussion marks. The solution action on the grain surface gives rise to etched and chemically altered surface. Three stages of silica precipitation are also observed on the fluvial quartz grain surfaces. The breakage microtextures seen on the quartz grain surfaces of aeolian miliolite samples are patches of fresh fracture surfaces, linear fractures, small and large conchoidal fractures, upturned plates, broken and curved groove surfaces, straight or parallel fractures, radial fracture pattern, linear and parallel ridges and v-shaped and crescentic percussion marks. In addition, the solution action has resulted in the formation of abraded edges, weathered and rough surface, etched surface and irregular solution pits. Silica precipitation is found in the small grooves created due to chemical action on the grain surface.
4. The well preserved ~ 8 m high incised cliff section located in front the KHF scarps shows Late Quaternary sediments that are offset by ~ 8 m along the south dipping KHF fault plane that extends from the underlying Mesozoic rocks to the overlying Quaternary sediments. Previous and present study shows that the sediments were offset during three surface faulting events that occurred at 31.8 ±2.8 ka, 28.5 ±3.7 ka and 3.0 ±0.3 ka B.P. The Khari river section is the most complete and the most well exposed section along the entire length of the KHF zone. The section was studied in detail to deduce the surface faulting parameters. The lateral extension of the surface faulting was determined using field evidences, GPR studies and microscopic studies using SEM.
5. A slip history diagram to quantify the slip rate, is constructed by using the displacement values of 3.5m, 2.2m and 2.3m measured in the Khari river section showing three events of surface faulting during 31.8 ±2.8 ka (Event 1 – oldest event – OE), 28.5 ±3.7 ka (Event 2 – penultimate earthquake – PE) and 3.0 ±0.3 ka B.P. (Event 3 – most recent earthquake – MRE). The “true slip rate” thus calculated belonging to the three surface faulting events is 0.66mm/yr and 0.09mm/yr for the closed seismic cycle of 3.3 ka formed between the oldest earthquake (OE) and penultimate earthquake (PE) and that of 25.5 ka between the penultimate

earthquake (PE) and most recent earthquake (MRE) respectively. An apparent slip rate of 0.25 mm/yr is obtained by considering the length of open cycles. Late Quaternary surface faulting events suggest a much longer recurrence interval for the KHF compared to other seismically active faults in the Kachchh Basin.

6. The field investigation along the KHF zone revealed two locations, which showed deformation of the Late Quaternary miliolite deposits – (i) south of bharasar and (ii) south of Bhujodi. Therefore, other than the three sites of Late Quaternary deformation (including the Khari river section), other outcrops of Late Quaternary deposits encountered during field studies in the KHF zone showed no evidence of macroscopic deformation related to faulting, indicating highly erosional and anthropogenically modified landscape.
7. The GPR survey carried out along the KHF zone to precisely locate the trace of KHF in the shallow sub-surface near Bharasar, Tapkeshwari, Bhujodi and Ler. At these locations, the GPR results confirmed the propagation of faulting from the Mesozoic rocks in to the overlying Quaternary sediments found on the surface. The variable thickness of Quaternary sediments in the shallow sub-surface at all these locations can also be observed. The knowledge of the exact trace of KHF obtained from the GPR results facilitated in the miliolite sample collection from along the KHF zone to observe the microscopic effects of surface faulting.
8. The thin section analysis of fluvial and aeolian miliolites observed under optical/petrological microscope disclose faulting-related microfeatures such as development of microcracks along the grain boundaries of detrital mineral grains and prominent breakage and fracturing of peloid bioclasts, shape-preferred or crystallographic orientation among the elongated allochems and detrital mineral grains, formation of macro-sparite by recrystallization of calcitic cement and detrital quartz grains and occurrence of polycrystallinity of quartz grains.
9. The SEM results of the quartz grains of both fluvial and aeolian miliolites displayed the microtextures such as striation, exfoliation, fresh fractured surfaces, rolled and euhedral quartz grains and adhering particles in addition to the extremely broken and fractured grain surfaces. All the above-mentioned microtextures found in the quartz grain samples collected from the fault zone can be attributed to the neotectonic processes/surface faulting, as these are not observed in the samples collected from the locations away from the fault zone.

10. The length of Late Quaternary surface faulting along the KHF is ~ 21 km as derived from the multiple evidences of surface deformation/faulting provided by field, GPR and microscopic studies.
11. Based on fault parameters deduced, like the length of surface rupture, displacement and slip rate, the estimated magnitude of Late Quaternary surface faulting events and thus, the seismogenic potential of the KHF, calculated using empirical equations yielded M_w values consistently in a narrow range from 6.6 to 7.1.
12. The field and GPR based study of the Gunawari and Gangeshwar river basins located in Katrol Hill Range shows that drainage reorganization occurred during the last ~30 ka B.P. in response to tectonic titling induced by surface faulting along the range bounding Katrol Hill Fault (KHF). Geomorphic features like a wind gap, buried paleo-valley, aeolian and fluvially reworked Late Quaternary miliolite deposits, along with anomalous channel reaches along the Gunawari river such as along strike straight channel segments and the unusual 'V' and 'S'-shaped bends with knickpoints suggest drainage rearrangement in the recent geologic past by carrying out by top-down and bottom-up processes. The present study also suggests that the absolute influence of tectonic factors on the complex processes of drainage rearrangement are more explicit for younger and shorter timescales than geologically older drainage adjustments interpreted for regional and continental scales involving longer time periods.
13. The present study demonstrates that the KHF has produced high magnitude seismic events during the past ~ 30 ka B.P., and is, therefore, a potential seismic source capable of generating surface rupture hazard in the Kachchh Basin. Late Quaternary surface faulting events suggest a much longer recurrence interval for the KHF compared to other seismically active faults in the Kachchh Basin. Reconstructing revised seismic hazard assessment and mitigation strategies for the Kachchh Basin is recommended in view of its proximity to civilization structures.
14. As Kachchh basin is an intra-plate seismic zone source, long recurrence intervals between earthquakes, is not unusual, which forms an important input for evaluation of seismic hazard. A combination of approach that incorporates both the probabilistic and deterministic methods of seismic hazard assessment and also integrates the results contributed by various geological and geomorphic methods, including results from the present study, is suggested. The seismic hazard analysis of the Kachchh region done by different workers have used different input values

for same parameter, specifically for the KHF and have arrived at different estimates of ground motions for the Kachchh region and in the area around KHF, which is not acceptable for such a seismically active region.