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TERC

University of Hormozgan

IGCP-740 West Makran Paleo-Tsunami Investigation

Final Report

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West Makran Paleo-Tsunami Investigation

Exacutive summery

After 2004 tsunami, many studies have been initiated for improving tsunami science around the world, one such initiative is identification of historical tsunamis to improve the tsunami risk assessment. Though the Indian Ocean has threat from two known subduction zones viz., Andaman-Sumatra Subduction Zone (ASSZ) and the Makran Subduction Zone (MSZ), the MSZ is still need to be studied extensively due to its complex nature. It needs to be further evaluated in terms of the hazard it can generate especially near-field regions of Northern Arabian Sea. In the historical past it has generated several major earthquakes, some of which have also been associated with catastrophic landslides, such as the 1945 event. The hazard along the MSZ needs the urgent attention of seismologists, geophysicists, and geologists for unearthing the remnants of past activity, so as to visualize the futuristic hazard it can generate. Such an exercise has been initiated as part of the West Makran Paleo-Tsunami Investigation.

The West Makran Paleo-Tsunami Investigation project has been initiated with a kick-off meeting and initial studies in Iran region. A catalog of local historical data from published and documentary evidence has been prepared as part of historical records survey. Based on previous records a few sites in Iran were selected for trenching. A team of experts visited the identified locations which may have been potentially affected by past tsunamis during July and August 2021. The activities under the proposed project are being conducted phase-wise in Iran, Pakistan, India, UAE, Yemen, and Oman countries. A workshop was conducted on October 29, 2021 with national experts of Iran and international experts drawn from various specialized fields. The initial results from the field visit of 17 sites viz., (1) Gavbandi, (2) Rig (3) Sourgalm (4) Vanak (5) Karati (6) Tang (7) Chabahar (8) Comb (9) Ramin (10) Lipar lagoon (11) Anjir Maabed (12) Kacho Beach (13) Martian mountain lagoon (14) Roudig Beach (15) Beris harbor (Lagoon) (16) Beris beach and (17) Beris-Pasabandar Police station were demonstrated to the experts and discussions were carried out to extend the task to other regions in future.

1. Introduction

Tsunamis are a threat to most of the coastal regions. The national development plans generally depend upon the maps that forecast threats to the region from multiple hazards such as tsunamis and earthquakes. The study of prehistoric tsunamis provides important feedback for long-term rates of tsunami occurrence to improve confidence in such forecasts. The studies show catastrophic tsunamis are too infrequent for the hazard to be characterized by historical records alone. Long-term geologic records provide opportunities to assess tsunami hazards more evocatively.

The studies show catastrophic tsunamis are too infrequent for the hazard to be characterized by historical records alone. Long-term geologic records provide opportunities to assess tsunami hazards more fully (Rhodes et al., 2006). Advances in geodesy and seismology have contributed to our understanding of rupture patterns of large earthquakes, but the devastation caused by recent Indian Ocean tsunamis make it clear that estimates of earthquake size and tsunami potential are woefully inadequate (Rubin et al., 2017). The repeat times of such giant tsunamis span over centuries to millennia apart (Satake, and Atwater, 2007; Meltzner et al., 2006; Lay and Kanamori, 2011; Sieh et al., 2008; Meltzner et al., 2006) and are not fully captured in historical and instrumental records (Satake, and Atwater, 2007; Meltzner et al., 2006). A more refined understanding of the long-term variations in timing and recurrence of giant tsunamis is essential for producing realistic vulnerability assessments for coastal communities (Rubin et al., 2017).

Makran Subduction Zone is one of the noted places as deficient in data on tsunami size and frequency. Logistical constraints have made much of the Makran essentially inaccessible in recent years, curtailing earlier field investigations. Seismicity differs in the eastern and western parts of the Makran Subduction Zone, with a boundary at about the Iran/Pakistan border. No large-magnitude earthquake is known in the western Makran where the recorded seismicity is sparse. By contrast, large-magnitude and frequent earthquakes characterize the eastern Makran. This geographical dissimilarity in seismicity is attributed to a hypothetical segmentation of the subduction zone at ca 62°E longitude or to a locked plate boundary that experiences great earthquakes with long repeat times in the west. The 1945 earthquake rupture one-fifth the length of the subduction zone. The faulting caused uplift at Ormara and the tsunami attained reported heights of 12-15 m in Pasni, east of Ormara, and caused fatalities as far south as present Mumbai, India.

Makran and its seismic historical background raises many questions: the relation between great earthquakes and associated tsunamis, duration of the tsunami recurrence, probability of it happening in populated places, most affected places, extent of the potential damage, the time needed for tsunami hazard alert (i.e., arrival time), the probability of major earthquakes occurrence.

The two major tsunamigenic sources in the Indian Ocean region are Andaman-Sumatra subduction zone (ASSZ) and Makran Subduction Zone (MSZ). The ASSZ has witnessed many major tsunamis in the past (historical as well as long-term). However, in the case of MSZ, neither we have many historical records nor any long-term studies. No large-magnitude earthquake is known in the western Makran, raising the question of locked or aseismic nature. By contrast, the large-magnitude and frequent earthquakes characterize the eastern part of the Makran Subduction Zone. Consequently, the hazard scenarios prepared based on historical data underestimate the tsunami threat to the Oman Sea. The dated deposits allow us to estimate the time and recurrence intervals of past tsunamis, ~ a gap that needs to be filled with robust data quickly. Such information guides mitigation efforts and improve our understanding which may reduce the losses from the future tsunamis.

The Makran Subduction Zone is located offshore of Iran, Pakistan and Oman (Mokhtari et al., 2008), in an inhabited region with a traditional population, and growing seacoast cities rapidly. The best evidence for the subduction zone is south in Iran and Pakistan on the Makran coast, where marine terraces record tectonic uplift (Jacob and Quittmeyer, 1979; Vita-Finzi, 2002; Pirazzoli et al., 2004) and extensive mudflats lie within reach of the highest tides (Snead, 1969; Snead, 1970). Uplifted terraces, subsided lowlands or sand blows that record the associated paleo-earthquakes may be associated with paleo-tsunami deposits (Satake and Atwater, 2007). The recent evidence collected onshore Oman resulted in confidence that a tsunami hit the northern coast of Oman around 1000 years ago. Evidence for past extreme-wave events that dislocated boulders is available for numerous sites along the 200 km long coastal stretch near Muscat (Hoffmann et al., 2020).

Due to very fewer paleo-tsunami records in Makran Subduction Zone, it is essential to conduct comprehensive studies to understand the relationships governing the mega earthquakes that can trigger a major tsunami. The 1945 Makran tsunami and the associated magnitude 8.1 earthquake are the results of the rupture of the subduction zone's length. A field study is necessary by a team of scientists from the tsunami threatened countries in the region to assess the vulnerability of the area. The first report of this project titled "Report of the past Tsunami (II-a)" included the Collect of Local Historical Data Form Published and Documentary Evidences submitted on 6 July 2021. In this report, a general review of the main structural elements and the tectonic setting of the Makran region, the previous studies conducted in the area and for future use other parts of the Indian Ocean were presented. The main goal of the IGCP 740 project was to find locations with preliminary evidence of a paleo-tsunami. The confirmation of the findings, of course, needs more detailed studies that will be done in the second phase of this project. A big part of the coastal area of the western MSZ was visited, during July and August 2021.

The final report includes the evidence from field works in the coastal area of the west Makran, the proposed location of future trenches and/or bolder studies, report of the First workshop on the IGCP 740 West Makran Paleo-tsunami Investigation on 29 October 2021 for sharing the results with national and international experts, and recommendation for future studies.

2. Review on the first report

The first report started with a review of Makran Seismicity and Tectonic evolutions of the northern Indian Ocean. Local historical data collected from published and documentary evidence includes the near- and far- field sources investigated for paleotsunami in the Makran Subduction Zone and also, dated marine terraces of Oman Sea, including methodology, results and time of events. Investigated near-field sources include the west Makran Subduction Zone (near Chabahar). The reconstruction of boulder movements along the Oman coastline contributes to a better understanding of storm and tsunami dynamics. Investigated far-field sources include north and west Gujarat, India and Andaman Island, with comparative analysis of soft- sediment deformation and other sedimentary signatures using an extensive survey of sandy beaches indicative of paleotsunami. The methodology for paleotsunami investigations includes site selections, and trenching. Other activities will be done on trenches i.e. sediment & stratigraphy analysis, micropaleontology, geochemistry, and dating of tsunami events. Also, boulders can be used for identifying past high-energy tsunami events is common practice. The reconstruction of boulder movements along coastlines contributes to a better understanding of storm and tsunami dynamics. The Figure 1 shows the flowchart, based on previous studies.

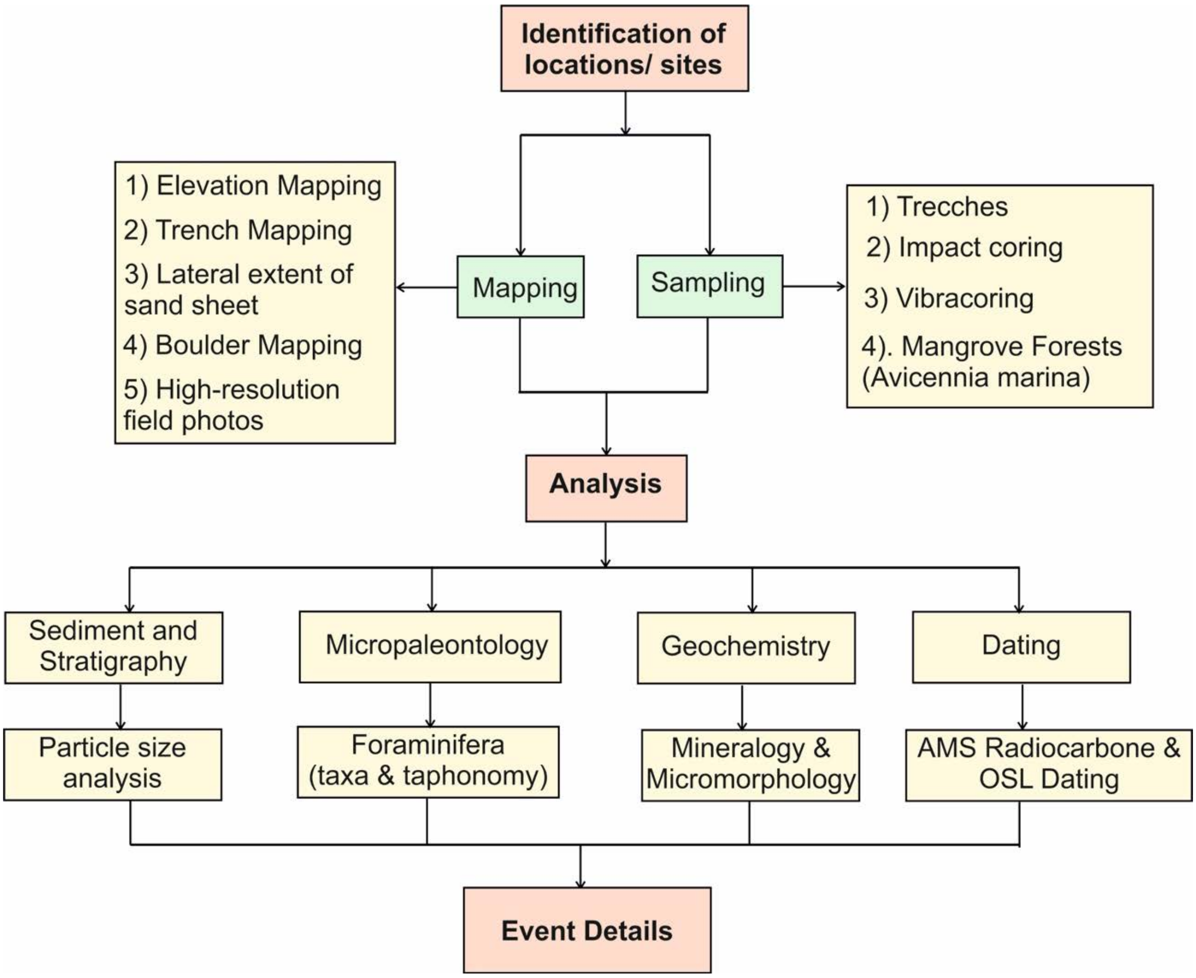

Figure 1. General flowchart for Paleo-tsunami studies.

3. Tectonic setting of the Makran Subduction Zone (MSZ)

Makran subduction zone (Fig. 2) is one of the noted places as deficient in data on tsunami size and frequency. North-dipping subduction of the Arabian plate beneath Central Iran and Afghan blocks is believed to have begun during the Cretaceous and is still going on. GPS measurements document a nearly NE convergence rate of ca 20 mm/a between the Arabian and Eurasian plates at the longitude of the Gulf of Oman. The toe of the Makran wedge has migrated southward at ~ 1 cm/a since the Pleistocene. Current motions recalculated from seafloor spreading rates and fault azimuths for the major plates account for convergence rates increasing from 35.5–36.5 mm/a in western Makran to 40–42 mm/a in the east. This is apparently corroborated by the anticlockwise rotation of the rigid Arabian plate with respect to Eurasia around a vertical axis located somewhere in Kurdistan. Seismicity differs in the eastern and western parts of the Makran Subduction Zone, with a boundary at about the Iran/Pakistan border. No large-magnitude earthquake is known in the western Makran where the recorded seismicity is sparse. By contrast, large-magnitude and frequent earthquakes characterize the eastern Makran. This geographical dissimilarity in seismicity is attributed to a hypothetical segmentation of the subduction zone at ca 62°E longitude or to a locked plate boundary that experiences great earthquakes with long repeat times in the west. The faulting caused uplift at Ormara and the tsunami attained reported heights of 12-15 m in Pasni, east of Ormara, and caused fatalities as far south as present Mumbai, India.

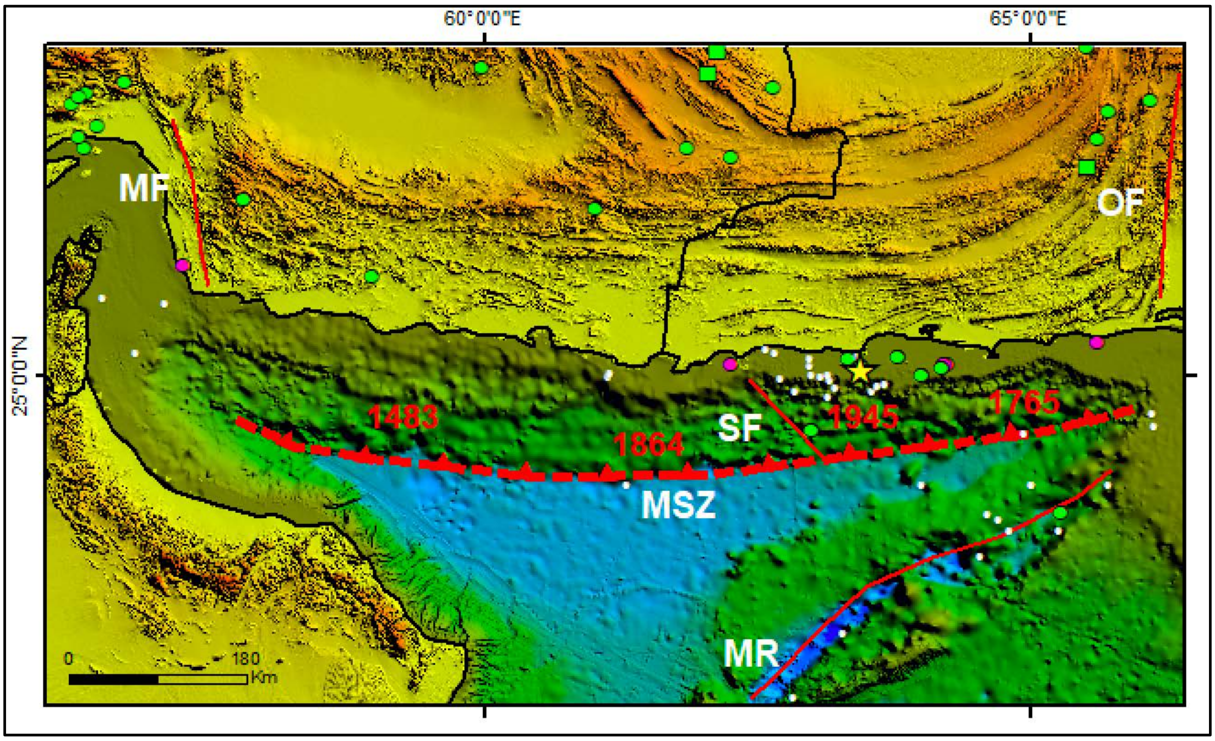

Figure 2. General tectonic framework of the Makran Subduction Zone (MSZ) on satellite image. SF (Sonne Fault), MR (Murray Ridge), MF (Minab-Zendan Fault), OF (Ornach-Nal Fault), white circles (earthquakes from 5 to 5.9), green circles (earthquakes from 6 to 6.9), green squares (earthquakes from 7 to 7.9), yellow star (1945 tsunami event), the numbers on the map present probable historical tsunami events.

Makran and its earthquake historical background raises many questions: the relationship between great earthquakes and associated tsunamis, duration of the tsunami recurrence, probability of it happening in populated places, most affected places, the extent of the potential damage, the time is needed for tsunami hazard alert, the probability of major earthquakes occurrence.

In September 2017, three 200 km long deep seismic sounding profiles have been acquired in the Makran region, Iran, which, for the first time, provide constraints on the internal structure of the subaerial accretionary wedge and the subduction plate geometry. The quality of the data was generally good, and (crustal) Pg, (Moho) PmP and (upper mantle) Pn phases were observed up to the ends of the profiles. To derive the 2-D seismic velocity models a first-arrival travel-time tomographic inversion based on a trans-dimensional, hierarchical Markov chain Monte Carlo method (Ryberg & Haberland, 2018) was applied. This was complemented by an automatic line drawing migration of coherent later phase arrivals (wide-angle reflections; Bauer et al., 2013) potentially originating from intra-crustal discontinuities and the crust-mantle boundary. Low seismic P-wave velocities and characteristic velocity heterogeneities indicate basal underplating and accretion of subducted sedimentary material. Wide-angle Moho reflections constrain the geometry of the subducting plate dipping ~8° northward in the central part of the subaerial wedge (Haberland, et al., 2020).

4. Geology of the Coastal Makran

Coastal Makran, generally preserves a basin-fill Miocene to Plio- Pleistocene sequence. Upper Miocene sandstones recycled mainly Eocene – Lower Miocene deep-marine sediments of the Makran basin (Mohammadi et al., 2016), which suggests that the northern parts of wedge may have been exposed at this time. Lateral facies transitions and interdigitations between marl-dominated and calcareous sandstone-dominated units can be followed over kilometers and generally denote finer sediments southward. Coarsening-up from mudstone-dominated to sandstone-dominated sequences with abundant bioturbation along with mollusc shells, in particular marine gastropods, represents the transition from the shallow marine shelf into foreshore deltaic and fluviatile conditions. Bidirectional cross-bedding indicate a very shallow-water and intertidal depositional environment of the sand layers. The youngest marine sediments comprise 1 Ma oyster shells ($^{87}Sr/^{86}Sr$ method, Dolati, 2010) and shell fragments near the coast. Locally gypsiferous mudstones with mud cracks in the upper part represent lagoonal or intertidal sabkha environments. Younger, overlying successions consists of fluvial, fine- to coarse-grained conglomerates, sandstones and siltstones which are in general barren fossils although one ostracod was recorded by (McCall, 1985). These rocks rest unconformably on older units. The uppermost sequence consists of Pleistocene and younger marine terraces, which are laterally equivalent to thick-bedded continental conglomerates and fluvial terrace deposits which occur inland (Haghipour et al., 2015). In Pakistan, The Upper Miocene mainly consists of mudstones with fine-grained thin sandstones that become channelized upward, which indicates decreasing water depth. Shallow-water Pliocene deposits and middle-outer shelf Pleistocene sediments record several generations of shelf-slope lobes, which may indicate that the Iranian coastal region emerged earlier than the Pakistan side. This sequence overlaid with younger Quaternary fluvial and sand dunes sediments.

5. Geomorphology and paleotsunami deposits

A major limitation in paleotsunami research is the lack of preservation of tsunami deposits which leads to fragmentary record. Geomorphology and coastal configuration play a vital role during the tsunami events, as it is understood that different coastal geomorphic units respond differently to a tsunami hazard. So, an understanding of response mechanism of coastal geomorphic features to paleotsunami events help in identifying with higher preservation potential. The different coastal geomorphic units respond differently to a tsunami hazard (Ramasamy, et al., 2006; Shukla et al., 2010):

Facilitator- Geomorphic features like river mouth, creek, estuary and mudflats are kept under this category due to their capability of allowing the tidal water to get inside during the time of tsunami.

Carrier/conveyor- River channels and creeks will serve as a carrier during the time of tsunami. Tsunami waves can easily go inside and cause wide destruction up to considerable distance inland ward.

Accommodator- The swales, backwaters, paleomudflats, salt pans and mangrove swamps will serve as accommodators. Although, they can't reduce the intensity of tsunami wave but they have the capacity to accommodate the energy of tsunami waves due to their large extent which is little higher than the present mean sea level.

Absorber- Sandy beaches and mangroves swamps comes under this category. It was suggested that sandy beaches have the capacity to absorb the tsunami energy; the Marina beach saved the Chennai city during 2004 tsunami. The width of the beaches is a matter of concern because narrow beaches probably will absorb little tidal energy. Mangroves are well known for effectively reducing tsunami wave velocity and energy.

Barrier- Beach ridges and costal dunes will act as natural barriers during the time of tsunami. The capacity of such barrier will depend upon height of tsunami surge and elevation and width of the barrier.

Facilitator, Carrier and conveyor act as carrier during the time of tsunami and increase the possibility off tsunami run-up and facilitate the inundation. Accommodators serves as good archive for paleotsunami deposits. Barrier and Absorber leading to reduction in tsunami velocity and energy and act as most suitable configurations for preserving the tsunami sedimentary record for longer period.

6. Project planning

The activities under the proposed project are conducted phase-wise starting with Iran and continued with Pakistan, India, UAE, Yemen, and Oman countries.

The project kick-off meeting will be conducted during which the methodology will be finalized for Paleo-tsunami studies in the Makran subduction zone, it will continue with

- Collection of local historical data from published and documentary evidences for the region.
- Site selection for trenching based on the initial field work in consultation with other experts internally and internationally. In this step the existing geological, topography data (local) maps (surface and structural) will be used. The area that we plan is rather large so it can be time consuming and we need to conduct at a certain time of the session as it can be very hot.
- Based on the above item appropriate location maps with geographical and geological map will be prepared. A summary sheet will be prepared for each suggested site for trenching.
- The resulted map and summary sheet will be shared with national and international experts for finalizing (that is before actual trenching) the locations.
- Final reporting.

The present project includes a collection of local historical data from published and documentary evidence for the region, revision of the methodology during which the methodology was be finalized for Paleo-tsunami studies in the Makran subduction zone, field visit in MSZ and site selection for trenching and other studies (Table 1).

Table 1. Project planning steps of paleo-tsunami studies in the West Makran Subduction Zone.

Items	Activities	Date					
		Jun	Jul	Aug	Sep	Oct	Nov
1	Collect of local historical data form published and documentary evidences						
2	Kick-off meeting to finalize methodology		1 Jul				
3	Field work 1- kuhmobarak to Zarabad (identification of potential locations effected by past Tsunami)						
4	Field work 2- Zarabad to Chabahar (identification of potential locations effected by past Tsunami)						
5	Map generation with geographical and geological where the location of the future trenches will be indicated						
6	Share the resulted maps and summery sheet with national and international experts						
7	Final reporting and recommendation						

6. Field observations

Field visit for identification of potential locations effected by past tsunami was done during July and August, 2021 (Table 1). Total of 17 sites visited for paleotsunami evidences (Fig. 3). Following is a detailed description of each site including geography and local geology.

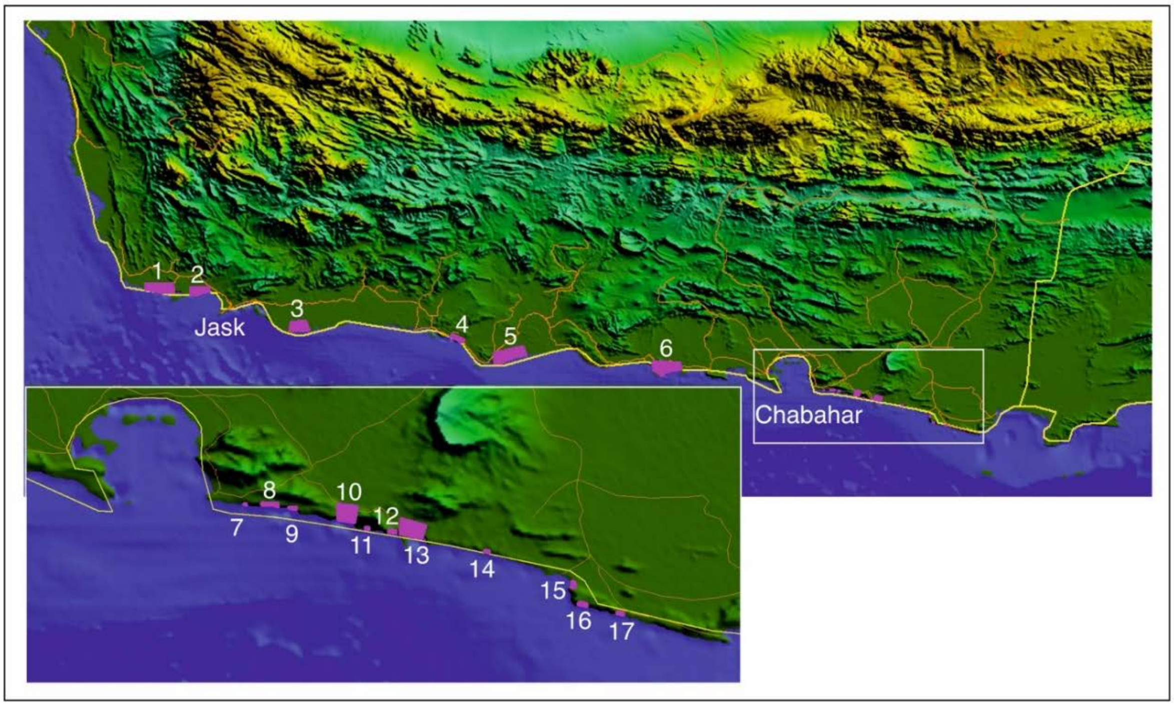

Figure 3. Map of the studied areas. Violet colors: area studied, visited and mapped in this project (Figs. 4-26). The lower-left corner of the image shows the enlarged square of the sites near Chabahar.

6-1. Gavbandi Site

Gavbandi Site is located in east of the Kohmobarak area.

Elevation

The altitude of the coastal area is very low. The coastal area reaches at height of about 3 meters (with handheld GPS) up to a distance of ~8 km from the coastline (Figs. 4a, b). Based on discussion with local people, during a marine storm, very large area is covered with sea water (large horizontal flooding or inundation). Long sandy linear barrier beach (>11 km long) in coastal area and Estuary behind it, present a very good situation for trapping paleo-tsunami evidence (barrier backed accommodator).

Geology:

The area is covered by marine terraces, sandy linear barrier beach, silty deposits with shell fragments (coastal plain landform), and high-supratidal salt marsh (Sabkha type) (Figs. 4c, d).

Geomorphic features:

Paleomudfalt (8 km), back swamp, linear barrier beach (3 m), tidal/river channel.

6-2. Rig Site

Rig Site is located west of the Jask.

Elevation: The altitude of the beach in this area is very low. It reaches a height of about 3 meters (with handheld GPS) up to a distance of about 3 km from the coastline (Figs. 5a, b). Sandy linear barrier beach (~2 km long) in coastal area and Estuary behind it, present a good situation for trapping paleo-tsunami evidence. (Barrier backed accommodator).

Geology:

The area is covered by a Quaternary sandy linear barrier beach, silty deposits with shell fragments, and a high-supratidal salt marsh (Sabkha type) (Figs. 5c, d).

Geomorphic features:

Paleo-mudflat (3 km), linear barrier beach (3 m), tidal/river channel.

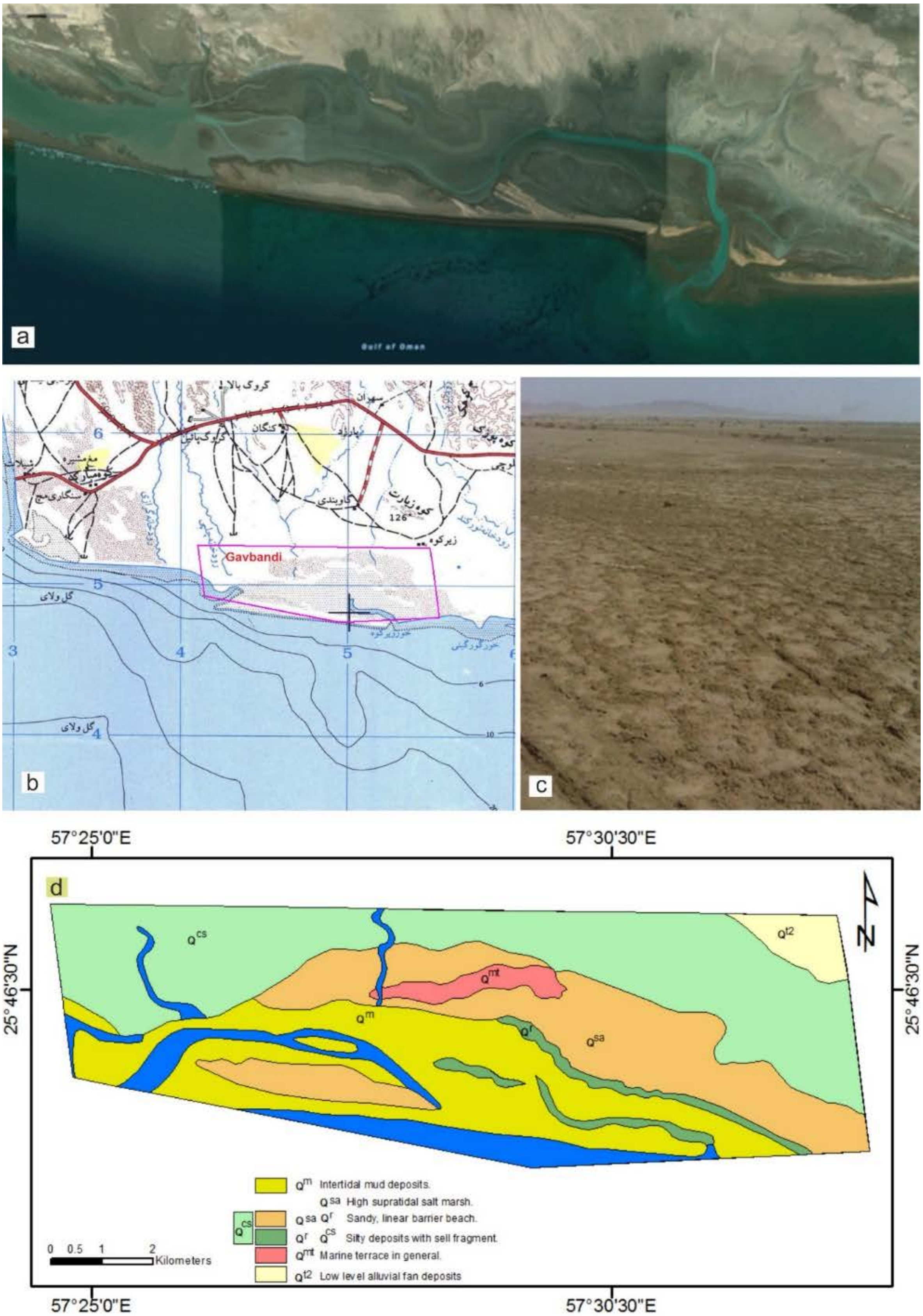

Figure 4. a). Satellite image (Google Earth) shows a long sandy linear barrier beach (>11 km long) in a coastal area and Estuary in the Gavbandi Site (No. 1 in Fig. 3). b). The topographic map shows the location of the Gavbandi coastal site in east of the Kohmobarak area. c). Field Photograph of Gavbandi Site (GPS: 25.77º N, 57.50º E) ~ preferred for trenching. d). Geology map of the Gavbandi area (1: 100 000 Jask-Gattan sheet).

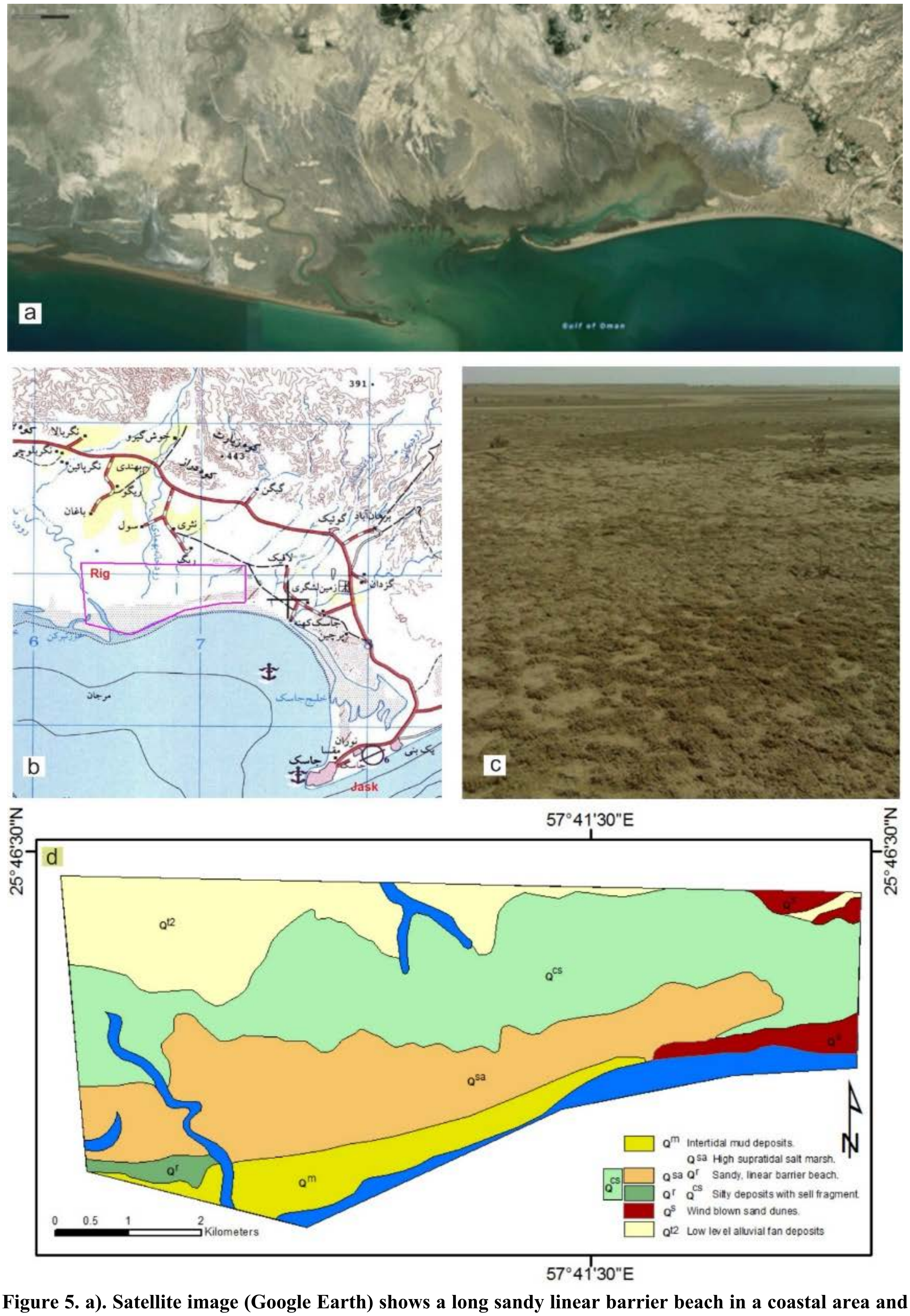

Figure 5. a). Satellite image (Google Earth) shows a long sandy linear barrier beach in a coastal area and Estuary in the Rig Site (No. 2 in Fig. 3). b). The topographic map shows the Rig coastal Site in the port of Jask. c). Field Photograph of Rig Site (GPS: 25.75º N, 57.68º E). d). Geology map of the Rig area (1: 100 000 Jask-Gattan sheet).

6-3. Sourgalm Site

Sourgalm Site is located in the east of the Jask.

Elevation:

The altitude of the beach in this area is very low. It reaches a height of about 3 meters (with handheld GPS) up to a distance of about 6 km from the coastline (Figs. 6a, b). Based on discussion with local people, during a storm, a very large area is covered with water (large

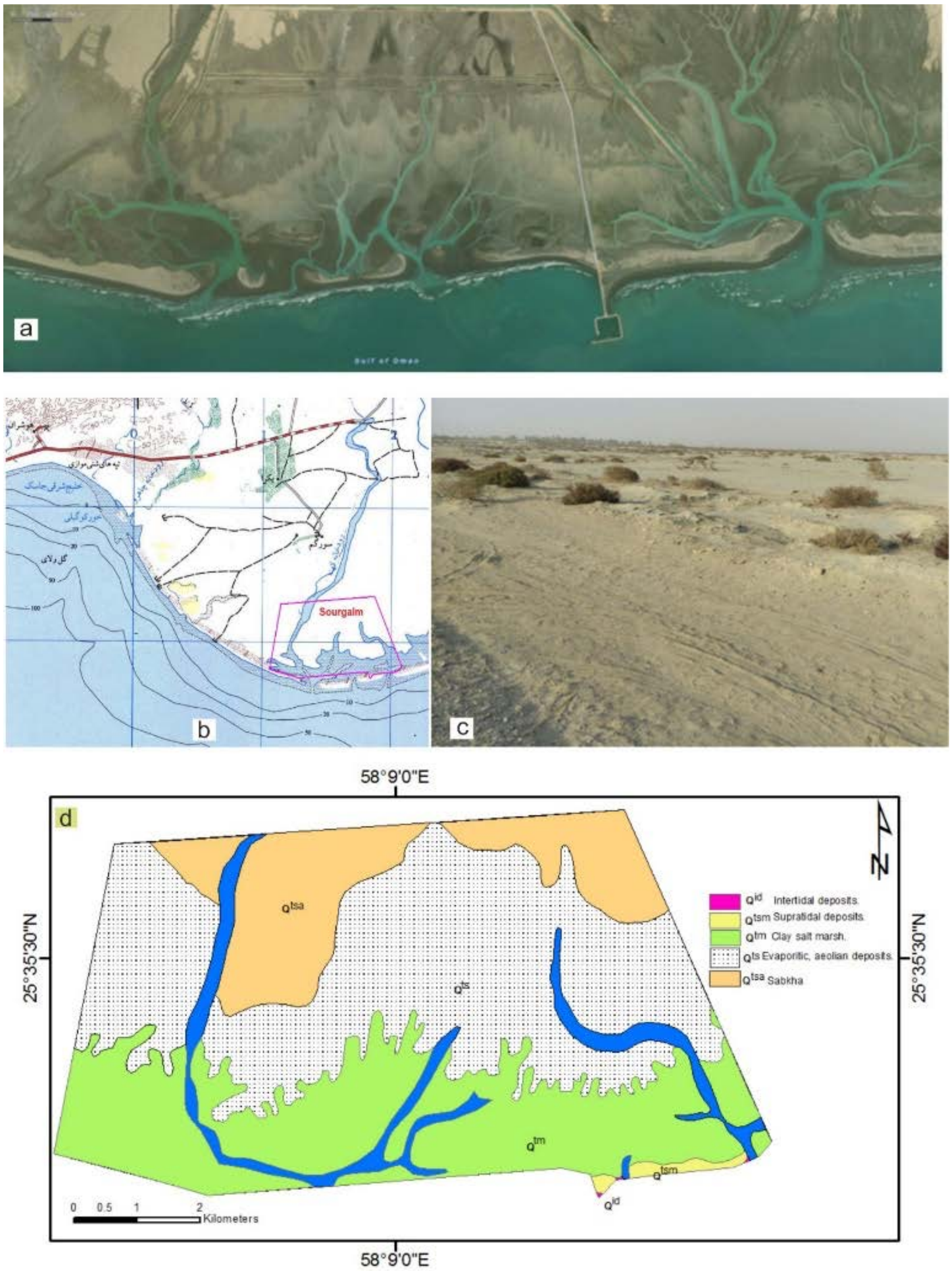

Figure 6. a). Satellite image (Google Earth) shows a long sandy linear barrier beach in a coastal area and Estuary in the Sourgalm Site (No. 3 in Fig. 3). b). The topographic map shows the Sourgalm Site in east Jask. c). Field Photograph of Sourgalm Site (GPS: 25.32. 38º N, 58.12.56º E) can be explored with shallow trenches. d). Geology map of the Sourgalm area (1: 100 000 Gabric-Yekdar sheet).

horizontal flooding or inundation). A complex barrier beach in coastal area and Estuary behind it, at the present it is a good situation for investigating paleo-tsunami evidence. On the other hand, due to alluvial fan activity, the area is probably covered by young sediments of recent years. So, deep trenching is expected in this area.

Geology:

The area is covered by Quaternary Intertidal deposits (free shells and fine-medium grained particles), supratidal deposits (sand and mud), clay salt marsh, evaporitic aeolian deposits (Figs. 6c, d). The area is a marginal part of a large range-front active Alluvial fan (Figs. 6b).

Geomorphic features:

Paleomudfalt (6 km), tidal/river channel.

6-4. Vanak Site

Vanak Site is located south of the Lirdaf city.

Elevation:

Because of the nearby Biyask anticline in the northeast, moving away from the shore, the altitude of the area increases rapidly. It reaches a height of about 3 meters (with handheld GPS) up to a distance of about 500 m from the coastline (Figs. 7, 8a). A lot of sand (coastal and windy) has accumulated on the beach, so this is not easy for trenching.

Geology:

The area is covered by Quaternary clay salt marsh, high-level marine terrace, Sabkha, unconsolidated wind-blown sand deposits (Figs. 8b, c).

Geomorphic features:

Limited paleomudfalt. Beach-ridge plains can be candidate for breaches through sand ridges and for deposits in intervening swales.

Figure 7. Satellite image (Google Earth) shows a long sandy linear barrier beach in a coastal area and Estuary in the Vanak Site (No. 4 in Fig. 3).

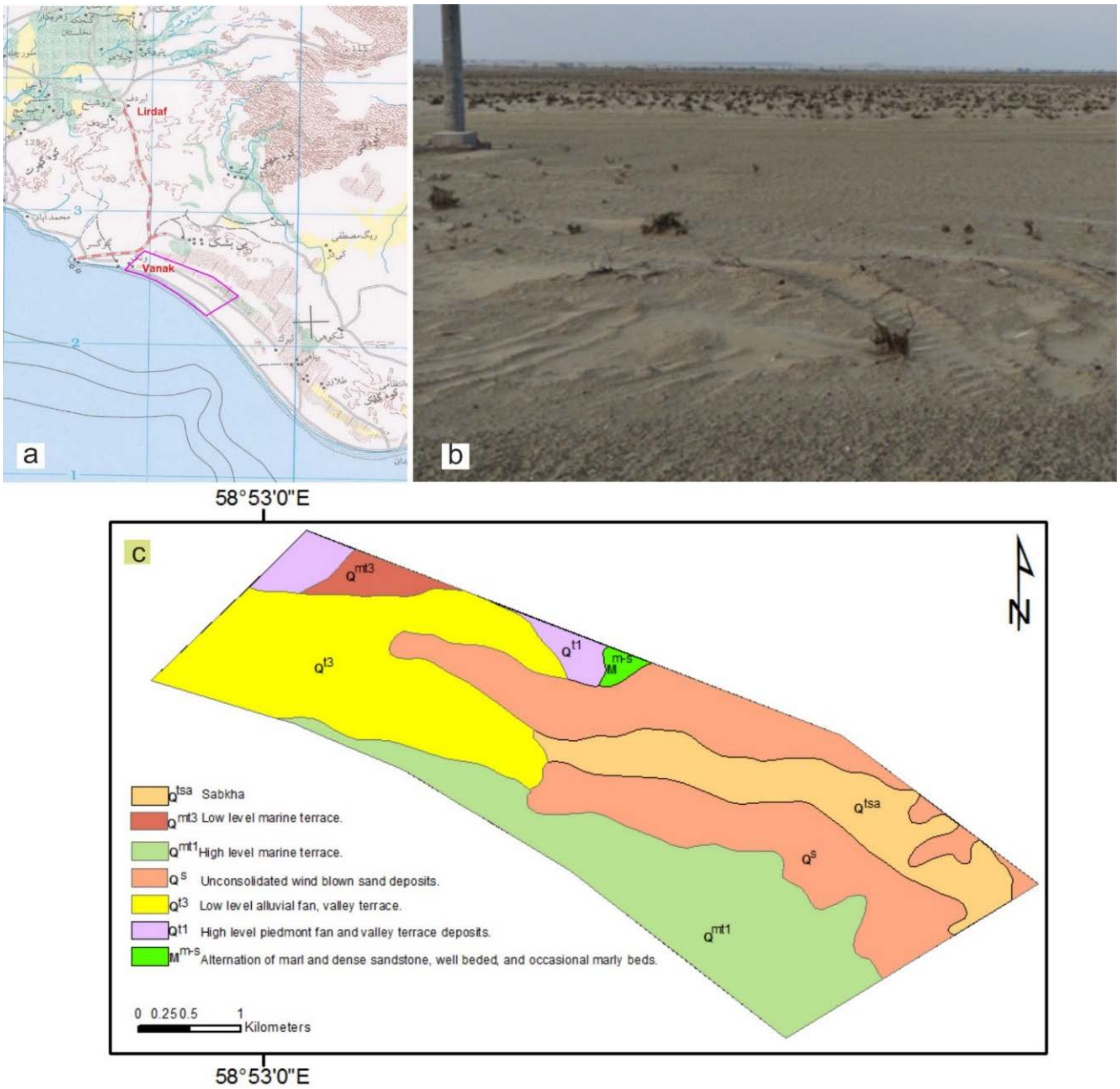

Figure 8. a). The topographic map shows the Vanak Site in south of the Lirdaf city. b). Field Photograph of Vanak Site (GPS: 25.32. 38º N, 58.12.56º E). c). Geology map of the Vanak area (1: 100 000 Pibeshk sheet).

6-5. Karati Site

Karati Site is located west of the Zarabad.

Elevation:

Long sandy linear barrier beach (>11 km long) with an elevation of 3-6 meters in coastal area and lagoon behind it, at the present it is a good situation for investigating paleo-tsunami evidence (Figs. 9a, b).

Geology:

The area is covered by intertidal deposits, free and fine-grained supratidal deposits, backshore sand dunes, unconsolidated sand dune with different forms, mudflats, low-level terraces, piedmont and alluvial fans (Figs. 9c, d). The area is a marginal and inactive part of a large range-front Alluvial fan.

Geomorphic features:

Paleomudflat (8 km), back swamp, linear barrier beach (3-6 m), tidal/river channel, lagoon.

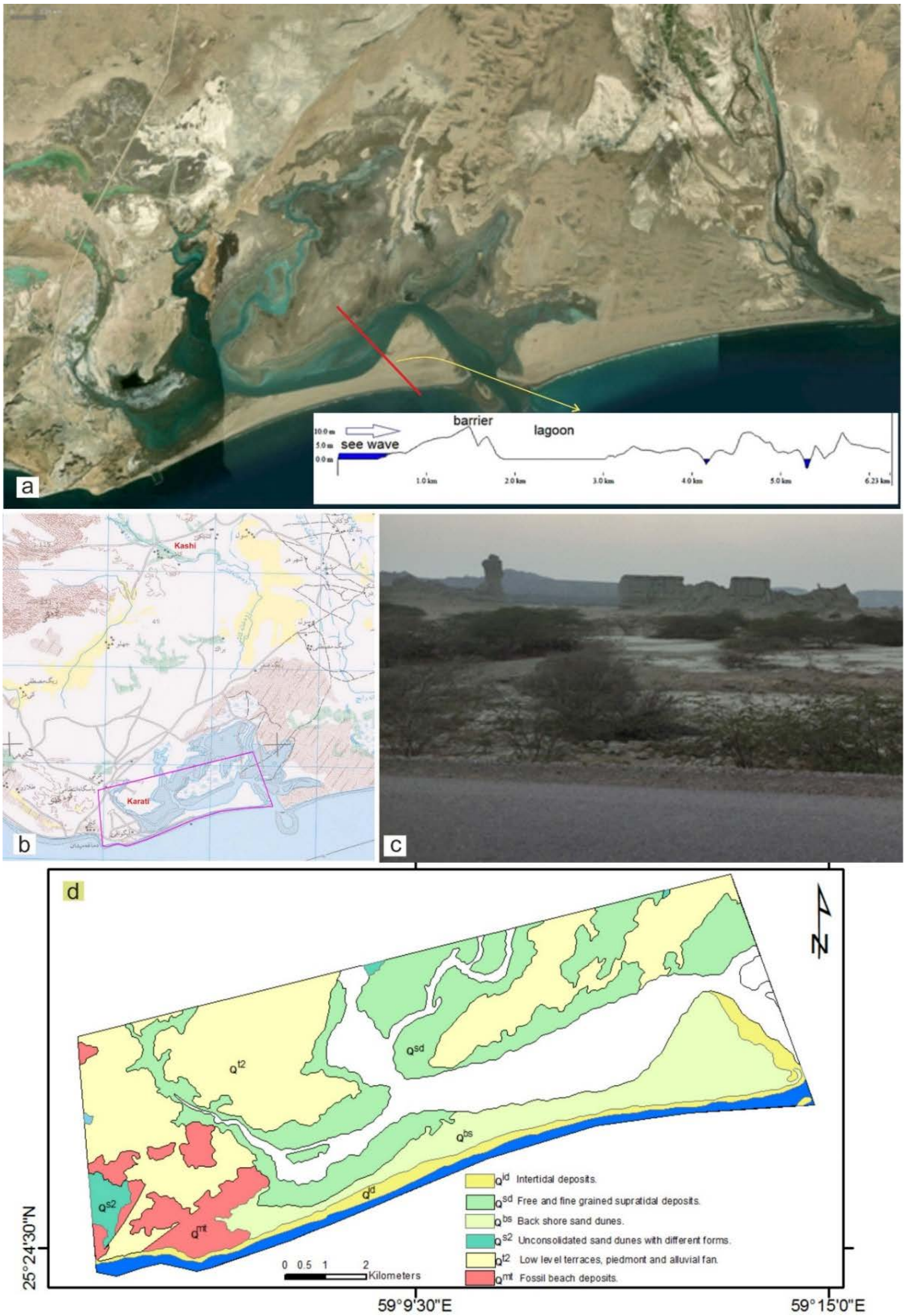

Figure 9. a). Satellite image (Google Earth) shows a long sandy linear barrier beach in coastal area and Estuary in the Karati Site (No. 5 in Fig. 3). Redline presents topographic profile across Karati coastal area. The lower-right corner of the image shows the topographic profile across Karati shows barrier and lagoon conditions. b). The topographic map shows the Karati site west of the Zarabad. c). Field Photograph of Karati Site ~ preferred for trenching. d). Geology map of the Karati area (1: 100 000 Zarabad sheet).

6-6. Tang Site

Elevation:

Long sandy linear barrier beach (9 km long) with an elevation of 2-5 meters in coastal area and lagoon behind it (Figs. 10a, b), present a very good situation to trap paleo-tsunami evidence.

Geology:

The area is covered by intertidal deposits, Shell fragments bearing backshore sand dunes, unconsolidated and fine-grained sand dunes, supratidal deposits, marine terraces (fossil beach deposits) (Figs. 10c, d). Tang area is a good candidate for relative sea level change, specially sudden changes (sea level change can be induced the sediments preservation).

Geomorphic features:

Paleomudfalt (3 km), wide back swamp, linear barrier beach (2-5 m), tidal channel, lagoon.

6-7. Chabahar Site

Elevation:

Long sandy and conglomerate coastal line with an uplift seen in the coastal area (Fig. 11a, b).

Geology:

Coastal Makran is characterized by a series of prominent sandstone- conglomerate headlands with narrow sandy shores separated by bays (such as Gurdim, Pozm, Chabahar and Gawater bays). Along the coast, outcrops are mainly sequences of calcareous mudstones (Snead, 1970). Uplifting Plio-Pleistocene mudstone and sandstone highlands show badland topography due to intensive erosion. Holocene episodic uplift of coastal fault blocks has caused coastal uplift rate between 0.1 and 0.6 m/ka along the coast (Prins et al., 2000) (Fig. 11c). The coastline has been prograded since the mid-Holocene owing to both slight uplift and marine and alluvial sedimentation.

A series of boulder trains with clasts ranging more than 2 m is deposited on top of the platform along the cliff (Figs. 11a, 12a). Imbricated clast structures (Fig. 12b) in the boulder train can be used for identifying past high-energy tsunami events is common practice. The reconstruction of boulder movements along coastlines contributes to a better understanding of storm and tsunami dynamics (Fig. 12c). Critical parameters for both determining their origin of the event, include boulder size, shape, weight, age and lithology.

Geomorphic features:

Marine terrace.

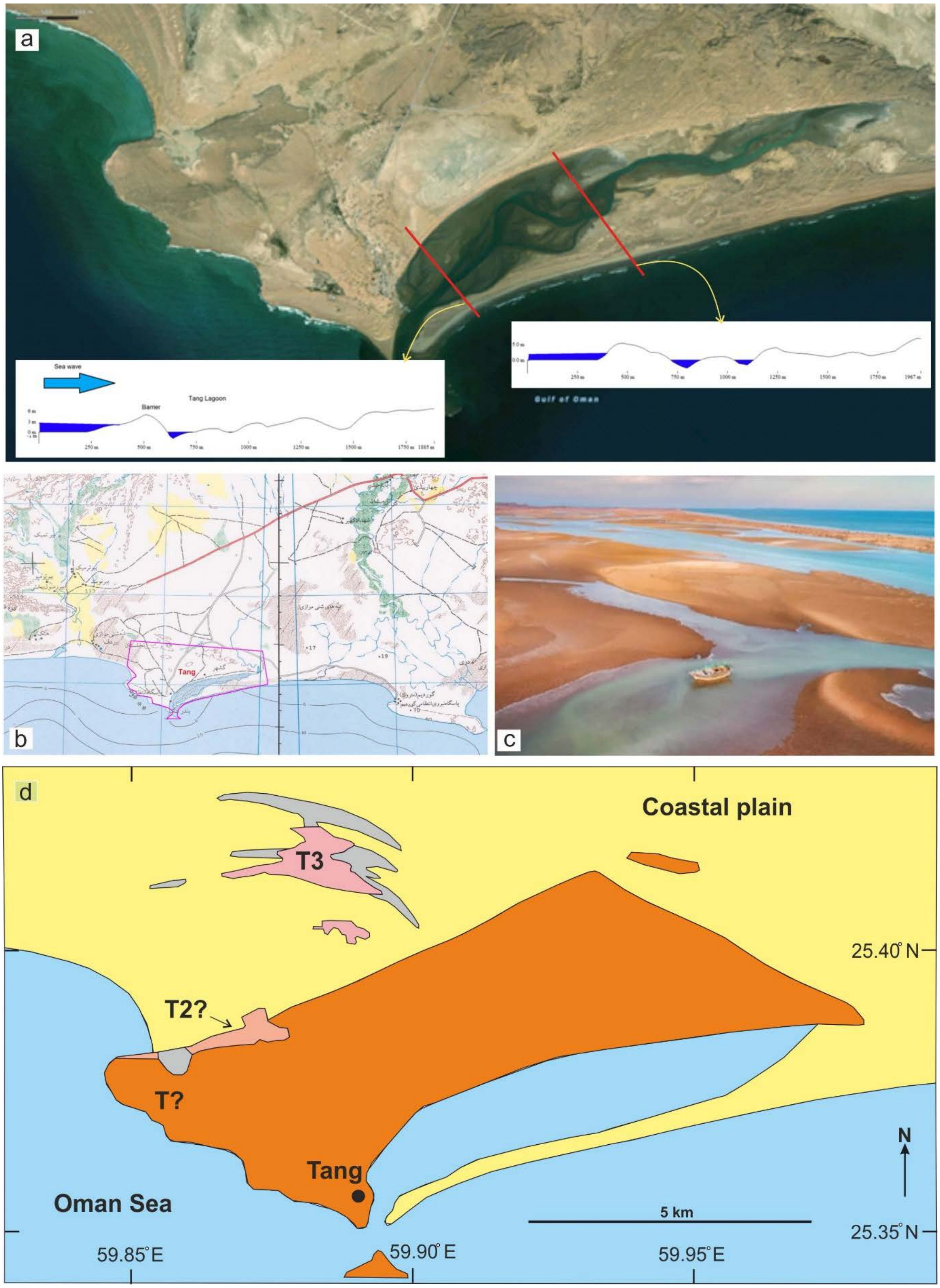

Figure 10. a). Satellite image (Google Earth) shows a lagoon and a barrier in the Tang Site (No. 6 in Fig. 3). Two redlines present topographic profiles across Tang coastal area. The lower-right corner and the lower-left corner of the image show the topographic profile across Tang show barrier and lagoon conditions. b). The topographic map shows the Tang Site. c). Field Photograph of Tang Site. d). Geology map of the Tang area (modified from Normand et al., 2019).

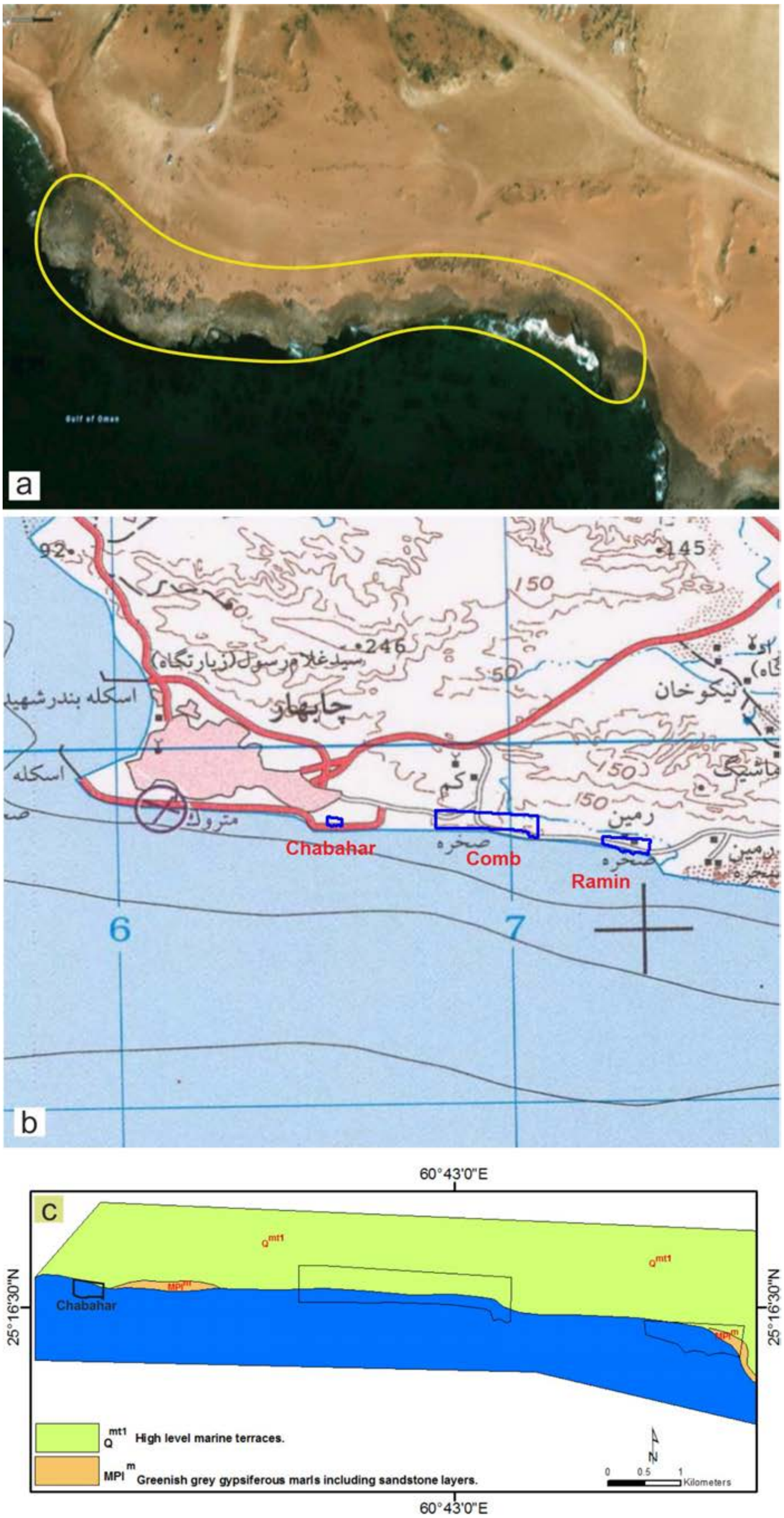

Figure 11. a). Satellite image (Google Earth) showing accumulated boulder train (~500 boulders) resting on a steep, high-energy cliff near Chabahar at about 10 m above present sea level. The area dimensions are about 250m×20m (No. 7 in Fig. 3). b). The topographic map shows the Chabahar Site. c). Geology map of the Chabahar area (1: 100 000 Chabahar sheet).

Figure 12. Field photographs show: a). Erosion of elevated marine terrace and paleocliff resulted in megaboulders fall in tidal area. b). Single boulders and accumulated boulder train resting on a steep, high-energy cliff near Chabahar. c). Imbricated clast structures in the boulder train. Note the imbrication and seaward dipping of the boulders and the elevated marine terraces in the background ~ excellent site for studying boulder – wave dynamics. View towards the east (GPS: 25º 16″ 34.60′N, 60º 40″ 15.37′E).

6-8. Comb Site

Elevation:

Long sandy and coastal line with an uplift seen in the coastal area (Fig. 13a, b).

Geology:

The area is covered by unconsolidated sand dunes, marls, and sandstone layers (Figs. 13c). Figure 13 shows the marine boulder beds (Figs. 14a, 15) and large clasts, shelf fragments and the cavities (Figs. 14b-d, 15) at Comb Site.

Geomorphic features:

Marine terrace.

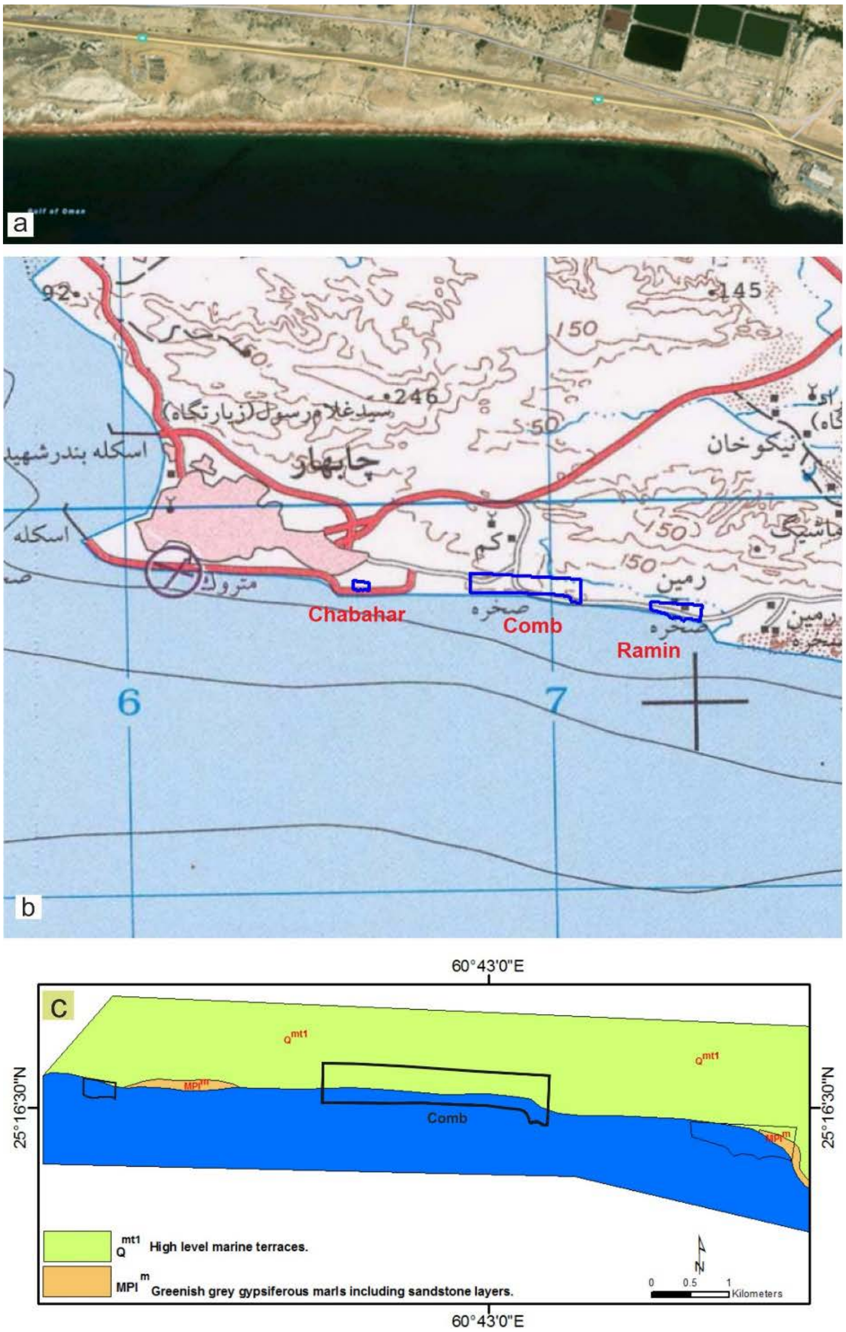

Figure 13. a). Satellite image (Google Earth) shows a sandy and conglomerate coast in the Comb Site (No. 8 in Fig. 3). b). The topographic map shows the Comb Site (No. 7 in Fig. 3). c). Geology map of the Comb Site (1: 100 000 Chabahar sheet).

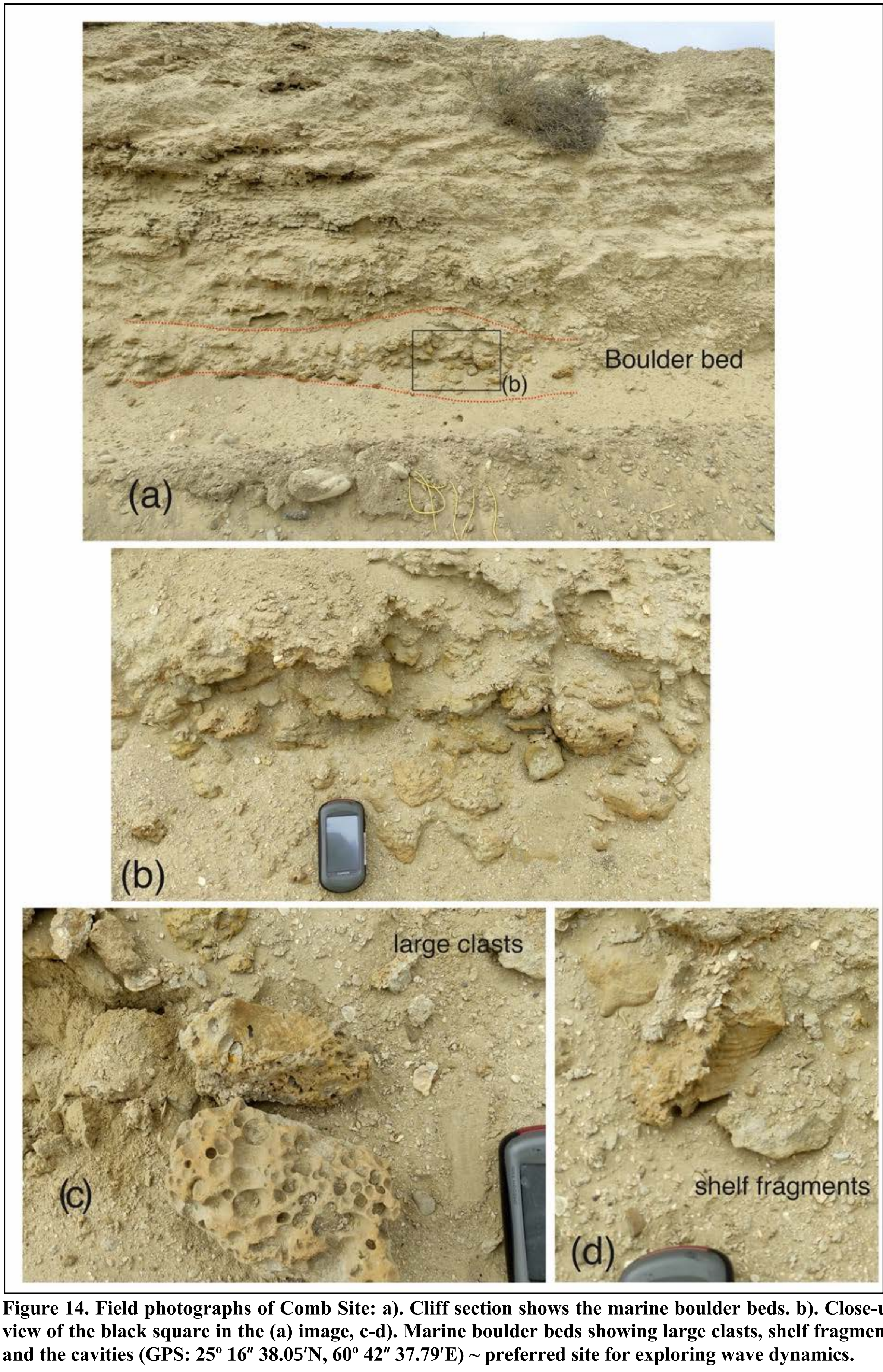

Figure 14. Field photographs of Comb Site: a). Cliff section shows the marine boulder beds. b). Close-up view of the black square in the (a) image, c-d). Marine boulder beds showing large clasts, shelf fragments and the cavities (GPS: 25º 16″ 38.05′N, 60º 42″ 37.79′E) ~ preferred site for exploring wave dynamics.

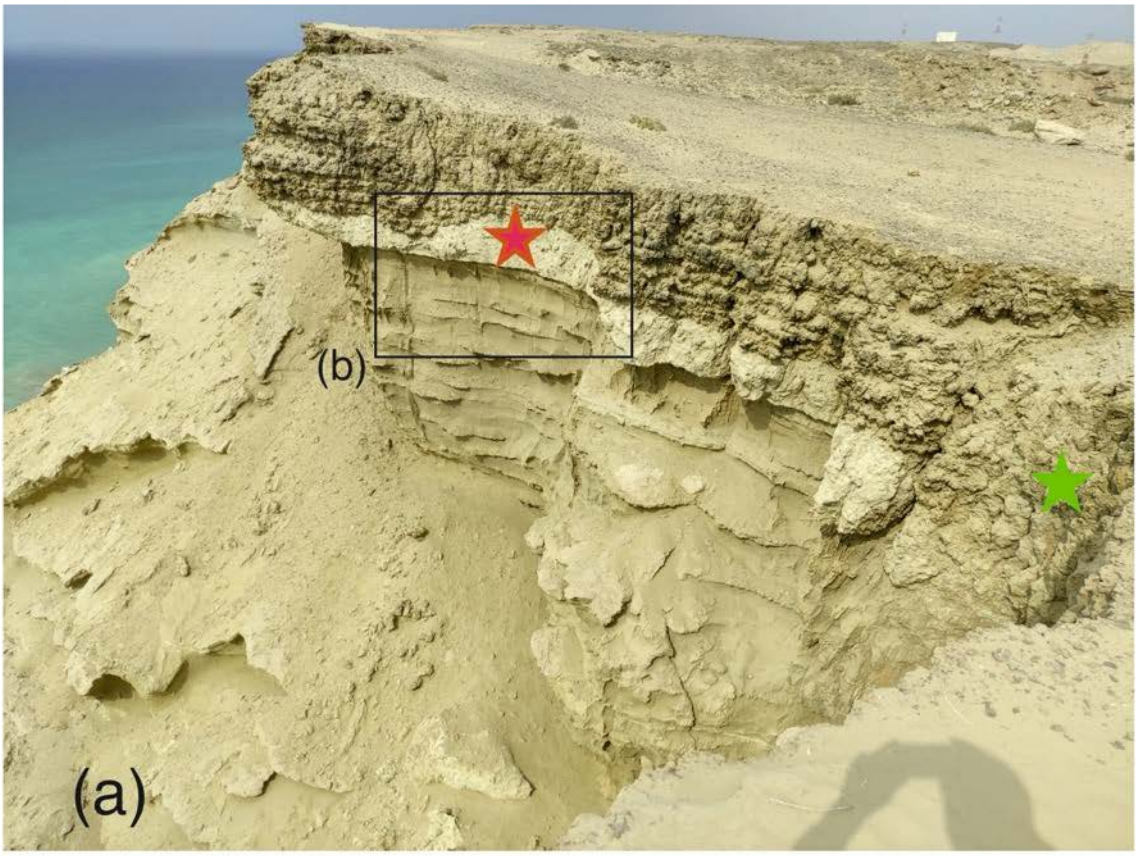

Figure 15. Field photographs of Comb Site: a). Occurrence of boulders along with bivalves out of life position with angular fragmented shells inside a layer with variable thickness. b). Close-up view of the black square in the (a) image. Green star: crushed rocks or breccia. Red star: crushed shelf fragments (GPS: 25º 16″ 33.76′N, 60º 42″ 51.16′E).

6-9. Ramin Site

Elevation:

A short sandy, and a marly coastal line and a small port is seen in the coastal area (Fig. 16a, b).

Geology:

The area is covered by Greenish gray gypsiferous (and fossiliferous) marl including sandstone layers, high-level marine terraces (sandstone to conglomerate with shell fragments), and unconsolidated sand dunes (Figs. 16c, 17). Figure 16c shows the crushed boulders in the site that may be evidence for paleotsunami.

Geomorphic features:

Marine terrace

Figure 16. a). Satellite image (Google Earth) shows a coastal line in the Ramin site (No. 9 in Fig. 3). b). The topographic map shows the Comb Site. c). Field photographs of cliff section at Ramin Site with crushed boulders may be evidences for paleotsunami preferred site for past wave dynamics (GPS: 25º 16″ 17.43′N, 60º 44″ 38.43′E).

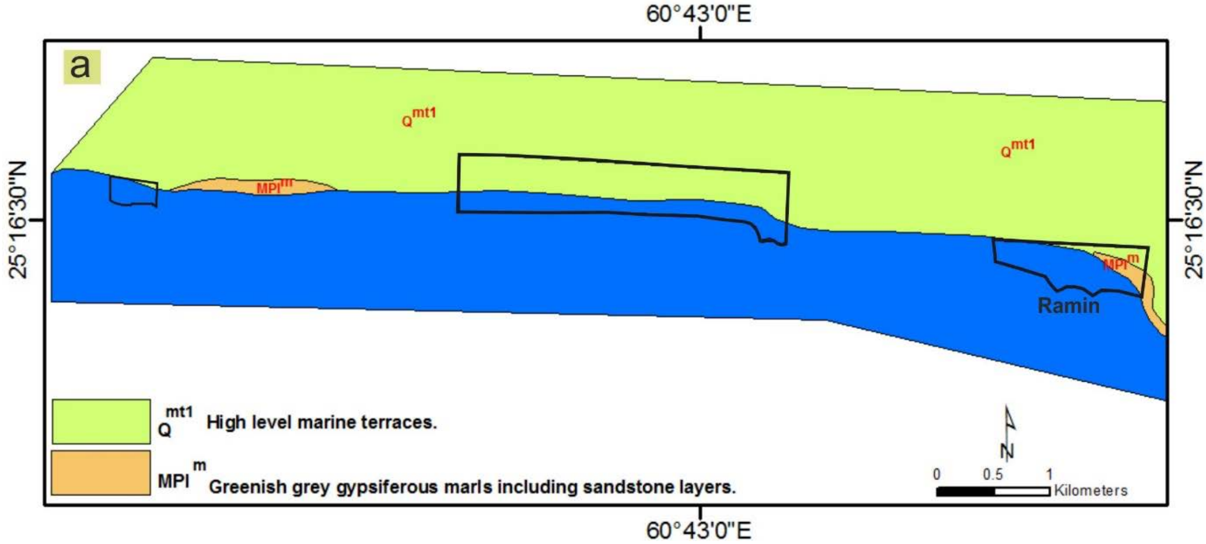

Figure 17. Geology map of the Ramin Site (1: 100 000 Chabahar sheet).

6-10. Lipar lagoon Site

Geology:

The area is covered by greenish gray gypsiferous (and fossiliferous) marl including sandstone layers, low-level marine terraces (sandstone to conglomerate with shell fragments), unconsolidated sand dunes, sandstone, conglomerate, with thin bedded silty marl, mud flat deposits (Fig. 18, 19).

Geomorphic features:

Paleomudfalt, back swamp, river channel, lagoon.

Figure 18. Satellite image (Google Earth) shows a coastal line in the Lipar lagoon Site (No. 10 in Fig. 3).

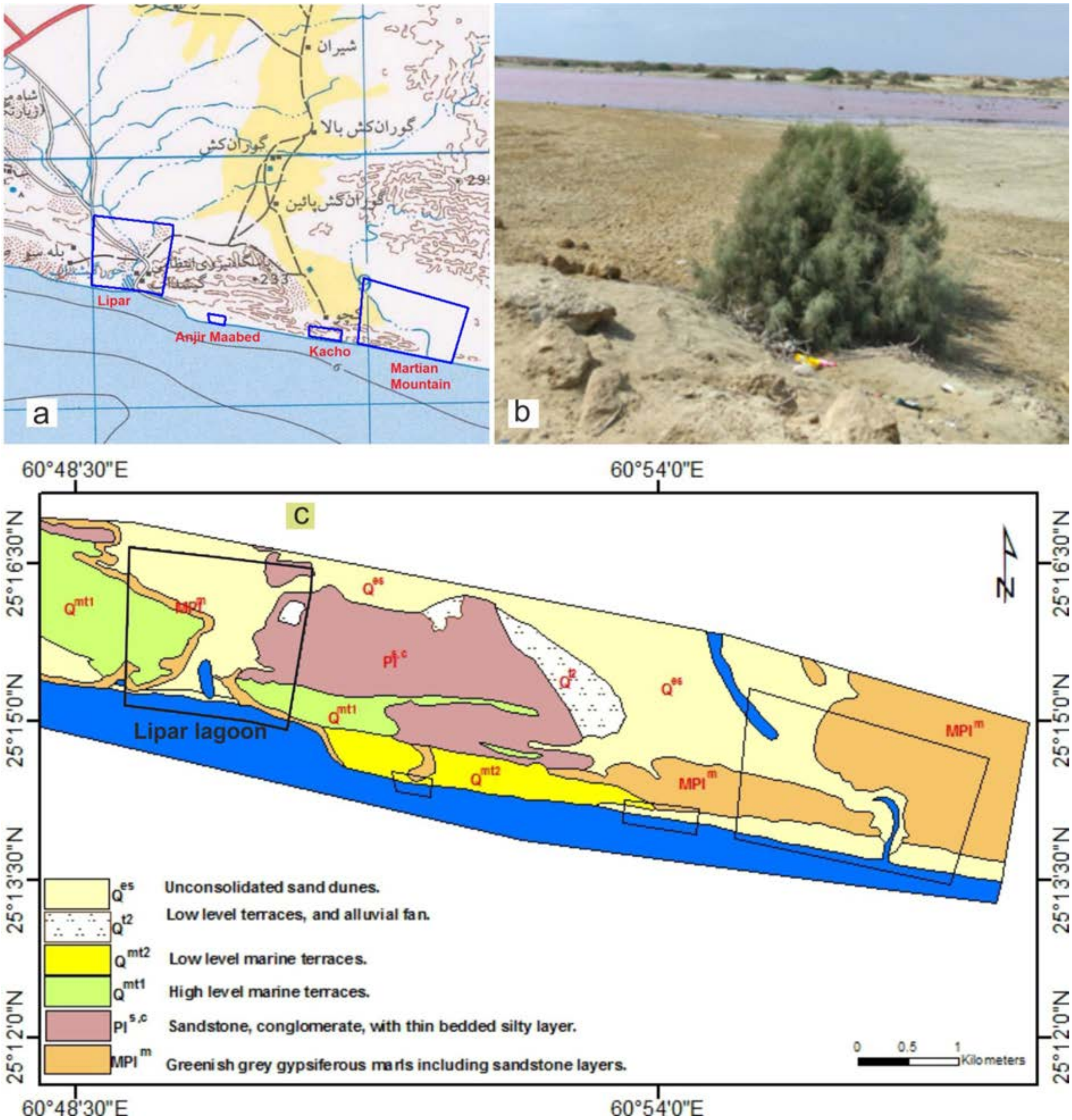

Figure 19. a). The topographic map shows the Lipar lagoon Site. b). Field Photograph of Lipar lagoon Site (GPS: 25º 15″ 23.62′N, 60º 49″ 48.54′E). c). Geology map of the Ramin Site (1: 100 000 Chabahar sheet).

6-11. Anjir Maabed Site

Geology:

The area is covered by unconsolidated sand dunes, recent alluvial channel deposits, Greenish gray gypsiferous (and fossiliferous) marl including sandstone layers (Fig. 20).

Geomorphic features:

Marine terrace.

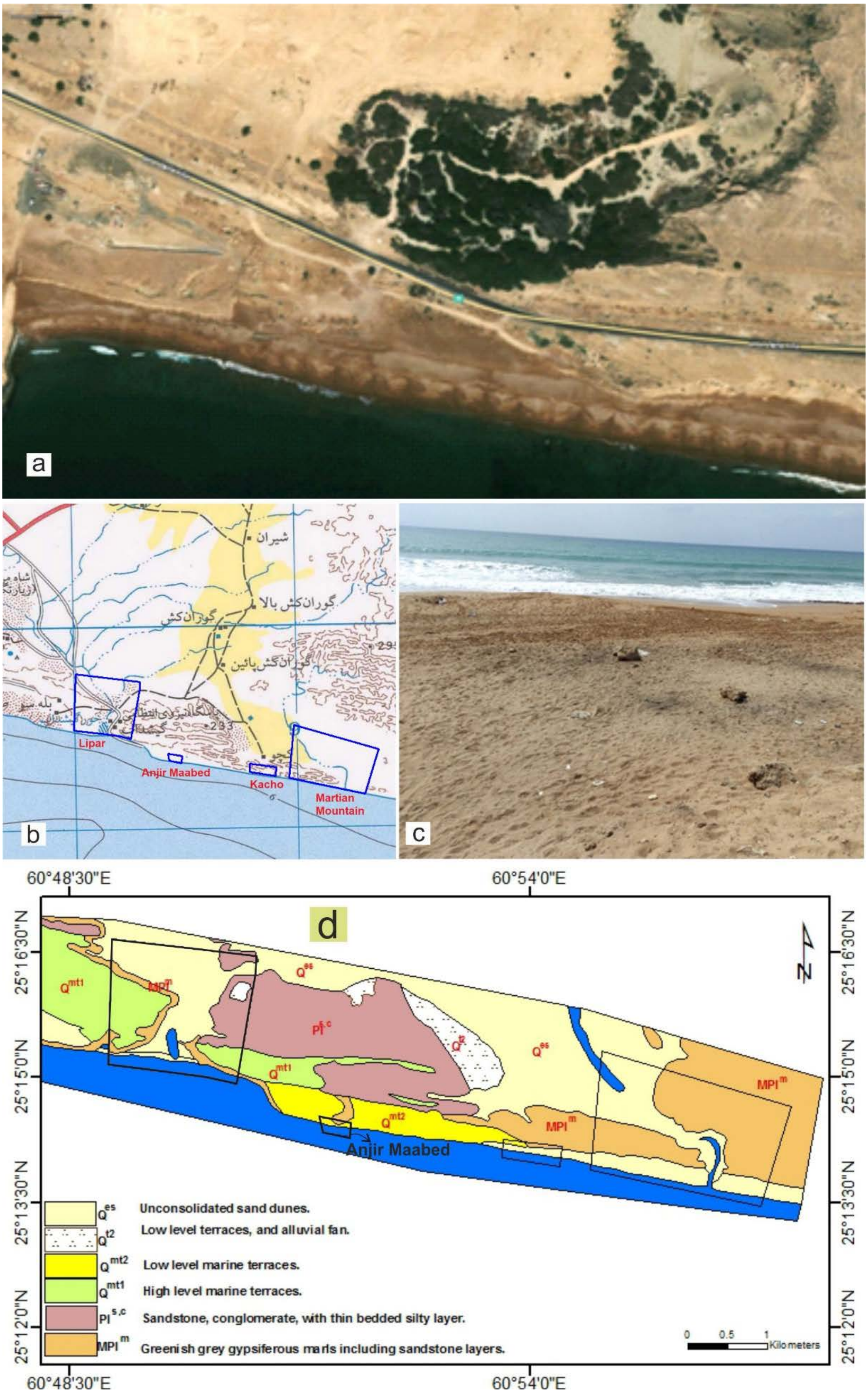

Figure 20. a). Satellite image (Google Earth) shows a coastal line in the Anjir Maabed Site (No. 11 in Fig. 3). b). The topographic map shows the Lipar lagoon Site. c). Field Photographs Anjir Maabed Site (GPS: 25º 14″ 20.51′N, 60º 51″ 43.14′E). d). Geology map of the Anjir Maabed Site (1: 100 000 Chabahar sheet).

6-12. Kacho Beach Site

Geology:

The area is covered by unconsolidated sand dunes, recent alluvial channel deposits, Greenish gray gypsiferous (and fossiliferous) marl including sandstone layers (Fig. 21).

Geomorphic features:

Marine terrace, river channel.

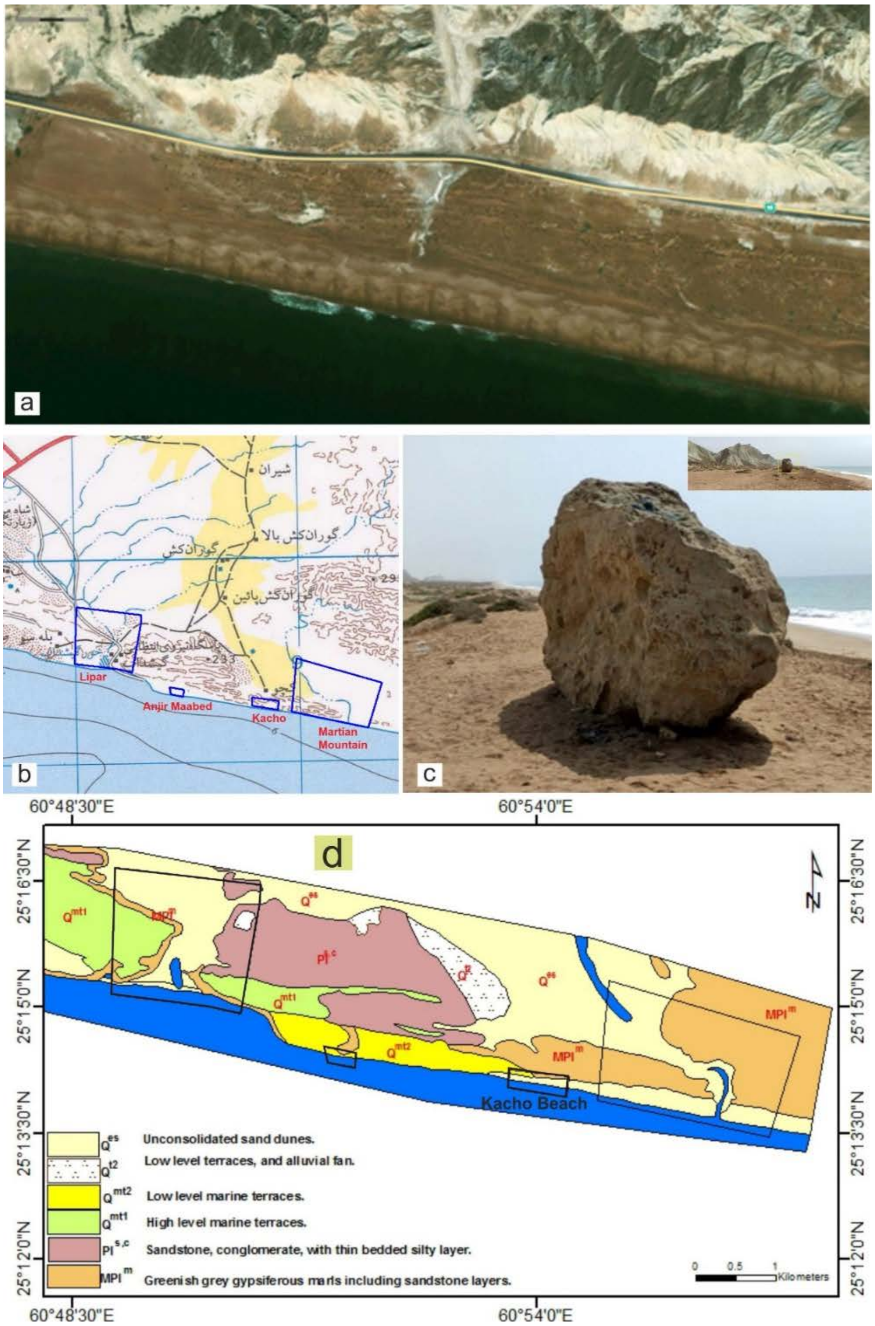

Figure 21. a). Satellite image (Google Earth) shows a coastal line in the Kacho Beach Site (No. 12 in Fig. 3). b). The topographic map shows the Kacho Beach Site. b). Field Photographs of coastal blocks (?) for identifying past high-energy tsunami events at the Kacho Beach Site. Close-up view of the yellow square in the upper-right corner image (GPS: 25º 14″ 00.24′N, 60º 54″ 05.12′E). d). Geology map of the Kacho Beach Site (1: 100 000 Chabahar sheet).

6-13. Martian mountain lagoon Site

Geology:

The area is covered by mud flat, Greenish gray gypsiferous (and fossiliferous) marl including sandstone layers, unconsolidated sand dunes (Fig. 22).

Geomorphic features:

Paleomudflat, river channel, lagoon.

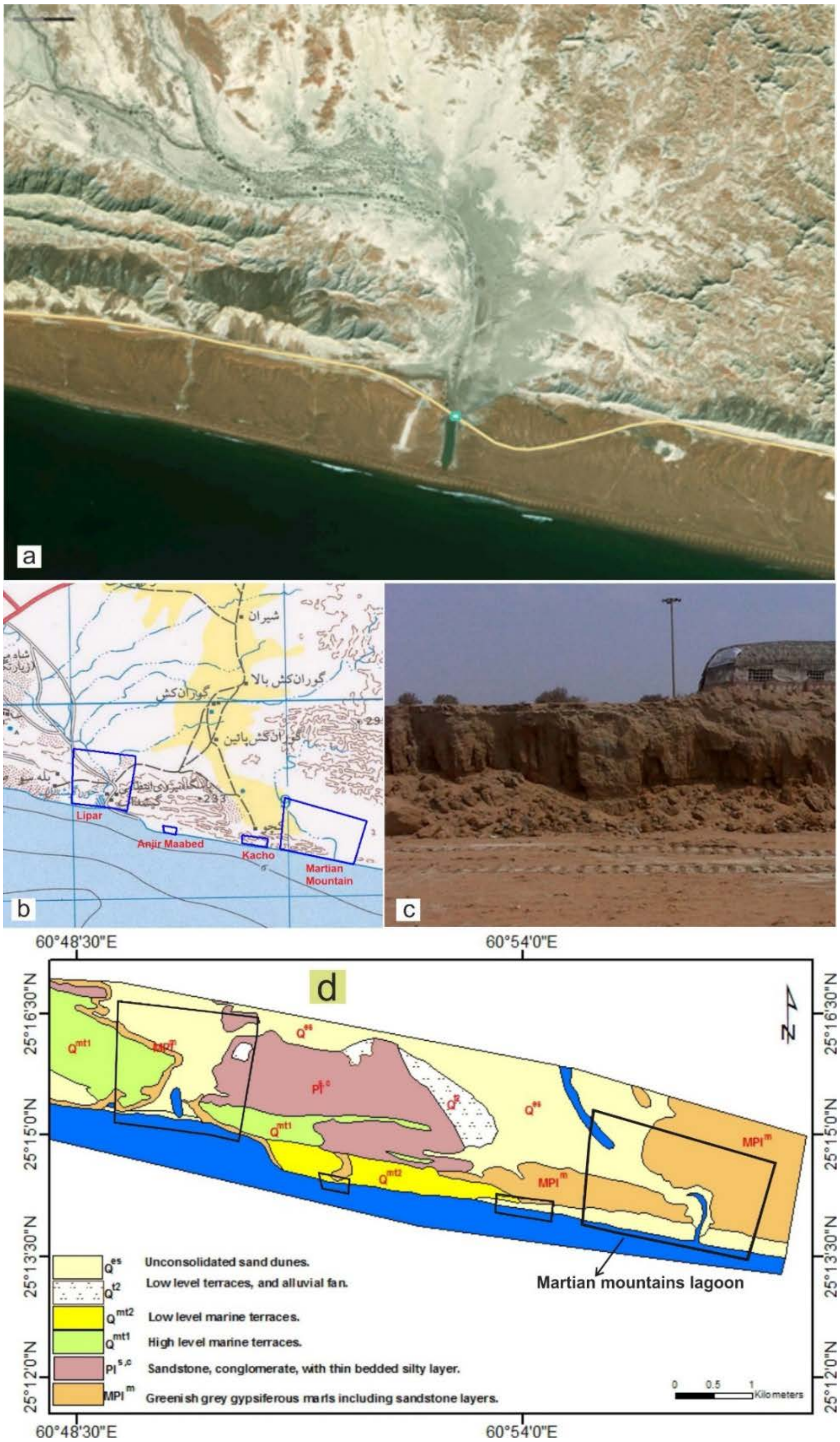

Figure 22. a). Satellite image (Google Earth) shows a coastal line in the Martian mountain lagoon Site (No. 13 in Fig. 3). b). The topographic map shows the Martian mountain lagoon Site. c). Field Photograph of the Martian mountain lagoon Site (GPS: 25º 13″ 47.37′ N, 60º 56″ 08.01′E) preferred site for trenching. d). Geology map of the Martian mountain lagoon Site (1: 100 000 Chabahar sheet).

6-14. Roudig Beach Site

Geology:

The area is covered by unconsolidated sand dunes, recent alluvial channel deposits, Greenish gray gypsiferous (and fossiliferous) marl including sandstone layers (Fig. 23).

Geomorphic features:

Marine terrace.

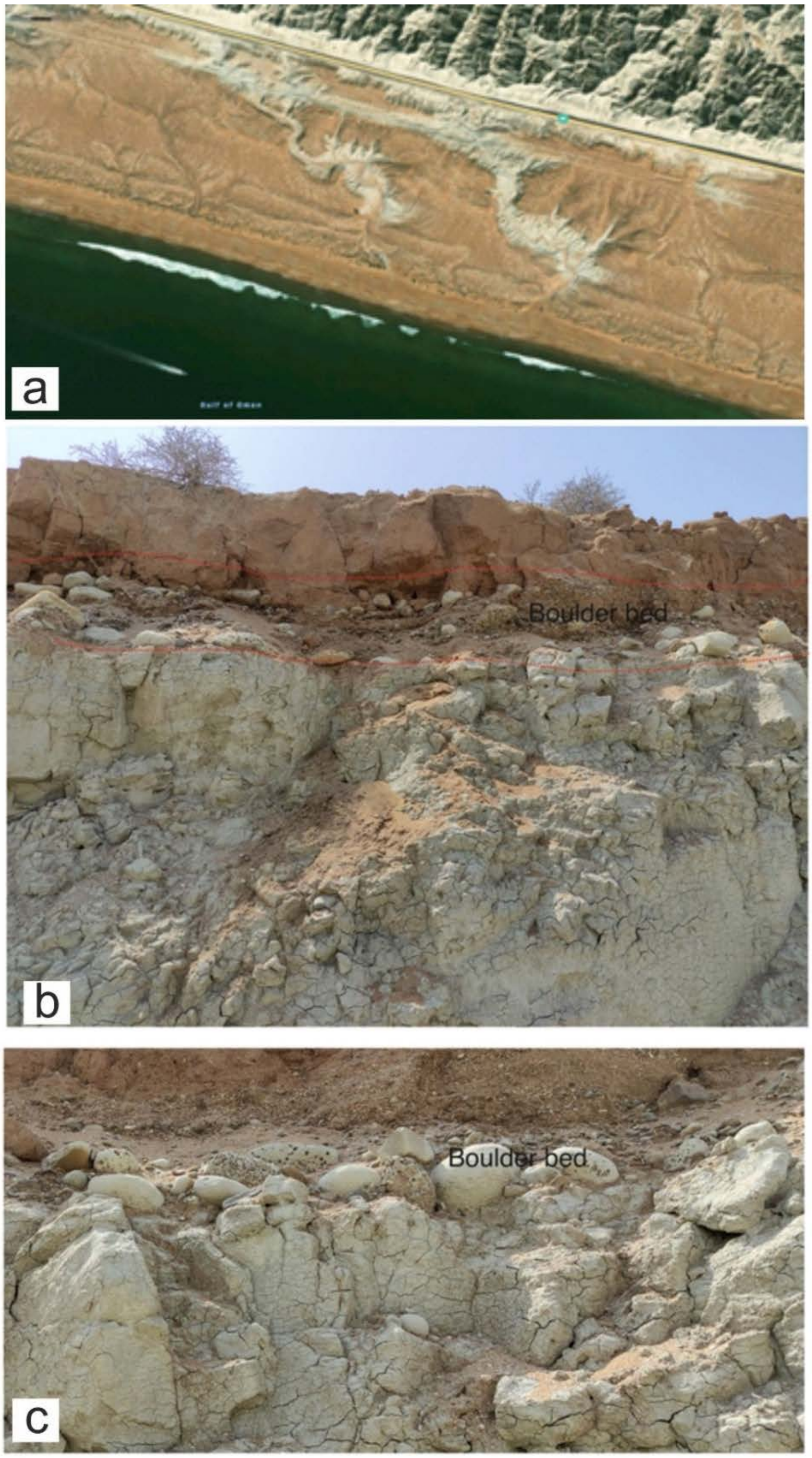

Figure 23. a). Satellite image (Google Earth) shows a coastal line in the Roudig Beach Site (No. 14 in Fig. 3). b-c). Field Photograph of boulder bed at the Roudig Beach Site (GPS: 25º 12″ 17.61′ N, 61º 02″ 53.86′E).

6-15. Beris harbor (Lagoon) Site

Geology:

The area is covered by unconsolidated sand dunes, recent alluvial channel deposits, Greenish gray gypsiferous (and fossiliferous) marl including sandstone layers (Fig. 24).

Geomorphic features:

Paleomudflat, back swamp, lagoon.

Figure 24. a-b). Satellite images (Google Earth) show a coastal line in the Beris harbor (Lagoon) Site (No. 15 in Fig. 3). b-c). Field Photograph of Beris harbor (Lagoon) Site (GPS: 25º 09″ 04.69′ N, 61º 10″ 57.16′E).

6-16. Beris beach Site

Geology:

The area is covered by unconsolidated sand dunes, recent alluvial channel deposits, Greenish gray gypsiferous (and fossiliferous) marl including sandstone layers (Fig. 25).

Geomorphic features:

Marine terrace

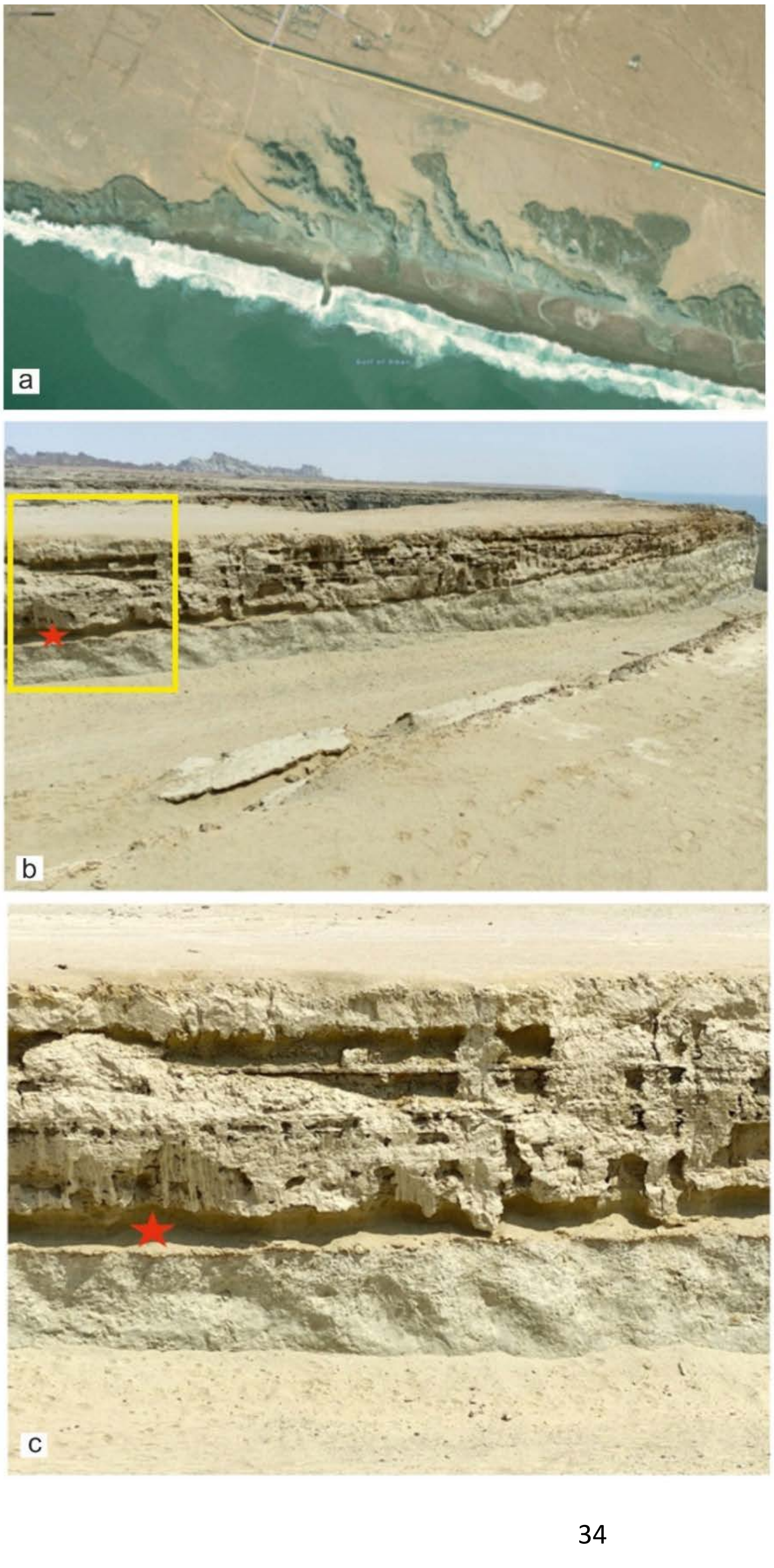

Figure 25. a). Satellite images (Google Earth) show a coastal line in Beris beach Site (No. 16 in Fig. 3). b). Field Photograph of Beris beach Site. c). Close-up view of the yellow square in the (b) image (GPS: 25º 07″ 21.55′ N, 61º 11″ 31.65′E).

6-17. Beris-Pasabandar Police station Site

Geology:

The area is covered by unconsolidated sand dunes, recent alluvial channel deposits, Greenish gray gypsiferous (and fossiliferous) marl including sandstone layers (Fig. 26).

Geomorphic features:

Marine terrace

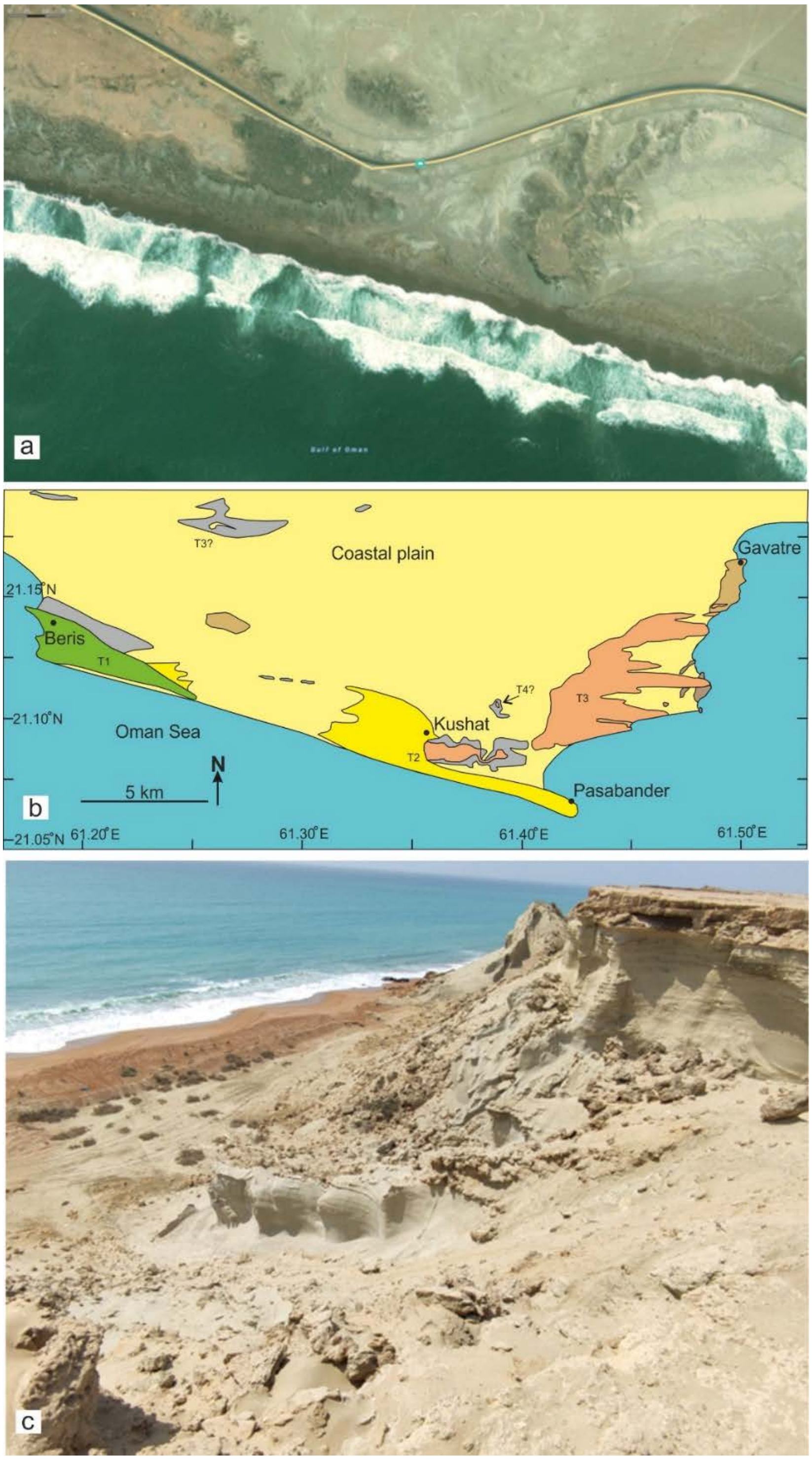

Figure 26. a). Satellite images (Google Earth) show a coastal line in the Beris-Pasabandar Police Site (No. 17 in Fig. 3). b). Geology map of the Beris-Pasabandar Police station area (modified from Normand et al., 2019). c). Field Photograph of the Beris-Pasabandar Police station Site.

7. Discussion

Geomorphic features play an important role in preserving the tsunami sedimentary records for longer period. This study used field observation together with satellite image analysis for recognizing/categorizing geomorphic assemblages (Table 2)

Table 2. Characterization of visited areas of the west Makran subduction zone for the geomorphic assemblage along with their preservation potential of tsunami sediments.

Site name	Geomorphic assemblages	Response during a tsunami event	Category for Preservation potential
Gavbandi	Paleomudfalt (8 km), back swamp, linear barrier beach (3 m), tidal/river channel	Carrier, accommodator, barrier	1**
Rig	Paleomudfalt (3 km), linear barrier beach (3 m), tidal/river channel	Carrier, accommodator, barrier	2***
Sourgalm	Paleomudfalt (6 km), tidal/river channel	Carrier, accommodator	1**
Vanak	Limited paleomudfalt	Accommodator	0*
Karati	Paleomudfalt (8 km), back swamp, linear barrier beach (3-6 m), tidal/river channel, lagoon	Carrier, accommodator, barrier	1**
Tang	Paleomudfalt (3 km), wide back swamp, linear barrier beach (2-5 m), tidal channel, lagoon	Carrier, accommodator, barrier	1**
Chabahar	Marine terrace with boulder assemblage	Accommodator	1**
Comb	Marine terrace	-	2***
Ramin	Marine terrace	-	2***
Lipar lagoon	Paleomudfalt, back swamp, river channel, lagoon	Carrier, accommodator, barrier	1**
Anjir Maabed	Marine terrace	-	0*
Kacho Beach	Marine terrace, river channel	Carrier, accommodator	2***
Martian mountain lagoon	Paleomudfalt, river channel, lagoon	Carrier, accommodator, barrier	1**
Roudig Beach	Marine terrace	-	0*
Beris harbor (Lagoon)	Paleomudfalt, back swamp, lagoon	Accommodator, barrier	2***
Beris beach	Marine terrace	-	0*
Beris-Pasabandar Police station	Marine terrace	-	0*

0*: no priority, 1: first priority/category for detail investigation, 2***: second priority/category for detail investigation**

8. Conclusion and Recommendation

Based on field observation, topographic profile and geomorphic features the Gavbandi, Sourgalm, Tang, Karati, Lipar, Martian Sites are proposed for trenching and Chabahar Site proposed for boulder study (Fig. 29). The next steps (phase II) of the project will continue with trenching, mapping, sampling, dating, analysis, final report and workshop/trainings.

It is important to mention that based on agreement within the project team we plan to organize several workshops for training the young students (<35 years old) in the future during the continuation of the project.

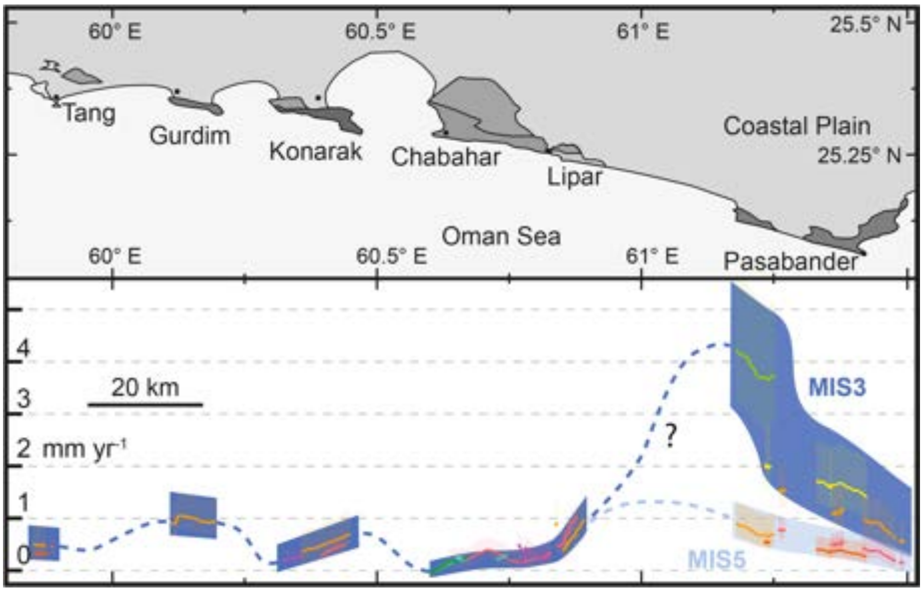

Figure 28. Uplift rate spatial variation along the coastal area (modified from Normand et al., 2019).

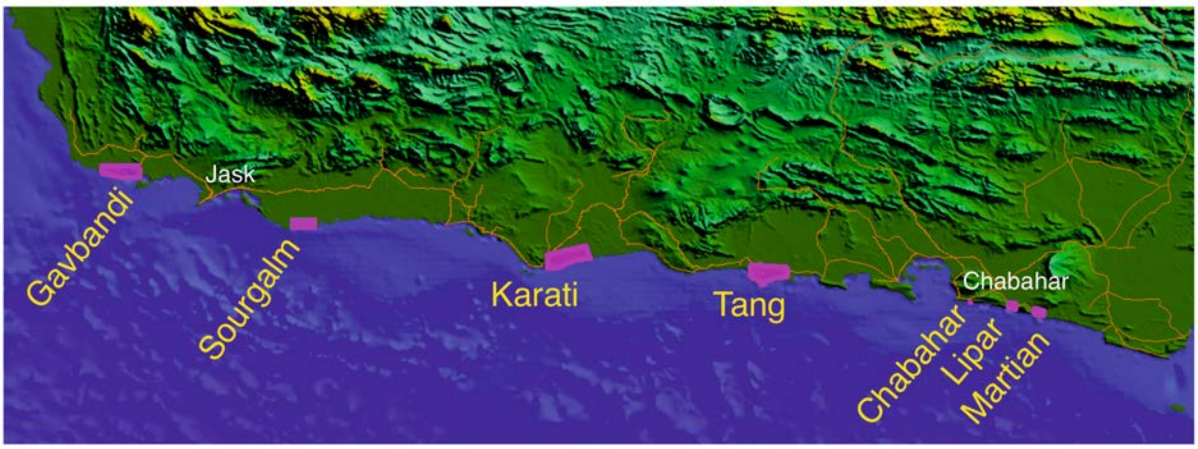

Figure 29. The proposed sites for more investigations (phase II) (the Chabahar Site for boulder study and the others for trenching).

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Appendix I: Educational activities

Educational workshops for young-local students (were held online because of COVID-19 pandemic)

Date of workshops	Total number of participants	Number of young scientists/students (<35 years old)	Number of male participants	Number of female participants
August 31 2021 (Local)	10	8	6	4
September 4 2021 (local)	6	4	2	4
29 October 2021 (international) Workshop	56 From 11 countries	37	22	34

Appendix II

Number of participants from the regional countries who will co-operate in the project

	Total	Male	Female
Number of participating scientists	13	11	2
Number of young students (<35 years old)	10	3	7
Number of scientists from developing countries	10	4	6

In addition, we plan to organize several workshops for training the young students (<35 years old) in the future during the continuation of the project.

Share the results with national and international experts

First workshop for

Project IGCP 740 West Makran Paleo-tsunami Investigation

Tsunami and Earthquake Research Centre (TERC)

University of Hormozgan, Iran

0600 – 0800 UTC on Friday 29th October 2021
Chair Dr. Mohammad Mokhtari

Concept note:

Tsunamis are a great threat to most coastal regions. The national development plans generally depend upon the maps that forecast threat to the region from multiple hazards, such as tsunamis and earthquakes. The study of prehistoric tsunamis provides important feedback for long-term rates of tsunami occurrence to improve confidence in such forecasts. The studies show catastrophic tsunamis are too infrequent for the hazard to be characterized by historical records alone. Long-term geological records provide opportunities to assess tsunami hazards more evocatively.

The two major tsunamigenic sources in the Indian Ocean region are Andaman-Sumatra subduction zone (ASSZ) and Makran subduction zone (MSZ). The ASSZ has witnessed many major tsunamis in the past. In the case of the MSZ, however, we have neither many historical records nor any long-term studies. No large-magnitude earthquakes are known in the western Makran, raising the question of locked or aseismic? By contrast, large-magnitude and frequent earthquakes characterize the eastern MSZ. Consequently, the hazard scenarios that have been prepared based on historical data underestimate the tsunami threat in the Oman Sea. The dated deposits allow us to estimate the times and recurrence intervals of past tsunamis. Such information guides mitigation efforts and may reduce losses from future tsunamis.

The MSZ is a very vital component of the Northern Arabian Sea in terms of the hazard it can generate. In the historical past it has generated several major earthquakes, some of which have also been associated with catastrophic landslides, such as the 1945 event. The hazard along the MSZ needs the urgent attention of seismologists, geophysicists, and geologists for unearthing the remnants of past activity, so as to visualize the futuristic hazard it can generate. Such an exercise would aid the coastal communities of Iran, Pakistan, India and Oman in better planning and managing of the vital assets along the shorelines.

Within the framework of the major programme of UNESCO on Natural Sciences- Main Line of Action 2 “Advancing science for sustainable management of natural resources, disaster risk reduction and climate change action”, UNESCO Teheran Cluster Office and UNESCO Earth Sciences at the Paris Headquarters of UNESCO are supporting the University of Hormozgan to undertake the first phase of the International Geoscience Program (IGCP) Project 740 on “Paleo-tsunami in West Makran Subduction Zone”. The outcomes of the project will contribute to the work of the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning & Mitigation System (ICG/IOTWMS) supported by the Intergovernmental Oceanographic Commission (IOC) of UNESCO

The project aims to:

a) Investigate the relationship between great earthquakes and associated tsunamis in Makran subduction zone, duration of the tsunami recurrence, probability of it happening in populated places, identification of the most affected places, extent of the potential damage, time needed for tsunami hazard alert, probability of major earthquakes occurrence, leading to the reduction of humanitarian and property damage.
b) Develop a building stone for further analysis to support the identification of the most probable tsunami occurrence from geological point of view, including identification of the major locations that have been affected by past (paleo) tsunami.

First workshop on the
IGCP 740 West Makran Paleo-tsunami Investigation
Tsunami and Earthquake Research Center -University of Hormozgan

0600 – 0800 UTC on Friday 29th October, 2021

جمعه ۷ آبان ماه ۱۴۰۰ ساعت ۹:۳۰ الی ۱۱:۳۰

Chair Dr. Mohammad Mokhtari

Introduction

The MSZ is a very vital component of the Northern Arabian Sea in terms of the hazard it can generate. In the historical past it has generated several major earthquakes, some of which have also been associated with catastrophic landslides, such as the 1945 event. The hazard along the MSZ needs the urgent attention of seismologists, geophysicists, and geologists for unearthing the remnants of past activity, so as to visualize the futuristic hazard it can generate. Such an exercise would aid the coastal communities of Iran, Pakistan, India and Oman in better planning and managing of the vital assets along the shorelines.

Proposed audience.

1. Scientists and faculty members
2. Doctoral and masters' students
3. Community leaders, society representatives, Government and Non-Governmental Organization representatives.

Organizers:

TERC, University of Hormozgan, Contact persons: Dr. Mohammad Mokhtari and Dr. Mehdi Masoodi
UNESCO International Geoscience program (IGCP) secretariat
IOC-UNESCO Secretariat for the Indian Ocean Tsunami Warning and Mitigation System

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mehdi.masoodi@gmail.com / masoodi@hormozgan.ac.ir +989126945118

Joining The Workshop

To join the WORKSHOP please register at the event website on the UNESCO-IOC Tsunami Calendar where all other information will also be available: https://oceanexpert.org/event/3316

لینک ورود به کارگاه از طریق سایت روبرو در دسترس است

Agenda

Title	Time	Speaker
Opening Ceremony: Introduction about the project and the upcoming plan and support	20	**Dr. Özlem Adiyaman** (Director of UNESCO International Geoscience program (IGCP) secretariat) **Mr. Rick Bailey** (Head of Secretariat IOC-UNESCO Indian Ocean Tsunami Warning and Mitigation System) **Dr. Mohammad Mokhtari** (Chair of NWIO-WG at IOC/IGC UNESCO)
International Geoscience Program (IGCP): 50 years of worldwide capacity building, research support and sustainable development.	10	**Prof. Sobhi Nasir** (Chair of the UNESCO- IGCP)
MSZ seismicity	10	**Dr. Issa El-Hussain** (Director of Earthquake Monitoring Center, Sultan Qaboos University, Oman)
MSZ general tectonics	10	**Dr. Mehdi Masoodi** (Director of Tsunami and Earthquake Research Center -University of Hormozgan, Iran)
Towards comprehensive probabilistic tsunami hazard assessment in the Arabian and Red Seas and in Persian Gulf	10	**Dr. Andrey Babeyko** (GFZ, Germany)
Role of various coastal landforms in paleo-tsunami research	35	**Dr. Siddharth Prizomwala** (Institute of Seismological Research, India)
Discussion and future plan	20	All presenters/ participations
Summary and closing remarks	5	**Dr. Mohammad Mokhtari** (Leader of the IGCP 740 West Makran Plaeotsunami project)

Sample photo from participants: