TSUNAMIS OF THE ARABIAN PENINSULA
A GUIDE OF HISTORIC EVENTS

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ABSTRACT

The Arabian Peninsula has been affected by tsunamis in the past. The Peninsula is bounded by the Persian Gulf on its northeast side, the Red Sea on its west side, and the Arabian Sea, the Gulf of Aden, and the Indian Ocean to its east and south. Each of these areas is very different geographically, tectonically, and bathymetrically. Only two, localized tsunamis have been recorded in the Red Sea and one, doubtful, tsunami in the Persian Gulf. Almost all of the recorded tsunamis along the Arabian Peninsula have occurred on its eastern and southern edge, some, such as the one formed by the 1945 Makran earthquake, were extremely destructive. The Indian Ocean is the most likely source area for future destructive tsunamis that would impact the Arabian Peninsula.

Keywords: Tsunami, Arabian Peninsula, Arabian Gulf, Persian Gulf, Arabian Sea, Indian Ocean

1. INTRODUCTION

The Indonesian tsunami of 26 December 2004 illustrated the horrific destruction and loss of life that a large tsunami can cause. Over 225,000 people were killed (Kerr, 2005; Geist et al., 2006) by a tsunami generated by a 9.0+ magnitude earthquake off of the northwest coast of Sumatra, where the India Plate is subducting beneath the Burma Microplate. The earthquake ruptured the seafloor surface and displaced the water column above it by several meters. The resulting wave heights near the epicenter were determined to be 32 m high. In Kenya, ~5,000 km away, wave heights were still 2-3 m high (Jaffe et al., 2005).

Minor effects from the tsunami reached the Arabian Peninsula in about 7 hours, producing mostly small waves less than 1 m in height along its coasts, except in the areas in southern Oman, especially around Salalah, where wave runup reached 3.3 m (Okal el al., 2006). Most of the Arabian Peninsula was shielded from large effects of the tsunami due to the Indian Peninsula, which took the brunt of the waves that would have otherwise inundated the peninsula's Arabian Sea/Indian Ocean coasts (Kowalik, 2005).

Another internationally well-known, large tsunami that impacted the Peninsula was the 1945 Makran tsunami. This tsunami devastated the coasts of Iran, Pakistan, and possibly Oman (Berninghausen, 1966).

The purpose of this paper is to summarize the historical records of tsunami events, both confirmed and suspected, and to discuss their impacts on the Arabian Peninsula. No specific summary has been made previously of tsunamis affecting the coasts of the Arabian Peninsula. This is partly due to the lack of and difficulty in obtaining historical records for the area and partly because until the 2004 Indonesian tsunami, little widespread interest was focused on this part of the world.

2. GEOLOGICAL BACKGROUND

The Arabian Peninsula makes up the majority of the Arabian Plate, which is moving in a northeastward direction, away from the spreading center that runs the length of the seafloor beneath the Red Sea, to where it is colliding and subducting beneath the Iran Microplate. Subduction is indicated by the seismicity of the region and the presence of the Makran-Baluchistan volcanic arc. The many earthquakes in Iran and Pakistan are a result of this collision and subduction. The volcanic arc consists of mostly Quaternary andesitic volcanoes. There are also many present-day, active, mud volcanoes in the Makran region of Pakistan (Quittmeyer and Jacob, 1979). The rate of movement is estimated to be between 4 and 5 cm/yr (Jacob and Quittmeyer, 1979; Hutchison et al., 1981; Platt et al., 1985).

The peninsula itself can be divided into three very different geographic and oceanographic regions (figure 1):

- The Persian Gulf coast
- The Indian Ocean (Gulf of Oman and Arabian Sea) coast
- The Red Sea coast

The Persian Gulf coast of the Arabian Peninsula is a flat area of dunes and sabkha, a supratidal area consisting of mud flats just above the normal high tide level in arid and semi-arid coastal regions.

Oceanographically, the Persian Gulf is a shallow sea with a maximum depth of only 60 m. The Indian Ocean coast has narrow, alluvial plains between the ocean and the steep slopes of the Omani Mountains. These mountains often extend directly to the water. This eastern coast faces the open ocean, with only a small continental shelf. The Red Sea coast extends from the Gulf of Aqaba for approximately 2,200 kms to the Gulf of Aden. Its coast is similar to that of the Indian Ocean, with alluvial plains extending from the mountains that form the Arabian Shield complex. The Red Sea has maximum depths up to ~2850 m, but 65% of it is less than 50 m in depth. It is also very narrow, ranging between 306 to 355 km at its maximum (SGS, 2006).

Figure 1: The Arabian Peninsula with its three coastlines.

3. TSUNAMI GENERATION

The largest sources of tsunamis in the Eastern Hemisphere are along the Sumatra subduction zone on the eastern side of the Indian Ocean (Jaffe, 2005). Since tsunami height is related to water depth, the deeper the water the larger the potential size of a tsunami. It is believed that the very large size of the Indonesian tsunami was due not only to the magnitude of the earthquake and seafloor rupture, but also because the seafloor displacement took place near a deep sea trench, in very deep water (Geist et al., 2006). The depth of the Indian Ocean then allowed the wave to travel great distances without losing much energy.

Large storms and cyclones occur in the region, but not frequently. The flooding and damage caused by their storm surges sometimes has been confused with that of tsunamis. On 4-5 June 1890, a large cyclone generated a destructive storm surge that swamped Muscat in Oman and killed several hundred people. This event was followed by another large storm in June of 1898. A similar storm is thought to have struck in same area in 863 A.D. (Lorimer, 1815). There was confusion, particularly in ancient times, between what would be considered true tsunamis and large storm-generated waves. This has made it difficult to properly determine historical tsunami events. In this paper, all known and suspected events are presented and discussed.

3.1 Methods

The historical data of tsunamis relative to the Arabian Peninsula presented in this study is based on a survey of past records, a review of the scientific literature and on media reports. All the information from the scientific literature was taken from studies related to the seismicity of the region and past eartquakes. The best resources summarizing historical seismic events in the region are the catalogs prepared by Ambraseys and Melville (1982) and by Ambraseys et al. (1994). Although these studies focus on earthquakes, they note also a number of tsunami events. Also examined for additional tsunami information were other historical records held at the Zayed Center for Culture and Heritage in the UAE. Although many recent publications already contain much of the tsunami information as for example in Rastogi and Jaiswal (2006), the significance of this paper is that it brings together, to the extent possible, a compilation of information specifically related to the Arabian Peninsula region.

3.2 Tsunami Events

The following are recorded tsunami events that have impacted the Arabian Peninsula. They are organized by geographic and oceanographic regions and are summarized in Table 1:

Persian Gulf.

978 – Siraf, Iran. On 17 June 978 A.D. the port town of Siraf, Iran, located in the Bushehr Province along the northeastern Persian Gulf coast (figure 1) - near the present port of Taheri - was struck by an earthquake which killed about 100 people. According to historical records the land shook for seven days and that some of the buildings of the town fell into the sea (McEvilly and Razini, 1973). Although there is no mention that this event generated a specific tsunami, forty years later in 1008 A.D. another earthquake (see event below) reportedly did.

1008 – Siraf, Iran. In the spring of 1008 A.D. an earthquake occurred in this region and reportedly generated waves that sunk a number of ships, with the loss of all hands on board. Also, McEvilly and Razani (1973) indicate that many people were killed when "the sea inundated the land". Although, Ambraseys and Melville (1982) concur on the loss of several ships, they state that there is no evidence of waves inundating the land. According to them, at least one other source refers to the sinking of the ships but did not associate the waves with the earthquake. Other records show that high winds affected the region during this same time period, thus the reported flooding and destruction of ships could have been caused by storm surge. Also, there is no definitive record that waves were generated when the more destructive 978 A.D. earthquake occurred in the same location (McEvilly and Razini, 1973; Ambraseys and Melville, 1982, p. 39, 107, 176). It is possible that the reported waves may have been generated by an earthquake-triggered coastal landslide – although the historical records do not indicate that one occurred in conjunction with this particular event, or any other earthquake in the Persian Gulf region. Given this uncertainties, it is difficult to evaluate what possible effects from such a tsunami may have had along the Arabian coast or to estimate its maximum height and runup. Given the fact that wave activity was only reported in the earthquake's epicentral region, the implication is that this event was localized and if a tsunami was indeed generated, its energy was quickly attenuated, given the shallowness of the Gulf.

The Red Sea

1879 – Tor (present-day El Tor), Egypt. On 11 July 1879, three moderate earthquake shocks were felt in upper Egypt. Although the exact locations of these earthquakes are not known, it was reported that a tsunami flooded the village of Tor on the Sinai peninsula in the Gulf of Suez (Ambraseys et al., 1994) (figure 1). A landslide is a possible source for this tsunami, but there is no such documentation in the historical records.

1884 – Massawa (present-day Mitsiwa), Eritrea. On 20 July 1884, an earthquake occurred at sea offshore from Massawa (figure 1). Reportedly, sea waves built up in the Massawa harbor, mostly between the localities known as Taulud and Edaga Barai. The waves swept over a causeway and ships in the harbor were seen swaying violently. Multiple flooding from the sea over land left dead fish onshore (Ambraseys et al., 1994).

Indian Ocean/Arabian Sea

325 B.C. – Port of Alexander (Near present-day Karachi, Pakistan). Some reports have dated this event to 326 B.C., but 325 B.C. may be more accurate. A large wave believed to be a tsunami, damaged the Macedonian fleet of

Alexander the Great while at anchor east of the present-day Karachi. The damaging waves probably originated in the same source region as the destructive 1945 Makran tsunami. Its effects on the Arabian Peninsula would likely have been similar to those in 1945 event. The description of Diodorus Siculus (c. 90 BC - c. 30 BC) of a tsunami that struck the Macedonian Fleet has been credited by some to be describing this event (Oldfather, 1989), but is more likely describing an event that occurred elsewhere in Alexander's Empire
(see http://www.drgeorgepc.com/Tsunami325BCIndiaAlexander.html).

1524 - Dabul, India. In 1524 the arrival of Vasco de Gama's fleet on the western coast of India also coincided with a large "sea quake" and tsunami (Bendick and Bilham, 1999; PMD, 2005). It is not known if this event occurred only locally or regionally. Since an earthquake was not reported onshore, this may indicate that the tsunami was generated at a more distant location. The Makran region of Pakistan has been suggested as a possible source (Bilham, 2004). If that is the case, then the eastern coasts of the Arabian Peninsula would have been impacted by the tsunami as well.

1819 – Rann of Kachchh, India. A large (7-8 M_s) earthquake occurred on 16 June 1819, in the Kutch region on the western coast of India. It has been suggested that the quake was caused by a near-surface reverse fault (Bilham, 1999). It is estimated that 7-9 m of crustal displacement occurred (Quittmeyer and Jacob, 1979), which generated a destructive tsunami. The Indian town of Sindri was submerged by an inrushing flood that occurred as the coastal land sank an estimated 4-5 m (Berninghausen, 1966; Quittmeyer and Jacob, 1979; Bilham, 1999). In addition, a dam was formed, backing up a distributary of the Indus River (Bilham, 1999). Just as with the previous event, the most likely area of the Arabian Peninsula that would have been affected by this tsunami would have been the southern and eastern coasts. The tsunami travel time would have been approximately 4 hours (Bhaskaran et al., 2005).

1845 – Kutch, India. Following an earthquake, eyewitnesses described a large wave from the sea that caused the mouth of the Indus River to overflow the surrounding land. Unfortunately, other than the general region of the Indus, other geographical names used in the description cannot be located (Berninghausen, 1966). In the event that this was a true tsunami, it is highly unlikely that it had a any significant effect on the Arabian Peninsula.

1851 – Makran, Pakistan. The Makran coast of Pakistan lies on the southern edge of Pakistan, to the northeast of Oman. Okal et al. (2006) mention a seismic event that may have occurred in 1851 off Makran, west of the 1945 tsunamigenic earthquake but with no details as to whether a tsunami was generated. However, given the proximity of this event to the 1945 tsunami source, it is possible that a tsunami was generated and that the region has the potential to generate tsunamis that could impact the Arabian Peninsula.

1883 – Krakatau, Indonesia. The eruption of Krakatau Volcano near the Sunda Strait of Indonesia on 28 August 1883 produced a destructive tsunami that devastated villages and towns and killed nearly 36,000 people in the immediate area. Sea level oscillations were observed worldwide and recorded by tide gauges at distant locations. The tsunami was generated by a combination of caldera and slope collapse, pyroclastic flows, subsidence and final explosion and collapse (Berninghausen, 1966; Pararas-Carayannis, 2003; Winchester, S., 2003). Once outside the Sunda Strait the waves attenuated quickly in height. In Karachi, Pakistan the maximum wave was measured at 37 cm in height. It took an estimated 12 hours travel time for the wave to reach the Gulf of Aden on the southern end of the Arabian Peninsula, where the tide gauge registered a tsunami wave that was 13 cm in height (Berninghausen, 1966; Pararas-Carayannis, 2003). The eastern portion of the peninsula would have felt the affects of the wave in about 9.5 hours (Bhaskaran et al., 2005) with somewhat greater wave-heights, but no other Arabian records could be found for the event.

1945 – Makran, Pakistan. At 03:26 IST (Indian Standard Time) on 28 November 1945 an 8.1 magnitude earthquake was generated in the northern Arabian Sea off the Makran coast (Berninghausen, 1966; Quittmeyer and Jacob, 1979; Ambraseys and Melville, 1982). The earthquake was felt in Karachi, Pakistan, where ground motions (figure 2) lasted approximately 30 seconds, stopping the clock in the Karachi Municipality Building and interrupting the communication cable link between Karachi and Muscat, Oman (Omar, 2005). Ground motions were felt as far away as Calcutta, on the eastern side of the Indian subcontinent (Ambraseys and Melville, 1982; Byrne et al., 1992; Pacheco and Sykes, 1992; Pararas-Carayannis, 2006; Omar, 2005).

The epicenter is estimated to have been at 24.20 N, 62.60 E, about 408 km SSW of Karachi and 465 km NNE of Muscat, Oman. The quake caused extensive damage throughout the region. Subsequent eruptions of mud volcanoes in the Balochistan region of Pakistan, formed four small islands.

The damage from the earthquake was great, but the greatest destruction to the region was caused by the tsunami that was generated. Tsunami waves "swept the whole of the Arabian Sea coast" (Berninghausen, 1966, p. 73). It is estimated that 4,000 people were killed. The fishing village of Khudi, Pakistan and its entire population, 48 km west of Karachi, was swept away. The trading towns of Pasni and Ormara, Pakistan, located 100 km away from the epicenter, were flooded by a ~15 m high wall of water (Murty and Bapat, 1999; PTI, 2004; Omar, 2005). At least three waves (05:30, 07:00, 08:15 IST), over 2 m high, reached Karachi 408 km away, as well as Bombay, which was 1,200 km away (Ambraseys and Melville, 1982; Omar, 2005). In Karachi the waves persisted for so long that significant harbor damage and loss of life occurred. During the strong drawdown of the water preceding the tsunami in Keti Bandar of the Indus Delta "low-lying hills collapsed and spread out, totally destroying a number of fishing villages" (Ambraseys and Melville, 1982, p. 90). This tsunami reached eastward as far as Karwar, India, 1,600 km away (IST, 2004).

The tsunami was recorded along the coasts of Iran and in Muscat, Oman, which is 580 km from the source, and where there was considerable damage and loss of life (ASC, 2003; Pararas-Carayannis, 2006). In addition, a boat traveling from Muscat to Karachi was lost (Ambraseys and Melville, 1982, p. 90, 193).

The tsunami travel time to the Arabian Peninsula would have been less than an hour (Bhaskaran et al., 2005). It is assumed that if the tsunami affected Muscat as well as coastal cities in Iran, more than likely it affected also the United Arab Emirates (UAE) and Indian Ocean coastal communities, such as Khorfakkan and Fujeirah. Persistent seismic activity in the Northern Arabian Sea since 1945, implies that the potential for other large earthquakes may exist for this region (Quittmeyer, 1979).

Although there are also no direct records of this tsunami in the Arabian Gulf, at Julfar, the forerunner of Ras al-Khaimah, UAE, there was a large sandbar that ships use to have to transport goods over. It was noted that sometime before 1964 this bar was breached by a "tidal wave", which formed a direct channel from the open sea to the harbor. Ambraseys and Melville (1982, p. 193) have suggested that this wave was associated with the 1945 Makran tsunami.

1983 – Chagos Archipelago. On 30 November 1983 the Chagos Archipelago and the island of Diego Garcia were struck by a 6.6 M earthquake. The epicenter was at 6.85 S, 72.11 E. Locally, the quake produced a tsunami with maximum height of 1.5 m. By the time this tsunami reached Seychelles to the west, 1,700 km away, it had attenuated to 40 cm in height (USGS, 2002). Although this tsunami had no obvious impact on the Arabian Peninsula, the location of the Chagos Archipelago in the middle of the Indian Ocean indicates that a larger earthquake from this region has the potential to produce a tsunami that can adversely impact affect other Indian Ocean coasts, including those of the Arabian Peninsula.

2004 – Aceh, Indonesia. As mentioned previously, the 26 December 2004 earthquake generated a large tsunami that affected the entire Indian Ocean basin. It did not greatly impact the Arabian Peninsula, but small waves ranging from 3 to 30 cm in height occurred along the northern Arabian Peninsula coasts, adjacent to the Gulf of Oman (Kowalik et al., 2005). However, further south, from Shannah, Oman to Dhalkut, Oman, the wave runup heights varied between 0.8 m to 3.3 m (Okal et al, 2006). At the port of Salalah, large eddies formed. One freighter actually broke loose from its mooring and drifted for several hours (Okal et al. 2006). Local fisherman in Rakhyut (just north of Dhalkut), near the Oman-Yemen border, where the tsunami runup was 2.6 m (Okal et al., 2006), noticed a discoloration of the water and unusual surface wave behavior (local fishermen-personal communication).

Table 1. Summary of tsunamis related to the Arabian Peninsula

Date	Source Location	Description
	Persian Gulf	
A.D. 978, 17 June	Siraf, Iran	Large earthquake, but not followed by a tsunami.
A.D. 1008, Spring	Siraf, Iran	Large earthquake with reports of ships sinking, but ships likely sank due to a concurrent storm, not tsunami.
	Red Sea	
A.D. 1879, 11 July	Tor (present-day El Tor), Egypt	Moderate earthquakes were felt in upper Egypt, village of Tor inundated by tsunami.
A.D. 1884, 20 July	Massawa (present-day Mitsiwa), Eritrea	Offshore earthquake occurred, sea waves built up in harbor and swept over causeway.
	Indian Ocean/Arabian Sea	
326 B.C., November	Southern Pakistan	Tsunami sank Macedonian ships - this event probably did not occur.
A.D. 1524	Dabul, India	Tsunami occurred, but no earthquake was felt - this event was probably local and did not affect Arabia.
A.D. 1819, 16 June	Gujrat, India	Large earthquake in western India generated a large tsunami - the wave would have arrived in Arabia in about 4 hours, but there is no record of affects in the Arabian Peninsula.
A.D. 1845	Kutch, India	An earthquake was followed by a small tsunami - this event was probably too small to have affected the Arabian Peninsula.
A.D. 1851	Makran, Pakistan	An earthquake occurred off of the Makran coast with an epicenter west of the better known 1945 earthquake epicenter and tsunami.
A.D. 1883, 8 August	Krakatau, Indonesia	The eruption of Krakatau volcano generated a large tsunami, which was measured worldwide. A station located in the Gulf of Aden measured a small tsunami 13 cm in height. No other records are apparent for Arabia.
A.D. 1945, 28 November	Makran, Pakistan	A large earthquake off of the southern coast of Pakistan generated a large tsunami that devestated the region, killing more than 4,000 people. This wave may have also swept into the Persian Gulf and washed out a large sandbar at Ras al-Khaimah, UAE.
A.D. 1983, 30 November	Chagos Archipelago	An earthquake at the Island of Diego Garcia produced a small tsunami (1.5 m high) - its small size did not produce any recordable impacts on the Arabian Peninsula, but future events from the same location could.
A.D. 2004, 26 December	Aceh, Indonesia	An extemely large earthquake generated a 10-15 m high tsunami that killed over 225,000 people. It had minor impacts along the southern Arabian coast.

4. DISCUSSION

Similarly, there appears to be very little tsunami threat in the Red Sea. In spite of the fact that the Red Sea is a seismically active region, only the two small tsunami events described here have been documented for the Red Sea. Given that the sea is a tectonically divergent environment, the likelihood of very large, tsunami-generating, earthquakes is relatively small.

It is obvious from the historical summary that the greatest tsunami threat facing the Arabian Peninsula comes from sources in the Indian Ocean. The Sunda Arc, presents the major tsunami hazard in the Indian Ocean, due to its earthquakes and volcanic eruptions, however is not likely a major source of danger to the Arabian Peninsula given the buffering effect of the Indian Subcontinent. Instead, the region of greatest danger is that of the Northern Arabian Sea. The 1524 and the 1945 events had their sources in the Arabian Sea and both generated significant and destructive tsunamis. Okal and Synolakis (2008) provide a more detailed explanation of the Indian Ocean tsunami hazards, including a detailed discussion of seismic sources near the Makran coast of Pakistan that generated the 1945 event.

Within the Persian Gulf it is rather unlikely for large tsunamis to form. Given that the Gulf is shallow, does not have coastlines prone to landslides, and is without volcanoes, the likelihood for tsunamis is relatively small. Although the Gulf is a tectonically active region, most of the earthquakes take place inland, away from the coasts. This is reflected in the historical record. With the exception of the 1008 A.D event, which is not conclusive – as it may have been the result of storm surge - none of the other historical or more recent submarine or coastal earthquakes have generated tsunamis of any significance. Table 2 lists the known large earthquakes that have occurred within the Persian Gulf and its coasts. In every case, except for the questionable 1008 A.D. event, no tsunamis resulted. The possibility of the 1945 event breaching the bar at Julfar notwithstanding, the coasts of the Persian Gulf are protected from tsunamis generated in the Indian Ocean by the protective buffer of Musandam Peninsula in the Strait of Hormuz.

5. CONCLUSIONS

There are only a few recorded tsunami events that have impacted the Arabian Peninsula. The most destructive ones had their origin in the Indian Ocean. There are indications that the one tsunami event in the Persian Gulf may not have even been a tsunami at all and the two events in the Red Sea were small and localized. Given the shallow nature of the Persian Gulf and the lack of confirmable tsunami events in the past, it can be concluded that the risk of tsunamis in the Arabian side of the Persian Gulf is very small. The same is true for the Red Sea since, although active, does not have the very large seismic events that result in a convergent environment. On the other hand the Arabian Sea and Indian Ocean, which borders the eastern coasts of Arabia are large potential source areas for tsunamis that could seriously affect its coasts.

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Table. 2: Recorded large earthquakes in the Persian Gulf

Year (A.D.)	Date	Location	Tsunami	Comments
1008	Spring	Siraf, Iran	large waves sank ships	It is not clear if this was a tsunami or storm surge
1426	November	near Bahrain	none recorded	
~1832		Hufuf, Saudi Arabia	none recorded	
1858	13 June	Bushire, Iran	none recorded	
1884	19 May	Qishm, Iran (island)	none recorded	Felt at Ra's al-Khaima
2005	27 November	Qeshm, Iran (island)	none recorded	Felt in Dubai and Sharjah, UAE

Taken from Ambraseys et. al. (1994) and newswire (AP) services

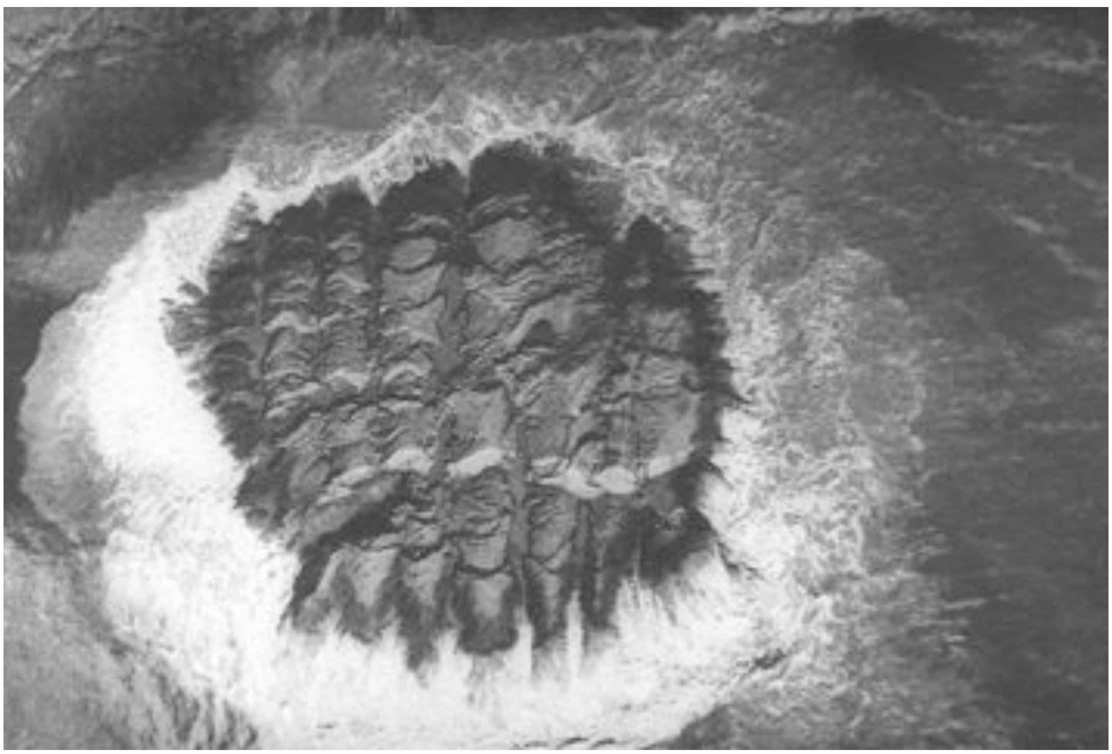

Figure 2. "Frozen Earthwaves" – photograph of an island off of the Makran, Pakistan coast during the 1945 Makran earthquake. The picture from the Karl V. Steinbrugge collection at the University of California-Berkeley. Image courtesy of the National Information Service for Earthquake Engineering (nisee), University of California-Berkeley. Slide number S821.