The Geological Society of America
Special Paper 471
2010

The door knockers of Mansurah: Strong shaking in a region of low perceived seismic risk, Sindh, Pakistan

Roger Bilham
Cooperative Institute for Research in Environmental Science and Department of Geological Sciences, University of Colorado, Boulder, Colorado 80309-0399, USA

Sarosh Lodi
Department of Civil Engineering, NED University of Engineering and Technology, Karachi 75270, Pakistan

ABSTRACT

Mansurah, the eighth-century Arabic capital of Sindh province, Pakistan, flourished for a mere 200 yr. Its destruction by an earthquake ca. 980 A.D. was first proposed by archaeologists who reported the discovery of crushed skeletons amid dateable coins found among its rubble. An abrupt natural death to the city was challenged by others who noted that the absence of wood or valuables was consistent with the city being sacked and systematically looted. The recent discovery of four decorated door knockers beneath the collapsed walls of one of the largest structures in Mansurah, however, reopens the case for an earthquake, since an invading army would almost certainly have removed them as booty. We suggest that an earthquake not only destroyed the city and its suburbs (intensity ≈ VIII), but resulted in postseismic avulsion of the river on which its citizens depended for agriculture, sanitation, and trade. Since natural levees have been observed in India to collapse in intensity VII shaking, it is unnecessary to invoke coseismic uplift as a requirement for upstream river avulsion. The absence in the past two centuries of large earthquakes in the region has resulted in central Sindh being depicted as a region of low seismic hazard, yet in 1668, in the same province, an earthquake destroyed nearby Samawani and also initiated avulsion of the Indus. A case can be made for reevaluating the five millennia of archaeological ruins in Pakistan to establish a long-term view of seismicity unavailable from the short instrumental record.

INTRODUCTION

The ruins at Mansurah (25.882°N, 68.777°E) were brought to the attention of the archaeological community in a series of reports published in Bombay and London magazines in the mid-nineteenth century (Bellasis 1857a, 1857b; Sykes, 1857a, 1857b). At the time of writing, and for many years thereafter, the numerous ruined sites in the region were identified with different historical cities that had been described by Arabic and Mughal historians. Bellasis used the name Brahminabad, but later writers have referred to the ruins as Mansura, al-Mansurah, Bhramanabad, and Bhamanabad, and Cousens (1929) lists a dozen more. It is now known that the ruins described by Bellasis were the ruins of al-Mansurah, the capital of the Arabic province of Sindh established ca. 734 A.D. It is less accepted that Mansurah was constructed on the ruins of the earlier Hindu city of

Bilham, R., and Lodi, S., 2010, The door knockers of Mansurah: Strong shaking in a region of low perceived seismic risk, Sindh, Pakistan, *in* Sintubin, M., Stewart, I.S., Niemi, T.M., and Altunel, E., eds., Ancient Earthquakes: Geological Society of America Special Paper 471, p. 29–37, doi: 10.1130/2010.2471(03).

Bhamanabad (Farooq, 1986). The evolving discussion concerning the nomenclature of the site and nearby urban centers can be followed in Elliot (1867), Cunningham (1871), Haig (1874, 1894), Raverty (1893), Cousens (1905, 1929), Panhwar (1983a, 1983b), Wheeler (1992), Hodīvālā (1939), Farooq (1986), and most recently Khan (1990). To avoid confusion, and since the identification of the city with earlier ones is irrelevant to the present discussion, we shall refer to the ruins as Mansurah.

The vast area of rubble (2 km × 1.5 km) and the apparently orderly layout of the city led Bellasis to characterize Mansurah as the "Pompeii of the East," a city frozen in time with many of its citizens interred within its ruins. The ruins are located 30 km east of the present path of the Indus, 60 km NNE of Hyderabad and 16 km ESE of Shahdadpur, Pakistan (Fig. 1). They consist of heaps of fragmented bricks separated by rubble-clogged ancient streets in orthogonal rows on a gently undulating area elevated above the meander of an abandoned river (Figs. 2 and 3). Mansurah was a planned city. Some of the streets were 65 m wide and were paved with bricks usually laid on edge (longest and narrowest dimension down), and underlain with wastewater drains (Farooq, 1986). In places, wastewater and sewage were led via conduits to terracotta-lined soakaway pits (Khan, 1990). The ruins are encircled by the remains of a 3-m-wide fortified wall with a perimeter length of 6.4 km, which some accounts (Elliot, 1867) describe as being surmounted by 1200 bastions—clearly an exaggeration if these ornamented the perimeter of the main city. A more conservative estimate is provided by Abul Fazl writing in the sixteenth century (Jarrett, 1891), who enumerated the number of ruined bastions as 140, spaced ~50 m apart (Cunningham, 1871). This very closely matches the measured perimeter, which would have required a 45 m mean spacing between 140 bastions. Khan (1990) describes the bastions as semicircular and spaced at 33 m intervals with remnants found at a height of 3.5 m. The remains of the bastions are now indistinguishable from the irregular mounds that characterize the level of the city.

The several Arabic accounts that describe the founding of the city describe it as an island surrounded by a branch of the Mihran (the Indus). It was noted for its verdure and cleanliness, although some accounts complain of abundant fleas (Elliot, 1867). In the nineteenth century, at the time of the annexation of Sindh to India, the region was arid, with water found only in wells. Twentieth-century irrigation fed by the nearby Jamaro canal has now ponded parts of the abandoned river, which is distinctly concave where it abuts the eastern walls of the city. Elsewhere the ancient path of the river is obscured by agriculture. The description of the city as occupying an island is consistent with its current elevation 5–10 m above the shore of the present water in the river. The straightness of the SW wall and its continuation to a contiguous ruined settlement to the SE are suggestive of the existence of an artificial moat to the SW rather than a river meander. The path of the Jamaro canal was excavated with a 5° inflection to avoid crossing the Mansurah ruins (Fig. 1).

Dominating the ruins, there is a single masonry tower known as the Thul (Fig. 4) that afforded subsurface access to a well (Cousens, 1929). The bricks of the town consist of thin fired clay bricks cemented with mud, but in the Thul, these bricks were cemented above ground with a gypsum-based cement. The foundations of the Thul used much larger bricks. Few intact bricks remain in the town, presumably because they have been scavenged for construction elsewhere. Pottery shards and glazed

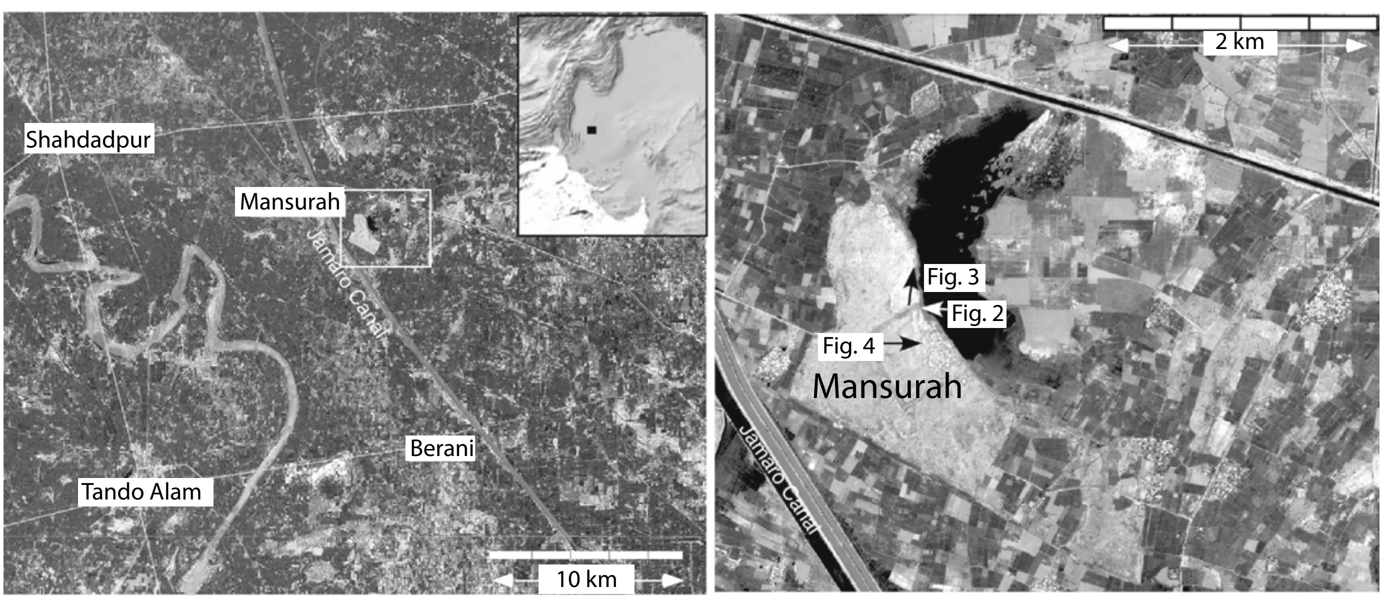

Figure 1. Google map view of Mansurah and its suburbs. A canal passes SW and a drain runs NE of the ruins, which show as light gray. An oxbow lake has now occupied the formerly abandoned river to the east of the city. Arrows to the right show photo angles of Figures 2–4.

Figure 2. Close-up of pottery and brick shards with limestone fragments typical of the Mansurah ruins. The muzzle to butt length of the gun is ~80 cm.

Figure 3. A view from the eastern side of the Mansurah ruins near the perimeter wall facing north showing the abandoned river course, now occupied by a lake.

earthenware fragments are abundant. Coins found among the ruins in the past 150 yr are mostly copper, with some silver coins. A single gold coin has been reported, the location of which is now unknown (Khan, 1990). Even the soils and dust of the ruins have been removed by local farmers who have found their composition desirable as a fertilizer (Cousens, 1929).

EVIDENCE FOR AND AGAINST AN EARTHQUAKE

According to Bellasis (1857a, 1857b) and Sykes (1857), Mansurah was destroyed by an earthquake sometime after 975 A.D. Their evidence comes from the large number of skeletons discovered during excavations in doorways and room corners, and from the dates of coins scattered throughout the ruins:

> The human bones were chiefly found in doorways, as if the people had been attempting to escape, and others in the corner of rooms. Many of the skeletons were in sufficiently perfect state to show the position the body had assumed; some were upright, some recumbent with their faces down, and some crouched in a sitting posture. One in particular I remember finding in a doorway; the man had evidently been rushing out of his house, when a mass of brickwork had in its fall crushed him to the ground, and there his bones were lying extended full length and the face downwards. (Bellasis, 1857a, p. 417)

The coins provide the latest date for the layer of widespread collapse of structures in the city. Bellasis in his excavation found thousands of badly corroded specimens that were passed (in a 14 kg bag) to experts for identification (Thomas, 1858). The reports on these focused on the earliest coins indicative of minting in Mansurah (e.g., A.D. 750), and dwelled little on the details of coins of younger vintage, and hence the date of the inferred earthquake is poorly bracketed. The latest coins suggest internment after A.D. 975, but the date could be earlier according to Haig (1874, p. 287), who noted that Mansurah was in ruins "when

Figure 4. The Thul at Mansurah in 1897 (left from Cousens, 1929) and in 2008 (right). The integrity of this 12-m-high structure, which is bonded with a tough mortar, suggests that in the past millennium, the maximum shaking intensity in the region cannot have much exceeded Mercalli intensity X. The faced reentrant corner remains approximately vertical. Cousens excavated through the foundation of the Thul to virgin soils at a depth of 5 m below ground level. The 3-m-thick walls enclosed a 2.2 m central spiral staircase leading to a well within.

Biladuri wrote his Futuh-as-Sindh—perhaps about 870–880 A.D." It is not certain on what authority Haig formed this conclusion because Biladuri died ca. 892 A.D. never having visited Sindh. Biladuri may have been confused by the identity of Mansurah and Brahmanabad mentioned above. Moreover, Elliot's (1867, p. 122) translation of the Arab conquest indicates that ruination was a consequence of the battle for the city ca. 664 A.D.: "Then Muhammad, son of Kasim, went to old Brahmanabad, two parasangs from Mansurah, which town did not then exist, its site being a forest. The remnant of the army of Dahir rallied at Brahmanabad and resistance being made, Muhammad was obliged to resort to force, when 8, or as some say 26 thousand men were put to the sword. He left a prefect there. The place is now in ruins."

Returning to the ca. 980 A.D. damage following the establishment of the Arab capital, Cunningham (1871) also favored the destruction of the city by an earthquake. He suggested that the sack of the city by an aggressor was unlikely because of the absence of reports of charred timber, pillage being invariably preceded or followed by arson in medieval warfare. He found compelling evidence in the disposition of crushed skeletons, especially a quote by Richardson cited in Bellasis (1857a, p. 423), who described a brick "which entered corner-ways into a skull, and which, when taken out had a portion of the bone adhering to it." His unstated implication is that a brick, particularly the lightweight Arabic tabular brick, would not have been a weapon of choice for an invading army.

Cousens (1929), however, who substantiated the absence of a burn layer, dismissed earthquake damage. He pointed to a slow decline in the city that may have persisted to the thirteenth century before its abandonment. He found the absence of any gold coins or other items of value to support an alternate interpretation—warfare followed by systematic looting. He invoked the scattered skeletons as characteristic of a massacre. Citizens found in doorways, rooms, and streets were killed and interred by invaders intent on hurriedly dismantling a city. Cousens (1929, p. 71) adds, "Walls were thrown down in order to get at the door and window frames and roof timbers; and being brick ornamented with mud, were easily overturned with this rough treatment."

Panhwar (1983b) also attributed the destruction of the city to a punitive army, citing Farrucki's account of Mahmud of Gazni sacking the city in 1025. It is possible that the city had by then had recovered economically from earthquake damage, sufficiently for survivors to have attracted a punitive attack, but had not yet reconstructed its defensive walls, rendering it an easy target for Mahmud's army. Although the historical evidence for or against an earthquake remains inconclusive, there is no disagreement on two issues: that around the end of the tenth century, Mansurah underwent a catastrophic change—widespread ruin, followed by a significant decline in the availability of water. The ultimate abandonment of the city is linked, by all, to a change in the course of the river.

This chronological sequence of damage followed by a change in hydrology is deduced from archaeological excavations. Cousens' excavations in 1897 and 1909 revealed three layers of stratigraphy at the site: a pre-Muslim layer of occupation, a layer of orderly city structures (Mansurah), and finally a layer of disordered structures with numerous cylindrically lined wells that cut through the two lower levels, suggesting the drying up of the river and the need to tap groundwater supplies. Cousens theorized that following the sack of the city, the survivors reconstructed the city from the ruins of Mansurah and needed to sink wells to access drinking water. Excavations by the Department of Archaeology, Pakistan, have added details to this layered chronology (Farooq, 1986; Khan, 1990), and although the earlier confusion between ancient Brahmanabad and Medieval Mansurah remains unsettled, the excavations agree on the impoverishment of the most recent structures, and the apparent dependence of the later citizens on well water. The village that now occupies the westernmost part of the site also uses well water.

Previous historians have considered the timing of the destruction of the city and the drying up of the river to be a coincidence. Certainly, had the events occurred in reverse order, we should agree with them. However, the historical record of large earthquakes contains many examples of rivers for which courses have changed following a nearby earthquake. A well-known case is the permanent shift in the geometry of Mississippi following the 1811–1812 New Madrid earthquakes (Johnston and Schweig, 1996). Other examples are described by Schumm (2005).

Assuming that the river near Mansurah was confined within banks and levees not more than 3 m above the normal level of the river, an earthquake with uplift exceeding 3 m would be required to divert the course of the river. This would require a substantial earthquake (e.g., M >7) and the development of a surface uplift feature for which there is no evidence.

We note, however, that strong shaking from a deep earthquake (associated with minimal or zero local uplift) could also trigger avulsion. To have affected the flow near Mansurah, avulsion of the river must have occurred upstream. During the 1811 New Madrid (Schumm et al., 2000) and 1897 Shillong earthquakes (Oldham, 1899), the most striking earth movements near rivers involved the collapse of river banks. In the New Madrid earthquake, the banks of the river plunged into the river, creating waves that further undermined the shaken banks, and briefly raised the bed level, impeding channel flow. Whether or not the natural levees that confined the river north of Mansurah would open to permit flooding of the hinterland would depend to some degree on their width, but fissuring and slumping would no doubt have weakened their ability to confine the river in a flood. Overbank flooding may not have been immediate, but in the absence of a reliable levee, extreme flood levels would no longer be a requirement. Flooding could therefore have occurred during the first heavy monsoon. Once the river breached through the banks of the river upstream, avulsion and the abandonment of the former channel would have been almost inevitable.

We thus find the account of city collapse followed by a change in the course of the river, typical of earthquakes elsewhere, to represent a neglected consideration relevant to the earthquake-related destruction of Mansurah. The 1668 Samawani earthquake

(Ambraseys, 2004), seven centuries later but in the same Mughal province of Nasirpur, appears also to have initiated avulsion of the Indus (Bilham et al., 2007). River shift was not immediate. In the half century following the 1668 earthquake, the river slowly shifted its course westward, eventually finding a path to the west of Hyderabad. Cities were hastily founded and abandoned in a half-century-long attempt to keep up with its evolving path, eventually leading to the establishment of Hyderabad in 1768 (Haig, 1894).

THE DOOR KNOCKERS OF MANSURAH

The collapsed remains of three large structures were exhumed in the post-1966 excavations: a grand mosque (50 m × 80 m with 2-m-thick walls), and two nearby civic buildings with slightly smaller scales (Farooq, 1986; Khan, 1990). These ancillary buildings are interpreted to represent administrative assembly buildings or schools having roofs supported by 1.8-m-square brick pillars. Deep beneath the prodigious quantities of rubble from one of these enormous buildings, four ~50 kg bronze door knockers were found (Fig. 5). Their improbable survival owes everything to the depth of their burial. The size and quality of these decorative knockers—50 cm wide, 80 cm high, and 10 cm deep—made them a significant feature of this civic structure (Khan, 1990), and it is doubtful that a pillaging army, had they seen them, would have failed to regard them as a valuable souvenir. The knockers were fastened by 2-cm-diameter bolts or nails to what may have been the largest wooden doors in the city; the removal of this material elsewhere, Cousens (1929) argued, was the reason for the collapse of the structures in which they were embedded. We consider it doubtful that an invading army would have the resources or inclination needed to demolish these three large civic structures. To demolish them without first removing these attractive souvenirs appears to us even less likely.

The survival of these remarkable fittings is presumably because they were buried by the collapse of the large building of which they were part. The pile of rubble was presumably too daunting to be removed by survivors or subsequent scavengers. It is difficult to escape the conclusion that the door knockers of Mansurah were buried by the collapse of the entrance of a civic structure in an earthquake.

DISCUSSION

From the foregoing arguments, we present evidence that favors the destruction of tenth-century Mansurah by an earthquake of sufficient severity to tumble the 2-m-thick walls of the huge central Mosque, and other equally substantial civic structures. Much of the city collapsed with these larger structures, but survivors and scavengers were able to remove most of what was of value from the smaller rubble piles of private dwellings and shops of the commercial districts. The Thul, a tower assembled from numerous courses of bricks bound together with a strong cement fared better in the earthquake and has survived ten centuries of weathering. It has also survived determined efforts to dismantle it for its bricks.

From these observations, we conclude that the brick-and-mud structures of the city were destroyed by at least MSK intensity VII, and probably intensity VIII shaking. The conclusion is similar to that formed by Quittmeyer et al. (1979), who indicated a solitary intensity VIII on their Figure 2. The survival of the Thul (Fig. 4) provides an upper limit to accelerations since its construction ca. 800 A.D. We estimate that it could probably survive intensity X but that higher intensities would have disrupted the structure. The foundations of the tower itself have not been exposed to soil liquefaction, because, despite the fact that its foundations extended to sediments near the medieval water table, its few remaining finished walls appear approximately vertical. The archaeological excavations reveal no obvious examples of liquefaction or warping of the drainage courses within the city. No excavations have been undertaken in the lower ground adjoining the city where liquefaction would have been more likely.

Subsequent avulsion of the river is also consistent with intensity VIII shaking. A single breach in a levee upstream caused by bank collapse would be sufficient to facilitate a shift in the river in flood. The intensity of shaking required to do this can be inferred from bank integrity at the time of the Mw = 8.1 1897

Figure 5. The bronze door knockers of Mansurah (Khan, 1990). The diameter of each 1-cm-thick circular plate is 56 cm, with raised relief of 17 cm and an average weight of 53 kg. The Sufic characters engraved on the outer annulus are from the Qu'ran and include the name of the Habbari ruler Abdullah.

Great Assam earthquake. Bank collapse was noted by LaTouche in areas assigned MSK intensity VII or greater on the Brahmaputra and Surma River systems (Bilham, 2008). Thus, one would not need to invoke vertical deformation of the form recorded in the 1819 Allah Bund earthquake to restrict or divert flow of the river, nor would avulsion need to have occurred immediately after the earthquake. It may have occurred in the first severe monsoon floods a year or more later. The ensuing shift in the river would have made the site less attractive to survivors, both from the resulting restricted availability of water, but presumably also because the city had lost much of the river trade that supported its former prosperity.

The causal faults of the ca. 980 Mansurah and Samawani 1668 earthquakes are currently unknown, and few clues to their present-day activity are available from recent microseismicity in the region (Fig. 6). The sediments of the Indus are known to be faulted at depth where these have been subjected to seismic prospecting, but none is known to cut the surface (Nakata et al., 1991). Several lineations have been mapped by Kazmi (1979) near Sibi, and to the SE of the river by Kazmi and Rana (1983) from Landsat imagery. Figure 7 shows an enhanced view of digital elevations in the Indus floodplain surrounding Mansurah, illuminated at an angle to minimize the artifacts of seams in the SRTM image. Undulations with wavelengths of 10–30 km, and

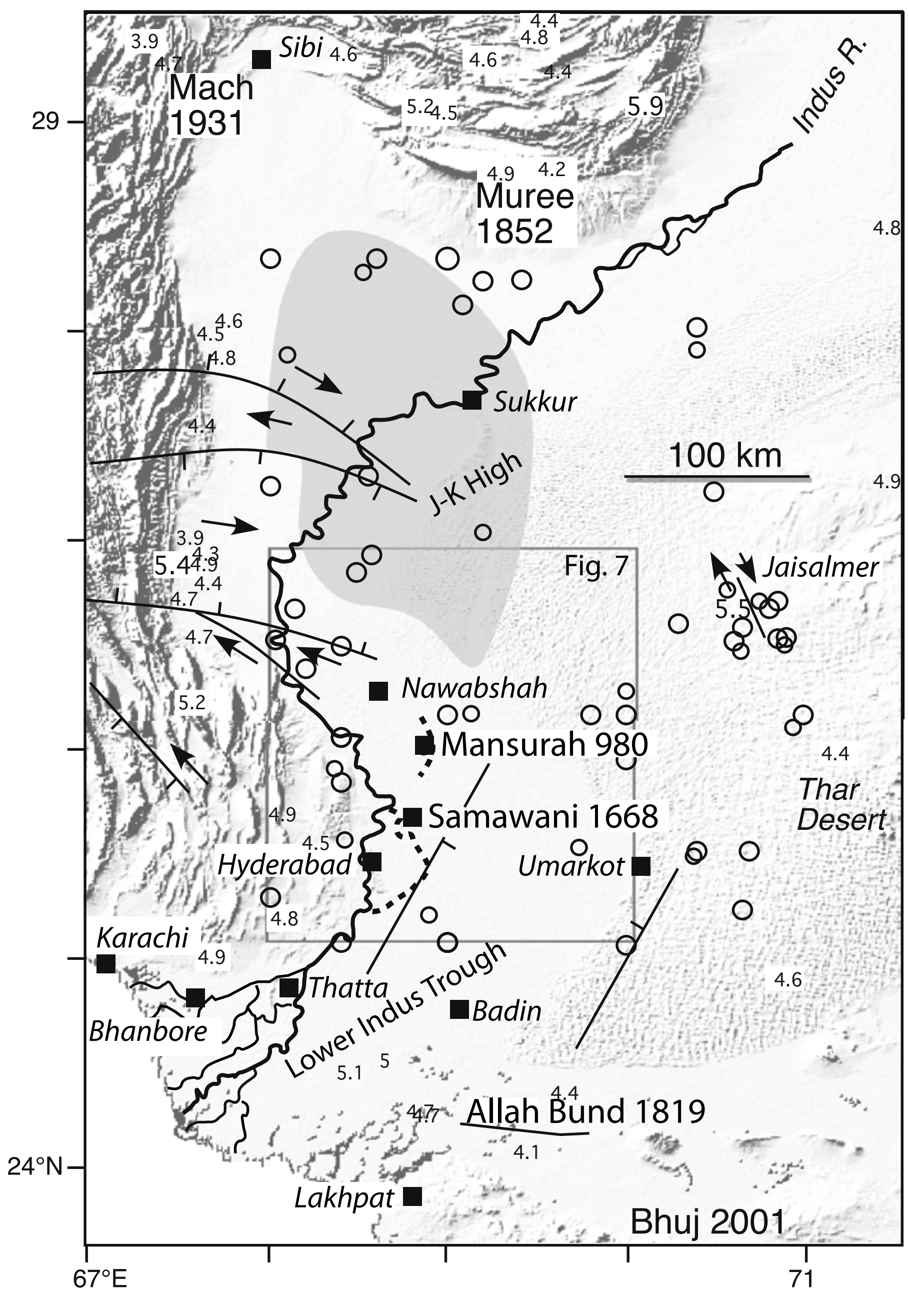

Figure 6. Basement faulting between 25.7°N and 27.8°N is inferred from aeromagnetic contours of Zaigham and Mallick (1999). The two parallel lines between 68.3°E and 70.3°E indicate the approximate location of an inferred ancient rift system, and the shaded area delineates an area of shallow subsurface bedrock identified as the Jacobabad-Khairpur (J-K) High (Kazmi and Rana, 1982) that outcrops near Sukkur. Tick marks indicate down. Numbers indicate location and magnitude of instrumental epicenters (omitting the Bhuj 2001 aftershocks) from Villasenor and Engdahl (2007). Less accurate locations for M>3 events in central Sindh from the International Seismological Centre catalog are shown as open circles. Abandoned river channels following the 980 A.D. and 1668 A.D. earthquakes are shown as heavy dashed lines. Place names are in small italics; significant earthquakes are named with dates (Ambraseys and Bilham, 2003).

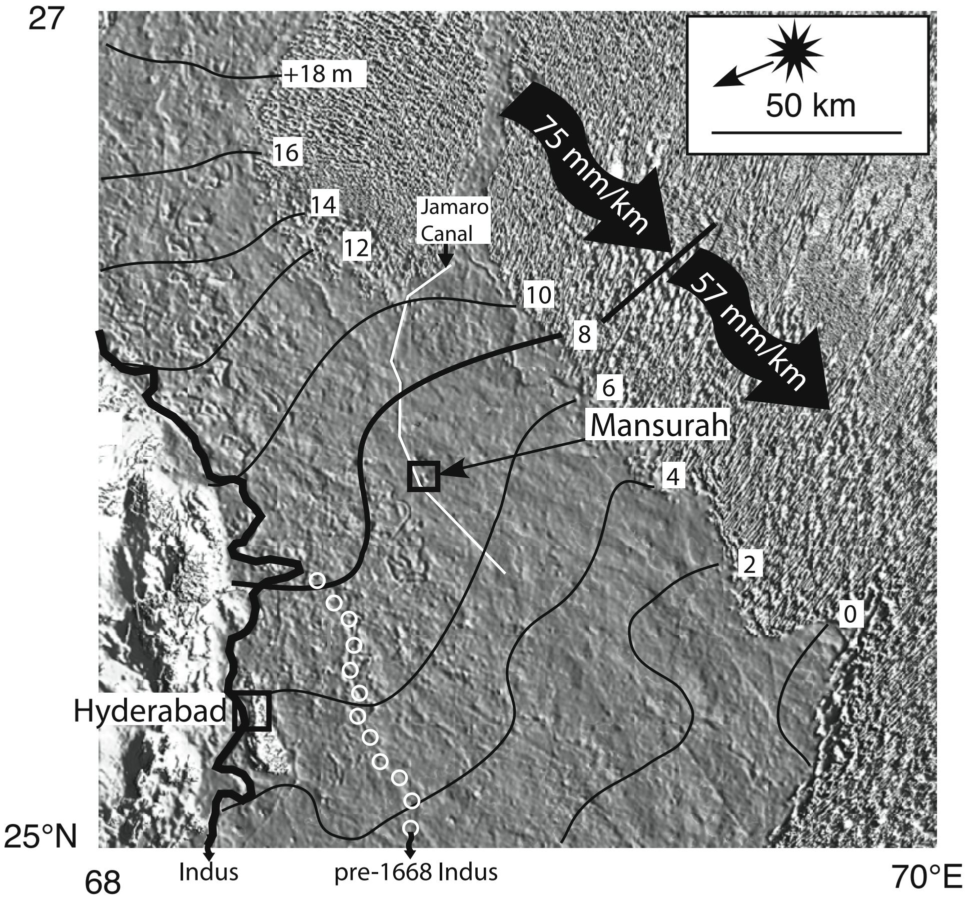

Figure 7. Shuttle Radar Tomography Mission digital elevation image of the Indus floodplain with smoothed 2 m contours referred to an arbitrary datum to the SE. Illumination is from N68E at an elevation angle of 5° (arrow). A dune field occupies the NE quadrant of the map. The 8 m contour indicates the approximate axis of a reduction in the mean down-valley slope from 75 mm/km in the 100 km north of Mansurah, to 57 mm/yr in the 100 km SE of Mansurah. Circles outline the pre-1668 bed of the Indus, which appears to follow a gentle dome in the topography. Numerous other abandoned paths are evident.

several lineations, are evident in the data, but the most prominent features of note are a subtle reduction of down-valley slope from 75 mm/km NW of Mansurah to 57 mm/km to the south, and gentle dome following the pre-1668 course of the Indus. It is tempting to conclude that the dome-like ridge is causal to the 1668 avulsion, since it is subparallel to the fold belt west of Hyderabad; however, it is possibly a sedimentary feature. The seismic significance of the down-valley change in gradient is unclear; however, the avulsion of the river in the tenth century and seventeenth centuries near this location is suggestive that block tilting may be active. The sense of slope change is, however, opposite to the sense of basement uplift described by Zaigham and Mallick (1999), suggesting that if the morphology is related to tectonics, a reversal of the geological sense of slip is now occurring.

The principal seismicity in the surrounding region follows the fold belts along the Kirthar fold-and-thrust belt to the west, and the Sulaiman Range to the north (Fig. 6). Significant $6 < Mw < 7.6$ earthquakes have occurred historically north of 28°N (Quittmeyer et al., 1979; Ambraseys and Bilham, 2003), and south of 25°N. Relatively minor seismicity occurs to the east, most notably a shallow $Mw = 5.5$ dextral earthquake that produced a surface rupture near Jaisalmer in 1992. The region near Mansurah shows little recent microseismicity.

With the exception of the uplift accompanying the Allah Bund earthquake, geological mapping reveals no recent faults that have disturbed the surface of the Indus sediments. However, Zaigham and Mallick (1999) using aeromagnetic methods identified offset structural features at 5–9 km depth beneath the cover of thin-skinned tectonics in the west that they projected eastward into the Indus basin. These trends suggest that Samawani and Mansurah both may be located above a buried horst 5 km beneath the sedimentary cover. The block on which they are apparently located is elevated 2 km above the contiguous structural block to the north. Strike-slip geological offsets are also observed on these structures, and Zaigham and Mallick (1999) argued that recent seismicity west of Nawabshah indicates that they are presently active. They proposed further that seismicity throughout the region is attributable to reactivation of faults related to an ancient allochogen along the western margin of India. The significance of a buried, poorly defined rift system in the Indus basin on assessing seismic hazards in the region is also discussed by Sawar (2004); however, the lack of clarity of structural features (Kazmi, 1979; Kazmi and Rana, 1982) beneath the Indus provides considerable room for speculation.

Spatial variations in river sinuosity support the notion of present-day vertical tectonics in Sindh (Schumm et al., 2000;

Schumm, 2005). Jorgensen et al. (1993) demonstrated that the geometry of the Indus, and its evolving path, responds to geomorphic segmentation of the valley apparently related to tectonic forcing. Basin and domal structures recognized in geological investigations appear to be mimicked by present-day vertical displacements inferred from lateral variations in river sinuosity.

The structural trends mapped by Zaigham and Mallick (1999) are orthogonal to the thin-skinned thrusts of the Kirthar range but may be understood in the context of the shear stresses of India's convergence with Asia, which would tend to activate block rotation in the region. In order to account for the 1819 Allah Bund and 2001 Bhuj Mw ≥7.6 earthquakes Stein et al. (2002) proposed that the Sindh region has been fragmented and is converging with India as a result of this collision. If this is occurring, it must be doing so at rates of less than 1.5 mm/yr, the current rate of global positioning system (GPS) motion we have measured between Karachi and the Indian plate.

Seismic Hazards in Sindh

The occurrence of two damaging earthquakes NE of Hyderabad in the past millennium suggests that the structures beneath the Indus sediments must be considered active. The Mansurah earthquake resulted in intensity VIII, but it is uncertain how large were the intensities in the Samawani 1668 earthquake. The absence of damage reports from other towns suggests that they may have been relatively modest earthquakes (Mw <6.5). The assignment of any magnitude to an earthquake with information from one location is entirely speculative, and this magnitude should not be used for estimates of seismic risk.

The absence of significant microseismicity, and the apparent absence of significant strain rates indicated in preliminary GPS results in the past 3 yr provide few clues on which to improve our knowledge of the source regions of the two events. The large number of ruins in the region of Mansurah, however, may in the future provide additional data on the scale of damage. The same can be said of the Samawani earthquake, although here we know of many more towns that existed in the seventeenth century that were apparently undamaged in 1668.

Despite our lack of precision (no epicenter or magnitude has been identified for either earthquake), the two damaged towns lie in the current zone 2A of Pakistan's tentative 2006 zonation map (cf. Bilham et al., 2007). In contrast, the GSHAP hazard map (Giardini et al., 1999) shows a lobe of higher shaking potential at the latitude of Mansurah, presumably accommodating Bellasis's (1857a, 1857b) accounts and Quittmeyer et al.'s (1979, Fig. 2) earlier evaluation of intensity VIII damage at Mansurah.

CONCLUSIONS

The ruins of the eighth-century Arabic capital of Mansurah are comparable in scale to those of Taxila or Mohenjodaro, yet Mansurah flourished as a capital for less than 200 yr, and it had been completely abandoned by 1300. Coins indicating a prominent layer of destruction prior to its final abandonment are dated some time near the end of tenth century. The recent discovery of a set of attractive bronze door knockers that were buried deeply beneath the ruins of one of the three largest civic structures in the ruined city provides compelling evidence that an earthquake was the cause of the destruction of the city. Had Mansurah been destroyed by an enemy, or simply abandoned due to river avulsion, these, like more accessible treasures and construction materials that have long since been removed, would have been stolen. Moreover, the deliberate destruction of these massive buildings by the inferred conquerors would have required considerable effort. We estimate that shaking intensities of at least VII and probably VIII caused the collapse of most of the dwellings and shops in this city of bricks and dried mud. Weak evidence for maximum shaking intensity X is inferred from the presence of a surviving tower that incorporated tough and tenacious mortar in its construction.

We find no clear evidence for localized vertical crustal deformation near, or upstream from, Mansurah, although we note that the region lies close to a change in mean valley gradient. The valley 100 km south of Mansurah slopes ~25% less than the valley to the north. A change in the course of the river occurred following the inferred earthquake, possibly due to a change in valley slope, but more probably because of bank collapse and avulsion during a subsequent flood. From evidence elsewhere in India, we deduce that shaking intensity VII is sufficient to promote the collapse of river banks. Upstream collapse of a river bank may have created a gap in the natural levee that lined the river upstream, catalyzing avulsion. The inferred decline and eventual abandonment of Mansurah is attributable to the drying up of the river near the town.

We note that a similar fate befell Samawani following the 1668 earthquake (Bilham et al., 2007). The location of Samawani has been lost since it was described by Hodīvālā (1939), but it is believed to have been located on or near a former bank of the Indus near the present town of Nasirpur, within the administrative district in which it was located in Mughal times (Sarkar, 1947, 1978; Habib, 1982). The river near Samawani shifted westward over the next century, eventually to a location west of the current city of Hyderabad, the foundation of which in 1768 is indirectly attributable to the 1668 earthquake.

It has not been possible to identify a causal fault for either the Mansurah or Samawani earthquakes, and although several basement structures are known, microseismicity in the past 40 yr is unable to clarify which of these structures are active, or to confirm the boundaries of east-trending structural elements that have been established beneath the Kirthar range. Preliminary GPS data from Pakistan indicate that deformation in the region occurs at less than 2 mm/yr between Karachi and the Indian plate, suggesting low rates of seismic productivity, with a return time for large earthquakes that may be many hundreds of years. Despite the apparent seismic quiescence of the southern Indus plains, the occurrence of two damaging earthquakes in the past millennium suggests that seismic hazards in the region may be underestimated. A systematic reevaluation of the five millennia of archaeological sites in Pakistan for their possible ruin by damaging earthquakes would be of immense benefit to supplement the relatively short instrumental record.

ACKNOWLEDGMENTS

The study was made possible by grant EAR-0739081 from the National Science Foundation. Walter Szeliga processed the global positioning system (GPS) data from Karachi reported in this article. We thank our military escort for the use of the firearm used as scale in Figure 2.

REFERENCES CITED

Ambraseys, N.N., 2004, Three little known earthquakes in India: Current Science, v. 86, no. 4, p. 506–508.

Ambraseys, N., and Bilham, R., 2003, Earthquakes and crustal deformation in northern Baluchistan: Bulletin of the Seismological Society of America, v. 93, no. 4, p. 1573–1600, doi: 10.1785/0120020038.

Bellasis, A.F., 1857a, An account of the ancient and ruined city of Brahminabad, in Sind: Journal of the Bombay Branch of the Royal Asiatic Society, v. 5, p. 413–425.

Bellasis, A.F., 1857b, Further observations of the ruined city of Brahminabad, in Sind: Journal of the Bombay Branch of the Royal Asiatic Society, v. 5, p. 467–477.

Bilham, R., 2008, Tom LaTouche and the Great Assam Earthquake of 12 June 1897; letters from the epicenter: Seismological Research Letters, v. 79, no. 3, p. 426–437, doi: 10.1785/gssrl.79.3.426.

Bilham, R.S., Lodi, S., Hough, S., Bukhary, S., Khan, A.M., and Rafeeqi, S.F.A., 2007, Seismic hazard in Karachi, Pakistan: Uncertain past, uncertain future: Seismological Research Letters, v. 78, no. 6, p. 601–631.

Cousens, H., 1905, Conservation of ancient monuments in the Bombay Presidency, *in* Scott, R., ed., J. Bombay Branch R. Asiatic Society, Extra Number, Centenary Memorial Volume: London, Kegan Paul, Trench, Trübner & Co., p. 149–162.

Cousens, H., 1929, The Antiquities of Sind, with Historical Outline: Oxford, Archaeological Survey of India, Imperial Series 46, 184 p.

Cunningham, A., 1871, The Ancient Geography of India: London, Trubner and Co., 589 p.

Elliot, H.M., 1867, A History of India by Its Own Historians: The Muhammadan Period, Volume 1: London, Trubner, 543 p.

Farooq, A.A., 1986, Excavations at Mansurah (13th Season) 1974–1986: Pakistan Archaeology, v. 10–22, 35 p.

Giardini, D., Grunthal, G., Shedlock, K., and Zheng, P., 1999, The GSHAP Global Seismic Hazard Map: Annali di Geofisica, v. 42, p. 1225–1230.

Habib, I., 1982, An Atlas of the Mughal Empire: Political and Economic Maps with Detailed Notes, Bibliography and Index: Oxford, Oxford University Press, 105 p.

Haig, M.R., 1874, On the sites of Brahmanabad and Mansurah in Sindh; with others of less note in their vicinity: Journal of the Royal Asiatic Society, v. 16, p. 281–294.

Haig, M.R., 1894, The Indus Delta Country; A Memoir Chiefly on Its Ancient Geography and History: London, Kegan Paul, Trench & Trübner, 148 p.

Hodīvālā, S.H., 1939, Studies in Indo-Muslim History: A Critical Commentary on Elliot and Dowson's History of India as Told by Its Own Historians, Volume 1: Bombay, Kokil and Co., 712 p.

Jarrett, H.S., 1891, The A'in-i Akbari by Abu'l-Fazl Allami, Volume 2; Translated from the original Persian by Col. H.S. Jarrett, Asiatic Society of Bengal: Calcutta, Baptist Mission Press, 432 p.

Johnston, A.C., and Schweig, E.S., 1996, The enigma of the New Madrid earthquakes of 1811–1812: Annual Review of Earth and Planetary Sciences, v. 24, p. 339–384, doi: 10.1146/annurev.earth.24.1.339.

Jorgensen, D.W., Harvey, M.D., Schumm, S.A., and Flam, L., 1993, Morphology and dynamics of the Indus River: Implications for the Mohenjo Daro site, *in* Shroder, J.F, ed., Himalayas to the Sea: Geology, Geomorphology and the Quaternary: London and New York, Routledge, 429 p.

Kazmi, A.H., 1979, Active faults of Pakistan, *in* Farah, A., and DeJong, K.A., eds., Geodynamics of Pakistan: Quetta, Geological Survey of Pakistan, p. 285–294.

Kazmi, A.H., and Rana, R.A., 1982, Tectonic Map of Pakistan: Quetta, Geological Survey of Pakistan, scale 1:2,000,000, 1 sheet.

Khan, A.N., 1990, Al Mansurah—A Forgotten Arab Metropolis in Pakistan: Department of Archaeology and Museums, Government of Pakistan, Museum and Monuments Series 2, 112 p.

Nakata, T., Tsutsumi, H., Khan, S.H., and Lawrence, R.D., 1991, Active faults of Pakistan: Hiroshima, Japan, Research Center for Regional Geography, Hiroshima University Special Publication 21, 141 p.

Oldham, R.D., 1899, Report on the Great Earthquake of 12th June 1897: Memoirs of the Geological Survey India, v. 29, 379 p.

Panhwar, M.H., 1983a, Chronological Dictionary of Sind: Jamshoro, Pakistan, Institute of Sindhology, University of Sind, 203 p.

Panhwar, M.H., 1983b, Locations of Bhramanka, Patala, Demetrias, Minnaggara, Brahmano, Brahmanva, Brahmanabad, Daluri and Mansurah: Sindh Quarterly, v. 11, no. 2, p. 15–22.

Quittmeyer, R.C., Farah, A., and Jacob, K.H., 1979, The seismicity of Pakistan and its relation to surface faults, *in* Farah, A., and DeJong, K.A., eds., Geodynamics of Pakistan: Quetta, Geological Survey of Pakistan, p. 271–284.

Raverty, H.G., 1893, The Mihran of Sind, and its tributaries: Journal of the Asiatic Society of Bengal, v. 61, p. 155–297.

Sarkar, J., 1947, Maasir-i-Alamgiri—An English Translation of Saqi Must'ad Khan's History of the Emperor Aurangzib: Lahore, Suhail Academy, Reprint 1981, 350 p.

Sarkar, J., 1978, The A'in-i Akbari by Abu'l-Fazl Allami; Translated from the Original Persian by Col. H.S. Jarrett, Corrected and Further Annotated by Jadunnath Sarkar (2nd edition reprint): New Delhi, Oriental Books Reprint Corp., 236 p.

Sawar, G., 2004, Earthquakes and the neo-tectonic framework of the Kutch-Hyderabad-Karachi triple junction area, Indo-Pakistan: Pakistan Journal of Hydrocarbon Research, v. 14, p. 35–40.

Schumm, S.A., 2005, River Variability and Complexity: Cambridge, UK, Cambridge University Press, 220 p.

Schumm, S.A., Dumont, J.F., and Holbrook, J.M., 2000, Active Tectonics and Alluvial Rivers: Cambridge, UK, Cambridge University Press, 276 p.

Stein, S., Sella, G.F., and Okal, E.A., 2002, The January 26, 2001, Bhuj earthquake and the diffuse western boundary of the Indian plate, *in* Stein, S., and Freymueller, J., eds., Plate Boundary Zones: Washington, D.C., American Geophysical Union, Geodynamics Series, v. 30, p. 243–264.

Sykes, W.H., 1857a, Relics from the buried city of Brahmunabad: Illustrated London News, 846, 21 February 1857, p. 166–167.

Sykes, W.H., 1857b, The ancient and ruined city of Brahmunabad in Sind: Illustrated London News, 847, 28 February 1857, p. 187–189.

Thomas, E., 1858, Essays on Indian Antiquities, History, Numismatics and Palæographic, of the late James Prinsep, to which are added useful tables illustrative of Indian History, Chronology, Modern Coinages, Weights Measures etc., Volume 2: London, John Murray, 120 p.

Villasenor, A., and Engdahl, E.R., 2007, Systematic relocation of early instrumental seismicity: Earthquakes in the international seismological summary for 1960–1963: Bulletin of the Seismological Society of America, v. 97, p. 1820–1832, doi: 10.1785/0120060118.

Wheeler, R.E.M., 1992, Five Thousand Years of Pakistan: An Archaeological Outline: Karachi, Pakistan, Royal Book Company, 149 p.

Zaigham, N.A., and Mallick, K.A., 1999, Prospect of hydrocarbon associated with fossil-rift structures of the southern Indus Basin, Pakistan: American Association of Petroleum Geologists Bulletin, v. 84, no. 11, p. 1833–1848.

Manuscript Accepted by the Society 19 May 2010