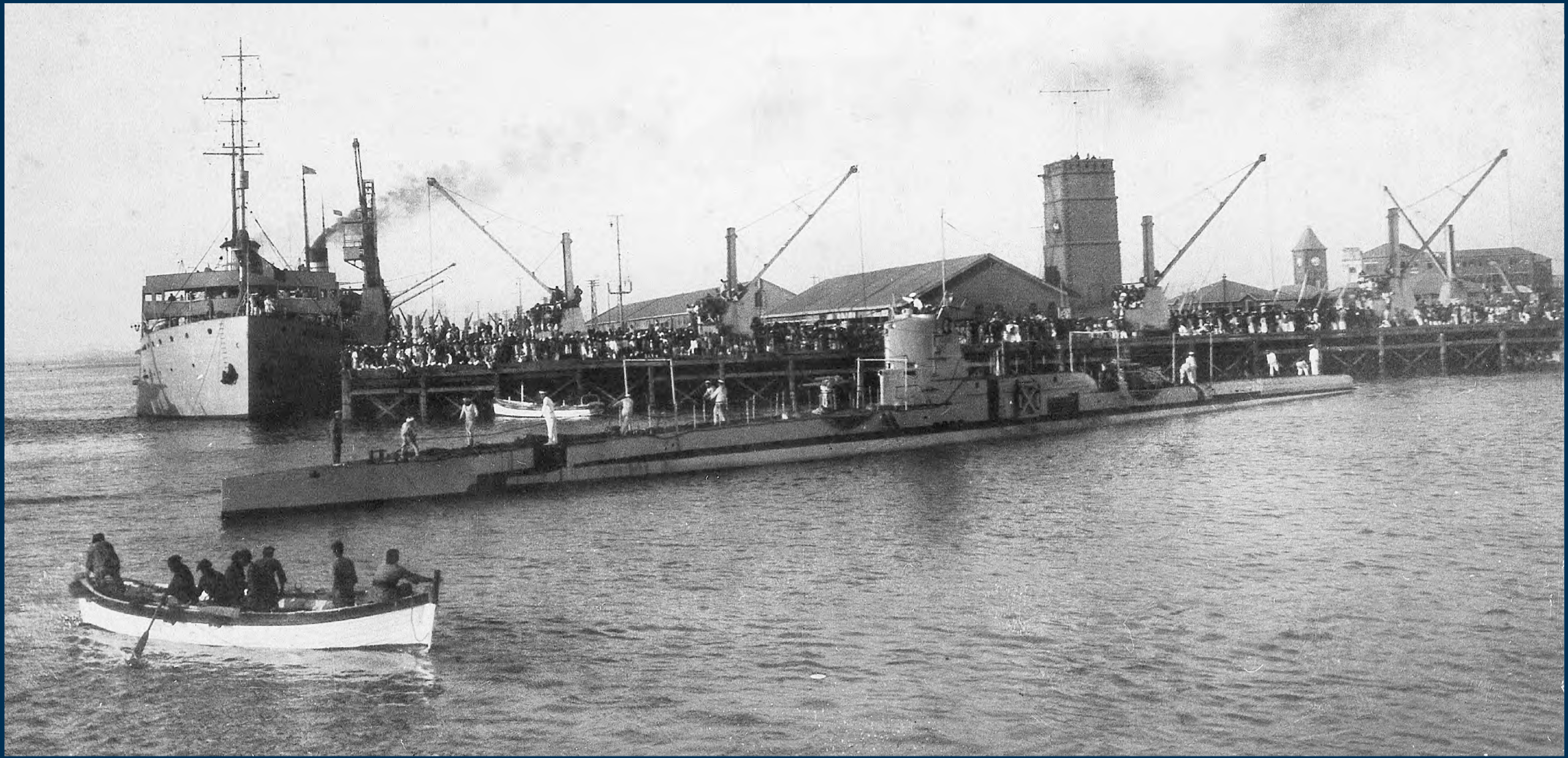
Karachi effects of the Makran earthquake and tsunami of November 1945



Mercury spilled, tide gauge impaired, seawalls overrun, boats displaced, mosque flooded

United Nations
Educational, Scientific and
Cultural Organization

Intergovernmental
Oceanographic
Commission

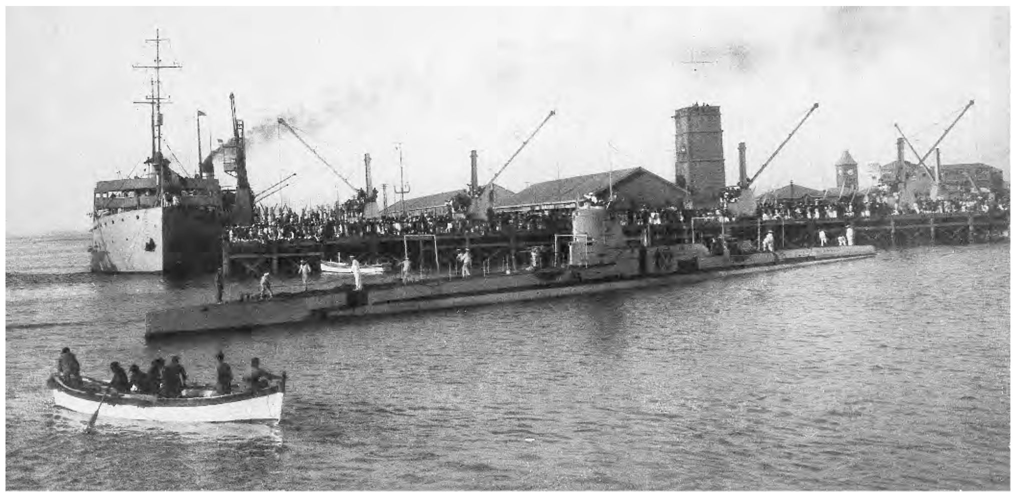
COVER A Karachi waterfront that an Arabian Sea tsunami probably overtopped on November 28, 1945. The tsunami reportedly lifted military landing craft onto Return and Railway wharves. View is northward across the entrance to the Boat Basin (p. 22, 23). The submarine, if correctly identified, dates the photograph to 1942.

Return Wharf
Crowded with onlookers of the submarine.

Railway Wharf
Out of view, fronting building at far right.

Passenger liner
Berthed north of Return Wharf. One of three V-class ships of the British India Steam Navigation Company—the *Vita*, the *Varella*, or the *Vasna*—that ran from Basra to Bombay and back, by way of Karachi.

Submarine
Identified as Her Dutch Majesty's Ship H.M.N.S. K XI (pennant N 53) on three grounds: it resembles other submarines of the K XI class; service records place N53 in Karachi after it fled the Dutch East Indies in 1942; and the sailors' uniforms do not resemble those of the British navy.



Clock tower
With peaked roof (p. 27), at what was then a transit hub for trains, trams, ocean-going ships, and Karachi Harbour ferries.

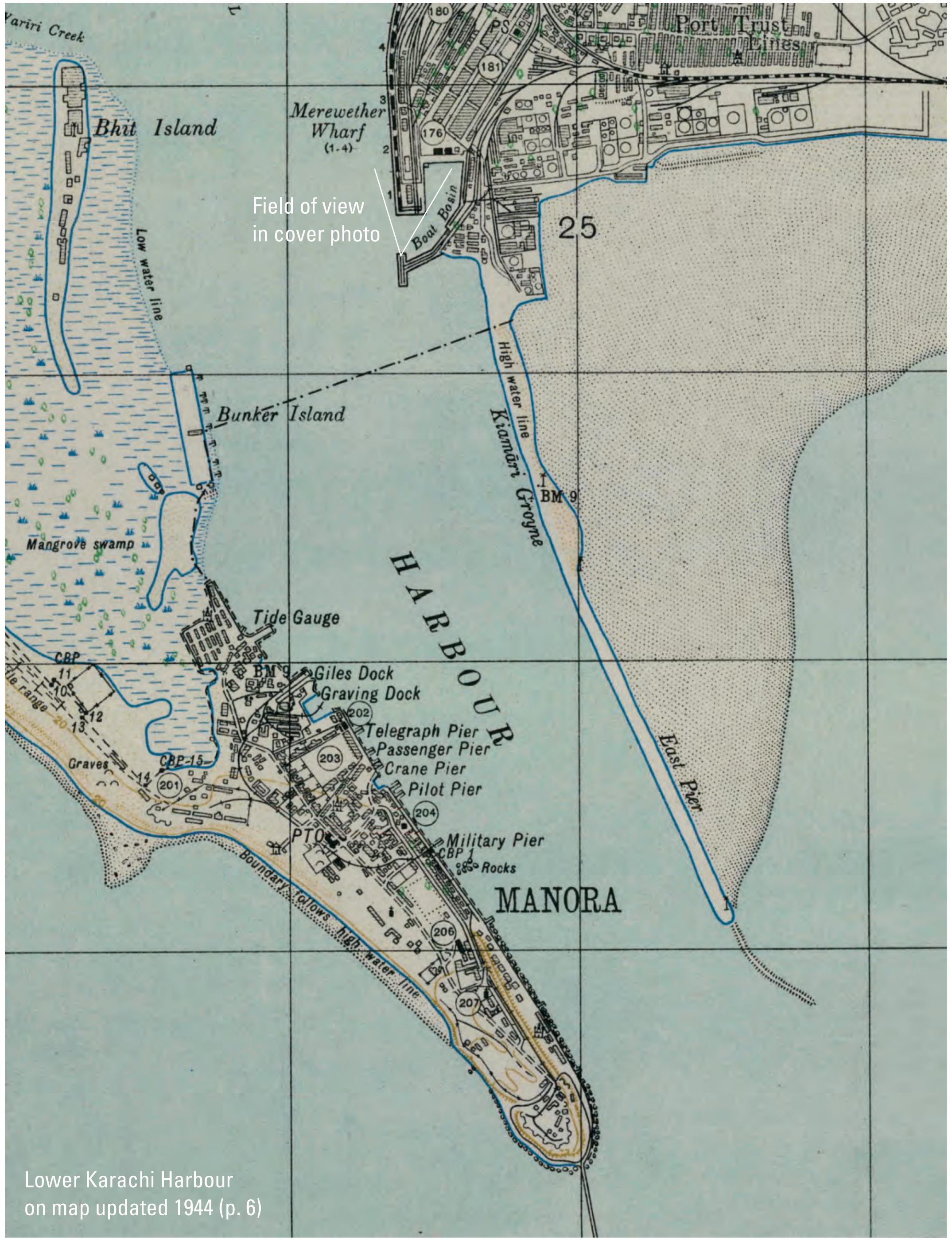
Boat Basin
Late in 1945, small landing craft of the Royal Indian Navy were likely berthed here to ferry personnel and supplies between the Karachi mainland and naval training schools at and northwest of Manora (p. 26–27).

Cranes
Maximum capcity 1,780 kilograms—one-fifth the unladen weight of the type of landing craft in flotillas relocated to Karachi in September 1945 (p. 26).

Signaling tower
Semaphore flags were displayed from this masted, rectangular structure into the early 1950s, for communication with ships in Karachi Harbour.

SUBMARINE N 53, built in 1921, departed Surubaya, Java on March 3, 1942. Later that year, under overall British command, it operated out of Karachi from June 4 to August 17 (Helgason, 2019).

LANDING CRAFT were stranded by the 1945 tsunami on Return Wharf and Railway Wharf, according to testimony from Cyrus Cowasjee in 2018 (p. 26–28). Mr. Cowasjee also contributed to the explanatory notes about the liner, cranes, signaling tower, and Boat Basin.



Lower Karachi Harbour
on map updated 1944 (p. 6)

Karachi effects of the Makran earthquake and tsunami of November 1945

Mercury spilled, tide gauge impaired, seawalls overrun, boats displaced, mosque flooded

Compiled by Brian F. Atwater[1,2], Haider Hasan[3], Ghazala Naeem[4], Din Mohammad Kakar[5], Asaf Humayun[6], Seshachalam Srinivasalu[7], Julia Elton[8], Noorul Ayen Hasan[9], Abdullah Usman[10], Hira Ashfaq Lodhi[3], Shoaib Ahmed[3], Lindsey M. Wright[11], and Loyce M. Adams[2]

United Nations Educational, Scientific and Cultural Organization
Intergovernmental Oceanographic Commission
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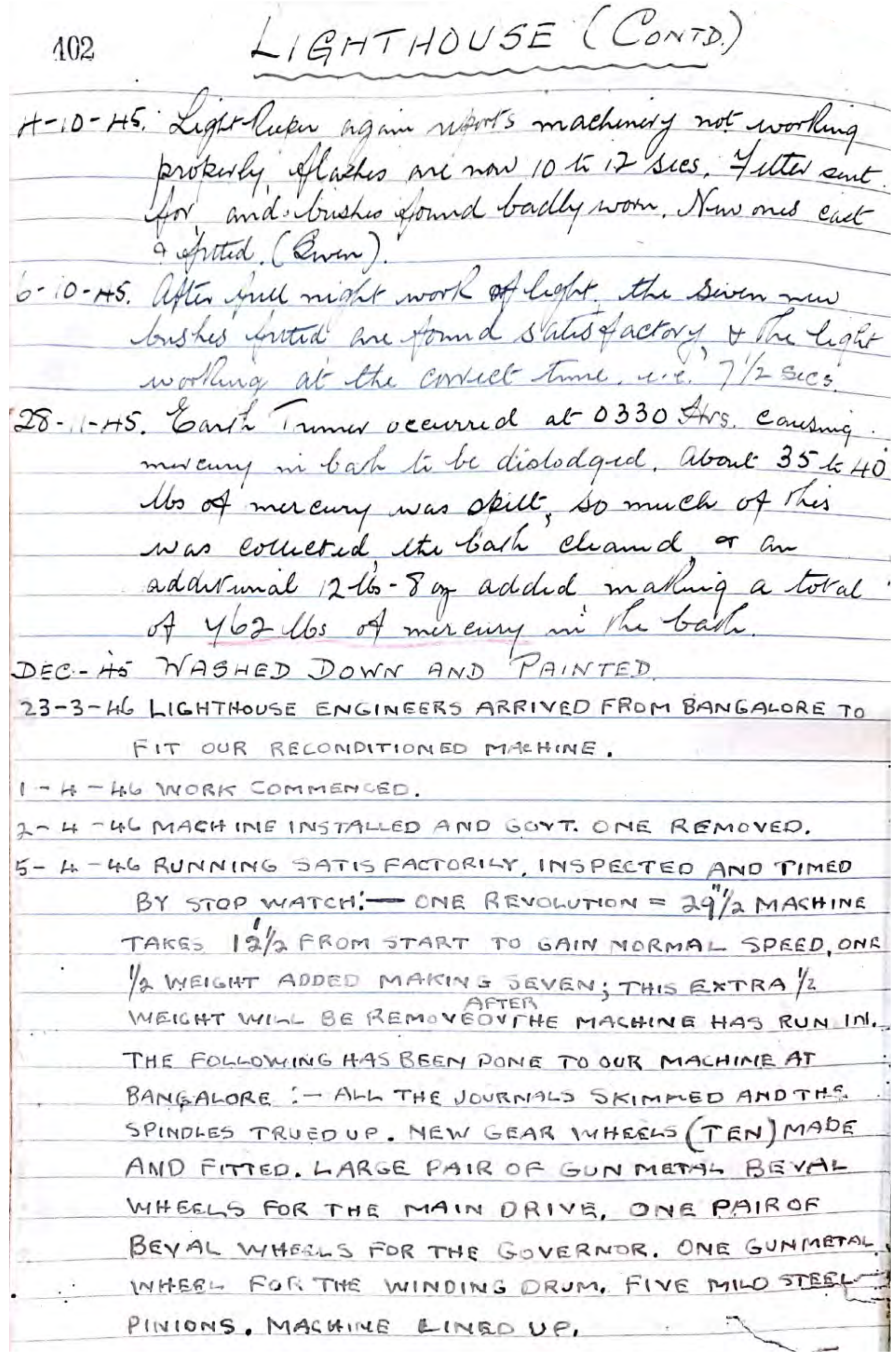
Illustration credits can be found on pages 37 (archival images) and 38 (modern photos).



102 LIGHTHOUSE (CONTD.)

4-10-45. Lightkeeper again reports machinery not working properly flashes are now 10 to 12 secs. Fitter sent for and brushes found badly worn. New ones cast & fitted. (Bven).

6-10-45. After full night work of light the seven new brushes fitted are found satisfactory & the light working at the correct time, i.e. 7½ secs.

28-11-45. Earth Tremor occurred at 0330 Hrs. causing mercury in bath to be dislodged. About 35 to 40 lbs of mercury was spilt, so much of this was collected the bath cleaned & an additional 12 lb-8 oz added making a total of 462 lbs of mercury in the bath.

DEC-45 WASHED DOWN AND PAINTED

23-3-46 LIGHTHOUSE ENGINEERS ARRIVED FROM BANGALORE TO FIT OUR RECONDITIONED MACHINE.

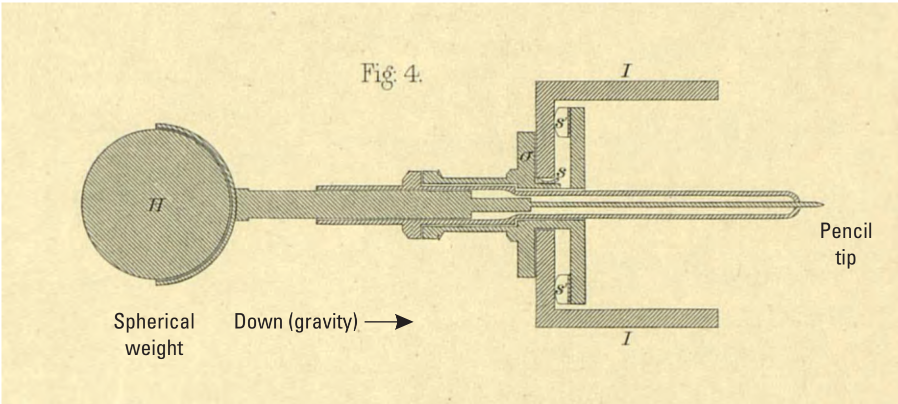
1-4-46 WORK COMMENCED.

2-4-46 MACHINE INSTALLED AND GOVT. ONE REMOVED.

5-4-46 RUNNING SATISFACTORILY, INSPECTED AND TIMED BY STOP WATCH:— ONE REVOLUTION = 29½" MACHINE TAKES 1½' FROM START TO GAIN NORMAL SPEED, ONE ½ WEIGHT ADDED MAKING SEVEN; THIS EXTRA ½ WEIGHT WILL BE REMOVED AFTER THE MACHINE HAS RUN IN.

THE FOLLOWING HAS BEEN DONE TO OUR MACHINE AT BANGALORE :— ALL THE JOURNALS SKIMMED AND THE SPINDLES TRUED UP. NEW GEAR WHEELS (TEN) MADE AND FITTED. LARGE PAIR OF GUN METAL BEVAL WHEELS FOR THE MAIN DRIVE, ONE PAIR OF BEVAL WHEELS FOR THE GOVERNOR. ONE GUNMETAL WHEEL FOR THE WINDING DRUM. FIVE MILD STEEL PINIONS. MACHINE LINED UP.

Mercury spilled in Manora Lighthouse, near Karachi, during the great Makran earthquake of November 28, 1945. The spill and its aftermath are logged at left in port-authority notes on lighthouse operations and maintenance. A little over one liter of quicksilver escaped from an annular trough, or bath, in which a heavy optical appartus usually revolved (p. 7–12).



A pencil holder probably like this one usually graphed the gradual rise and fall of water levels at Manora in late November 1945. A weight pressed down on a pencil lead, which drew a tide-gauge record on a revolving drum. The tsunami of November 28 registered incompletely on this marigram (p. 13–20).

MECHANICAL DRAWING reproduced from Eccles (1901a., plate IV). The drawing rotates the pencil holder 90° counterclockwise from the operational position (p. 14, 18).

PAGES OF THIS REPORT are formatted for printing in landscape orientation on paper 21.6 cm by 35.6 cm (8.5 inches by 14 inches; U.S. "legal") with left and right margins of 1.587 cm (5/8 inches). Fractional map scales quoted, such as 1:63,630 on page 5, will be accurate with those dimensions. Each page is proportioned to fill most of a computer screen of aspect ratio 9 (height) by 16 (width). Some displays span two facing pages with the odd-numbered page at right.

Contents

Karachi Harbour from Bhit Island, December 2016.

Summary

AN EARTHQUAKE AND TSUNAMI on November 28, 1945, sourced near the Makran coast of the Arabian Sea, disturbed port facilities and fishing villages to the east at Karachi Harbour.

Seismic waves, some 300 kilometers from their Makran source, spilled mercury high in a lighthouse at Manora. One liter of the heavy, toxic liquid escaped from an annular trough in which one of the world's heaviest assemblies of concentric glass prisms usually floated and revolved.

Ensuing tsunami waves registered incompletely at a tide gauge, also at Manora. Prior blockage of a stilling well may have held down the recorded level of the first few waves. The highest wave went ungauged by breaking a mechanical connection between water levels and a graphing pencil.

That highest wave overtopped seawalls of Keamari (Kiamari), according to newspaper accounts. The overflow reportedly flooded oil facilities, damaged 120 meters of Keamari Groyne, and destroyed a beacon on the groyne. By one account water apparently flowed from east to west in the bight south of Keamari.

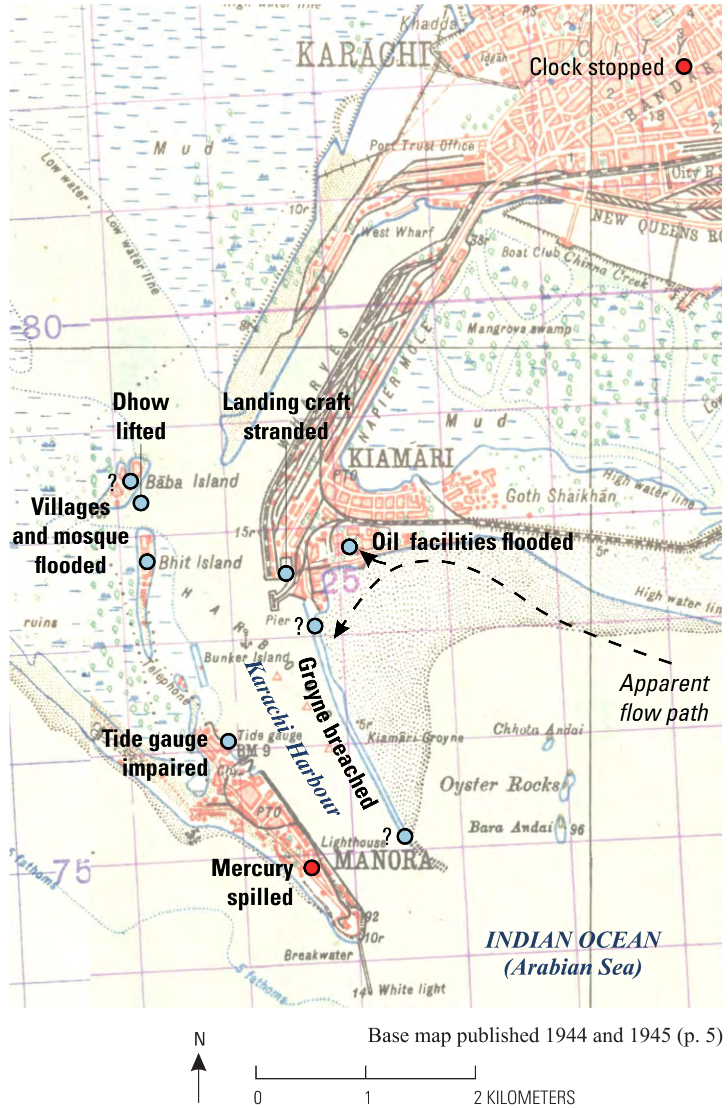
Interviews seven decades later elicited memories of displaced boats. In Karachi, a scion of a shipping family recalled observing, a few days after the tsunami, a pair of military landing craft atop Keamari wharves beside which the craft had been berthed, he said, as ferries serving schools of the Royal Indian Navy. In Gujarat, a former sailor and port official told of feeling the tsunami suddenly lift an ocean-going dhow that had been grounded for hull cleaning near Baba Island.

Others interviewed testified to flooding in fishing villages on Baba and Bhit islands. Three independent accounts told of water entering a Bhit Island mosque.

Likely water levels at the overrun seawalls, stranded landing craft, and flooded mosque all exceed the maximum wave height gauged at Manora.

A tsunami like the one in 1945 would today encounter more people and developed property in Karachi's port areas. The population of port villages has increased tenfold or more, as has the tonnage of imports and exports.

Reported effects of 1945 Makran earthquake and tsunami, plotted on a period map

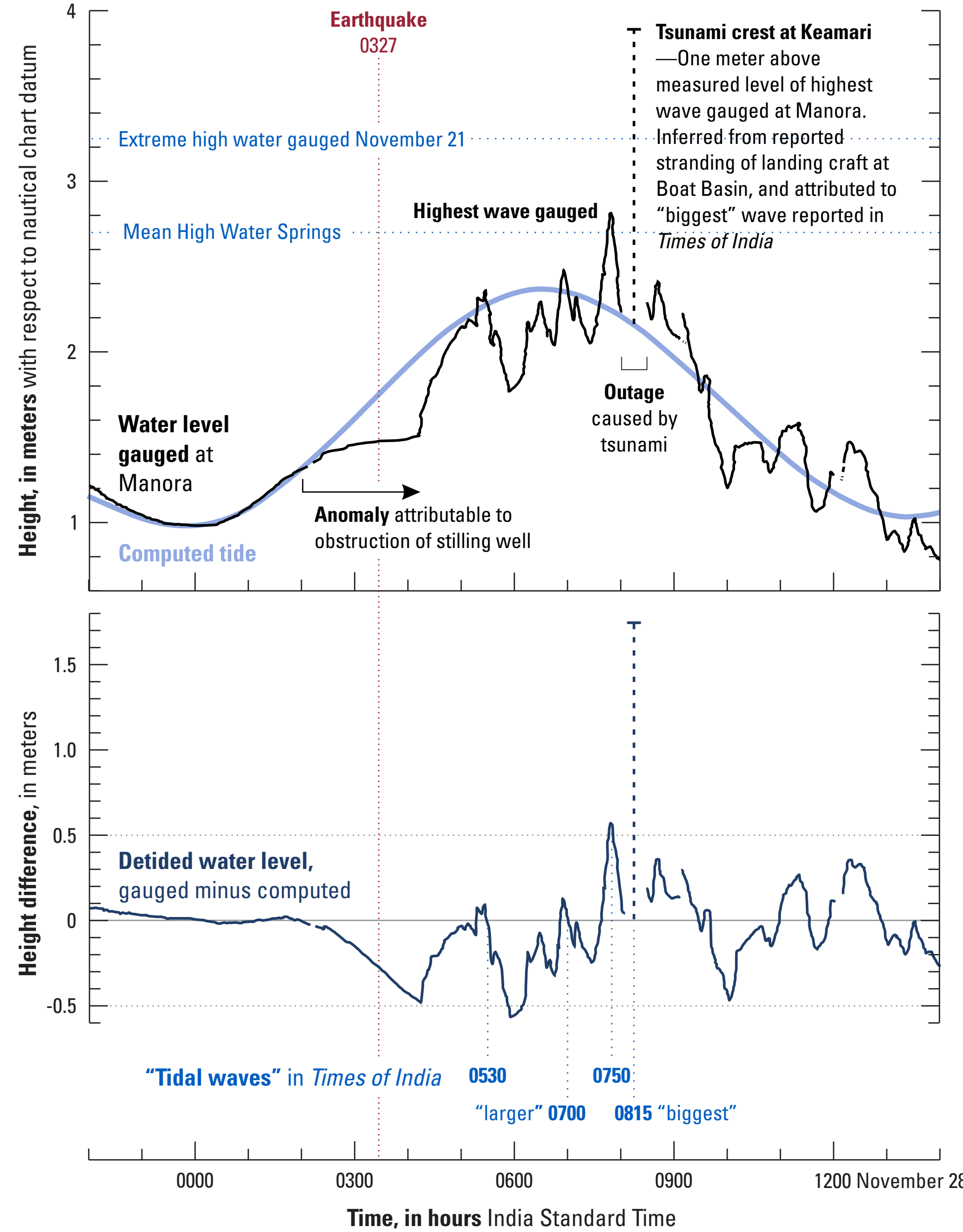


Base map published 1944 and 1945 (p. 5)

Earthquake

Tsunami—Queried to show uncertainty about where Keamari Groyne was damaged and whether Baba Island was flooded

Tide-gauge record compared with a computed tide, a peak wave height inferred from flooding, and reported wave arrivals



Introduction

THE MAKRAN SUBDUCTION ZONE, a boundary between tectonic plates, poses earthquake and tsunami hazards to northwest Indian Ocean shores. Assessment of these hazards is commonly grounded in their one clear manifestation: flooding around the Arabian Sea in the first hours after the great Makran earthquake, of magnitude 8, in November 1945. Hundreds of deaths were confirmed, most from the tsunami and all but fifteen in what is now Pakistan. These and other effects were noted in contemporary newspapers and government reports. Further evidence has come to light through interviews in Oman, Iran, Pakistan, and India.

The 1945 earthquake and tsunami registered abundantly at Karachi, the port city nearest the earthquake source. Archives this folio presents—a lighthouse notebook, tide-gauge record, local newspapers, large-scale maps, and photographs—complement eyewitness testimony gathered in 2014–2018. It is hoped that the stories told will inform precautions against natural hazards in Karachi and beyond.


ASK JACKS ABOUT ENGINEERS METAL AND WOOD WORKING SMALL TOOLS PHONE 2461 P. O. Box 179

The Daily Gazette

KARAMAT OIL for DEAFNESS AND ALL EAR TROUBLES PRICE Rs/ BALLABH & SONS PILIBHIT

Regd. No. S. 46.

VOL. LXVI. No. 321. | KARACHI: THURSDAY, NOVEMBER 29, 1945. | PRICE ONE ANNA.

TIDAL WAVE CAUSES INRUSH OF SEA-WATER

Sequel To Quake Shock In Karachi

REPORTED DAMAGE TO KEAMARI GROYNE

Hurley's Resignation And After

ATTACKS IN CONGRESS FORESHADOWED

WASHINGTON, Nov. 28 (Reu.) —The resignation of Major-General Patrick Jay Hurley, the United States' Ambassador to China, after a slashing condemnation of the State Department policy and the appointment of General George

I. N. A. Trial

WITNESS WAS TOLD "WHAT EVIDENCE TO GIVE"

Result Of Mr. Bhulabhai Desai's Persistent Probe

NEW DELHI, Nov. 28 (API)—Sepoy Saidullah Khan, a prosecution witness, stated before the I.N.A. court martial this afternoon

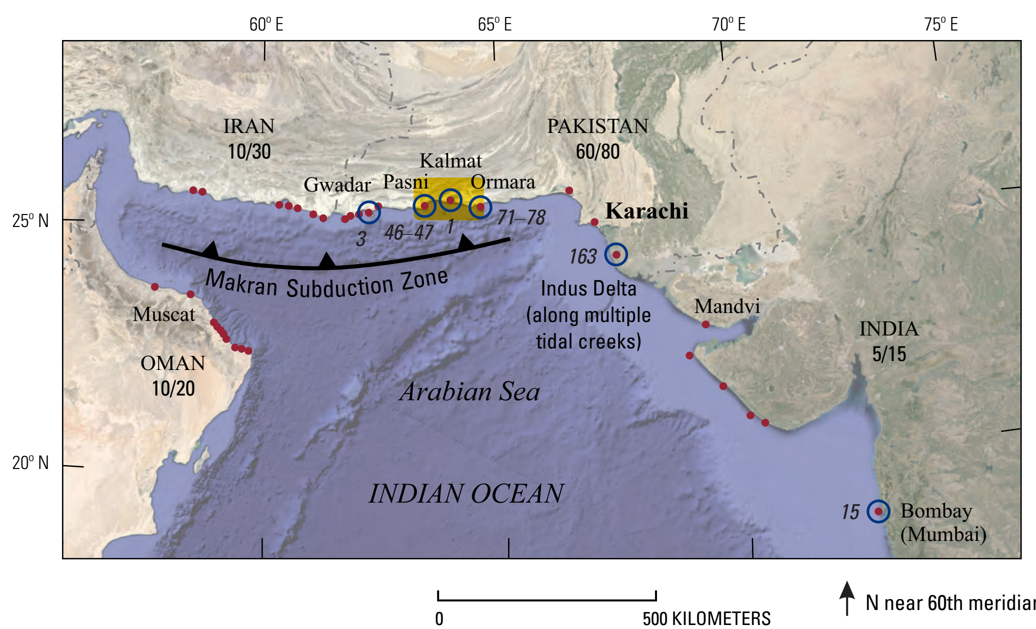
Karachi newspapers, including the *Daily Gazette*, reported on local effects of the 1945 earthquake and tsunami.

EFFECTS of the 1945 earthquake and tsunami have been described in contemporary reports (Pendse, 1946; 1948; Sondhi, 1949), an earthquake catalogue (Ambraseys and Melville, 1982), a review (Hoffmann and others, 2013), and testimony (Kakar and others, 2015; dots on map, right). Page 7 summarizes estimates of earthquake size and fault-rupture area.

THE TOTAL LOSS OF LIFE "does not seem to have exceeded 300," including 20 deaths from building collapse in Ormara, according to Ambraseys and Melville (1982, p. 89–90). Death tolls plotted at right, which total 305, are from the following sources:

Gwadar and Kalmat—Testimony from recent interviews by Kakar and others (2015, p. 22, 28, 38).
Pasni—46 or 47 deaths according to reports in Agent to the Governor General in Baluchistan (1948, p. 1 and 60, respectively).
Ormara—71 fatalities according to page 1 of that 1948 document; 78 dead and 12 missing according to its page 63.
Indus Delta—"Enquiries made from official agencies up to December 16," reported in the *Sind Observer* of December 23, 1945.
Bombay—*Times of India*, November 29, 1945.

AN UNOFFICIAL REPORT OF 4,000 TSUNAMI DEATHS, though "highly exaggerated" (Hoffmann and others, 2013, p. 10), persists in modern tsunami catalogs (Murty and Rafiq, 1991; Rastogi and Jaiswal, 2006; Dominey-Howes and others, 2007; National Centers for Environmental Information and World Data Service, 2018).



MAP EXPLANATION

15 ○ **Confirmed fatalities**—From the 1945 tsunami and, in Ormara, from the associated earthquake as well

Interviews—Since 2008, mainly through United Nations projects

• **Site or area visited**

5/15 **Persons interviewed**—Rounded counts summed by present-day country. Numerator gives number who convincingly recalled the 1945 tsunami, or had learned about it from family elders. Denominator gives the total number interviewed

Fault-rupture area—Approximate source of great earthquake of November 28, 1945 local time

Fault—Seaward edge of subduction thrust fault that descends northward beneath Iran and Pakistan

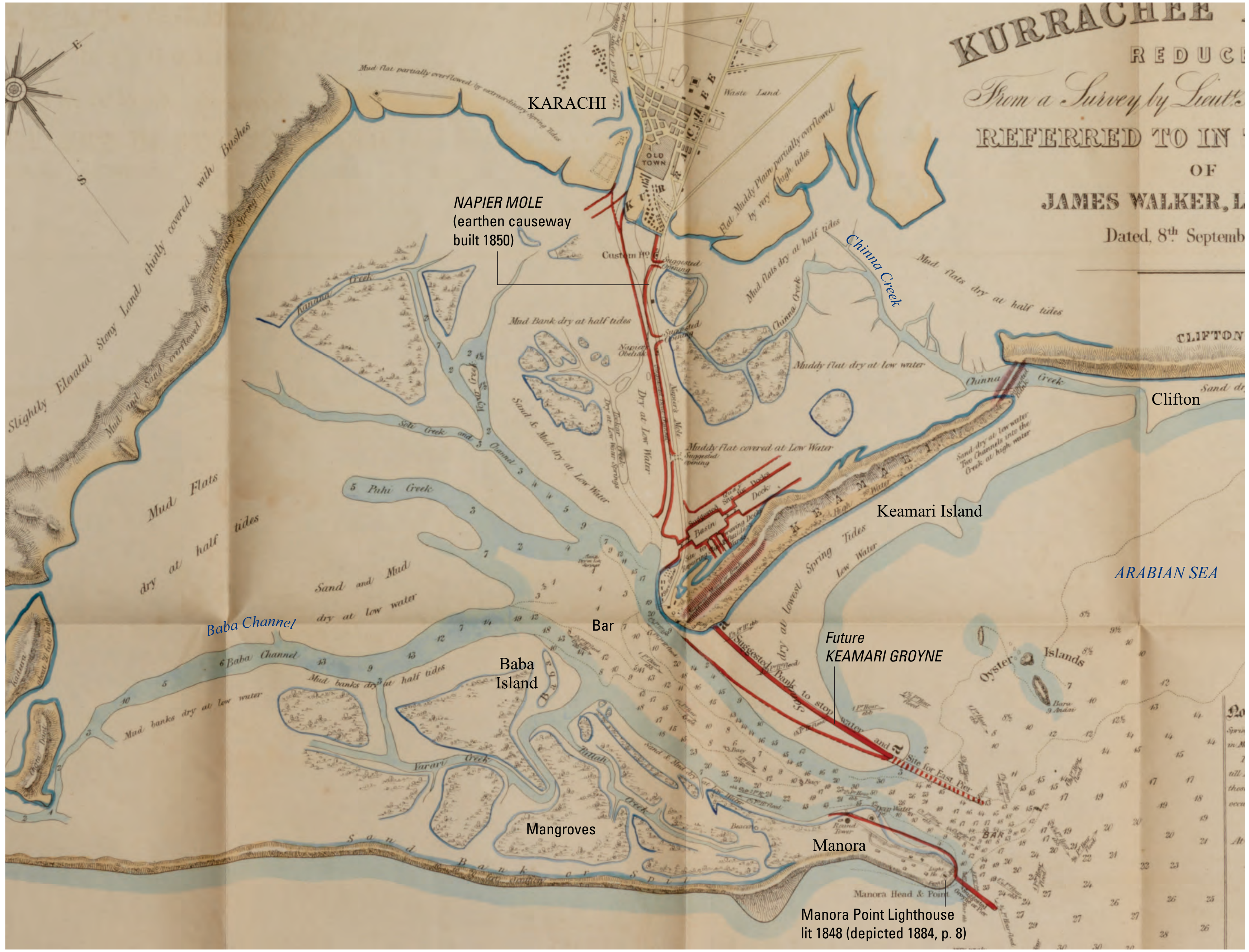
Karachi Harbour

Port plan of 1856

19TH-CENTURY ENGINEERING shaped the waterways and shores that the 1945 tsunami would encounter. Port works proposed in 1856 (red at right, on an 1854 nautical chart), were mostly implemented in the next two decades (p. 4). The works were intended to provide military ships with deep-water access to the west end of Keamari Island, which had already been connected to Karachi with a causeway, Napier Mole.

Shoals of Karachi Harbour were to be removed by strengthening its tidal currents in two ways. First, Chinna Creek was to be blocked between Keamari Island and Clifton, and its tidal prism captured at a cut beneath Napier Mole. Second, flows within lower Karachi Harbour were to be confined by a rock wall that would become known as Keamari Groyne, and which the 1945 tsunami would locally overflow (p. 24). This barrier was intended to prevent spillover between Karachi Harbour and a tidal flat to its east (p. 4).

The 1854 nautical chart on which the proposed works were plotted identifies a lighthouse at Manora Point. The 1945 earthquake would cause a mercury spill in its successor (p. 8–12).



N

0 1 2 KILOMETERS

Soundings in feet below average spring low water

1854 (nautical chart) and 1856 (plan in red)

THE PLAN MAP of Walker (1856) uses a nautical chart, surveyed by A.M. Grieve, on which the datum for the soundings refers to tides of large semi-monthly range, not to a time of year. “The main object of those works, as directed by Government, was to obtain such a depth of water as would allow Her Majesty's troop-ships to enter or depart at all times” (Baille, 1890, p. 58).

Rock wall built in 1861–1863

IT WAS ANTICIPATED in the 1856 plan that upon confinement by Keamari Groyne, tidal currents in lower Karachi Harbour would serve as natural dredges:

> "Southward of Keamari a great diversion to the eastward takes place, over a sand-bank upwards of a mile in length, which Lieut. Grieve's survey describes to be dry at the lowest spring tides . . . and to have over it at ebb and flood a current of 1½ mile per hour. Surely there is here an immense body of water—in other words, an immense power for clearing the entrance—lost. . . . This diminution of quantity causes a great and gradual diminution of the channel seaward of it.
>
> "There could be no difficulty in stopping this loss of scouring power, either by raising the sloping bank of the east side of the channel two or three yards above its present level with rough stone pitched on the channel side . . . or forming a separate bank of the same rough materials across the sand at a distance from the channel."

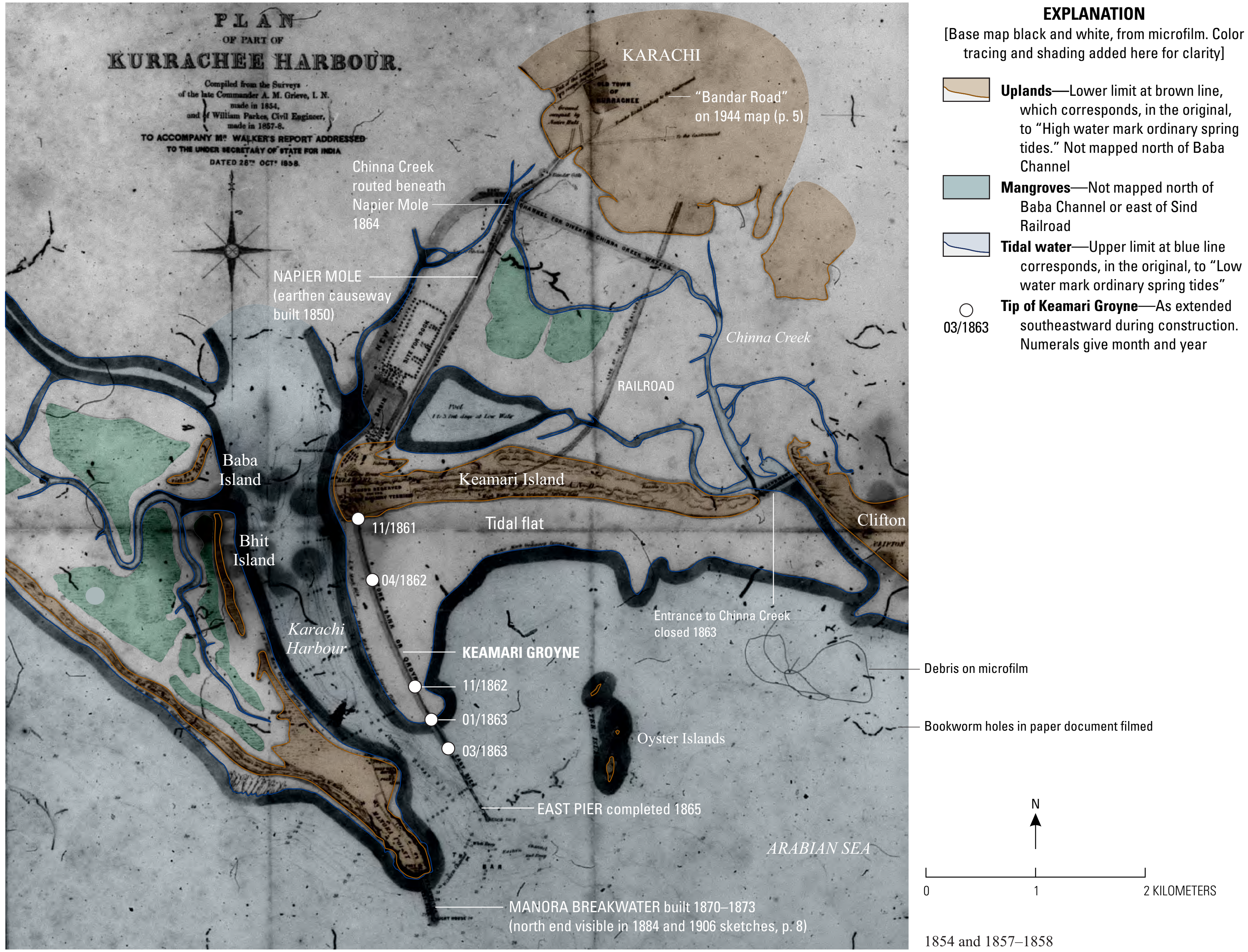
Construction of Keamari Groyne began in November 1861 and was completed in January 1863. The structure reportedly contained 177,591 tons of stone, which was probably quarried northeast of Clifton (footnote, p. 24). Repeat soundings between 1856 and 1863 provided early evidence that the groyne was having its intended effect.

KEAMARI AND KIAMARI are alternate spellings.

THE CURRENTS cited by Walker (1856, p. 16–17) were expected to affect the groyne's construction: "The only difficulty likely to arise in the construction will be from the scouring away of the sand immediately in advance of the end of the work by the strong currents setting across the bank, both on the ebb and flood" (Walker and Parkes, 1866, p. 40). Repeated soundings compiled in 1863 show an overall increase in cross-sectional area across lower Karachi Harbour (Parkes, 1866, p. 88–90).

ADDITIONAL PORT HISTORY from Rustomji (2007, p. 50), with stone tonnage from Baillie (1890).

BASE MAP from an 1858 report in an 1866 Bombay government collection (Walker and Parkes, 1866). The copy colored at right is from microfiche made in New Delhi in 1994 for the U.S. Library of Congress.



1854 and 1857–1858

City and port in 1945

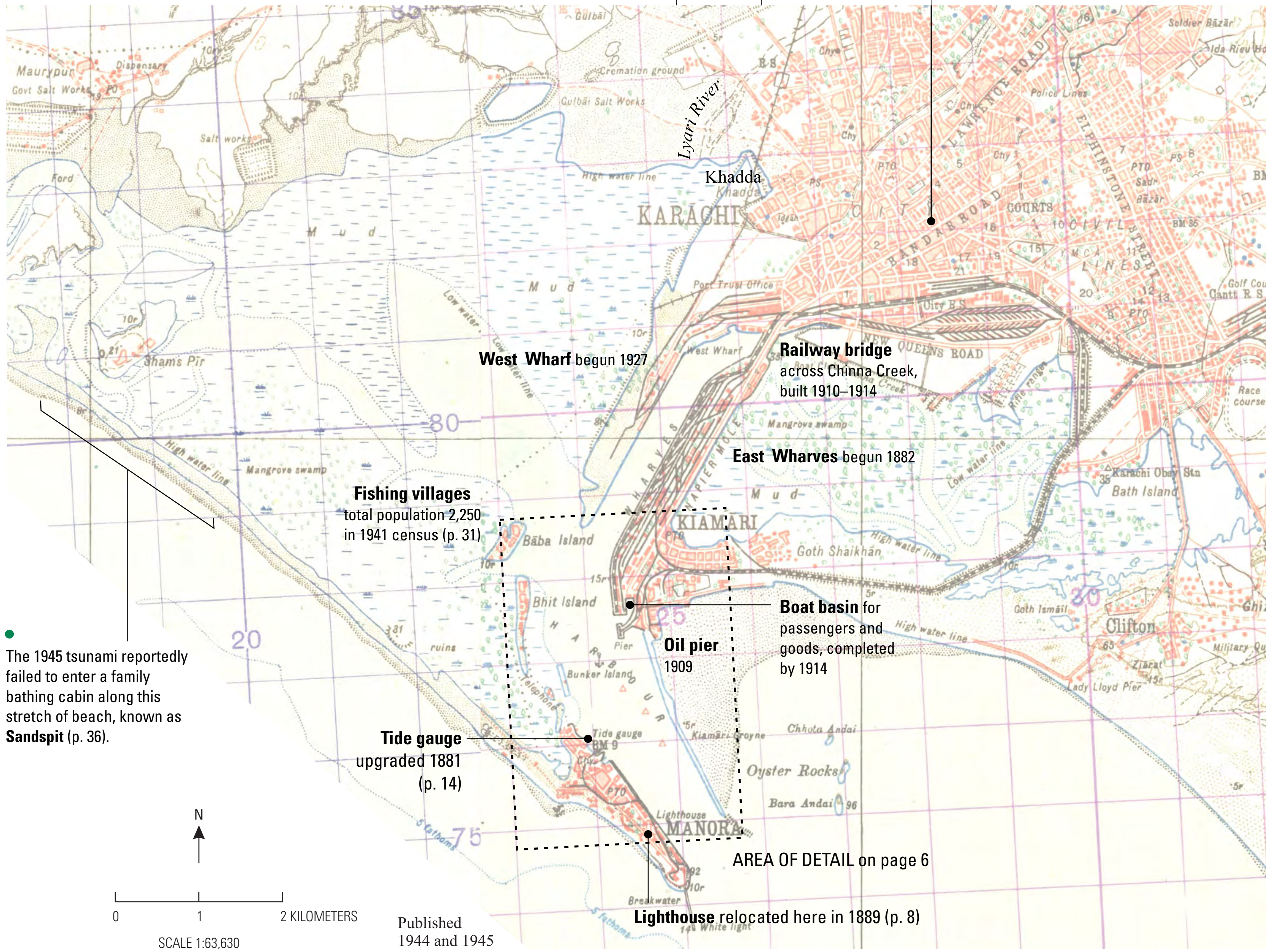
BY 1945 the town surveyed in 1854 (p. 3) had become a city of over 360,000, served at Keamari by wharves, piers, and a transportation hub. War had brought a record 2.5 million metric tons of total exports and imports in fiscal year 1944–1945 (p. 34). Fishing villages covered low-lying Baba Island and Bhit Island. Facilities to their south, in Manora, included a relocated lighthouse with enormous revolving lenses (p. 8–9) and a long-running tidal observatory (p. 12).

Effects of the 1945 Makran earthquake and tsunami have been reported from Keamari, the fishing villages, and Manora (next page). An additional earthquake effect was the stopping of a tower clock on the Municipal Corporation Building (right). Also noted at right are areas where the tsunami caused no confirmed damage: Lyari River, Khadda, and Sandspit.

PORT HISTORY through World War II is reviewed in Brow (1947). The Karachi engineering career of David Barrington Brow (left) began in 1921. For Karachi Port Trust he oversaw construction of West Wharf and, in 1937–1945, served as KPT's Chief Engineer (Anonymous, 1952). Brow certified that the 1945 tsunami briefly put the Karachi tide gauge out of action (p. 18).

THE KARACHI MUNICIPAL CLOCK TOWER clock stopped at 3-26 a.m." as did other public clocks in the city, according to the *Daily Gazette* of November 29, 1945.

THE MAP, brightened for added labels, contains parts of two Survey of India One-Inch Sheets: 35 L/13, 3rd ed., 1945, and 35 P/1, 4th ed., 1944. Both were initially surveyed 1925–1926. Purple grid 0.914 km.



Geographic index to earthquake● and tsunami● effects

Keamari (Kiamari) and vicinity

1 *Boat Basin*—Landing craft stranded atop wharves, according to testimony in 2018 (p. 26–28).

2 *Oil installations*—Facilities flooded, according to contemporary newspapers. Site or sites of flooding not identified but probably among tanks (circles) between Boat Basin and east edge of map (p. 22–23).

3 *Keamari Groyne*—120 m of rock wall damaged, according to two contemporary newspapers. Neither pinpointed the damage but one noted loss of a beacon on the groyne. A third paper told of apparent overtopping on a northern part of the groyne (p. 21, 24).

Baba Island and Bhit Island

4 *Fishing villages*—Flooding reported 2014–2016, definitely in the case of a Bhit Island mosque (p. 31–33).

5 *Shoal near Baba Island*—Trading vessel lifted according to testimony in 2014 (p. 29–30).

Manora

6 *Tide gauge*—Recorded rapid changes in water level except when disabled for about 25 minutes, according to a marigram from 1945 (p. 13–20).

7 *Lighthouse*—Mercury spilled according to contemporary newspapers and a maintenance log (p. 7–12).

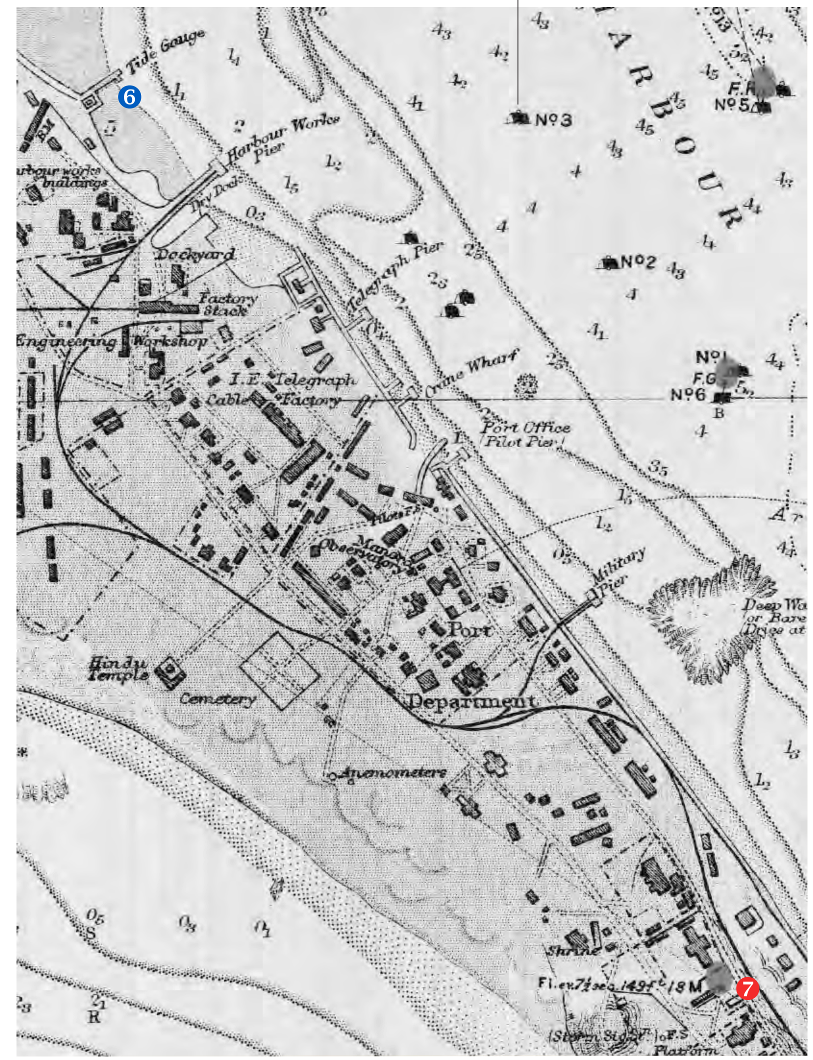
N
True north 3° 3″ east of grid north

0 500 1,000 METERS
SCALE 1:21,120
Contour interval 20 feet

Published 1944

Published 1935

Mooring buoy



0 100 200 METERS
SCALE 1:9,100

N

Water depths are in fathoms and feet. The "5" south of the tide gauge gives height in feet (other examples, p. 29). All these depths and heights are referenced to a chart datum 0.47 m below Mean Low Water Springs—a tidal datum that averages low tides from roughly fortnightly times of extreme tides.

BASE MAPS excerpted at published scales:
◀ *Survey of India Karachi Guide Map*, 2nd ed. revised, 1940, reprinted August 1944 with minor corrections. Surveyed 1926–1927, corrected 1933–1934 and 1936–1939. Grid 914 m.
▶ *British Admiralty chart 40*, 1935 ed., soundings to 1933, reduced to chart datum (p. 16; Hasan and others, 2018). 1:9,155 by rake scale on printed chart.

Spilled mercury

A mainly Makran earthquake

THE SEISMIC SHAKING in 1945, while destructive near its Makran source, caused little direct harm in distant Karachi.

Shortly before dawn, local time, seismic waves radiated from a fault rupture along the Makran coast a few hundred kilometers west of Karachi. The rupture extended beneath Pasni and Ormara (yellow rectangle on the map). Seismic shaking probably lowered land in Pasni and caused buildings to collapse in Ormara (testimony, right).

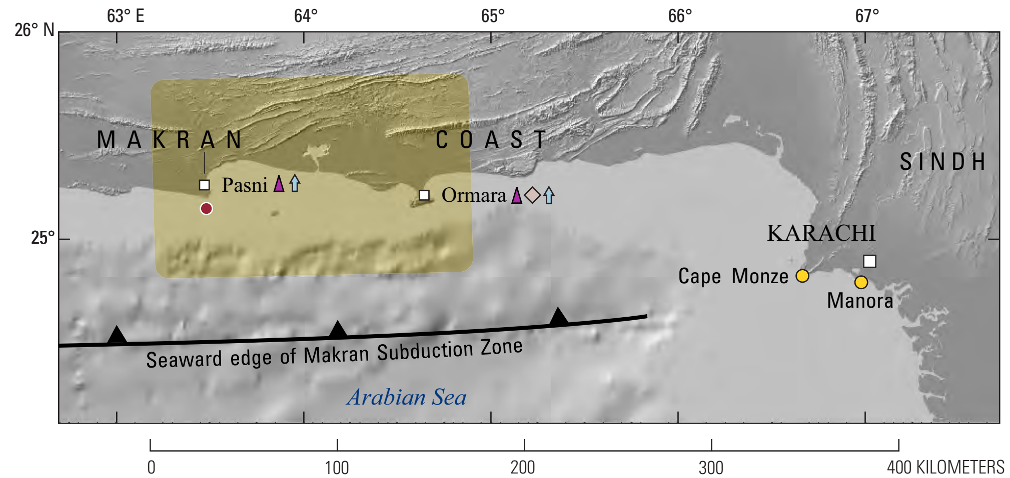
Local newspapers made light of weaker shaking felt in Karachi. The *Daily Gazette* told of office-workers who "attended late due to the temporary stoppage of timepieces" (p. 5). The *Sind Observer* quipped that "very few husbands left their beds," much less heeded their wives' requests "to carry their children out to safety."

Also reported, however, were mercury spills at two lighthouses near Karachi—one at Manora, the other to the west at Cape Monze. The Manora mercury issued from a float on which an enormous optic was still revolving in 2018. The next five pages relate the documented spill to the lighthouse lenses, their mercury float, and clockwork that controls their rotation.

THE 1945 MAKRAN EARTHQUAKE began 3:27 a.m., November 28, India Standard Time (9:57 p.m., November 27, UTC). Byrne and others (1992, p. 464, 468) derived a moment magnitude of 8.1 (range 8.0–8.2) and a rupture area of 100 km by 100–150 km (150 km as cartooned on p. 1 and at right).

DOCUMENTED EARTHQUAKE EFFECTS include collapse of "adobe" buildings in Ormara, breaks in a submarine cable, and eastern shaking "not perceptible beyond Karachi" (Ambraseys and Melville, 1982, p. 89–90). Uplift at Ormara was in the range 1–3 m according field observations and interviews by Page and others (1979, p. 536–538). Interviews excerpted at right are from Kakar and others (2015, p. 30–45).

LIGHTHOUSE DAMAGE (details, p. 12) was reported on November 29 by the *Daily Gazette* (Manora only) and on November 30 by the *Times of India* (Cape Monze as well). The reported damage at Cape Monze included cracking of a tower previously found defective in materials and workmanship (Stevenson, 1927, p. 39).



EXPLANATION

Indicators of earthquake shaking

- **Liquefaction**—Cracks opened in ground surface with water expelled from them
- **Collapsed buildings of stone and mud bricks**—Such buildings were more common Ormara than in Pasni
- **Lighthouse damage**—Chiefly spilled mercury

Further clues to earthquake source

- **Epicenter**—Surface projection of where rupture began, determined from seismic stations mainly in Europe
- **Uplifted shoreline**—Evidence for rupture beneath Ormara
- **Tectonic plate boundary**—Seaward edge of subduction thrust fault that descends northward beneath Iran and Pakistan
- **Approximate fault-rupture area**—Consistent with indicators of shaking, epicentral location, shoreline uplift, and fault strike

Strong shaking and land-level change near the Makran source of the 1945 earthquake

Shaking in **Pasni** caused land to sink and crack.

Much of a coastal neighborhood, Wadsar, sank into the sea. Sakhi Dad, above in 2014 at age 85, stated that Wadsar became today's harbour. Khudi Dost said that after the tsunami ended, the sea still covered Wadsar.

Ground cracks in Pasni were recalled by three persons interviewed in 2014. Mr. Dost stated that ground split open and blood-red water came out of the cracks. Karim Buksh reported observing these effects in Wadsar.

These effects imply that shaken sand lost strength and expelled water by liquefaction. Liquefied sand beneath Wadsar probably enabled the neighborhood to slide into the sea.

In **Ormara** the shaking took lives and was probably accompanied by coastal uplift.

The shaking brought down houses of stone or mud bricks. Victims included an elder sister, an uncle, and two cousins of Hawwa, above in Karachi in 2014 at age 72. All were trapped, she said, under rubble of her family's stone house. By contrast, houses of wood and mats reportedly withstood the earthquake only to be carried away by the tsunami.

An Ormara shoreline was raised above the sea in 1945. The emergence was reported during interviews in the 1970s and again in 2014, when Qadir Buksh and Fateh Mohammad Baloch recalled it at age 84.

Enormous revolving lenses

THE OPTICAL APPARATUS at right, when lit at Manora in 1909, ranked among the world's most powerful nautical lights. Its maker called the optic "hyper-radial" and expected its beams to pierce seasonal haze. The apparatus remained in use in 2018, when the photos on pages 9 and 11 were taken.

The Manora hyper-radial embodies 19th-century advances in lighthouse engineering (timelines, lower right). Each panel of concentric glass prisms collects and bends lamplight (p. 9). Such optics became lighthouse standards through advances in glass-making and in shaping and orienting annular prisms. Chance Brothers, the apparatus maker, contributed to these later advances.

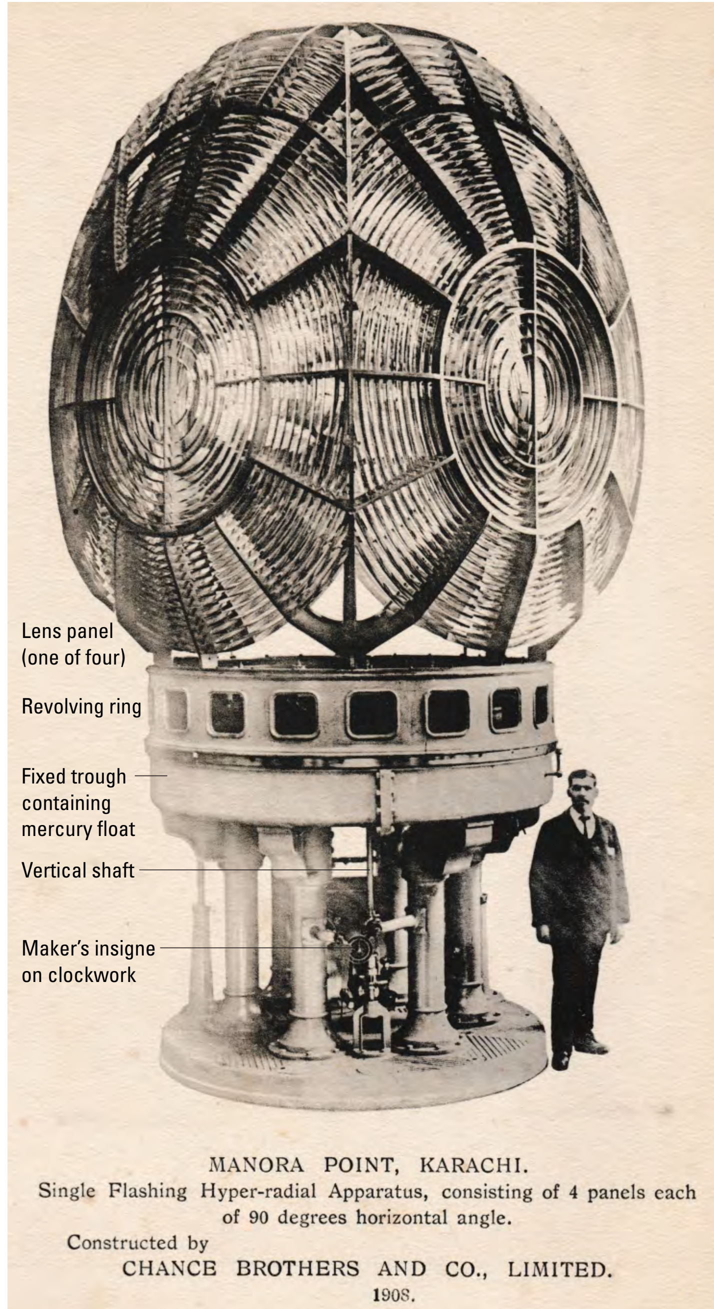
Also built in are late 19th-century discoveries about visual perception. Experiments showed that a flash of light, to be perceived, need not last more than a few tenths of a second. The lens-supporting ring at right was designed to revolve twice a minute to produce, in any given direction, a 0.3-second flash every 7.5 seconds (p. 9, "Fl. ev. 71/2 sec").

The revolving ring rests on a mercury float (p. 10) and is geared, through a vertical shaft, to weight-driven clockwork (p. 11). This float was the source of the mercury that the 1945 earthquake dislodged.

THE MANORA HYPER-RADIAL was extolled by a maker (Chance, 1919, p. 168) and a user (Brow, 1947, p. 169). Haze was cited by Chance Brothers and Co., Limited (1910, p. 42), who used the image at right as a frontispiece. After posing for this portrait, the apparatus was surely shipped out in pieces for reassembly on site. Douglass and Gedye (1911, p. 637) stated that the apparatus "was placed" at Manora in 1908, but Karachi Port Trust "completed" the Manora Lighthouse in 1909 (Brow, 1947, p. 169)—the same year headnoted in the KPT lighthouse log excerpted on page 12. Douglass and Gedye (1911, fig. 41) reported a flash duration of 0.3 seconds.

ADVANCES IN LIGHTHOUSE OPTICS AND MACHINERY outlined here are elaborated in Douglass and Gedye (1911, p. 633), Elton (2009, p. 191, 200–202, 233–236), and Levitt (2013, p. 76, 79–80, 116, 222–224).

"A DIOPTRIC LIGHT of 2nd order" was slated for installation at Manora soon after January 1877 (Carrington, 1877, p. 7). An "altered" optic went into service that year (Carrington, 1881, p. 11). By the early 1900s, an "ordinary lighthouse apparatus" deemed "dioptric" was, "strictly speaking, catadioptric" in using "both reflection and refraction" (Chance Brothers and Co., Limited, 1910, p. 7).



Apparatus at Manora

Manora Point Lighthouse 1848–1889

NW SE

1884

N 50 m 1884

Church

0.5 km between lighthouse sites

1906

mid-20th c.

Manora Lighthouse
1889 to present
(maps, p. 5 and 6)

Church (p. 25)

Plaque on 1889 tower

2018

1800 1850 1900 1950

Initial light
1848
Lit five years after British conquest of Sindh. Plotted on charts of 1854 (p. 2) and 1884 (above)

Refracting (and reflecting?) prisms
1877
Termed "dioptric" shortly before its installation

Refracting and reflecting prisms above mercury float
1909
Hyper-radial installed

Mercury spill
1945
Caused by earthquake

Advances in lighthouse technology in France and Scotland

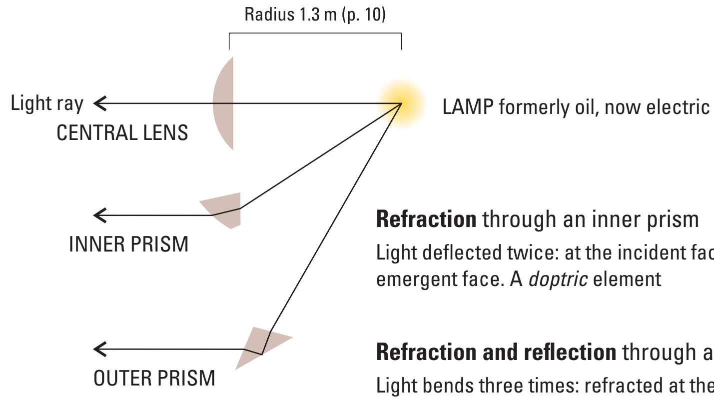
1800 1850 1900 1950

Concentric rings of glass prisms
1819–1854
Annular lens panel refracts and internally reflects light into powerful beam. Conceived 1819–1825; first installed in a large, revolving lighthouse optic, 1854

Mercury float
1890–1893
Enables frequent flashes from revolving sets of heavy lens panels. Invented 1890, first implemented 1892–1893

Diffuse light collected and directed

Each of the four lens panels is stepped with polygonal glass arranged concentrically about a central spherical lens. Together they gather light from an interior lamp and bend it into a beam. The inner prisms bend light by refraction only, while the outer ones both reflect and refract.

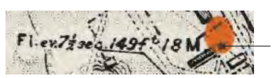


Refraction through an inner prism
Light deflected twice: at the incident face and at the emergent face. A *doptric* element

Refraction and reflection through an outer prism
Light bends three times: refracted at the incident face, totally reflected at a second face, and refracted again at the emergent face. A *catadioptric* element

Frequent flashes

With its four-panel assembly completing two revolutions per minute, the Manora hyper-radial can produce a flash in any given direction every eighth of a minute. This is the interval of 7.5 seconds advertised on Admiralty chart 40 (below) and called “the correct time” in a logbook entry from October 6, 1945 (p. 12).



Manora Lighthouse at location 1889 to present (p. 8)

Published 1935

Fl. ev. 7 ½ sec.

This above excerpt from Admiralty chart 40 associates Manora Lighthouse with a flash interval 7 ½ seconds long as of the early 1930s. Among other editions checked at Library of Congress, the chart published just before arrival of the hyper-radial—the 1906 edition—gives no flash interval for Manora Lighthouse. By contrast, every post-arrival edition checked—1918, 1921, 1939 (p. 6), 1948, and 1955—says 7 ½ seconds. A logbook entry from October 4, 1945 reports a flash interval of 10 to 12 seconds as evidence that lighthouse machinery was “not working properly” (p. 12).

149 ft. 18 M.

The focal plane of the beam is 149 ft (45.5 m) above a high-water datum. The beam in fair weather is visible for 18 nautical miles from a vessel deck 15 ft (4.6 m) above the sea surface—a horizontal distance limited by Earth’s curvature.

Daylight curtain

All photos 2018

The assembly of four **lens panels** is supported by, and turns with, a **revolving ring** (turquoise). The revolutions are guided by rollers. The revolving ring rests on an annular float that is immersed in mercury (p. 8, 10). Parts of all four panels are visible in the lower left image.

Mercury float

“ANY SOLID LIGHTER THAN A FLUID will, if placed in the fluid, be so far immersed that the weight of the solid will be equal to the weight of the fluid displaced.”

This mathematical proposition of Archimedes, applied in the Manora hyper-radial, enables its heavy optical apparatus to revolve in a modest quantity of liquid metal (diagrams, right). The revolving load floats in a mere 25 liters of mercury. “It is possible,” the maker noted in 1910, “to revolve an apparatus weighing several tons, if it is supported in this way, with the little finger only.”

The mercury spilled during the 1945 earthquake—a little over one liter—may have used a path that this easy rotation requires. A narrow clearance prevents the revolving ring from rubbing against the fixed trough beneath it. Within this trough is a nested float that supports the revolving load by Archimedian immersion in mercury. Pressed against the trough by earthquake motions, vertical or horizontal, the float may have squeezed the liquid metal through the narrow clearance.

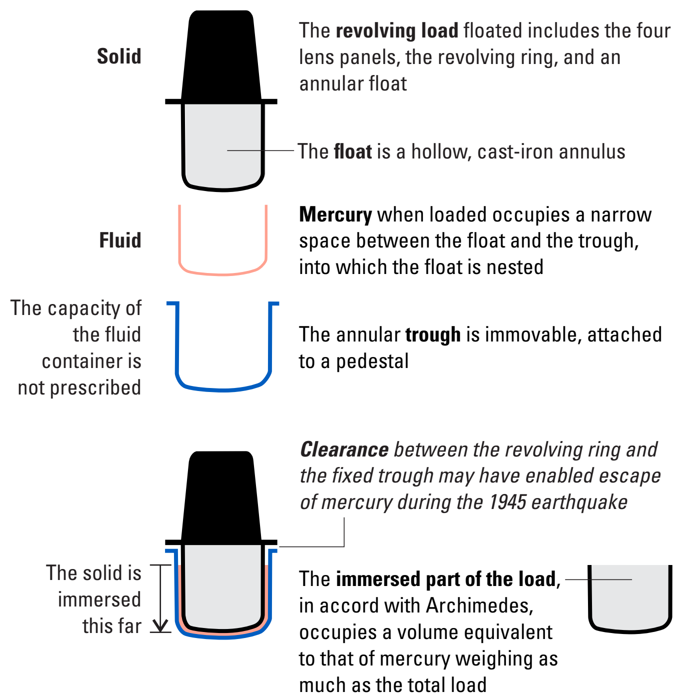
ARCHIMEDES explained flotation in the 3rd century B.C.E. The proposition quoted is from a translation by Heath (1897, p. 257).

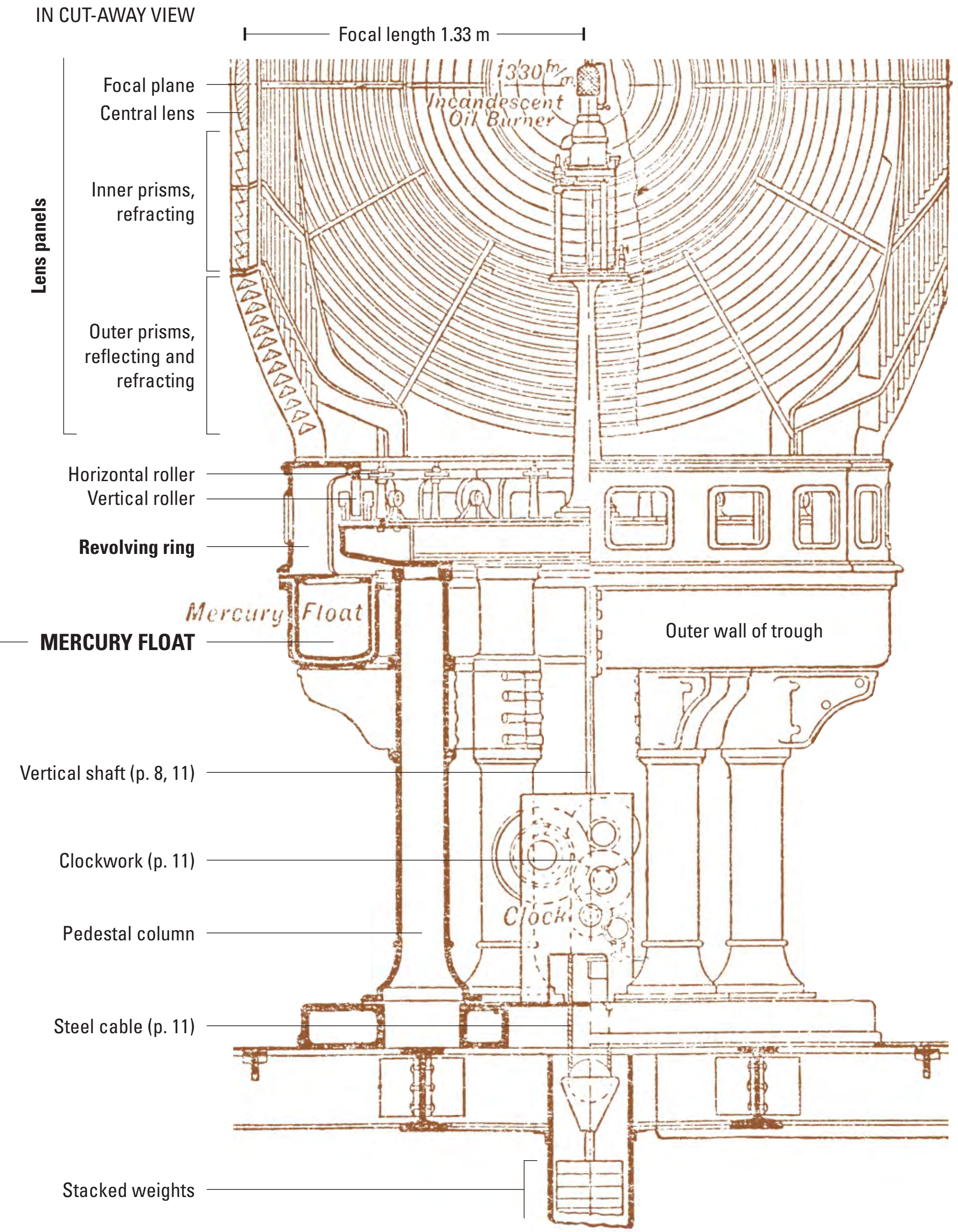
THE DRAWING at far right, showing the Manora hyper-radial, is excerpted from Douglass and Gedye (1911, their fig. 41; color added and lantern erased).

ANOTHER HYPER-RADIAL made by Chance Brothers was installed in Newfoundland in 1907. It used 950 pounds of mercury—200 pounds more than the logged weights at Manora. As at Manora, an assembly of four lens panels completed two revolutions a minute to produce a 0.3-second flash every 7 ½ seconds (Chance Brothers and Co., Limited, 1910, p. 26; Douglass and Gedye, 1911, p. 637). The “little finger” statement appears on page 24 of the 1910 Chance Brothers book.

THE NARROW SPACE between float and trough amounts to about 3 mm in the case of a telescope established in 1908 near Pasadena, California. “The float dips in a cast-iron trough which is machined to nearly fit the float, leaving a space of only one-eighth of an inch all around; this space is filled with 650 lbs (295 kilos) of mercury. The immersed part of the float gives a displacement of about 50 cubic feet (1.4 cu. m) of mercury, thus carrying 21 ½ tons (19,479 kilos) of the moving parts of the telescope in the fluid” (Ritchey, 1909, p. 203).

Flotation in Archimedes | **A heavy load floated in a heavy fluid at Manora**





Flotation numbers at Manora

Revolving load perhaps 7 tons—The Manora hyper-radial has been likened to a Newfoundland sibling that had a revolving load of 7 long tons (about 7,100 kilograms). At 13.6 kilograms per liter, mercury of that weight would occupy 500 liters, or 0.5 cubic meters.

Trough 0.6 cubic meters—A trough must hold more than 500 liters if mercury within is to float a load of 7 tons. As drawn at right the trough is big enough: with a circumference a little over 6 meters and sides of 0.3 meters, it has a capacity close to 600 liters.

Immersion in 25 liters of mercury—The trough usually contained some 25 liters of mercury. Refills in a logbook (p. 12) weighed 786, 762, 770, and 726 pounds (330–360 kilograms) in 1944, 1945, 1955, and 1960, respectively. The 1945 spill, logged as 35–40 pounds (16–18 kilograms), slightly exceeded 1 liter.

Displaced mercury several millimeters thick—The immersed part of the load is surrounded laterally by mercury in a narrow space between the float and the vertical sides of the trough. The inner surface area of the trough is about 5 square meters. Spread evenly across such an area, 25 liters of fluid would have a thickness of about 5 millimeters, or one-fifth inch.

Clockwork

THE MANORA HYPER-RADIAL runs much like a wind-up clock. The beam from any of its four lens panels completes two revolutions a minute. Falling weights drive the rotation, which is regulated by gears.

The revolving load, afloat in mercury, is stabilized by horizontal and vertical rollers. The vertical rollers have the further function of supporting the ring and its lens panels when the trough beneath is lowered for cleaning. Otherwise, while the apparatus is revolving, "the revolving ring should just clear the vertical rollers."

The revolving load is turned by a pinion gear at the upper end of a vertical drive shaft. This shaft is driven by a train of gear wheels on horizontal shafts, beginning with a large brass wheel on a winding drum.

Stacked weights that turn this drum fall in a tube below the pedestal (p. 10). They hang from a steel cable that coils around the drum. A keeper in 2018 reported that one full wind powers 45 minutes of rotation. A century earlier, "some Authorities" were said to prefer frequent rewinding "to make sure that the keeper in charge is constantly on the watch."

Gear wheels were replaced and shafts repaired in the first months after the 1945 earthquake. But it is unlikely that the earthquake occasioned this work (p. 12).

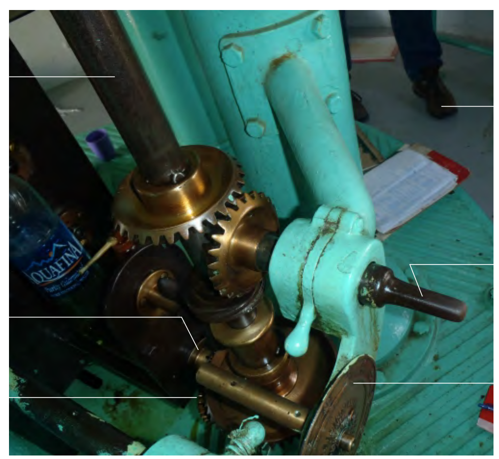
Maker's insigne
(near winding shaft, right;
at level of man's waist, p. 8)

CHANCE BROTHERS AND CO.
LIMITED
LIGHTHOUSE ENGINEERS
& CONSTRUCTORS
NEAR BIRMINGHAM

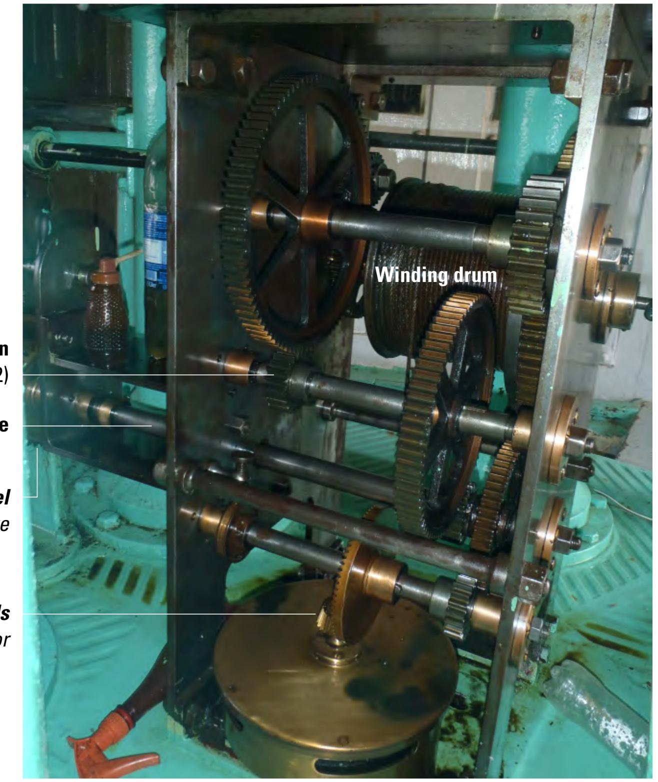
MANUFACTURER'S NOTES in Chance Brothers and Co., Limited (1910, p. 55, 56) are paraphrased and quoted on this page.

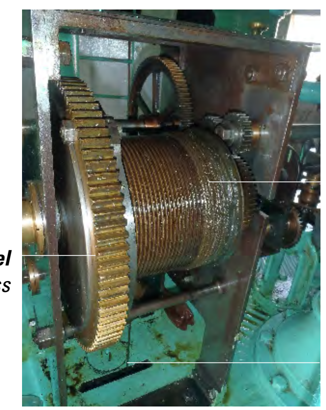
Stabilizing rollers

Vertical shaft



Gear wheels, horizontal shafts, and winding drum





Wheel types in italics *correspond to replacements logged in 1946 (p. 12)*

Mechanical repairs and toxic vapor

SEISMIC SHAKING in Manora Lighthouse caused little if any damage to the hyper-radial clockwork, as judged from repairs logged in a Karachi Port Trust notebook. Mechanical problems both precede and follow the earthquake without being linked to the earthquake itself. A major overhaul in 1946 likely began in 1944, given clockwork history inferred at right. If, as stated by *Daily Gazette* of November 29, 1945, “a certain portion of the lighthouse machinery” was “reported to have been put out of commission by the shock,” the problem went unreported in the KPT notebook.

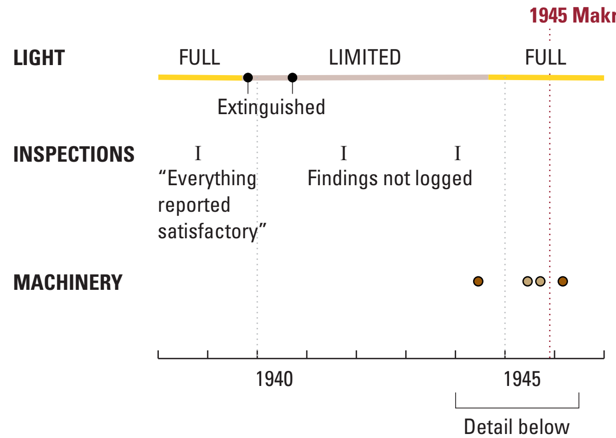
Compilers of this folio found no description of the mercury spill as a health hazard. Inhaled mercury vapor is widely recognized in the 21st century as a nervous-system poison. From an earlier time, the notebook simply reports that “much” of the mercury spilled “was collected.” Neither the notebook nor the newspapers mention precautions against mercury inhalation, whether from acute exposure during cleanup or chronic exposure to vapor from residual liquid.

THE MERCURY was held in an annular trough (p. 8, 10), or bath. A mercury spill of 35–40 pounds (15.9–18.1 kilograms) amounts to 1.2–1.3 liters given a specific gravity of 13.6 kilograms per liter. By the same token, a mercury refill of 762 pounds (346.4 kilograms) is equivalent to 25.4 liters of the liquid metal—under 5 percent of the trough's capacity (p. 10).

MERCURY VAPOR can cause “tremors, emotional changes (such as mood swings, irritability, nervousness, excessive shyness), insomnia, neuromuscular changes (such as weakness, muscle atrophy, twitching), headaches, disturbances in sensations, changes in nerve responses, poor performance on tests of mental function;” and a national response center is to be alerted about any mercury spill in excess of one pound (U.S. Environmental Protection Agency, 2019a, 2019b). In the era of the 1945 earthquake, laboratory scientists were said to be handling mercury carelessly (Giese, 1940), mercury vapor was implicated in nervous-system disorders among London repairmen of devices containing mercury floats (Lesley Bidstrup and others, 1951), and thresholds for mercury poisoning were being estimated by exposing laboratory animals to the vapor (Ashe and others, 1953).

LIGHTHOUSE RESPONSIBILITIES in British India were variously divided between local authorities and the central government under a 1927 law (Directorate of Lighthouses & Lightships, 1986). Notebook entries suggest that KPT maintained the Manora light with oversight by, and assistance from, engineers with the central government. The logged inspections were made by A.N. Seal (October 24, 1938 and September 29, 1941) and S.K. Lahari (January 20, 1944). The government lighthouse board was headed by Mr. Seal in 1939–1949 and by Mr. Lahari in 1949–1964 (Bhanti, 2003, pdf p. 7).

Manora Lighthouse events logged 1938–1946 in a Karachi Port Trust notebook

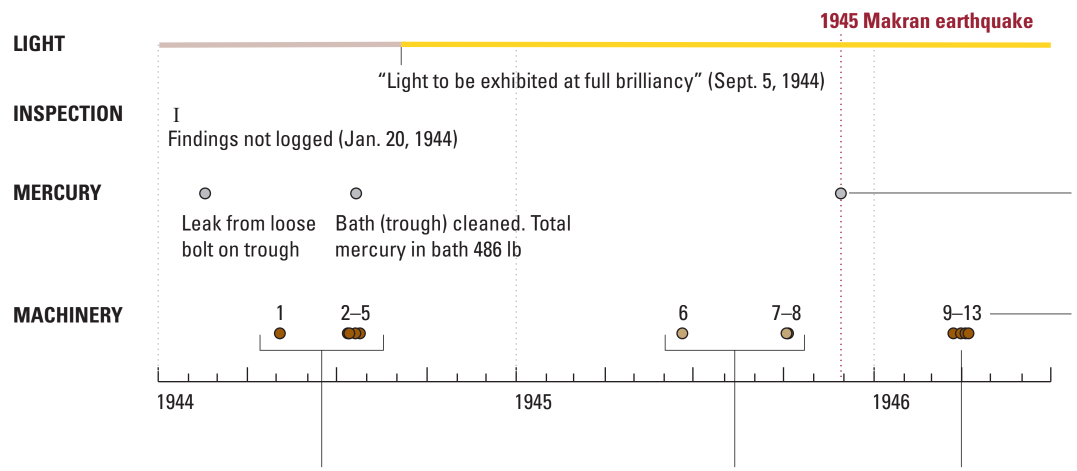


Wartime restrictions variously limited the brightness of the light, allowed it to be exhibited for aircraft and an expected vessel, and extinguished it altogether.

An inspection in October 1938 is said to have turned up no problems. Two later inspections, in 1938 and 1941, were logged without comment.

Clockwork was replaced in its entirety ● in 1944 and 1946, and was partly repaired ○ in 1945 (details below).

Details from entries of January 1944 – June 1946



“NEW” AND “OLD” MACHINES May–July 1944

1 “Removed the new machine and fitted old machine” (May 4)
2 “Government Eng. arrived to examine new machine” (July 12)
3 “Removed old machine Govt. altered clock work machine fitted not working satisfactory”
4 “Govt altered clock work machine working satisfactory” (July 20)
5 “Govt Eng. left machine working satisfactory”

REPAIRS June and October 1945

6 “Fitted new brass bushes to barrel shaft. Working OK” (June 20)
7 “Light Keeper again reports machinery not working properly, flashes are now 10 to 12 secs. Bushes found badly worn” (Oct. 4)
8 “After full night of work seven new bushes fitted are found satisfactory, & the light working at the correct time, i.e. 7 ½ secs” (Oct. 6; “Fl. ev. 7 ½ sec,” p. 9)

“OUR RECONDITIONED MACHINE” AND “GOVT.” MACHINE March and April 1946

9 “Lighthouse engineers arrived from Bangalore to fit our reconditioned machine” (March 23)
10 “Work commenced” (March 31)
11 “Machine installed and govt. one removed” (April 1)
12 “Running satisfactorily. The following has been done to our machine at Bangalore: — All the journals skimmed and the spindles trued up. New gear wheels (ten) made and fitted. Large pair of gunmetal beval [bevel] wheels for the main drive. One pair of beval wheels for the governor. One gunmetal wheel for the winding drum. Five mild steel pinions. Machine lined up” (April 5)
13 “Lighthouse engineers departed” (April 8)

Mercury spill caused by the 1945 earthquake

LOGBOOK (p. ii) “Earth Tremor occurred at 0330 Hrs. causing mercury in bath to be dislodged. About 35 to 40 lbs of mercury was spilt, so much of this was collected, the bath cleaned, & and an additional 12 lbs - 8 oz added, making a total of 762 lbs of mercury in the bath” (Nov. 28).

TIMES OF INDIA “After the shocks, the crew up on the lighthouse found that a considerable quantity of the mercury on which some of the delicate machinery floats spilled over the tray on to the concrete floor. Its weight was found to be over 30 pounds.” (Nov. 30)

Inferred history of clockwork repair and replacement

Karachi Port Trust shared responsibility for Manora Lighthouse with the colonial Indian government. Government engineers, after a 1944 inspection, tuned up a “new machine” (entries 1, 2) the government had likely supplied. This clockwork underwent pre-earthquake repairs in 1945 (6–8) while the “old machine” (1, 3)—“our machine” to KPT (9)—was overhauled 1,700 km distant in Bangalore (12). “Our machine” replaced the “govt. one” in 1946.

Impaired tide gauge

WATER LEVELS RECORDED by the Karachi tide gauge, at the end of a Manora pier, rose and fell smoothly most days from November 15 to December 1, 1945. On November 28 and 29, however, water levels fluctuated more abruptly, mainly in the first twenty-four hours after the great earthquake.

A ten-hour section of this Karachi marigram has gained use as a guide to sources of the 1945 tsunami. Underwater faulting and submarine slides have been tested by comparing computer models with water levels gauged at Karachi, and with a companion record from Bombay (Mumbai).

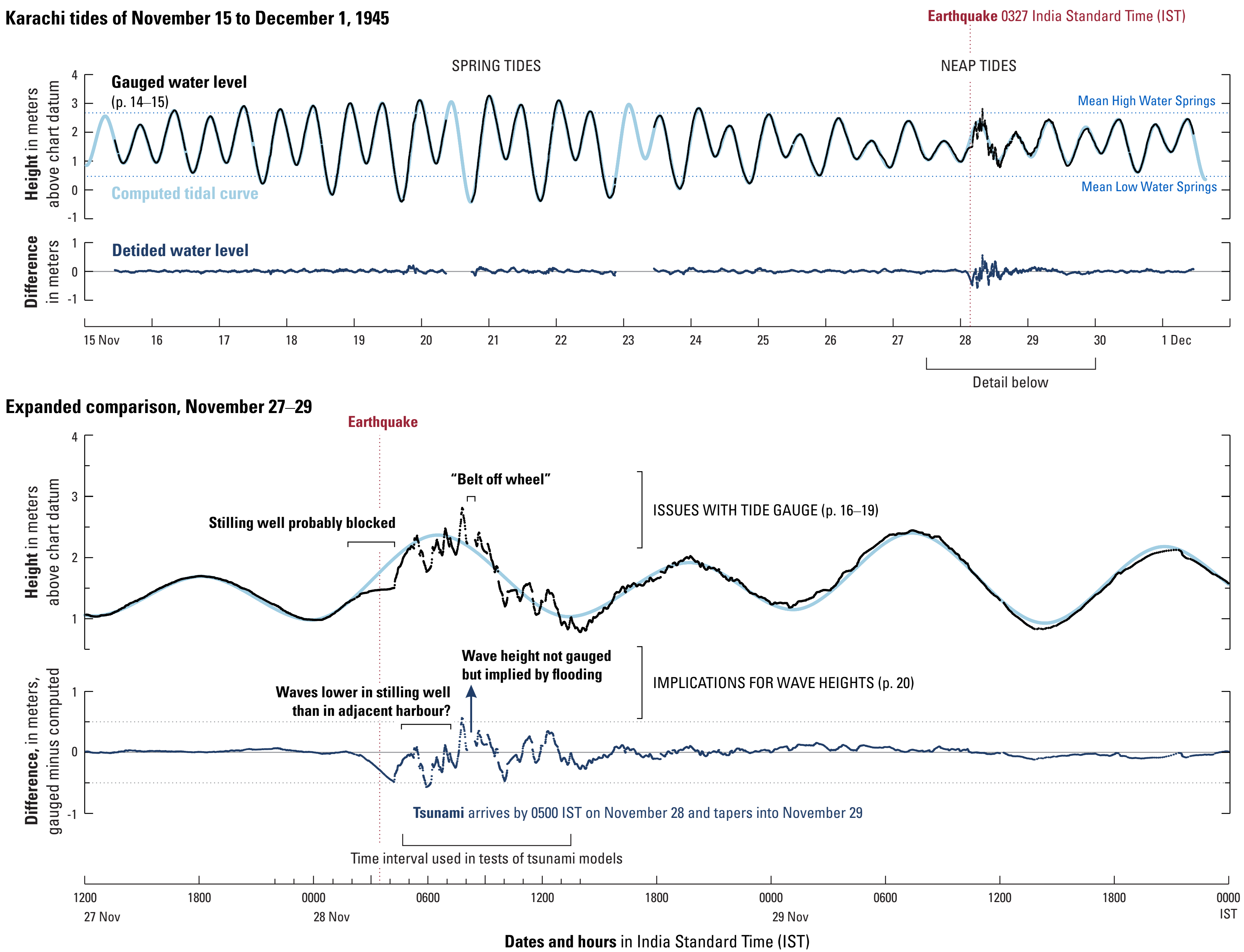
Highlighted on these pages are two underlying problems with the Karachi marigram. First, the gauged water levels lag behind a rising tide at the time of the earthquake. Obstruction of the gauge's stilling well most simply explains this lag (p. 16–17), whose continuation may have held down the gauged level of the first few tsunami waves (p. 20). Second, the tsunami caused a later mechanical outage that lasted nearly one-half hour (p. 18–19), and which probably coincided with the greatest tsunami flooding nearby. The outage leaves accounts of that flooding as the main guide to the largest wave of the 1945 Makran tsunami at Karachi (p. 20).

THE GAUGED WATER LEVELS at right are based on the marigram on page 15. They were introduced in part by Neetu and others (2011), and they have been digitized and tabulated in full by Adams and others (2018, Additional file 4, Table S1) and Survey of India and others (2019).

THE COMPUTED TIDAL CURVE is guided by high waters and low waters predicted in Admiralty tide tables (Hydrographic Department, 1944, p. 106) and by waters and low waters gauged outside the time of the tsunami, November 28 and 29 (Adams and others, 2018, Additional file 2, Appendix A). The computed curve is independent of the tide-gauge record from November 28 and 29.

THE DETIDED LEVELS are from Adams and others (2018, p. 10–12).

SUBMARINE LANDSLIDES during or soon after the great 1945 Makran earthquake have been invoked to explain the largest tsunami waves at Pasni and Ormara (locations, p. 2, 7). The inferred slides are evidenced most directly by submarine cable breaks between Karachi and Muscat (Ambraseys and Melville, 1982, p. 90). Combinations of tectonic and slide sources have been found necessary in most computer simulations (Heidarzadeh and others, 2008; Rajendran and others, 2008; Rastogftar and Soltanpour, 2016; Heidarzadeh and Satake, 2017). A purely tectonic source was inferred by Neetu and others (2011).



Instrumental record

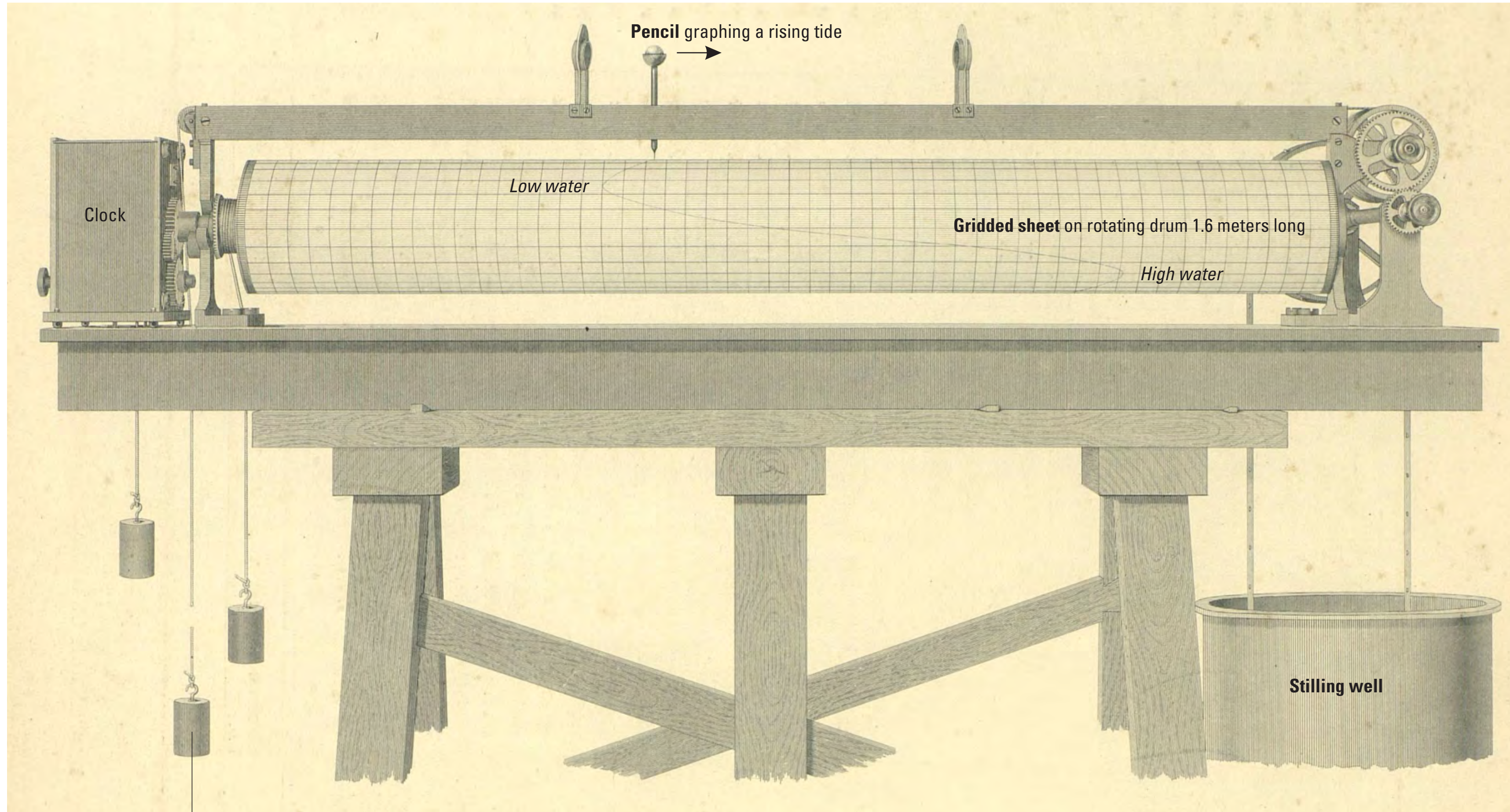
ROUTINE GAUGING of Karachi Harbour tides began in 1868. By 1881 the tidal observatory was situated near the end of a Manora pier. A "Tide Gauge" is labeled there on nautical charts and topographic maps into the early 1950s (p. 5, 6, 16).

The apparatus in operation in 1945 probably resembled the standard model at right. The sea is calmed in a cylindrical stilling well. As water levels rise and fall inside the well, the motion is communicated mechanically "to a pencil which traces a line on paper wound round a drum turned by clockwork once in twentyfour hours."

A gridded sheet 1.56 meters long records the 1945 tsunami among Karachi tides that were gauged between November 15 and December 1 (p. 15; excerpts, p. 17, 19). Time is lithographed in hours. Heights added in pencil (p. 17) probably refer to a nautical-chart datum (p. 16). Twice-daily inspections are evidenced by ink circles that mark pencil positions (examples labeled, p. 19). Outages spanned nine hours on November 20 (p. 13; endpoints labeled, p. 15, 19) and nearly fourteen hours on November 22–23 (p. 13).

Shorter gaps interrupt the record from the day of the earthquake, November 28. The first contains an "out of order" note early in an anomaly that probably resulted from blockage of the stilling well (p. 16–17). Two later gaps were likely caused by the 1945 tsunami itself (p. 18–19).

Self-registering gauge of the type evidently in use at the Karachi tidal observatory in 1945



Clock rotates drum.

Weight moves pencil holder to the left when rightward pull is relaxed by falling water levels.

Leaving paper on drum for 17 days produced a spaghetti of tidal curves that were later inked for analysis (p. 15).

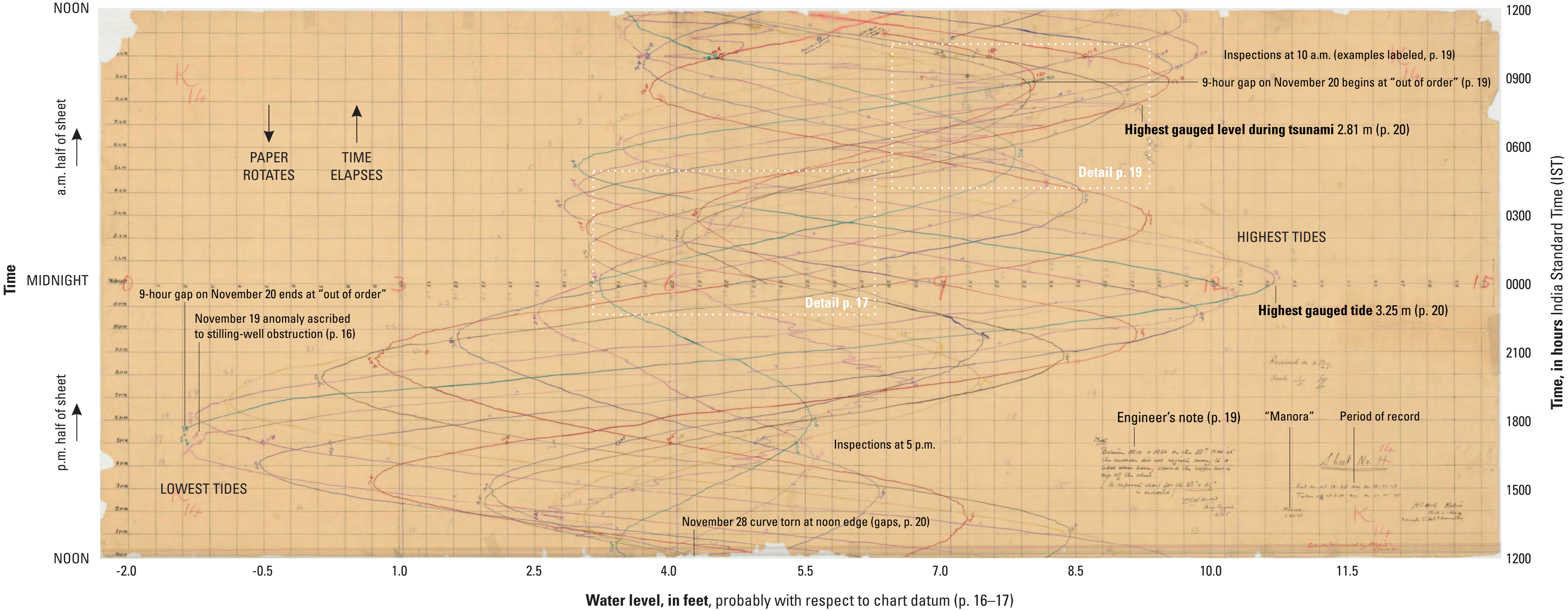
Rising tide pulls pencil to right by raising float in stilling well. Float is linked to pencil by perforated belt, gears, and wire (p. 18).

GAUGE HISTORY after Hogarth (2014, p. 7651; 2016, p. 3–6).

DRAWING from monograph of Eccles (1901a, 1901b), as are the overview quoted (1901a, p. 9) and operational details (1901a, p. 21). That the marigram on page 15 was graphed on a similar tide gauge is evidenced by the sheet's dimensions (1.562 m by 0.615 m in a Survey of India scan), gridding, and note about a belt being thrown off a wheel (p. 18).

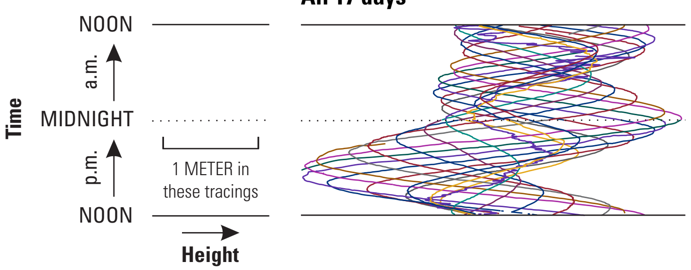
INKING OF THE CURVES is considered further on page 4 of Adams and others (2018) and on page 6 of that paper's Appendix C. Inspector's circles are lacking along the November 28 curve. The circle color for the other sixteen days matches the curve color. The curve inking is accurate enough to have taken place on a flat surface, after the sheet had been taken off the revolving drum. Inking of originally pencil curves is evidenced on the marigram (p. 15, 17, 19) by apparent show-through where ink is faint, divergence of gray pencil lines from color ones, variation in color line width and intensity, and overlap of colors at the midnight line.

Inked curves from 17 days, November 15 to December 1, 1945



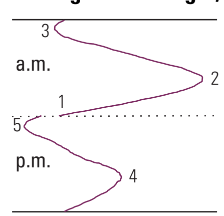
Traced versions of those inked curves

All 17 days



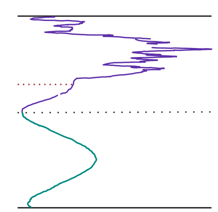
The gauged water levels on page 13 were digitized from these tracings after they had been rotated, reversed, and ordered by date. The tracings farthest right illustrate these transformations for parts of November 27 and 28.

Midnight to midnight, November 26

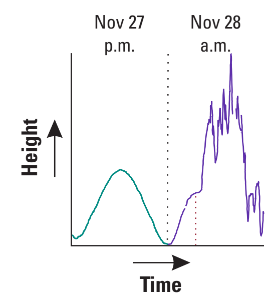


November 26 begins (1) on the a.m. half of the sheet with a rise to a morning high water (2). A low water close to noon (3) is followed, on the sheet's p.m. half, by an afternoon high water (4) and by a low water (5) close to the next midnight.

Noon to noon, November 27 and 28



Smoothly varying water levels late on **November 27** continue across midnight into a rising tide early on **November 28**. Anomalies begin shortly before the earthquake and continue as tsunami waves ride a morning high water.



Stilling well subject to fouling

MERCURY HAD YET TO SPILL in Manora Lighthouse when the nearby tide gauge, in shallow water, began recording a November 28 anomaly that was probably artificial.

This early anomaly indents the rising limb of a neap high tide between 0200 and 0415 IST (marigram excerpt, p. 17; traced, p. 13 and at right). First, the gauged water level, instead of continuing a normal rise, gradually levels out, then rises abruptly. An "out of order" is written through a gap in this part of curve. Detided, the anomaly stands out as a steady drop of one-half meter that segues into fluctuations of the tsunami wave train (p. 13, "Differences" graphs).

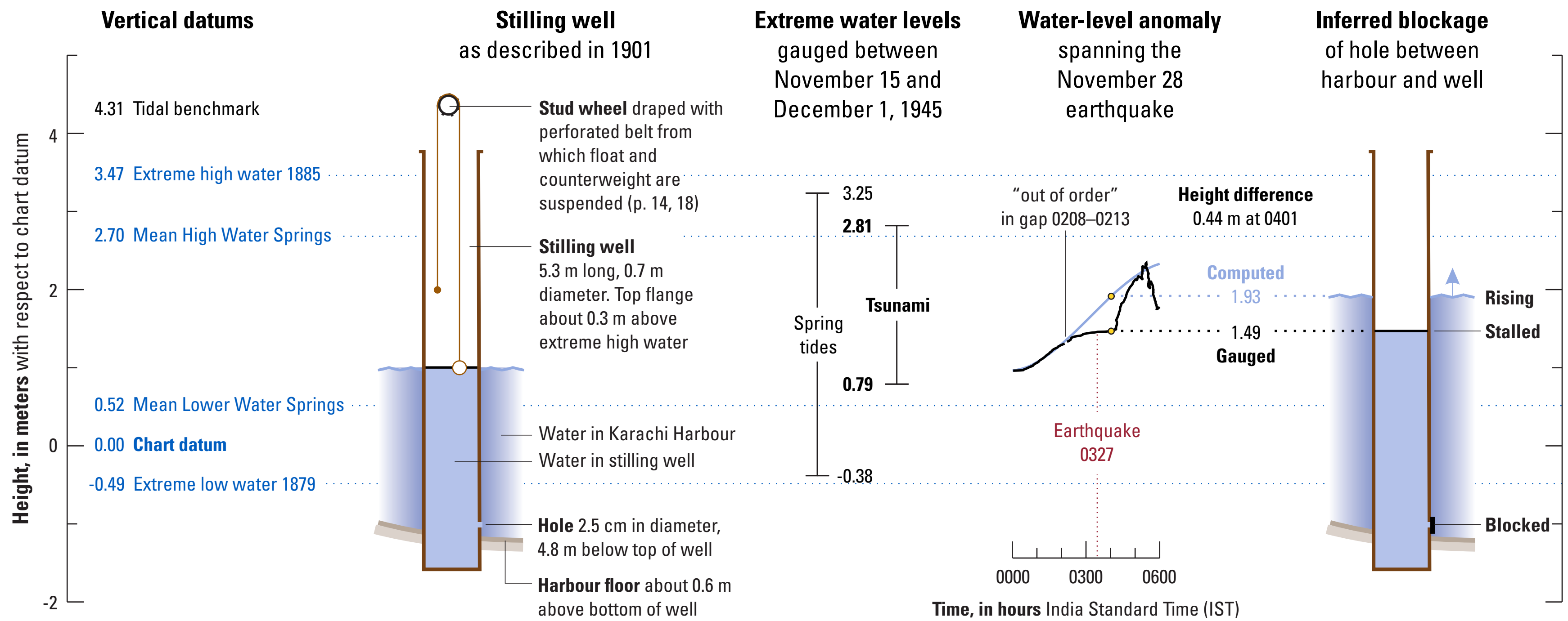
The anomaly can be explained most simply by obstruction of hole through which sea water ordinarily entered and exited the stilling well at Manora. Reported plans place this hole a half meter above a well bottom that was to extend about that far into sediment (sketch, upper right). A 1901 report tells of obstruction by mollusks and sediment infilling. A later report recounts the hiring of a diver, in 1922, to remove mud that had built up around the stilling well. These problems likely persisted into the 1940s: as surveyed in 1933, a tidal flat adjoins the tide gauge (right).

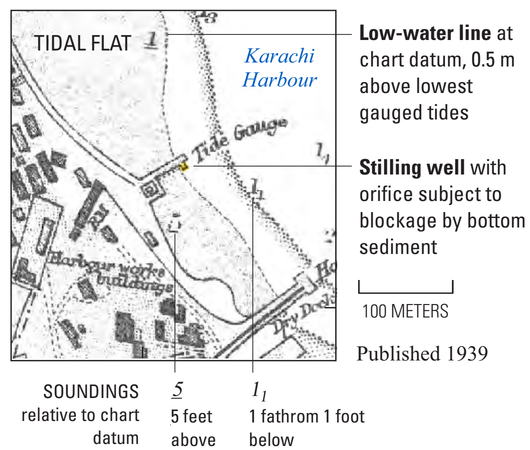
The early anomaly has been judged comparatively difficult to explain as an oceanographic effect of fair weather, or as a tsunami from faulting or slope failure during the last hours before the great earthquake.

REPORTED DIMENSIONS of the Karachi stilling well include one foot of freeboard above the highest tides (Eccles, 1901b, p. 9). A cyclone "carried away" and "wrecked" unspecified parts of the Karachi tidal observatory on June 6, 1907. The structure was soon being "re-erected" (Survey of India, 1908, p. 6, 28) and gauging resumed (Survey of India, 1909, p. 33).

VERTICAL DATUMS reported by Eccles (1901b, p. 10) were updated by Hydrographic Department (1944, p. 293), U.S. Coast and Geodetic Survey (1944, p. 357), International Hydrographic Bureau (1966, sheet 123), and Permanent Service for Mean Sea Level (2016). Chart datum served also as the zero for the Karachi tide gauge 1932–1948 and for predictions in Admiralty tide tables of that era.

A PRECURSORY TSUNAMI and weather are interpreted in Adams and others (2018, Appendix C, p. 9–11) as unlikely causes of the early anomaly.





Instrumental artifacts reported and inferred

1881–1901 Karachi
"Registrations commenced on the 1st January 1881 and have been highly satisfactory, though occasionally the curves have slight imperfections due to shell fish blocking the communication [hole]; and in 1892 silt accumulated [in the stilling well] to such an extent that extreme high and low tides were not properly indicated, owing to the float at extreme low water and the counterpoise at extreme high water resting on the accumulation, which was removed in January, 1893."

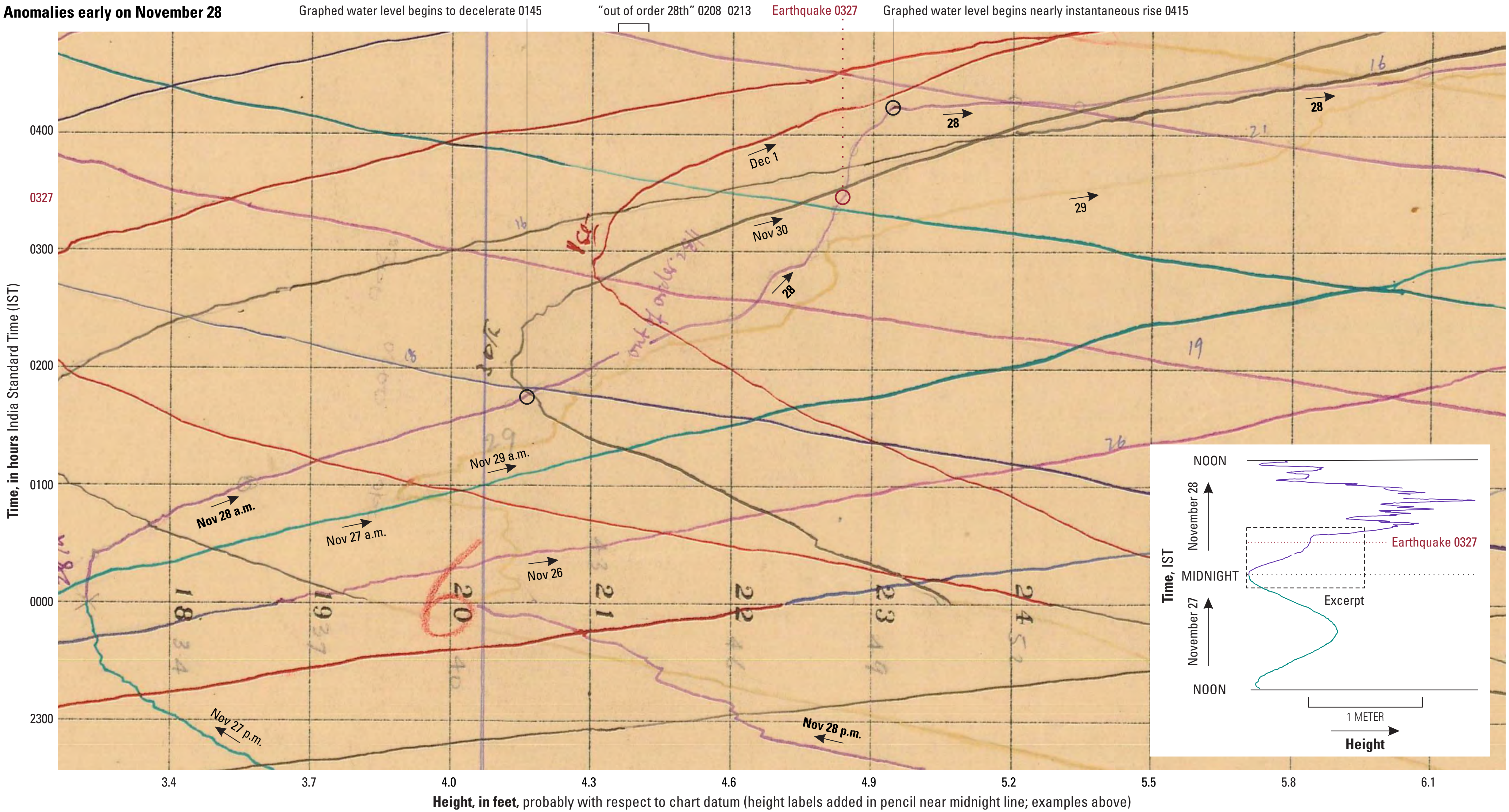
1921–1922 Karachi
"There were two interruptions during the past year owing to the communication hole in the cylinder being blocked with mud. A diver was employed on the 14th January and again on the 15th and 16th March 1922, to remove the mud which had accumulated round the outside of the cylinder."

1944–1945 Bombay
The tidal observatory at Apollo Bandar, Bombay was inspected annually "by the Port Trust Surveyor" in 1940–1947. Multiple-day outages were reported to have been caused by "silt in the well" in June and July 1944 and in June 1945, by "some obstruction in the well" in August 1944, and by "some unknown obstruction" in March 1945.

1945 Karachi
The marigram of November 15 to December 1 (p. 15) contains, from November 19, a diminutive of the two-part anomaly graphed above—anomalous slowing of a rising tide, followed by an anomalously rapid rise. The first part of the November 19 anomaly falls short of a computed tide by a maximum of 0.09 m, at 1947 hours IST. The second part crests two hours later 0.19 m above the computed tide.

STILLING-WELL PROBLEMS quoted above are from Eccles (1901b, p. 9), Survey of India (1924, p. 52), and Survey of India (1948, p. 88–89). The November 19, 1945 anomaly at Karachi is displayed at large scale in Figures C2 and C3 of Adams and others (2018, Appendix C).

Anomalies early on November 28



"Belt off wheel"

A MECHANICAL CONNECTION between water level and graphing pencil at the Karachi tide gauge was briefly disabled by the 1945 tsunami.

Ordinarily, changing water levels in the stilling well turned wheels on the gauge by means of a perforated copper belt. Water levels changed gradually enough for holes in this belt to remain engaged with studs on a wheel. The stud wheel turned gear wheels that controlled the graphing pencil (mechanical drawings, p. 14 and right).

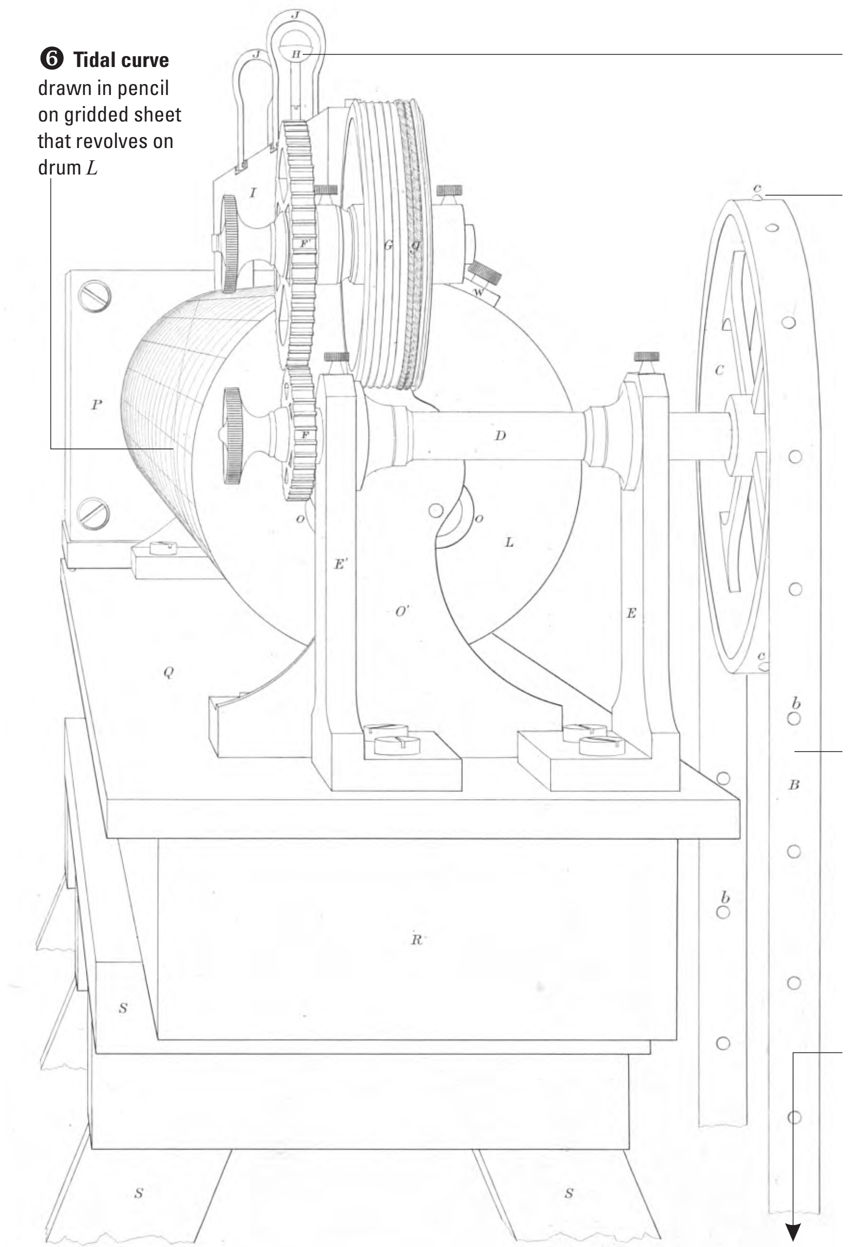
An engineer's note on the marigram evidently refers to the perforated belt and the stud wheel. The note, reproduced at far right, concerns a gap soon after 0800 (❶, p. 19). The writer, David B. Brow (p. 5), attributes this gap to a "tidal wave" that "caused the copper belt to slip off the wheel."

Not mentioned in the note are two further problems with the marigram for November 28—the probable artifact between 0145 and 0415 (p. 16–17), and a brief gap between 0908 and 0910 (❷, p. 19).

Gaps ❶ and ❷ may have each coincided with sudden interruption of a fall in water level. Though each follows and precedes times of rapid decline, each coincides with a net rise. Perhaps abrupt reversal of rapid drawdown lifted or twisted the belt at the stud wheel.

The outage ❶ described in the engineer's note probably left the Karachi gauge offline when the tsunami there was reaching its highest level. The *Times of India* reported four "tidal waves" at Karachi. The first was observed at 0530 ❶; the second, "larger," at 0700 ❷; the third around 0750 ❸; and the "biggest" around 0815 ❹. The first three of these times align with peaks in gauged water level between 0500 and 0800. But nothing on the marigram, other than an outage that the tsunami caused, corresponds with the "biggest" wave (p. 19, 20).

Mechanical connections between water level and graphing pencil



❻ **Tidal curve** drawn in pencil on gridded sheet that revolves on drum *L*

❺ **Pencil holder** *H* moved by chain *g* in slide centered over drum. Pressed down on paper by weight in cup.

❸ **Stud** *c* on **wheel** *C* engages with hole *b* in perforated belt *B*.

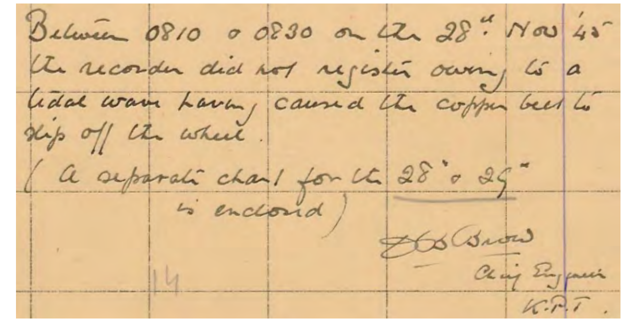
❹ Axle *D* of **stud wheel** *C* drives toothed wheel *F*, which turns toothed wheel *F'*. Diameters of *F* and *F'* control height scale of graph. Chain wheel *G*, on axle of *F'*, controls pencil holder by pulling chain *g* while tide rises and relaxing chain while tide falls. Weight below far end of drum maintains tension on pencil holder during ebb tides (p. 14).

❷ **Perforated belt** *B*, a copper band, turns stud wheel *C* in response to rise and fall of float in stilling well.

❶ **Stilling well** (p. 14, 16) contains float that usually rises and falls with water levels outside. Float is attached to perforated belt *B*. Well damps waves and wake.

GAUGE DESIGN from Eccles (1901a, p. 9–12), with the diagram cropped from his plate II.

Mechanical failure caused by tsunami



Between 0810 & 0830 on the 28th Nov '45
the recorder did not register owing to a
tidal wave having caused the copper belt to
slip off the wheel.

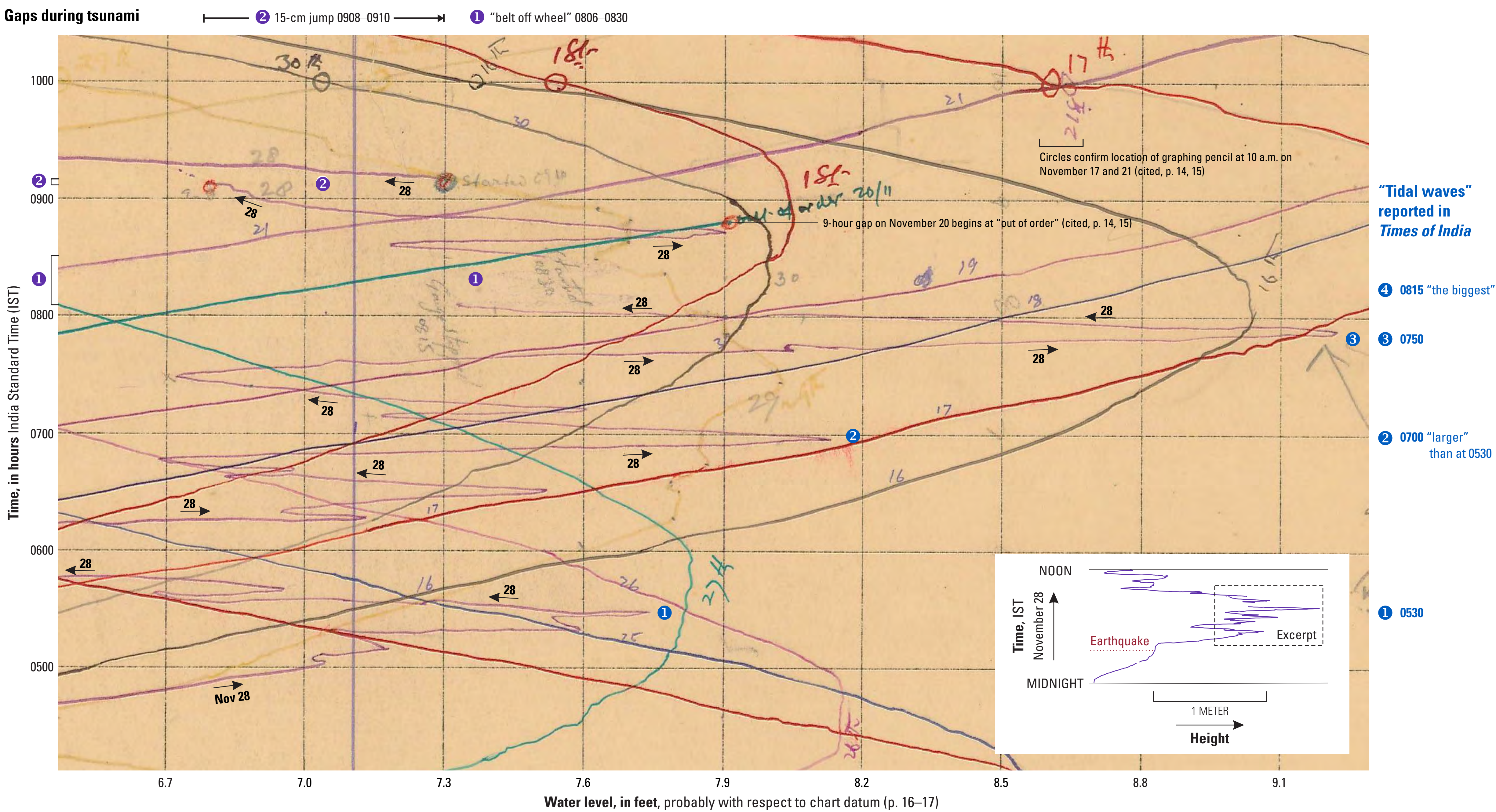
(a separate chart for the 28th & 29th
is enclosed)

DB Brow
Chief Engineer
K.P.T.

The **outage began** between 0806 and 0815 according to linework and lettering, respectively, on the marigram (❶, p. 19).

The **"separate chart"** is a one of the the documents that could be sought to clarify the Karachi record of the 1945 Makran tsunami (p. 40).

David B. Brow was Chief Engineer of Karachi Port Trust in 1937–1945 (photo, p. 5).


Gaps during tsunami
2 15-cm jump 0908–0910
1 "belt off wheel" 0806–0830
Circles confirm location of graphing pencil at 10 a.m. on November 17 and 21 (cited, p. 14, 15)
9-hour gap on November 20 begins at "out of order" (cited, p. 14, 15)
"Tidal waves" reported in *Times of India*
4 0815 "the biggest"
3 0750
2 0700 "larger" than at 0530
1 0530
Time, in hours India Standard Time (IST)
1000
0900
0800
0700
0600
0500
6.7
7.0
7.3
7.6
7.9
8.2
8.5
8.8
9.1
Water level, in feet, probably with respect to chart datum (p. 16–17)
Nov 28
28
NOON
MIDNIGHT
Time, IST
November 28
Earthquake
Excerpt
1 METER
Height

Wave arrivals and heights

THE TIDE GAUGE AT MANORA probably succeeded in clocking two initial tsunami waves but not in measuring their full heights, and it missed the highest wave altogether.

The marigram accords with the *Times of India* in placing the tsunami's first positive wave crest ❶ in Karachi Harbour two hours after the great earthquake. This delay, in computer models, provides enough travel time for the tsunami to have begun during the earthquake with seafloor displacement offshore Pasni and Ormara (modeling cited, p. 13; map, p. 7).

The tsunami record begins, however, with with the early anomaly that is discounted above as a probable artifact of an obstructed stilling well. Continuation of this anomaly may explain why waves ❶ and ❷ barely emerge above the computed tide. That is, blockage that began before the earthquake may have held down the water levels that these two waves attained inside the stilling well.

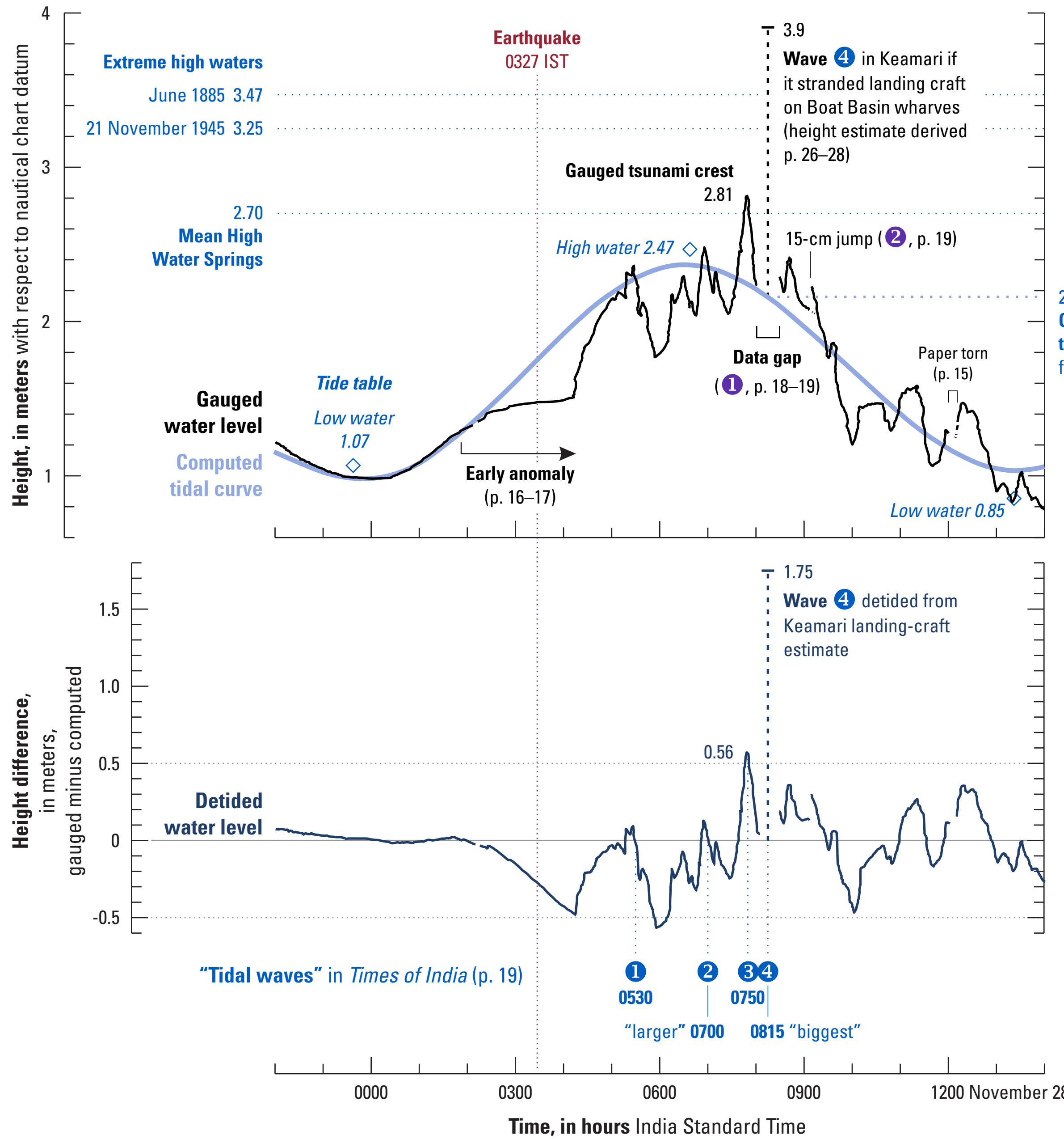
If the anomaly ended before the wave crest at 0750 ❸, its crest height of 2.81 meters represents the highest gauged level of the tsunami. That level exceeds the computed neap tide by little more than one-half meter, while falling short of the highest spring tides gauged one week before (p. 28).

The marigram is clouded most by the data gap that probably coincides with the "biggest" Karachi wave reported in the *Times of India* (❹; p. 18–19). This wave, where it overtopped surfaces above most or all high tides, surpassed the gauged level of the 0750 wave and probably accounts for peak heights estimated previously (right). The folio now turns to field evidence for peak water levels attained during the "belt off wheel" outage of wave ❹.

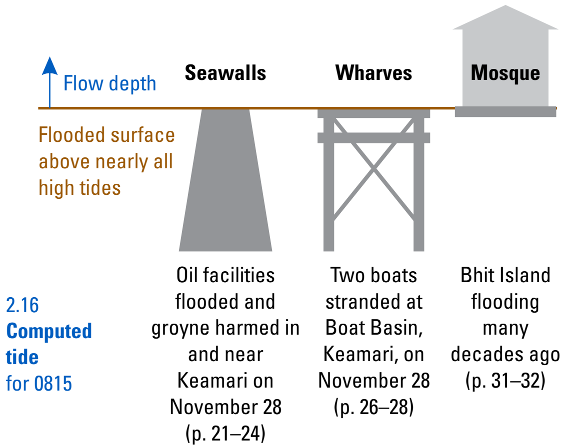
THE GRAPHED WATER HEIGHTS are adapted from Adams and others (2018). The graphed water level is a tracing of the marigram on page 15. The computed tide and detided heights are drawn manually through points from Table S1 of Adams and others (2018). Numerical values reported are from their Tables S1 and S2.

THE EXTREME HIGH WATER of June 1885 was reported by Eccles (1901b, p. 10). The Mean High Water Springs datum and the tide-table predictions for November 27 and 28, 1945 are from Hydrographic Department (1944, p. 106, 293)

Tide-gauge record



Reported flooding
attributable to wave ❹



OTHER ESTIMATES of tsunami heights for Karachi, excluding the tide-gauge record, are consistent for the most part with maximum heights 1.5–2.0 meters above chart datum:

"Nearly twelve feet"—The *Sind Observer* of November gave this figure without naming a place or datum. If estimated with respect to the partly gauged trough between waves ❸ and ❹, the figure implies a height approaching approaching 4 meters detided. If instead the reported water level refers to chart datum, the height becomes about 1.5 meters detided.

Biggest wave "4 1/2 feet above normal"—Pendse (1946, 1948) gave this detided figure in replicate summaries of the 1945 earthquake. If his "normal" refers to a 2.2-meter tide computed for 0815, adding 4 1/2 feet, or 1.4 meters detided, brings the water level to 3.6 meters above chart datum. Pendse may have adapted the *Observer*'s "nearly twelve feet" (nearly 3.7 meters) by assuming that it was referenced to chart datum.

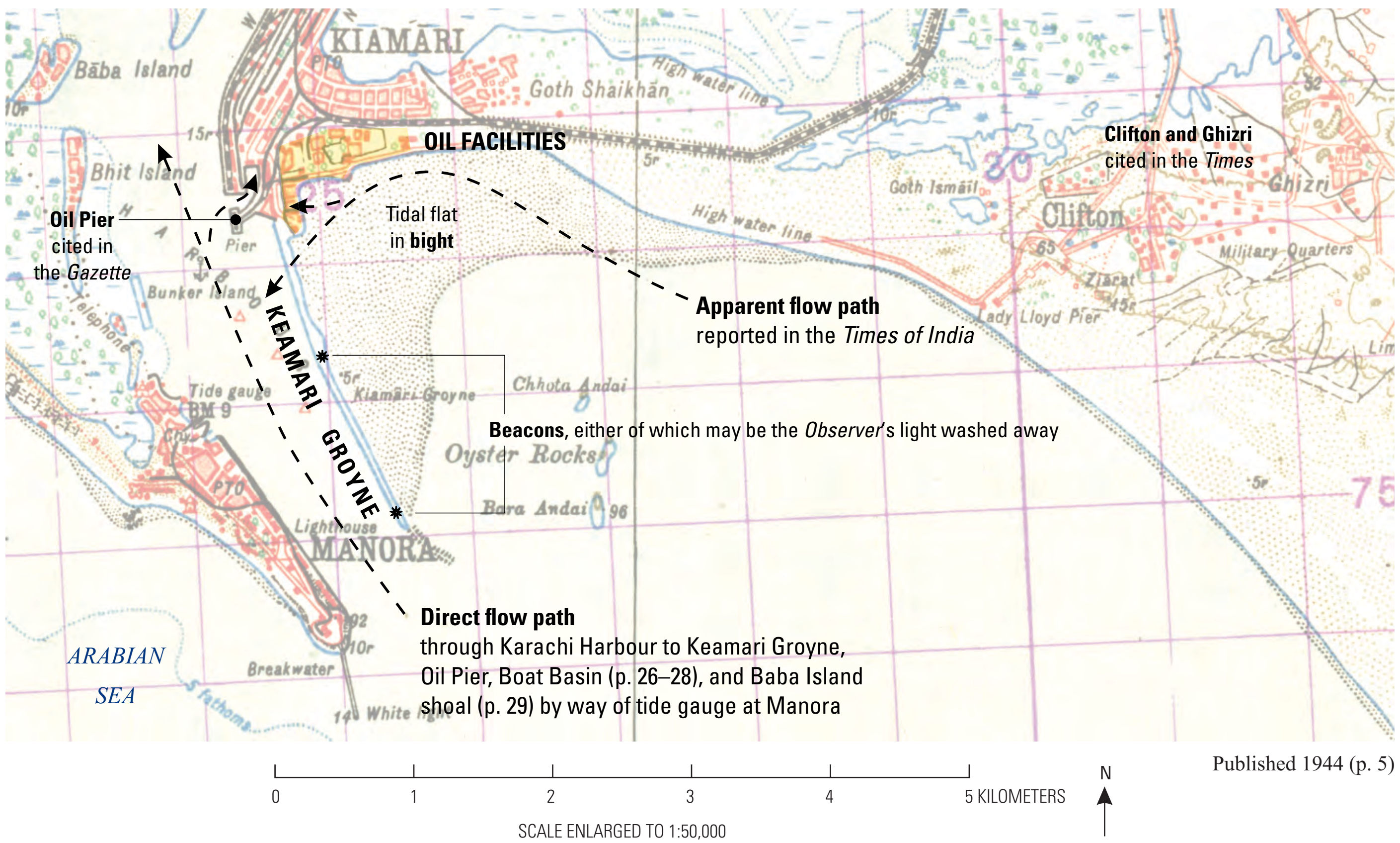
"Height on land of about 1.5 metres"—The authoritative earthquake catalog of Ambraseys and Melville (1982, p. 90) stated, without citing supporting evidence, that "waves" reached onshore heights "of about 1.5 metres." An earthquake catalog from 1982 gives this estimate without attribution. If the "land" begins at Mean High Water Springs, the corresponding minimum height is 4.2 meters above chart datum, or about 2 meters detided upon subtraction of the computed tide for 0815.

Overrun seawalls

THREE DAILY NEWSPAPERS—one published in Bombay, the others in Karachi—reported that the 1945 tsunami overtopped seawalls in and near Keamari. In each account, oil facilities at Keamari are said to have been flooded along with Keamari Groyne or its probable equivalent (right).

The accounts do not explicitly relate the flooding to flows that ran northward up Karachi Harbour by way of the tide gauge at Manora. To the contrary, according to a wire-service story in the Bombay-based *Times of India*, a tidal wave "appeared" to have come from the east and to have "burst" westward over northern Keamari Groyne. In that case the flood waters may have built up in the bight bounded by oil installations on the north and the groyne on the west. The Karachi dailies are silent on this possibility, except that the *Daily Gazette* locates the flooded oil facilities "at" the Oil Pier in Karachi Harbour. The *Sind Observer* reports loss of a beacon on Keamari Groyne without saying which one.

Whatever its exact locations, the reported overtopping required water levels above those of high tides that the seawalls blocked. This excess height affords rough estimates of water levels the tsunami attained on the south shore of Keamari (p. 22–25).



Published 1944 (p. 5)

Newspaper reports

The Sind Observer *November 29*

"The earthquake shock at 3-30 a.m. yesterday, it is learnt, caused an abnormal disturbance in the waters as a result of which nearly 400 feet of groyne—the low broad wall running out of Keamari to check drifting of breach and so stop encroachment of sea—along with a beacon light standing on it, were washed away at about 8 a.m. by the tide which rose nearly twelve feet high.

"The groyne, it is learnt, was under repairs and its washing away would necessitate its building a new [*sic*] with better materials calculated to stand the force of constant currents and the wear of sea-water.

"As a result of the abnormal rise of tide, the compound of the Burmah-Shell Installation at Keamari was flooded."

low broad wall running out of Keamari to check drifting—Only the *Observer* locates Keamari Groyne accurately. The groyne directed and confined tidal currents (p. 4).

a beacon light—Location of northern candidate corrected on map updated to 1949 (p. 24).

nearly twelve feet high—Meaning depends on vertical datum (p. 20).

the compound—Burmah Shell likely used multiple tracts at Keamari (p. 22–23).

The Daily Gazette *November 29*

"Four hundred feet of the groyne linking Karachi with Manora Island, which guards the entrance to Karachi harbour, is stated to have been damaged by a tidal wave which accompanied the earthquake this morning. Keamari, the harbour of Karachi, probably received the worst shock—the Burmah Shell and other installations at the Oil Pier having been flooded at eight o'clock this morning by the seawater due to the tidal wave, as an aftermath of the earthquake shock."

linking Karachi with Manora Island—The headline of this story reports damage to "Keamari Groyne" (p. 2). No groyne linked Karachi with Manora (p. 6).

at the Oil Pier—Connotes flooding by direct path up Karachi Harbour, consistent with stranding of landing craft on Boat Basin wharves (p. 26–28).

The Times of India *November 30*

"The tidal wave, which appeared to have come from the direction of the village of Ghizri and Clifton, ran along the side of the oil installations at Keamari, flooding certain adjoining compounds in that area, and eventually burst over the shore end of the east groyne at Manora."

eventually burst over the shore end of the east groyne at Manora—Keamari Groyne was the east groyne of Karachi Harbour. The East Pier continued this rock wall southward (maps, p. 4, 6, 24). The combined wall, and Karachi Harbor itself, stood in the westward path reported in the *Times*.

KARACHI'S ENGLISH-LANGUAGE DAILIES included the *Sind Observer* and the *Daily Gazette* (Barns, 1940, p. 427). The *Times of India*, published in Bombay, used Karachi reporting by Associated Press of India, which had a Karachi office in the early 1940s (Sharma, 1954, p. 6). The byline on the *Times* story reads A.P.I.

A LOW WESTERN GROYNE ran from Bhit Island to Manora according to British Admiralty chart 40. No such wall appears on Survey of India topographic maps.

Flooded oil facilities

WATER LEVELS above extreme high tides are estimated on this page for flooding of the south shore of Keamari by a tsunami wave that takes the roundabout, east-to-west flow path reported in the *Times of India*.

The areas flooded probably include at least one of those shaded yellow in the map at right. These areas were controlled around 1940 by Burmah Shell (p. 23), whose Keamari facilities the tsunami entered according to the *Daily Gazette* and the *Sind Observer* (p. 21). Two of the areas adjoin a road apparently atop a seawall, a third adjoins a seawall directly, and all three front on the bight into which a “tidal wave” apparently flowed, according to the *Times of India* (p. 21).

To surmount these engineered shorelines the tsunami in the bight had to run above the level of the highest tides the seawalls were designed to block. Such tides likely included the solstice spring tides gauged at Manora one week before the tsunami (p. 13). The highest of those tides, on November 21, crested 0.5 meter above Mean High Water Springs (p. 20). It surpassed the blue high-water line on the topographic maps at right if they, like the contemporary Admiralty chart of Karachi Harbour, used MHWS as the high-water shoreline.

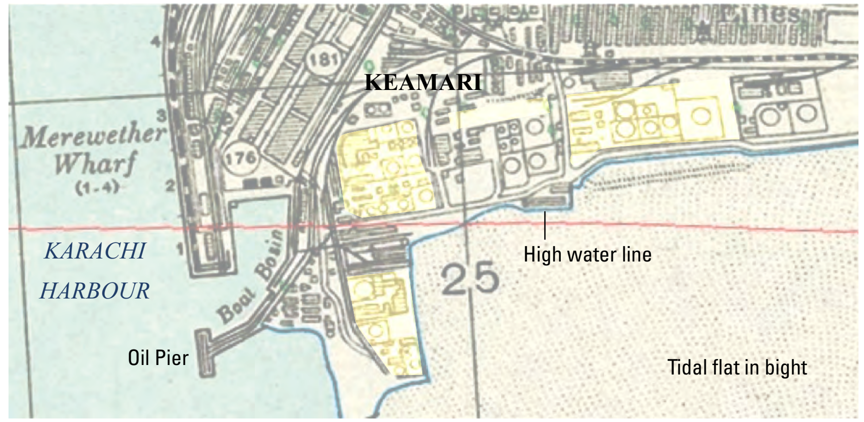
The minimal tsunami height estimate at lower right starts with the November 21 high water, allows for 0.15 meter of wind-wave freeboard, and presupposes a tsunami flow depth of 0.2 meter on the seawall crest. The sum surpasses, by 0.8 meters, the maximum tsunami level gauged at Manora.

The tsunami crossed more than a seawall if it entered Burmah Shell facilities of Keamari by way of Karachi Harbour and its tide gauge. Water levels in that case can be estimated most directly from the reported stranding of landing craft beside the Boat Basin (p. 26–28).

BASE MAPS from Karachi Guide Map, 3rd edition (published by Survey of India in 1944; p. 6) and 4th edition (published by Survey of Pakistan in 1951, “corrected up to 1949”).

OIL FACILITIES appeared on Admiralty chart 40 by 1906. They eventually covered an area that the 1889 edition had depicted as “low scrub” between a beach and Keamari Island, then a “sandy ridge covered with creepers.”

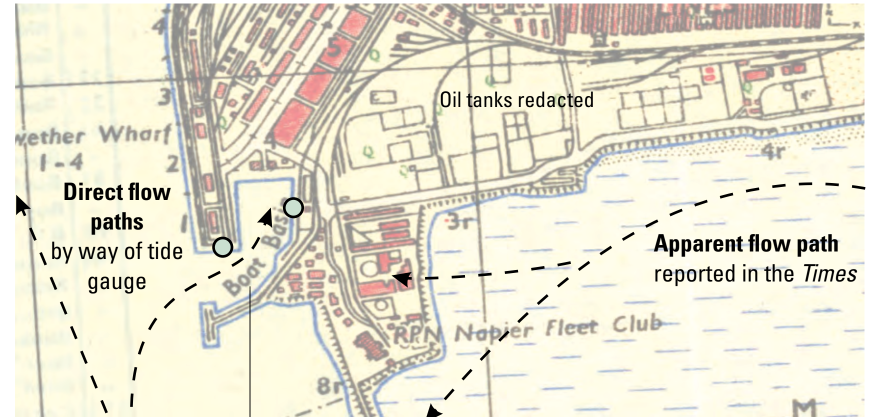
Oil-facility area on maps updated to 1944 (left) and 1949 (right)



Added highlight shows extent of Burmah Shell facilities (p. 23)

Published 1944

0 500 METERS
N



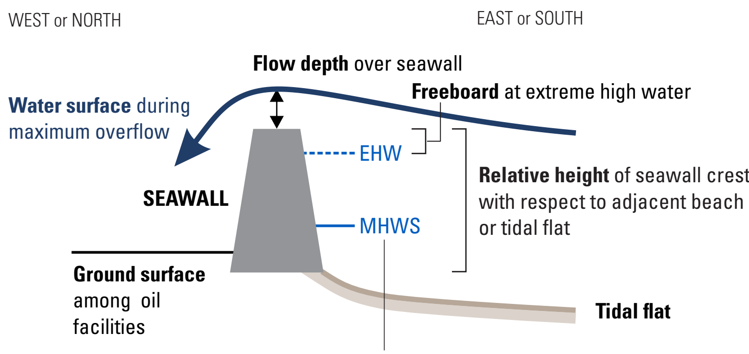
Published 1951

REPORTED FLOODING NEAR THE OIL FACILITIES

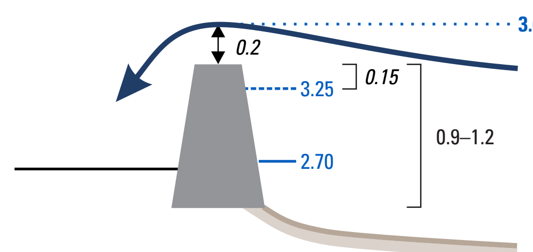
Keamari Groyne at its shore (north) end, across which the tsunami may have run from east to west (p. 21, 24)

Boat Basin, from which landing craft were lifted onto wharves ○ according to Cyrus Cowasjee (p. 26–28)

Schematic profile of seawall south or east of a Burma Shell facility



Estimated water level sufficient to flood Burma Shell facilities to north or west

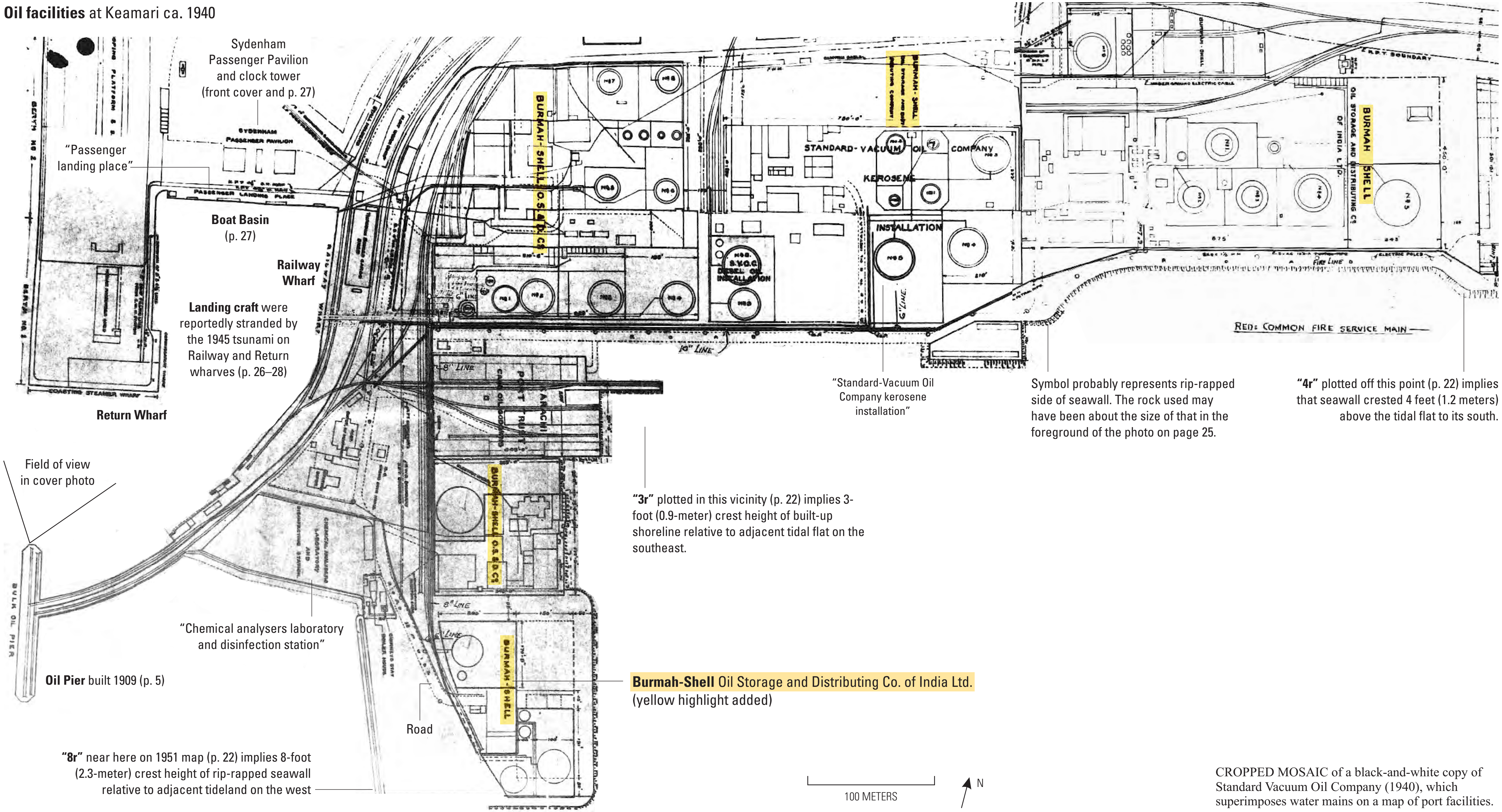


This height estimate, a minimum, is 0.8 meters above the highest water-level recorded at the Karachi tide gauge during the 1945 tsunami (crest at 2.81 m above chart datum, p. 20).

Blue numbers—Heights in meters above chart datum (p. 16, 20). Extreme high water of 3.25 meters was measured at the Karachi tide gauge on November 21, 1945 (p. 13, 20, 28)

Black numbers—Relative heights in meters. Numbers in italics are assumptions intended to err on the small side. Measured relative heights of 0.9–1.2 meters (3–4 feet) are denoted **3r** and **4r** on the 1951 map above

Oil facilities at Keamari ca. 1940



CROPPED MOSAIC of a black-and-white copy of Standard Vacuum Oil Company (1940), which superimposes water mains on a map of port facilities.

Damaged groyne

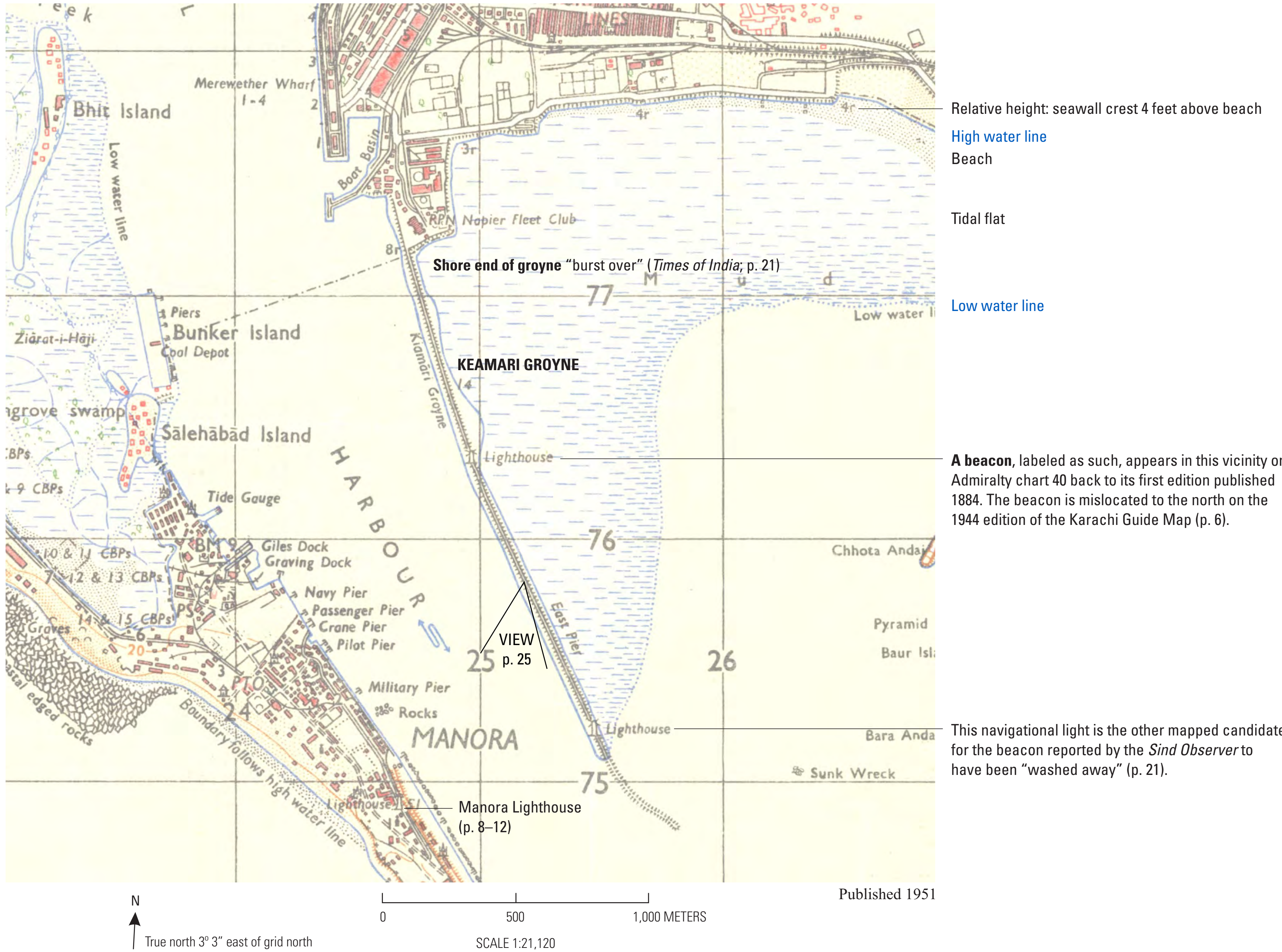
NEWSPAPERS HIGHLIGHTED tsunami damage to a stone wall that extended two kilometers southward from Keamari, at the east edge of Karachi Harbour.

This wall comprised Keamari Groyne and its southern extension, East Pier. Both had been built southward from Keamari in the early 1860s to block flows that formerly entered and exited Karachi Harbor across a sandy tidal flat to the east (p. 3, 4). Two mapped beacons were perched upon it —one opposite the Karachi tide gauge, the other on East Pier.

The tsunami reportedly damaged 400 feet, or 120 meters, of groyne, according to the *Daily Gazette* and the *Sind Observer* (p. 21). This damage may have occurred where, according to the *Times of India*, the tsunami "burst over the shore end" of a groyne, apparently near Keamari. Alternatively, or in addition, the damage occurred far enough south to take out one of the beacons.

The flows responsible for this damage may have approached heights as great as those estimated for flooding of Burma Shell oil facilities (p. 22). Whether spilling from Karachi Harbour or from its east, the damaging flows crossed the blue high-water line on period maps (p. 6 and right).

Keamari Groyne on map updated to 1949



THE ROCK WALL that became Keamari Groyne was expected to be formed "of loose rubble of approved quality, the larger stones, of a size not to be washed away by the action of the sea, being arranged near the face, the core being all the remainder of the stone quarried, large and small, so as to form a completely solid mass. After this mass of rubble has consolidated, it will be covered or pitched with blocks of stone of approved quality laid in straight courses" (Turner, 1866, p. 46). Limestone of Hands Hill was the rock of "approved quality." It was quarried northeast of Clifton (location, p. 21) and has been called the stone "out of which Karachi has been built" (Smyth, 1909, p. 66). The rock pictured on the next page, perhaps far enough south to be East Pier, consists of "loose rubble" without "blocks laid in straight courses."

KARACHI GUIDE MAP, 4th edition, "corrected up to 1949," published 1951 by the Survey of Pakistan. The back side of the map contains a table, partly visible in show-through, that lists places numbered on the map. Sydenham Passenger Pavilion (p. 27) is number 4 and Manora Lighthouse, 51.

Displaced boats

"THERE WAS NO DAMAGE to boats and port installations in Karachi." So said the Associated Press of India, in a "tidal wave" story run by the *Times of India* on November 30, 1945. But vivid memories from that era, gathered in interviews seven decades later, include impressive displacement of boats in inner parts of Karachi Harbour. In one account, landing craft have been lifted out of the Boat Basin at Keamari (p. 26–28). In another, a grounded vessel suddenly floats off a shoal near Baba Island (p. 29–30).

The landing-craft account implies a tsunami crest in the Boat Basin at least one meter above the highest tsunami water level gauged at Manora (p. 28). This crest, as an extreme, probably represents the *Times*'s "biggest" wave—the wave that likely coincided with, and caused, a mechanical outage of the tide gauge (4, p. 18–20). The Boat Basin evidence provides the simplest guide to Manora water levels during that outage: the direct tsunami path to the Boat Basin grazes the tide gauge (p. 21); and water levels attained in the Boat Basin can be estimated with straightforward assumptions about boat draft and wharf height (p. 28).

The floated-vessel account, while more difficult to relate to tsunami height, centers on an unusual incident that understandably left a lasting impression on a boy then twelve years old. The account places this incident near fishing villages that the tsunami reportedly entered (p. 31–33).

Sailing vessels in lower Karachi Harbour several decades before the tsunami

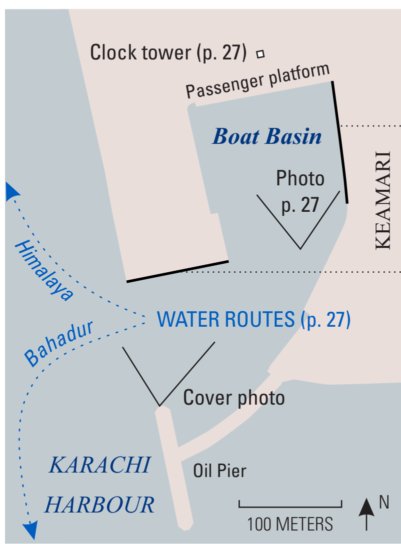
THE LARGEST VESSELS in the photo are dhows resembling *kotia* and *dhangi* described by Hornell (1946, p. 197–200) and Hawkins (1977, p. 139). A bunder boat (p. 27) is tied up to the rock wall.

VIEW to southeast (mapped, p. 24). Manora Lighthouse dates the scene to 1889 at earliest (p. 8). From a photo collection attributed to an engineer who worked in India in the early 20th century; British Library 940/1(35).

Landing craft on wharves

RECOLLECTIONS of Cyrus Cowasjee, interviewed at age 90 in 2018, include two landing craft atop Boat Basin wharves a few days after the 1945 tsunami. The interview began in person and continued through e-mail exchanges in which Mr. Cowasjee related the sighting to port activities and facilities. The details provided accord with maps and reports the folio's compilers have consulted.

Cyrus Cowasjee in 2018 (left) and as a college student (center). In 2018 Mr. Cowasjee recalled having accompanied his father, Rustom Fakirjee Cowasjee (right), on a outing to view landing craft atop wharves of the Boat Basin in Keamari the first weekend after the tsunami of November 28, 1945.



REMEMBERED SITES OF STRANDED LANDING CRAFT

Railway Wharf—In mind's eye, 2018

Return Wharf—Recalled less distinctly

APPROXIMATE LOCATIONS of boats reportedly stranded: 24.81728° N, 66.97574° E (Railway Wharf); 24.81602° N, 66.97419° E (Return Wharf).

Dubash

THE EARTHQUAKE of November 28, 1945 made no lasting impression on Cyrus Cowasjee, then 17. Seven decades later Mr. Cowasjee supposed that he had slept through the shaking and would have attended classes that day, a Wednesday.

As a business student in 1945, Mr. Cowasjee was preparing for a career in shipping. His father, Rustom Fakirjee Cowasjee, was then one of three partners in Cowasjee & Sons, Keamari. The firm held one of six Master Stevedore contracts with Karachi Port Trust. In that capacity it served both the port authority and the shipowner on the loading and unloading of cargo. An office sign advertised this dual role with "dubash" (p. 27), from the Hindi for "person of two languages."

Rustom Cowasjee kept abreast of port affairs. "To be successful in Keamari," went a stevedore maxim, "you should know when your competitor will pass water fifteen minutes before he starts to think of it." The KPT chairman at the time, W.S. Bushby, dined at the Cowasjee home as a family guest.

It was around the dinner table on November 28 that Rustom Cowasjee told of landing craft stranded that day. Rustom and Cyrus visited them together a few days later, over the weekend. One of the boats, atop Railway Wharf, would remain in Cyrus's mind's eye nearly three-quarters of a century later. A second landing craft he would recall less distinctly as resting on Return Wharf.

Landing Craft, Assault

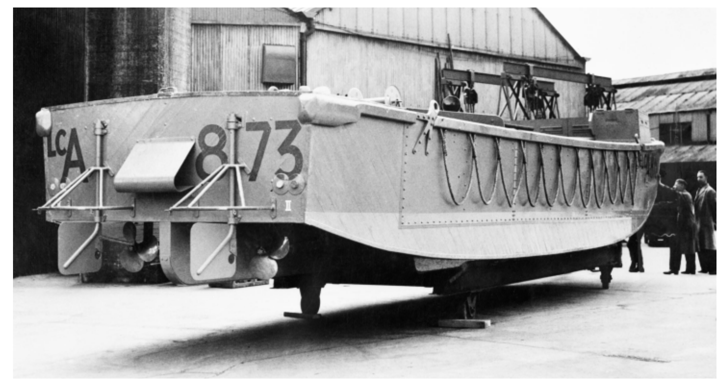
WHEN FIRST INTERVIEWED in 2018, in his Karachi home, Cyrus Cowasjee told of landing craft tens of meters in length. In e-mailed follow-up, after considering online photos of American landing craft of various sizes, he reported a better fit with the Higgins Boat, about eleven meters in length.

British landing craft about the size of a Higgins Boat were present in Karachi late in 1945, according to a Royal Indian Navy report. Ten meters long, they were known as the Landing Craft, Assault. Three LCA flotillas had been transferred to Karachi in September 1945.

A skeptical compiler asked what landing craft would have been doing in the Boat Basin in November 1945. Mr. Cowasjee replied that they served as ferries to RIN training establishments—the *Bahadur* to the south, and the *Himalaya* to the west (map, p. 27).

A skeptic also wondered whether the KPT cranes could have lifted landing craft onto Boat Basin wharves. "No can do," Mr. Cowasjee replied. The cranes pictured on the front cover and page 27 had a capacity under 2 metric tons both in his recollection and in a 1947 port history by David B. Brow (p. 5). An unladen LCA weighed 8–10 metric tons.

If the tsunami stranded landing craft on Boat Basin wharves, why not also bunderboats like those that plied its waters (photo, p. 27)? Bunderboats must have been stranded as well, Mr. Cowasjee replied, but not so memorably as military landing craft.



Great Britain, 1942

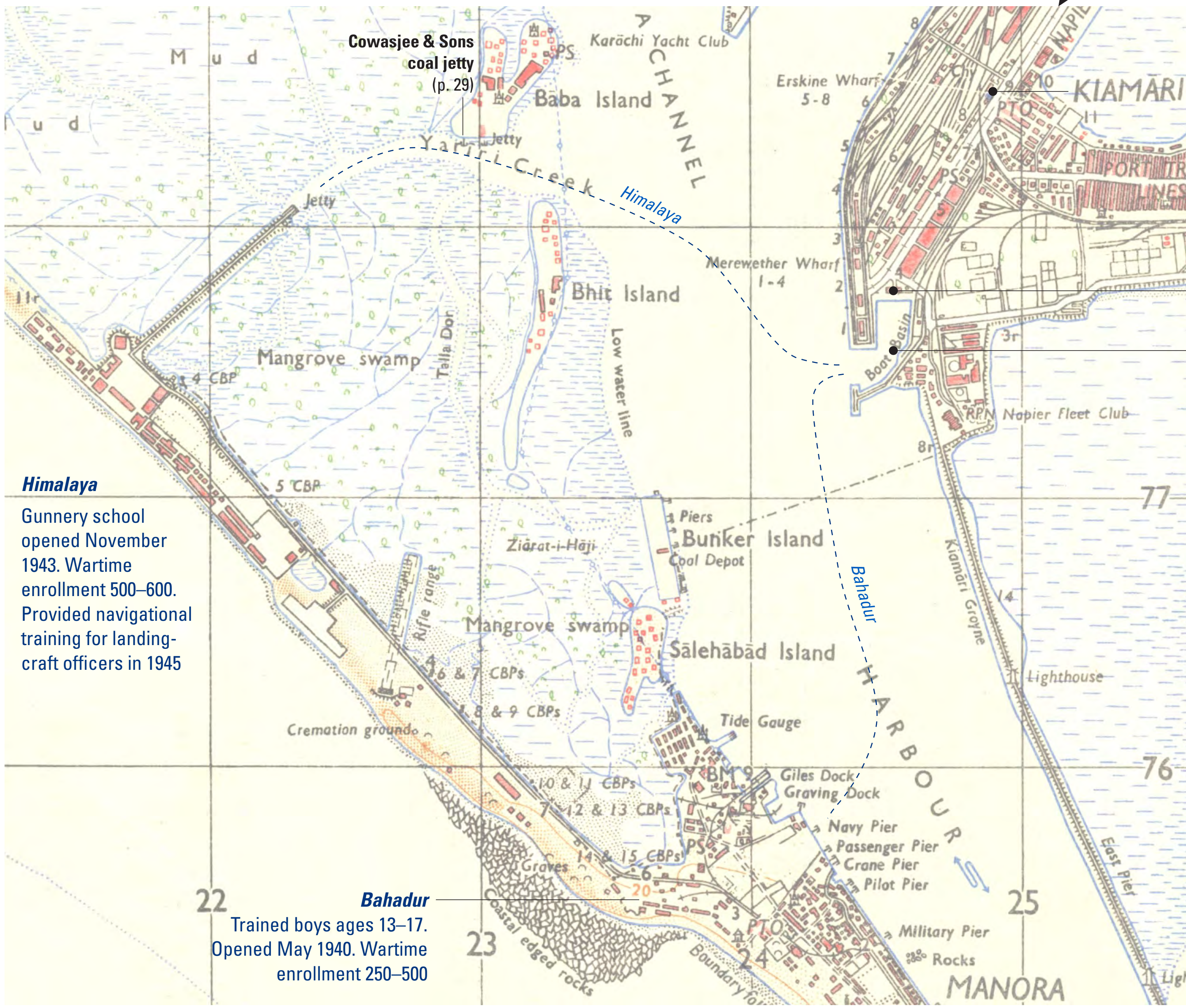
The Landing Craft, Assault made up part of the landing craft wing of the Royal Indian Navy. Three LCA flotillas were were moved to Karachi in September 1945. According to Cyrus Cowasjee, landing craft provided ferry service between the Boat Basin and RIN naval training facilities (p. 27).

A9838 Imperial War Museums https://www.iwm.org.uk/collections/item/object/205143621

ROYAL INDIAN NAVY landing-craft flotillas A, B, and F, consisting of LCAs (Collins, 1964, p. 237), were moved from Bombay to Karachi in September 1945 (Royal Indian Navy, 1946, p. 12). Neither report cited here mentions stranding of landing craft by the 1945 tsunami, but in each the tsunami receives no attention beyond a half-sentence summary of relief efforts in Pasni and Ormara by two RIN ships—the *Hindustan* and the *Karachi* (Royal Indian Navy, 1946, p. 2; Collins, 1964, p. 322).

THE LANDING CRAFT, ASSAULT is listed in U.S. Navy Division of Naval Intelligence (1945) with light displacement 8.5 tons (if short tons, 7.7 metric tons) and draft aft 1 foot 10 inches (0.55 meters). In Ladd (1976, p. 38) the displacement is 10 long tons (10.2 metric tons). Higgins boats (Strahan, 1994, p. 47) resembled the LCA. KPT crane capacity was 35 hundredweight (Brow, 1947, p. 169–171), or 1.75 long tons (1.8 metric tons).

Water routes between naval training schools and Boat Basin



Himalaya
Gunnery school opened November 1943. Wartime enrollment 500–600. Provided navigational training for landing-craft officers in 1945

Bahadur
Trained boys ages 13–17. Opened May 1940. Wartime enrollment 250–500

Published 1951 (p. 24)

NAVAL SCHOOLS: Collins (1964, p. 128, 145, 147–148, 239).

Trolley line from Karachi to vicinity of Boat Basin, by way of Napier Mole (p. 4)

"DUBASH" on balcony grill

1924

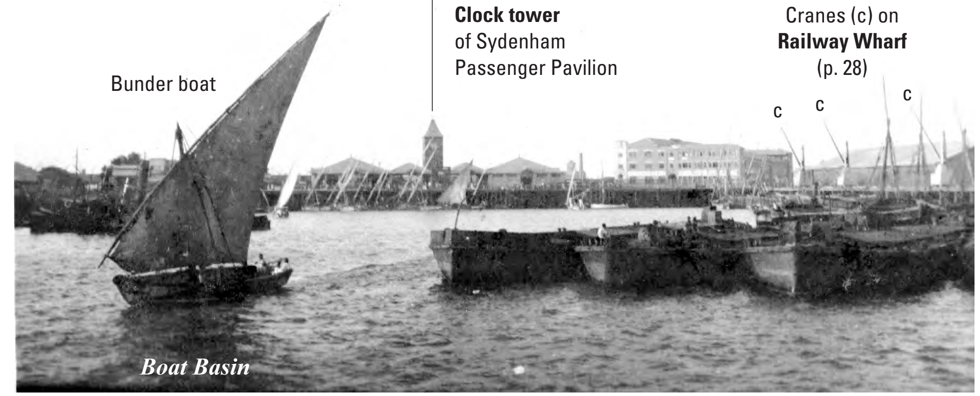
Cowasjee & Sons office behind trolley

VIEW POINT of Boat Basin photo below

Bunder boat

Clock tower of Sydenham Passenger Pavilion

Cranes (c) on **Railway Wharf** (p. 28)



mid-20th century

2016

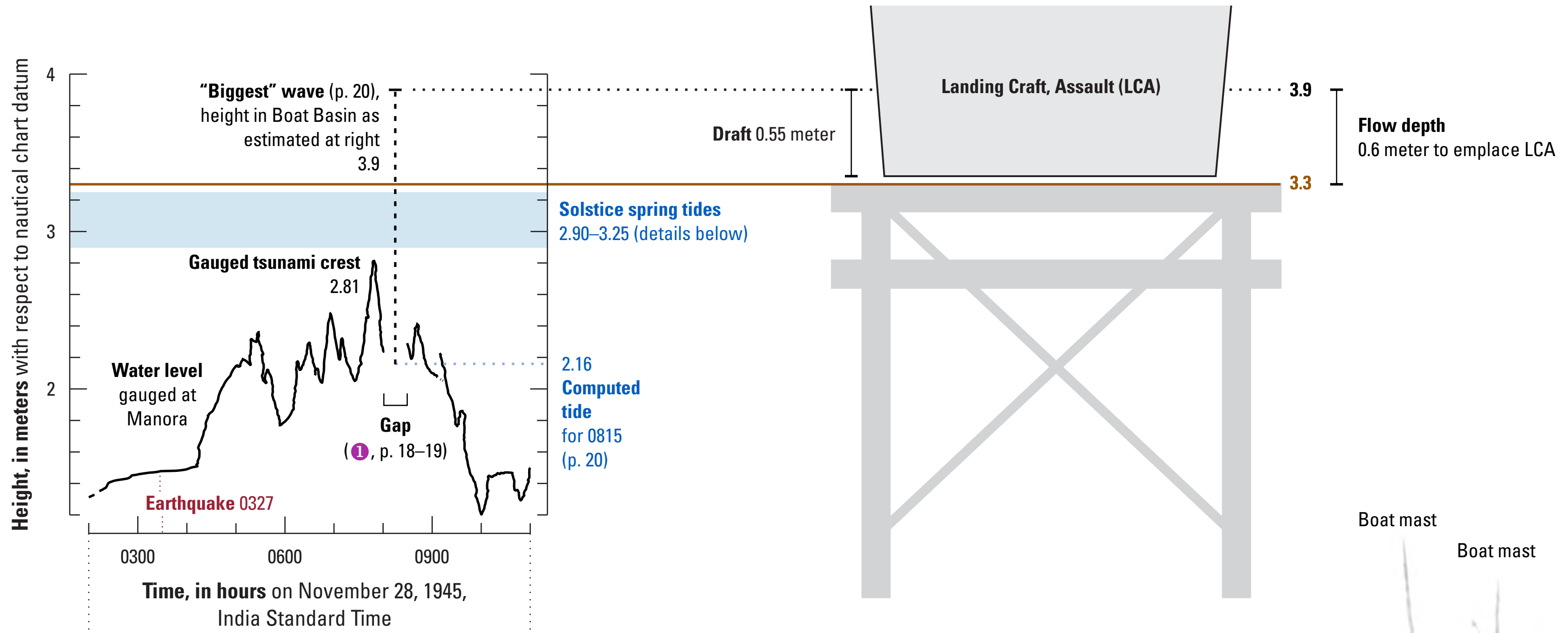
Sydenham Passenger Pavilion opened as a transit hub in 1913. Five decades later it served as a customs house.

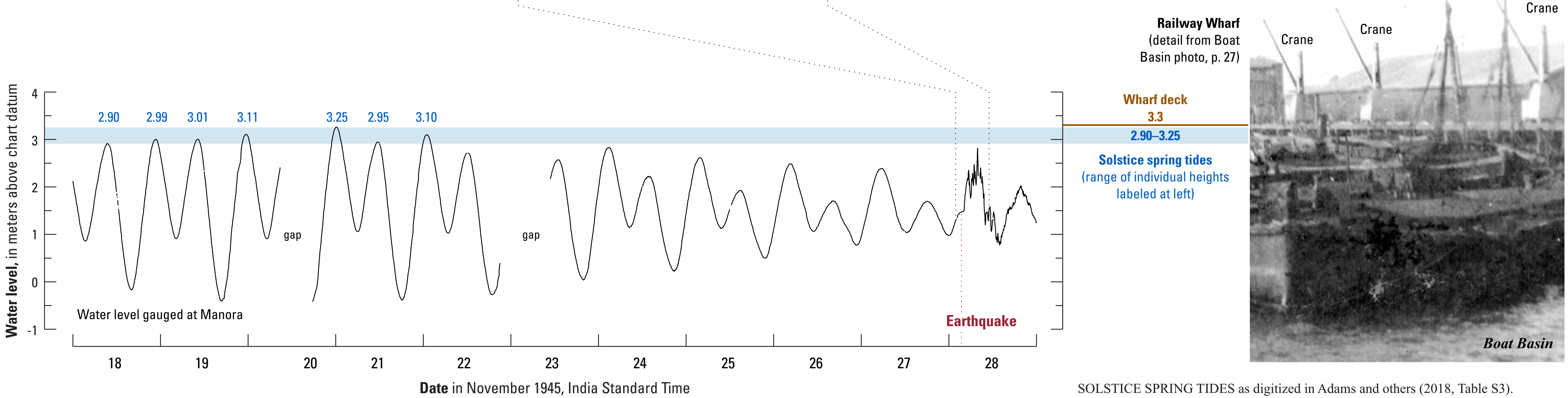
Estimated tsunami height in the Boat Basin

A TSUNAMI CREST one meter or more above the maximum gauged at Manora can be estimated from Mr. Cowasjee's account of landing craft atop Boat Basin wharves (graph, right). This estimate depends on assumptions about flow depth on the wharf deck and deck height with respect to spring tides:

1. *Flow 0.6 m deep on the wharf deck*—Probably a minimum flow depth for emplacing an unladen LCA. Specifications footnoted on page 27 give a draft of 0.55 m. Diagram at right.

2. *Wharf deck above extreme high tides*—Mr. Cowasjee recalled no tidal flooding of the decks of Boat Basin wharves. The graph below, traced from the marigram scan on page 15, relates an assumed deck height to solstice spring tides gauged at Manora on November 18–22, 1945.





SOLSTICE SPRING TIDES as digitized in Adams and others (2018, Table S3).

Trading vessel lifted and towed

SHIVAJI BHUDA FOFINDI, in 2014, recounted a sudden rise in the level of Karachi Harbour as a distinct memory from his boyhood aboard vessels akin to the large dhows on page 25.

Interviewed in his home town of Mandvi (location, p. 2), Mr. Fofindi traced his maritime work back to age ten, when he went to sea on an uncle's vessel, the *Leelavanthi*. As a youth he experienced storms at sea and voyaged as far as South Africa. As an adult he worked nearly four decades at the port of Mandvi.

Mr. Fofindi's encounter with the 1945 tsunami takes place on the *Parasmani*, which has been carrying passengers and cargo between Mandvi and Karachi. Passengers from Mandvi have disembarked in the port of Karachi. A port agent has advised of a two-day delay in loading cargo for the return trip. To make use of the delay the captain, Anathleela Kashta, orders the hull cleaned. At high tide the vessel enters shallows near "Bhaba." A falling tide grounds the vessel. The crew scrapes its hull for a while. They are back on board for a coffee break when they feel the vessel floated suddenly. The water level has risen by ten feet. Later the captain has the *Parismani* towed from a shore on which it was left stranded.

Graphed on the next page are two posited timelines for the core of Mr. Fofindi's account (p. 30). One, using times he offered hesitantly (in ❸ and ❺, right), compresses the grounding, cleaning, and sudden floating into a few morning hours of November 28. The other, by allowing the grounding to take place one day earlier, reduces discrepancies with the tide-gauge record and newspaper accounts.

MR. FOFINDI WAS INTERVIEWED in Gujarati by Seshachalam Srinivasalu (geologist) and Nilesh Bhat (translator). The full narrative, paraphrased in the first person, is available in Kakar and others (2015, p. 1).

STEAM COAL used to be stored on Baba Island near the shoal on which the *Parasmani* was probably grounded. Cyrus Cowasjee recalled in 2018 that the coal was used to power ships, a railway, and Karachi water works; and that it came from as far away as the United Kingdom and East Africa. Cowasjee & Sons and Nadirshaw Eduljee Dinshaw were the sole importers. A pier remains at the site of the eastern (Dinshaw) coal jetty (p. 31). NED University (p. 38) is named after Mr. Dinshaw. His son, Hoshang Dinshaw, was "senior proprietor" of the *Daily Gazette* in the early 1940s (Sharma, 1954, p. 80–81).

MAPS excerpted from British Admiralty chart 40, 1921 and 1935 editions.

Witness Shivaji Bhuda Fofindi, in 2014

Mr. Fofindi, center, with two interviewers in Mandvi, Gujarat (location, p. 2). He told them of sensing an abrupt rise in the level of Karachi Harbour in 1945, as a 12-year-old boy aboard a trading vessel, the *Parasmani*. He also recounted learning, upon returning Mandvi, that unusual seas had occurred there as well, on the same day as the Karachi incident. He recalled being told that the water had stopped short of the town gate, at rear in photo.

Sequence of events in Mr. Fofindi's account of an unusual rise in the level of Karachi Harbour

❶ **Reach Karachi** Drop off passengers from Mandvi. Learn of delay in loading cargo for return trip

❷ **Receive order** To make use of the delay, captain commands crew to clean hull

❸ **Move vessel** At high tide, perhaps 8 a.m. of November 28, go to bank of creek called "Bhaba"

❹ **Clean hull** A job done when tide is low enough for crew to stand in a foot or two of water

❺ **Take break** Back onboard for coffee, perhaps around 11 a.m. of November 28

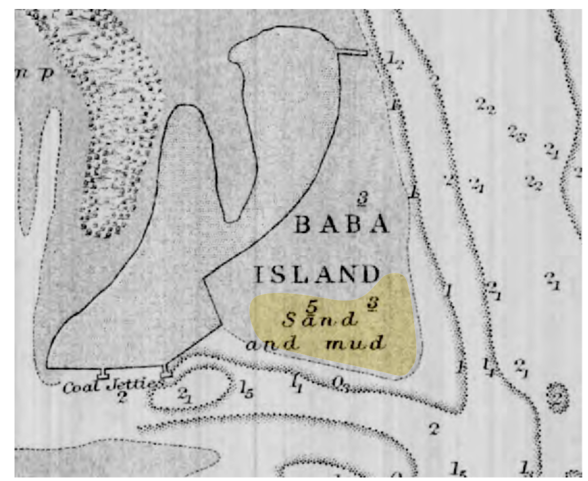
❻ **Feel lift** Suddenly afloat. Water level risen "around ten feet"

❼ **Need tow** Arrange to be pulled from shore, where apparently stranded

❽ **Trade stories** Learn of other vessels displaced in Karachi Harbour

Setting if vessel grounded on tidal flat east of Baba Island

Soundings in feet, ca. **1919**



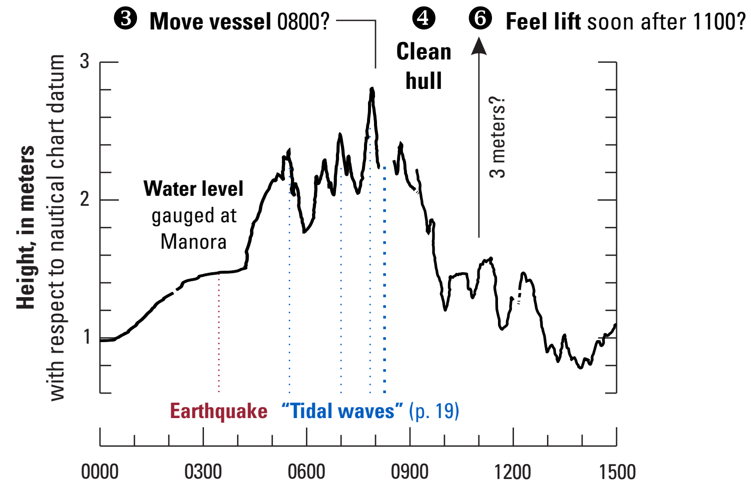
Soundings in feet (above datum) and in fathoms and feet, ca. **1933**

N 0 100 200 300 400 500 METERS

The bank of a creek called "Bhaba" is where, in Mr. Fofindi's account, the *Parasmani* suddenly floated after having been grounded for cleaning her hull. Cyrus Cowasjee (p. 26), whose family firm stored coal on Baba Island, recalled in 2018 that ocean-going dhows would be grounded, and their hulls scraped, in the area shaded yellow

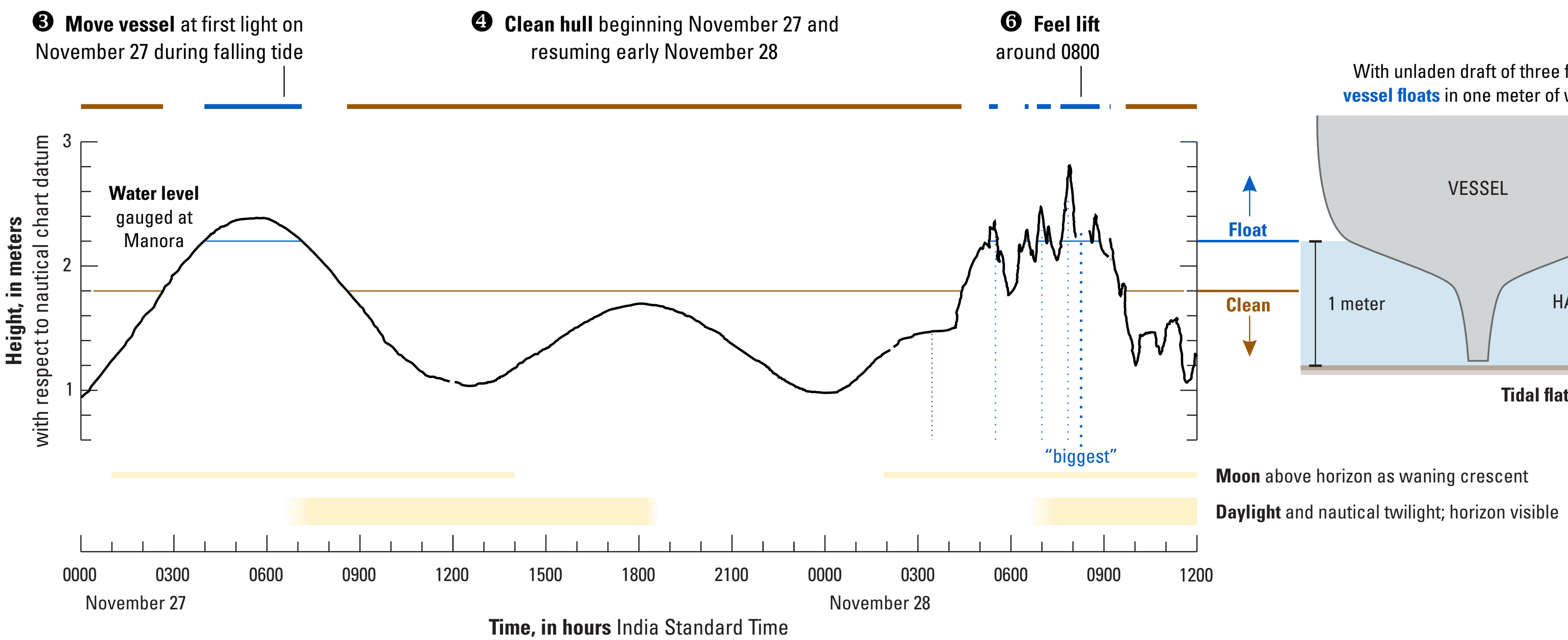
In the doubtful **timeline at right**, the *Parasmani* approaches its cleaning area around the time of the highest water levels of the 1945 tsunami. Cleaning takes place while water levels fall overall but still oscillate from the tsunami. A sudden lift, recalled as “around ten feet” (three meters), coincides with gauged fluctuations of just a few tenths of a meter.

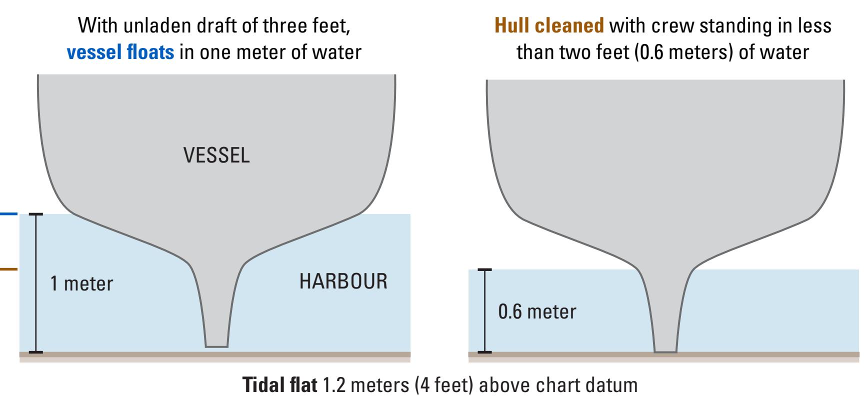
Timeline for key events in Mr. Fofindi’s account (p. 29), using times he questioned in 2014



On the more leisurely **timeline below**, grounding takes place and hull cleaning begins on the falling limb of the higher high water of November 27. On November 28, during the most memorable event, the vessel is lifted most noticeably by the wave the *Times of India* called “the biggest.” The vessel is assumed to have a draft of one meter unladen, and the shoal on which it is grounded stands 1.2 meters (4 feet) above chart datum, consistent with early twentieth-century soundings on the tidal flat east of Baba Island (chart excerpts, p. 29).

Alternative timing compatible with tide-gauge record and newspaper accounts





TRADING DHOWS with light draft of three feet were commonly beached on the tidal flat east of Baba Island, according to Cyrus Cowasjee in 2018. The sketch above is based on photos in Hawkins (1977, p. 101, 107) of beached *kotia* and *dhangi* (afloat, p. 25).

MOON AND SUN for Karachi in November 1945 from http://www.world-timedate.com/astronomy/

Flooded mosque

BABA AND BHIT ISLANDS had a combined population close to two thousand in the last decades before the tsunami. The 1931 census counted over 238 children between ages six and eleven, noted more huts than houses, and found five persons per dwelling on average.

Interviewers in 2014–2016 made three separate trips in search of persons who witnessed the 1945 tsunami on Baba or Bhit. Candidates were found on both islands, in Salehabad (right), and on the Karachi mainland in Khadda (p. 5). The next two pages summarize the accounts gathered.

Three of the men who recounted flooding of Bhit Island independently reported a memorable detail: water entering a wooden predessor of today's Hussaini Mosque (p. 32). Two men interviewed testified less definitely to tsunami effects on Baba Island (p. 33).

Three persons stated that flooding on Baba or Bhit coincided with flooding at Khadda. They may have been referring to a 1944 flood along a rain-swollen Lyari River (location, p. 5).

Baba Island

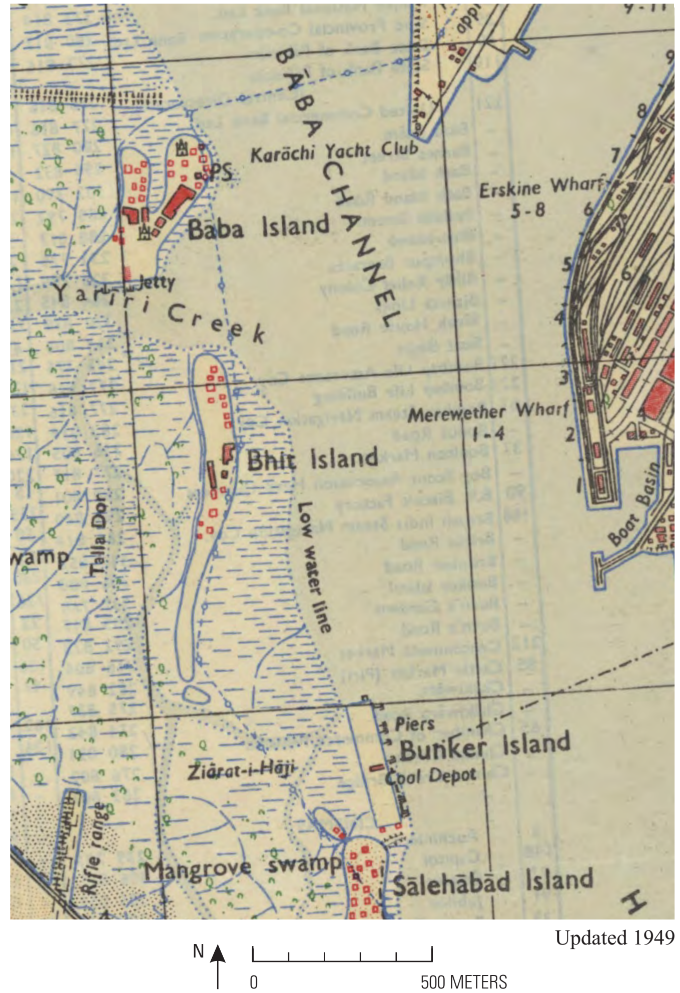
1931 census
Inhabited area *5.4 ha*
Population *1,202*
Female *388*
Male *614*
Children 6–11 *143*
Huts *197*
Houses *104*
Offices and shops *6*

1941 census
Population *1,397*

Bhit Island

1931 census
Inhabited area *3.7 ha*
Population *796*
Female *382*
Male *414*
Children 6–11 *95*
Huts *113*
Houses *59*
Offices and shops *1*

1941 census
Population *849*



Updated 1949

2017

CENSUS DATA from Sorley (1933, p. 138, 228, 336) and Lambrick (1942, p. 111). The Bhit figure for 1941 includes Salehabad.

FLOODING OF KHADDA, a market area of Karachi, was reported by Babu Murad (p. 32), Haji Qasim (p. 33), and Haji Abdul Rehman (Kakar and others, 2014, p. 51). Khadda adjoins the mouth of the Lyari River, an ephemeral stream. On July 27, 1944, heavy rain in Karachi caused flooding along the Lyari that swept away five persons, according to the *Daily Gazette* and *Sind Observer* of July 28. The five were found alive, according to the *Observer* of July 29.

MAP from Survey of Pakistan, Karachi Guide Map, published 1951, "corrected up to 1949." Aerial imagery, dated December 26, 2017, from DigitalGlobe via Google Earth.

THE PIER at right is in the vicinity of the eastern of the pair of coal jetties labeled on nautical charts excerpted on page 29.

Baba Island, south shore ,2016. Site of Dinshaw pier (p. 29).

Bhit Island

LONG-AGO FLOODING at Bhit Island was recalled by four elderly men interviewed independently. Three associated the flooding with an earthquake they said they felt, and three told of water entering the island's mosque. The four accounts agree further in mentioning no resulting loss of life.

The accounts disagree on whether and when the earthquake was felt, when the flooding took place, and how much damage resulted. In addition, the times given for the earthquake and the flooding differ from those established by congruence of instrumental records and other documents.

The reported flooding of the mosque provides a basis for estimating tsunami height. One of the men, Mr. Bhatti, stated that the mosque had been sited on high ground and founded on a stone platform. In that case, like the wharf decks beside the Boat Basin, the mosque floor may have stood above the level of most or all extreme high tides. Its flooding would then imply water levels above extreme tides such as those gauged one week before the 1945 tsunami (p. 28).

Hussaini Mosque is descended from a wooden structure that the 1945 tsunami entered, as judged from three of the accounts at right.

2016

2016 ENTRANCE to Hussaini Mosque: 24.8192º N, 66.9633º E.

BALOCHI SPEAKERS on Bhit Island may have heard that a saint halted the 1945 tsunami at Ormara (p. 2), as in an account in Kakar and others (2014, p. 44).




Name Age around 2015	**Ibrahim Bhatti** 85 or 90	**Dawood Abdullah (Mr. Doda)** 90	**Yousuf** 80	**Babu Murad** 80
Island in era of reported flooding	Population 300 or 400. Mosque on stone platform, and on land a few feet higher than where the huts were. At same place as today's mosque, but much smaller and made of wood	Mosque of wood and mats	Mosque with thatched walls	Population 600 or 700. Houses then of bamboo and mats, except planks for the rich. Dated flooding to "the year after Pakistan came into being" (that is, to 1948)
Occupation in that era. Location when flooding began	Fisherman, 15 or 20, born on Bhit Island. At Keamari until 11 p.m. Returned to Bhit Island around midnight	Fisherman living on Bhit Island before Pakistan came into being. Home with family, sleeping	Fisherman living on Bhit Island, home of his ancestors	Boy of eight or ten on Bhit Island; later became a fisherman
Earthquake	Felt around 12 a.m or 1 a.m., after his return from Keamari	Not felt. Later learned of strong earthquake at Ormara	Felt around 10 p.m. Shaking continued in morning	Later learned of strong 2 a.m. earthquake at Ormara
Flooding	After earthquake. Came in from south. Entire island covered. Some boats missing. Mosque damaged	Sea very high around 3 or 4 a.m. Hussaini Mosque flooded	All houses destroyed, being made of wood and mats. Belongings also drowned or washed away	Father in mosque to offer *Fajr* (dawn) prayer when water entered it. Houses of wood and mats destroyed. Boats stranded
Maximum water level	Water knee deep, stayed 24 hours	About waist deep	Three to five feet deep	Three or four feet deep
Survival	No deaths. Some people climbed onto a big boat and others went behind the mangroves	With others, went to boats for fear of drowning and stayed in boats until morning	No deaths except stranded fish. Villagers left in small boats ("tony boats") and stayed in them until the water receded	After flooding by first wave, Qasim Shah and another saint stood outside their tombs and ordered two later waves to stop
Interview(s)	*On Bhit Island: in Balochi on 13 January 2015, and in Urdu on 21 December 2016*	*In Balochi at Salehabad, 11 January 2015*	*In Balochi at Khadda Market, Karachi, 11 January 2015*	*In Balochi on Bhit Island, 13 January 2015*
Compilers' comments	*Mr. Bhatti's testimony diverged on damage from the flooding (not big, 2015, vs. all huts swept away, 2016) and on his age at the time of the flooding (15 vs. 20)*		*Granddaughter Zainab Bilal, also present at the interview, remarked that this was first time her grandfather had shared the story with the family*	*A saint is said to have halted the 1945 tsunami in Ormara*

Baba Island

Haji Qasim (left) and Haji Ismaeel were interviewed together on Baba Island in 2016.

HAJI QASIM AND HAJI ISMAEEL of Baba Island said they observed flooding there while in their early twenties. They were interviewed in 2014 and again, together, in 2016.

Haji Qasim recalled that the flooding took place when Baba Island had a mix of Hindus, Muslims, and Sikhs, including people from Kachchh (Gujarat), about 1,000 persons in all, with huts and without concrete buildings. Haji Ismaeel estimated the population at 100–150. He said in that era he was working for the Pakistan Army (2014) or the Karachi Port Trust (2016).

According to Haji Qasim, the sea rose suddenly during a daytime high tide without an accompanying storm. In 2014 he stated that there was no damage on Baba Island and that all people there survived. In 2016 he said that huts were swept away and that boats were damaged and stranded. Haji Qasim also stated, in 2016, that waves were seven or eight feet high, and that people left Baba Island for an area near Mangho Pir Hills—15 km north of Karachi.

Haji Ismaeel said that he was swimming when he noticed a change in the color of the water. He estimated wave heights of six to twelve feet. In 2014 he said the water started rising around 9 a.m., while in 2016 he said the flooding happened around 3:30 a.m. Haji Ismaeel mentioned losses of boats, huts, and human lives. He described boats overturned and beached.

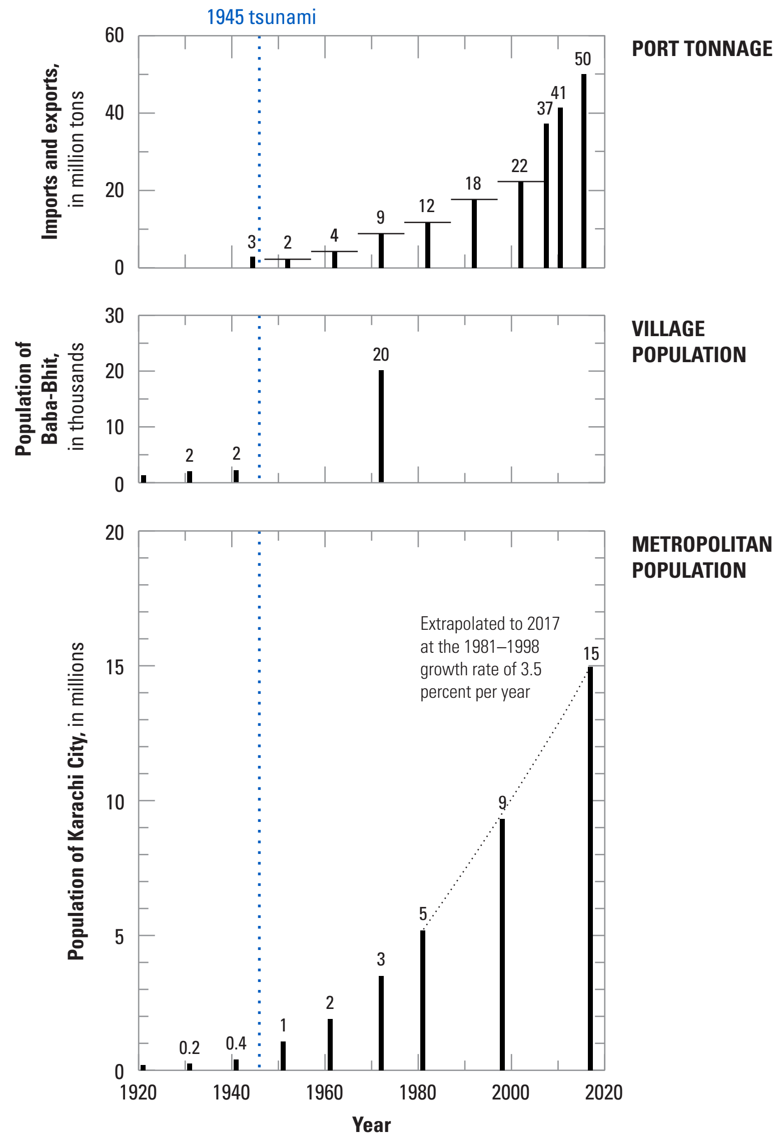
THE 2014 TESTIMONY is abridged from the collection by Kakar and others (2015, p. 50, 52). Not reproduced from that collection are unreliable lists of purported victims (its p. 51), and a second-hand account of flooding on Baba Island provided by a different, younger Haji Ismaeel (its p. 53). The later interview took place December 21, 2016.

Growing risk

THE KARACHI EFFECTS of a repeat of the 1945 earthquake and tsunami would likely reflect the port's growth in business and population.

Since 1945, the Port of Karachi has grown about twenty-fold in cargo handled. Total annual imports and exports at the Port of Karachi have risen from 2.8 million tons in the fiscal year 1944–1945 to 50.05 million tons in 2015–2016.

Concurrent population growth in mainland Karachi has been accompanied by sparsely measured gains on Baba and Bhit islands. From close to 2,000 in 1941 the combined island populations reached 20,000 by the 1972 census. The village footprints have also expanded, and the adjoining waters teem with boats (p. iv, 31).



PORT TONNAGE from Brow (1947, p. 172; fiscal year 1944–1945), Karachi Port Trust (2014), and Siddiqui (2016). The graph shows ten-year averages for the decades between 1947 and 2006.

VILLAGE POPULATION from Sedgwick (1922, p. cviii; 1,276 persons on "Baba Bhit Island"), Sorley (1933, p. 228; 1,202 persons on Baba Island and 796 persons on Bhit Island), Lambrick (1942, p. 111; 1,397 persons on Baba Island and 879 persons on "Bhit & Bunker Island," and Census Organization (1977, p. 22; 20,241 persons on "U.C. no. 28, Baba-Bhit Island). No counts specific to these islands are evident in reports from the 1951, 1961, 1981, and 1998 censuses. A newspaper article six decades post-tsunami gave unattributed population estimates of 12,000 for Baba Island and 11,000 for Bhit Island (Mansoor, 2007). Another decade later the tallies of registered voters were reported as 6,500 on Baba and 4,500 on Bhit (Siddiqui, 2015).

METROPOLITAN POPULATION from comparisons in Lambrick (1942, p . 16), Pakistan Bureau of Statistics (2006, section 2.6), and Pakistan Ministry of Statistics (2017). Uncertainties in the comparisons include changes in the extent of the areas grouped as Karachi City. Karachi has been called an "instant city" (Inskeep, 2011), and it is subject to earthquakes from multiple sources (Bilham and others, 2007).

On Baba Island, 2016.

Further questions

CLUES PRESENTED in this folio may raise more questions than they answer about the 1945 Makran earthquake and tsunami. Highlighted here are issues with the tide-gauge record from Manora and field observations nearby.

Tide gauge

This folio highlights a pair of problems—fouling of the stilling well (p. 16–17), and a mechanical outage from the tsunami (p. 18–19)—that limit the Karachi marigram as a modelers guide to Makran tsunami sources. Underlying questions include:

How was the marigram datum identified?

No label or line directly identifies the gauge datum, which in 1945 was the same as the datum for the nautical chart (p. 16). In the marigram height scale labeled in pencil, with grid lines at intervals of 0.3 feet, 0.0 feet projects between the grid lines corresponding to -0.2 feet and 0.1 feet (p. 15).

Four pairs of added purple lines may have registered the sheet to datum-related grooves in the rotating drum. The pairs are evenly spaced at height intervals averaging 1.002 feet on the sheet (just over 3 feet in gauged water level). None of them coincide with height lines in the lithographed grid. Only two registration grooves are labeled *v* on plate II of Eccles (1901a). Clues might be sought on additional marigrams conserved by the Survey of India, in Dehra Dun.

What are the marigram indicators of an obstructed stilling well?

This question underlies a broader one about tsunami sources beneath the northwest Indian Ocean: Did the Makran Subduction Zone produce a precursory tsunami in 1945 by means of an undetected earthquake or submarine slope failure. The possibility of such a precursor is already remote (Adams and others, 2018, app. C, p. 10–11). It could be discounted further if stilling-well obstruction were confirmed as the cause of the early drawdown in the detided marigram for November 28. To that end, tide-gauge records could be sought for reported obstructions at Karachi and Bombay (p. 16), and for "stoppages" of a few hours ascribed to "choking of the inlet hole" at Aden, Yemen, in 1921 (Survey of India, 1924).

What minimum orifice size was required for water level in the stilling well to rise and fall apace with the tsunami in the adjoining harbour?

The original design included an orifice 2.5 cm in diameter (p. 16). A reduced diameter might explain the meager detided height of the waves of 0530 and 0700 (p. 20). Calculations with methods of Cross (1968) and Loomis (1984) suggested little damping or delay for waves under 3 m amplitude and over 20 minute period for an orifice 2.5 cm across (Adams and others, 2018, app. C, p. 4). A nearly instantaneous rise in harbour level, from a bore, could be assessed as a cause of the outage between 0806 and 0830 on November 28.

How did observatory staff interpret each of the anomalies of November 28?

The "separate chart for the 28th & 29th" cited by David B. Brow (p. 18), apparently addressed to an audience outside Karachi Port Trust, may have explained the anomaly that began before the earthquake (p. 16–17) as well as the outage attributable to the tsunami's highest wave (p. 18–19).

Clerks at Indian tidal observatories were expected, at the turn of the century, to fill out daily reports (Eccles, 1901a, p. 22). No such records, however, are likely to have survived the roof collapse at right.

How high was the highest tsunami wave at the Karachi tide gauge?

The folio derives height estimates for the "biggest" wave reported in the *Times of India* (wave ❹, p. 20) from reported flooding of seawalls, wharves, and mosque floor (p. 28, 30, 32). Period bathymetry (Hasan and others, 2018) may assist tsunami modelers in projecting these indirect estimates back to Manora's tide-gauge pier, where that wave ❹ evidently caused Brow's outage and accordingly went ungauged (p. 18–19). Regional tsunami simulations could then be compared with a height probably greater than that of wave ❸, the highest gauged Karachi wave to which tsunami simulations have been calibrated (Neetu and others, 2011; Heidarzadeh and Satake, 2015; Heidarzadeh and Satake, 2017).

100 METERS

Published 1935

The Manora Observatory of Karachi Port Trust (location, left) once housed electric and solar clocks, chronometers, aneroid barometers, and a telescope, and was maintained through 1964, but lost its roof by 2018 (above). Daily tide-gauge records from November 1945 would be inaccessible at best if last conserved in this building.

OBSERVATORY HISTORY from Karachi Port Trust notebook of pages ii and 12. Map from central part of nautical chart excerpt on page 6.

Which, if any, of the Karachi waves were triggered or augmented by submarine landslides?

Partial triggering of the 1945 tsunami by slope failures (footnote, p. 13) is evidenced by an unattributed report of cable breaks in eight places (Ambraseys and Melville, 1982, p. 90), and is consistent with geological evidence for submarine slides in recent millennia (Bourget and others, 2010).

The Telegraph Museum Porthcurno, in Cornwall, England, holds records of the "Muscat–Karachi Section" of an imperial cable (museum file DOC/CW/7/27). One note states that service was interrupted for nearly two years, from November 28, 1945 to November 18, 1947. In 2015 the museum's collection manager, Charlotte Dando, sought details in the so-called minute books of Cable and Wireless Ltd., a holding company for imperial cables (Boyce, 2009). She found entries up to July 1945.

Seawalls, boats, and villages

More might be learned about flooding and damage in greater Karachi as guides to maximum water levels attained and as indicators of tsunami consequences.

Where and how was Keamari Groyne damaged?

Two newspapers gave a length but not a location; one noted loss of a beacon atop the groyne; and a third implied overtopping near the Keamari end of the groyne (p. 21, 24). Flow depths and current speeds might be estimated from records can be found of rocks the tsunami displaced.

How high were wharves around the Boat Basin in 1945?

The folio resorts to an assumed deck height, referenced to extreme high tides, in estimating water levels necessary to lift a landing craft onto Return and Railway wharves (p. 28). Records could be sought on designed or as-built heights from the Boat Basin's construction ca. 1914 (p. 5) and from later maintenance or upgrades.

Did Landing Craft, Assault provide ferry service to Karachi naval training facilities in November 1945?

A tsunami crest height estimated on page 28 hinges first and foremost on Cyrus Cowasjee's recollection of small landing craft having been stranded on Boat Basin wharves—a memory that could be supported by documented use of landing craft as ferries for the Royal Indian Navy (p. 26–28). Relevant archives from the RIN training facilities *Bahadur* and *Himalaya* would likely cover their operations during postwar months when the Royal Indian Navy demobilized. That demobilization, which included nearly 10,000 persons in all, took place between September 1945 and April 1946 (Collins, 1964, p. 328).

Which, if any, of the Karachi effects of the 1945 earthquake and tsunami were documented by the Karachi Collector?

The Karachi District, a colonial jurisdiction in 1945, encompassed the delta of the Indus River. Its lead administrator was known as the Karachi Collector (Hunt and Harrison, 1980; Potter, 1986; Pearce, 2001).

Officials under the Karachi Collector surveyed tsunami losses in the Indus Delta and oversaw relief efforts there. An official count of 163 deaths in the Delta exceeded death tolls in Pasni and Ormara combined (p. 2). The official count undercut larger estimates from representatives of the Congress Party according to newspaper stories (*Daily Gazette*, December 4; *Sind Observer*, December 9 and 23; *Times of India*, December 5, 10, and 11; all available at Indian Ocean Tsunami Information Center, 2016) and official correspondence conserved in Sindh Archives (Dow, 1945; McElhinny, 1945) and the British Library (Economic and Overseas Department record no. 9132, 9206, 9226, 9236, 9245, 9248, 9255, 9280, 9284, 9357).

Relevant reports of the Karachi Collector might be sought in Indian or Pakistani archives, not just to clarify tsunami losses in the Indus Delta, but also in case of comparisons with effects in Karachi Harbour and along the beach to its west.

What further tsunami effects in Karachi Harbour can be gleaned from a Sindhi-language newspaper?

The *Daily Al-Wahid*, published in Karachi, provided news in Sindhi for a mainly Muslim readership (Soomro, 1989, p. 114). In partial holdings at Jamshoro University (p. 37), an article published December 11, 1945 states that the tsunami destroyed a boat of Shiekh Khaddey Waley and drowned two persons from a boat of Haji Abdul Bukari. The text relates the losses to Karachi without stating where they took place.

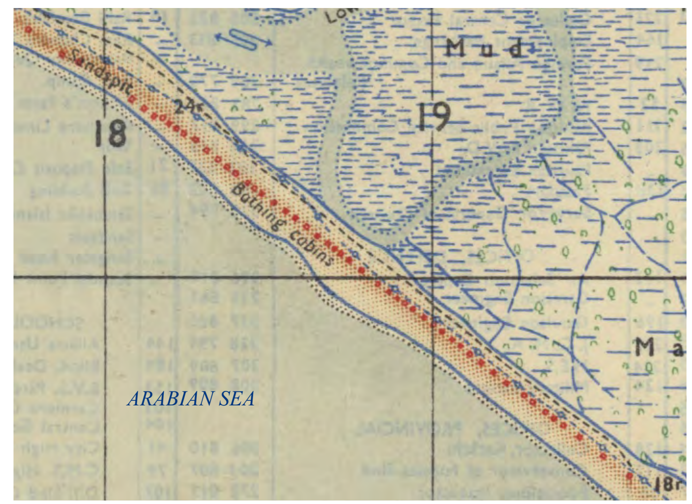
How high did the tsunami crest on the Arabian Sea shore northwest of Manora?

The naval training facility *Himalaya* adjoined this shore (map, p. 27). Do the facility's archives record tsunami inundation, or its absence, of buildings of known elevation?

Farther northwest stood cabins on Sandspit (maps, p. 5 and below). Cyrus Cowasjee (p. 26) testified in 2018 that the 1945 tsunami had no effect on his family's cabin, and that this cabin floated away on a high tide in 1978 after undermining by beach erosion. In the 1969 photo below, the cabin floor appears to stand a few meters above a swash line.

1969

This family cabin at Sandspit, facing the Arabian Sea northwest of Manora (p. 5), reportedly went undamaged by the 1945 Makran tsunami.



0 500 METERS N

Published 1951 (p. 24)

THE MAP SYMBOLS "24r" (upper left) and "18r" (lower right) give crest heights in feet relative to low ground nearby (as on p. 22).

Acknowledgments

THIS FOLIO EVOLVED from historical and geological studies, begun in 2008, of tsunami risk on Arabian Sea shores. Most took place under the umbrella of the Intergovernmental Oceanographic Commission of the United Nations Economic, Scientific and Cultural Organization (UNESCO-IOC). Funding was provided by the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), the U.S. Agency for International Development, and Pakistan's Higher Education Commission. Workshops were hosted in Oman by Sultan Qaboos University and Oman's Directorate General of Meteorology and Air Navigation. Workshop travel was arranged in part by Asha Varma and Asena Tongamoa. Project coordinators included Jane Cunneen, Nora Gale, Ardito M. Kodijat, and Tony Elliott.

2013

Testimony and documents about the 1945 Makran earthquake and tsunami brought this group together in Oman in 2013. From seven nations in all, the participants included Nora Gale and Ardito Kodijat of UNESCO-IOC (left) and five of this folio's compilers (p. 38).

The folio reproduces, with permission as needed, archival images from public and private sources:

British Library, London—Karachi Harbour (p. 25; copyright on high-resolution image used).

California State Library, San Francisco—1856 Walker plan for Karachi Harbour (p. 3), through Colyn Wohlmut.

Collection of Hutoxy C. Cowasjee, Karachi—Keamari waterfronts (front cover, p. 27), Manora Lighthouse (p. 8), Cowasjee family and office (p. 27), Sandspit cabin (p. 36).

Collection of Julia Elton, London—Optical apparatus of Manora Lighthouse (p. 8).

Imperial War Museums—Landing Craft, Assault (p. 26).

Karachi Port Trust—David B. Brow (p. 5); notebook (p. ii; quoted, p. 12), through Muhammad Altaf.

Library of Congress, Washington, D.C.—Geography and Map Division: British Admiralty Chart 40 (p. 6, 8, 16, 29); Survey of India Karachi Guide Map, 1944 ed. (title page and p. 6, 22); oil facility map (p. 23). Serials and Government Publications Division: *Daily Gazette* and *Sind Observer* (p. 2; quoted or paraphrased, p. 7, 12, 20, 21, 31).

National Library of Australia, Canberra—Survey of India One-Inch Sheets (p. 1, 5, 21, 26) and Survey of Pakistan 1951 Karachi Guide Map (p. 22, 24, 27, 31, 36), through Quentin Slade.

Permanent Service for Mean Sea Level, National Oceanography Centre, Liverpool—Excerpts from Eccles (1901a, 1901b) (p. iv, 14, 18), through Philip L. Woodworth.

Survey of India, Dehra Dun—Karachi tide-gauge record for November 15 to December 1, 1945 (p. 15, 17–19), through Satheesh C. Shenoi of the Indian National Centre for Ocean Information Services (INCOIS), with assistance from Srinivasa Kumar Tummala of UNESCO-IOC, Ajay Kumar Bardela of INCOIS, and Laura Kong of the International Tsunami Information Center.

2016

Jamshoro University holdings of *The Daily Al-Wahid* include a December 1945 issue that may relate tsunami losses to Karachi (p. 36). The university's Mohammad Hassan Quershi is at left.

Persons reproducing, from this folio, any of the above images are requested to cite the primary source or sources (p. ii).

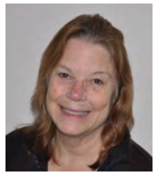
University libraries conserve many of the additional archives consulted. At University of Washington these include microfilm and online copies of the *Times of India* (p. 12, 18–22); microfiche of the Census of India (p. 5, 34); printed copies of the Census of Pakistan (p. 34); printed reports of the Survey of India (p. 16); and the 1911 edition of Encyclopædia Britannica (public domain image, p. 10). Interlibrary loan provided materials from Library of Congress and from Université Sorbonne, Paris. The Sindhology collection of Jamshoro University, Hyderabad, Sindh, enabled access to *Al-Wahid* through Mohammad Hassan Qureshi (photo, above).

Cyrus Cowasjee provided e-mail tutorials on port facilities and operations of the 1940s (front cover, p. 26–30) and photos from a family collection credited above. Sarosh Lodi initiated discussions with Mr. Cowasjee and, through Irfan Ahmed, with Asaf Humayun. Interviews about Baba and Bhit islands were arranged by Abdul Rehman.

John Porter shed light on lighthouse spindles (p. 11, 12), as did Peter Hogarth on tide-gauge design and outages.

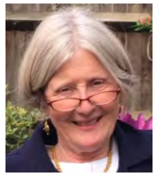
Folio drafts received reviews in 2016 from Paula Dunbar and Eric Geist; in 2018 by Noman Ahmed, Juma Al-Maskari, Andi Eka Sakya, and Rajib Shaw; and in 2019 by Carolyn

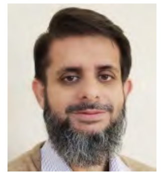
Compilers


Loyce Adams


Shoaib Ahmed


Brian F. Atwater


Julia Elton


Haider Hasan


Noorul Ayen Hasan


Asaf Humayan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Hira Lodhi


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Brian F. Atwater led the folio work as a scientist with the U.S. Geological Survey and the Department of Earth and Space Sciences, University of Washington, Seattle.

Julia Elton contributed to sections on lighthouse optics and machinery. She is a past president of the Newcomen Society for the History of Engineering and Technology, London.

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Noorul Ayen Hasan provided materials from archives of Karachi Port Trust, where she works as an executive engineer.

Asaf Humayun researched landing craft of the Royal Indian Navy and determined the likely identity of the submarine on the front cover. A retired Vice Admiral of the Pakistan Navy, he is affiliated with the Karachi branch of Bahria University.

Din Mohammad Kakar gathered testimony about tsunami effects on Baba and Bhit islands and along the Makran coast. He chairs the Faculty of Earth and Environmental Science, University of Balochistan, Quetta.

Hira Ashfaq Lodhi participated in interviews on Baba and Bhit islands. She is an assistant professor in the Department of Physics at NED University of Engineering and Technology, Karachi.

Ghazala Naeem initiated interviews of tsunami survivors on the Makran coast and of Cyrus Cowasjee in Karachi, in addition to gathering testimony from Baba and Bhit islands. She heads the Resilience Group, a consulting firm in Islamabad.

Seshachalam Srinivasalu interviewed Shivaji Bhuda Fofindi in Gujarat. He is a professor in the Department of Geology, Anna University, Chennai.

Abdullah Usman coordinated interviews with Balochi speakers on the Makran coast and in Karachi. He is a member of the Rural Community Development Council, along the Makran coast in Gwadar.

Lindsey M. Wright contributed to detiding and interpretation of the tide-gauge record. She is an information scientist with the National Oceanic and Atmospheric Administration, through the Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder.

ORIGINAL ILLUSTRATIONS by compiler and page: LA, graph 13; SA, photos 9, 11; BA, graphics throughout; JE, timelines 8; NAH, scan ii, photo 35; DMK, photos iv, 27 Sydenham, 31, 34; GN, photo 26; SS, photo 29; AU, photos 7, 32, 33.

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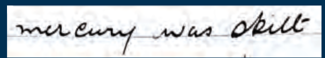
Index

Karachi effects of the Makran earthquake and tsunami of November 1945

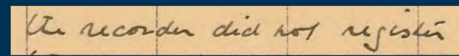
Mercury spilled



The earthquake dislodged a liter of elemental mercury from a float in which a heavy optic revolved high in Manora Lighthouse.

1

Tide gauge impaired



The tsunami began during a probable outage at the Karachi tide gauge, and the highest tsunami wave probably failed to register there after having caused a mechanical failure.

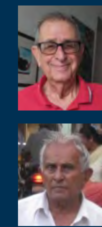
2

Seawalls overrun

The tsunami flooded oil installations behind a seawall at Keamari (Kiamari on map). In addition, the waters damaged 120 meters of Keamari Groyne, perhaps near its north end, and destroyed a beacon light atop the groyne.

3

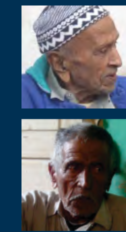
Boats displaced



The tsunami lifted two naval landing craft onto Boat Basin wharves at Keamari, and it floated a Gujarati trading vessel off a shoal near Baba Island, according to men interviewed in 2014 and 2018.

4

Mosque flooded



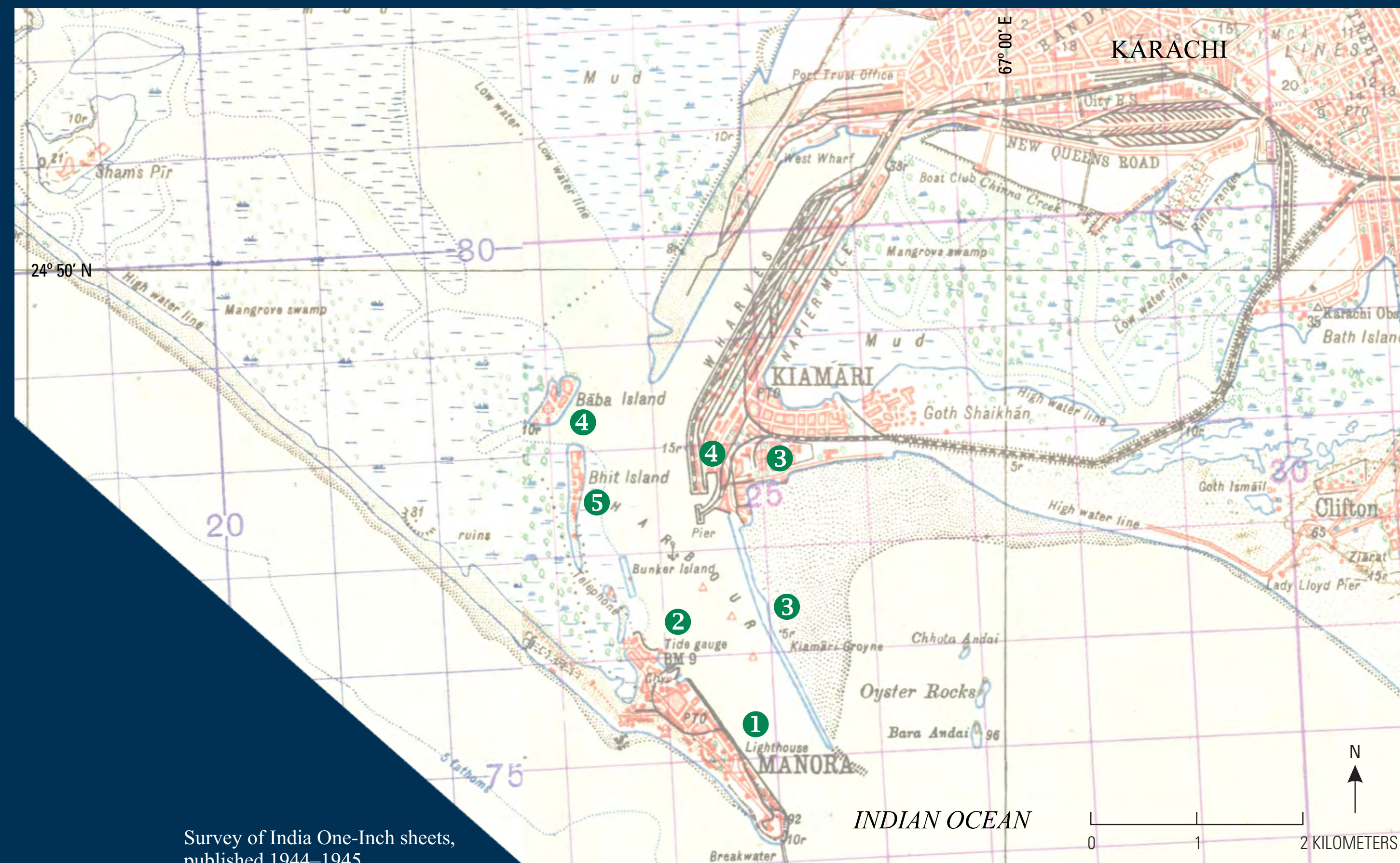
Elderly men in 2015 and 2016 recounted a sea flood in their youth that entered a fishing village on Bhit Island. Three of the men stated that the waters entered a wooden mosque.

5

HISTORY FOREWARNS of earthquakes and tsunamis on northwest Indian Ocean shores. The forewarnings include eyewitness testimony from mainly rural parts of present-day Oman, Iran, Pakistan, and India. Such recollections were gathered in "Remembering the 1945 Makran tsunami" (UNESCO-IOC, 2015),

Here, in an urban sequel, the 1945 tsunami and its parent earthquake register in Karachi, home then as now of the region's principal port. Shaking damages a giant assembly of lighthouse lenses. Tsunami waves that follow disable a long-running tide gauge, flood port facilities and fishing villages, and move boats.

Intended for a broad audience, the folio reconstructs this Karachi history from archives and interviews. The findings include water-level estimates that may aid in calibrating tsunami-hazard maps.



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