Damage at a distance

SIR—The Loma Prieta earthquake registered 7.1 on the Richter scale. It occurred at 17:04 hours on 17 October 1989, along the San Andreas fault in the Santa Cruz mountains. Surprisingly, it destroyed about 40 houses in the Marina district of San Francisco, 67 miles away from the epicentre. Here, I would like to suggest an explanation for this damage.

In the 5 minutes after the main shock, many residents of the Marina district observed a mixture of sand, water and mud surfacing in their garages or backyards. In one apartment building 1 metre of sand oozed through the concrete floor. Many people reported that the mixture of water and sand emanated from the cracks and from the drainage openings of their garage floors. The sand ejecta, also called sand boils, sand spouts, water spouts, craterlets or sand volcanoes, were caused by the phenomenon of liquefaction, a physical process that transforms a solid mass of wet sands into a liquid mixture of sand and water¹.

Figure 1 represents the 900 × 600 metre area of the Marina district which my students and I investigated. Located between the Presidio military reservation and Fort Mason, the area extends from Fillmore to Baker Streets from east to west, and from Marina Boulevard to Chestnut Street from north to south. We recorded a total of 74 sand boils in this area, the largest of which had a volume in excess of 3.5 cubic metres (Fig. 2). The ejecta were made of a grey and odourless mixture of fine dune sand and San Francisco bay mud.

The sand boils covered only the north-east corner of the Marina district (Fig. 1), a distribution related to the construction

history of the district. By 1894, a sea wall and a lagoon had been constructed along the original 1892 shoreline of the district. During the 1906 earthquake, Lawson reported² a severe ground shaking near this lagoon. By 1915, the lagoon had been filled to host the Panama-Pacific international exposition, after which some buildings were erected on the debris left over while others were directly built on man-made land. The Marina district was therefore constructed on a liquefiable landfill pre-disposed to ground motion amplification.

All our 74 observations on sand boils fall within the perimeter of the 1906 lagoon. The soils filling the lagoon were saturated by the high tide during the Loma Prieta earthquake. They liquefied, spread laterally and moved relative to the edge of the lagoon. As shown in Fig. 1, three apartment buildings collapsed and a serious fire was ignited along the shoreline of the old lagoon.

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1. National Research Council *Liquefaction of Soils during Earthquakes* 18–20; 72–73 (National Academy Press, 1985).

2. Lawson, A.C. et al. *Rep. State Earthquake Invest. Comm.* 404–405 (Carnegie Institution, Washington, DC, 1908).

FIG. 1 The 1892 shoreline, the landfill area, the lagoon in 1906, the liquefaction sand boils and the collapsed buildings of the Marina district of San Francisco.

Expanding zeolite-type nets

SIR—Zeolite materials have structures based on a framework of corner-connected tetrahedra with primarily silicon, aluminium or phosphorus at their centres and two-coordinated oxygen atoms at the corners. More than 60 topologically distinct frameworks of this type have been found so far in minerals and synthetic phases. Frameworks of this kind belong to the family of (4;2)-connected three-dimensional nets, of which an infinite number can be conceived¹. I would like to draw attention to a beryllium-containing structural unit, which could in theory be used to 'expand' any zeolite-type net, resulting in a structure of low density and large pore size.

Zeolites possess pores of well defined dimensions that are of importance in catalysis and in separation processes. Among the aluminosilicates, the largest known apertures consist of 12 tetrahedra; low-density nets with larger rings would have great potential for industrial applications. Theoretical structure-building mechanisms that allow the expansion of a few specific nets have been presented^{2–4} and one of these expanded nets, with 18-membered rings, has now been found⁵ in the aluminophosphate VPI-5.

The isolated $[\text{Be}_4\text{Si}_4\text{O}_{17}]^{10-}$ ion⁶ exists in the compound $\text{Na}_{10}\text{Be}_4\text{Si}_4\text{O}_{17}$ (inset in the figure). In the centre of the ion, four BeO_4 tetrahedra share an oxygen atom. The other three oxygen atoms of each BeO_4 group are two-coordinated through corner-sharing between BeO_4 and SiO_4 tetrahedra. Three of the corners of a SiO_4 tetrahedron are shared with BeO_4 tetra-

FIG. 2 A large sand boil (3.5 cubic metres) with two craters emerged in a backyard a few minutes after the main shock. The mixture of water, sand and clay flowed through the wooden fence and completely covered the neighbouring backyard.