

THE MAGNITUDE 8.3 JUNE 23 2001 SOUTHERN PERU EARTHQUAKE AND TSUNAMI: RECONNAISSANCE TEAM REPORT

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SUMMARY

We present a precis of our reconnaissance trip to the area of the magnitude 8.3 June 23 2001 southern Peru earthquake and tsunami. The trip was undertaken because of the relevance of the event to hazard assessment in New Zealand. It is the best example in nearly 40 years of the maximum-size earthquake that might occur on the Hikurangi subduction zone, an event that is absent from the historical record of New Zealand (since 1840) and therefore of unknown potential in terms of hazard. Despite the great magnitude of this subduction interface earthquake, it produced only "moderately strong" levels of earthquake shaking (peak ground acceleration of 0.3g on alluvium from the one strong motion accelerograph in the earthquake area, and Modified Mercalli Intensity 8 in the epicentral area), and relatively minor ground damage (liquefaction and landslides). It did however produce a large and devastating tsunami. Our comparison of the one accelerograph record and attenuation curves for subduction interface earthquakes shows that the strength of shaking was typical for subduction interface earthquakes. If we apply our observations to New Zealand, they imply that a Hikurangi subduction interface earthquake may be less damaging to built-up areas in the southeastern part of the North Island (e.g. Wellington and Napier/Hastings) than earthquakes on major active faults in the shallow crust. However, the lateral extent of the strongest shaking in a subduction earthquake (300 km for the southern Peru event) and the associated tsunami generation will make the earthquake very significant in the national context.

1.0 INTRODUCTION

1.1 General

In this report we present the main observations made during a two week reconnaissance trip to the area of the M8.3 June 23 2001 southern Peru earthquake and associated tsunami. The reconnaissance trip took place some five weeks after the earthquake and was funded by the Earthquake Commission Research Foundation (EQC) and the Institute of Geological and Nuclear Sciences (GNS). Unlike previous reconnaissance trips this trip was run by GNS rather than by the NZ Society of Earthquake Engineering's (NZSEE) earthquake reconnaissance programme. This is because the trip was largely for the purpose of understanding the physical features and natural hazards of the earthquake and the associated tsunami, rather than the more multidisciplinary scope of NZSEE trips.

This paper, and the original report on which the paper is based (Stirling *et al.* 2002), is focused on describing our observations and the implications for understanding subduction interface earthquake and tsunami hazards in New

Zealand.

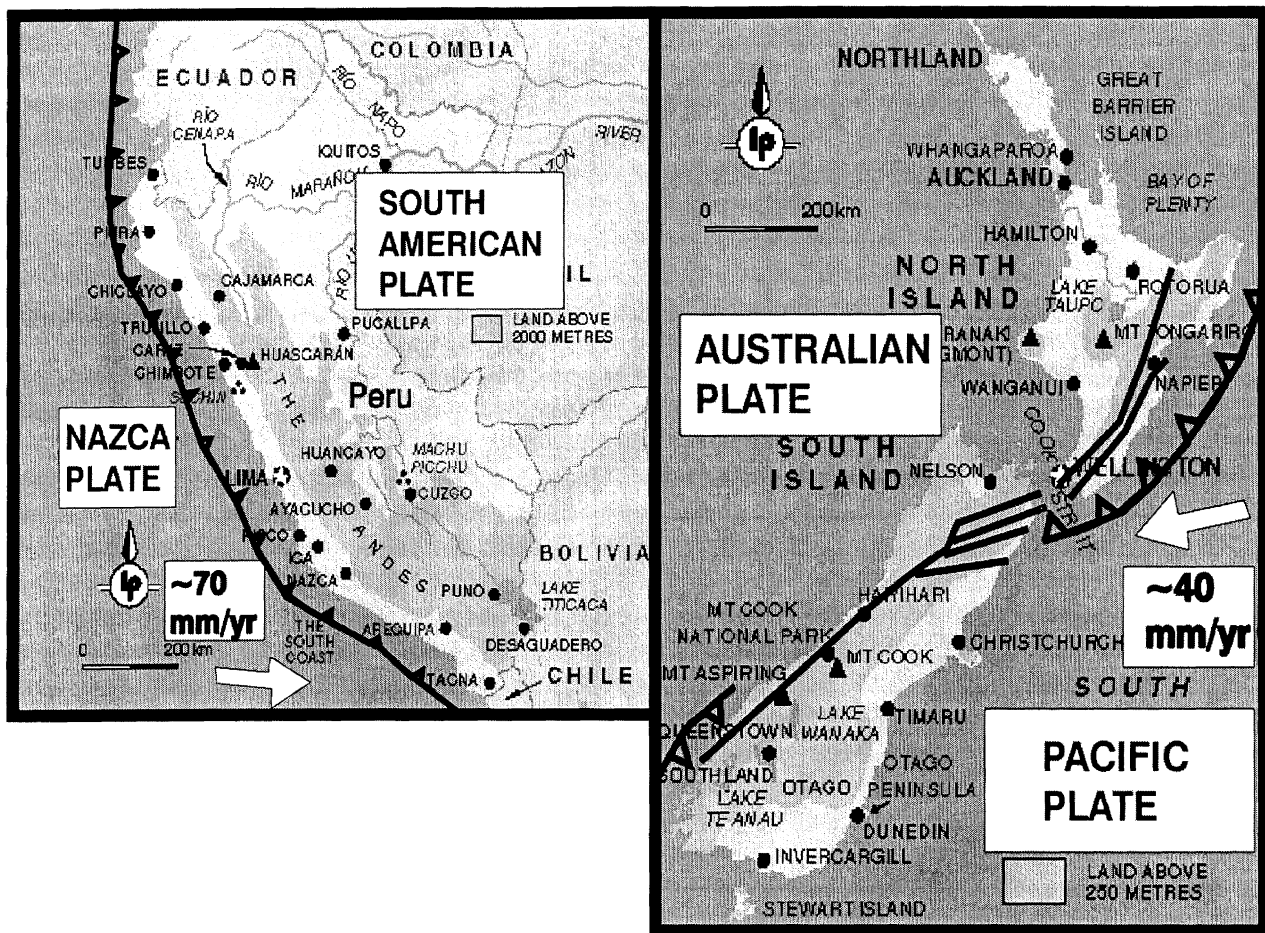
1.2 The Earthquake

On June 23, 2001, a large (c.30,000 km²) area of southern Peru and northern Chile was shaken for over a minute by a strong earthquake. The earthquake was centred approximately 175km west of Arequipa (Fig. 1a), and had a Moment Magnitude (M_w) of 8.3 (US Geological Survey; www.usgs.gov). The earthquake was produced by slip on the subduction interface between the Nazca and South American plates (Fig. 1), in which the Nazca plate thrusts beneath the South American plate at a long-term rate of about 70mm/yr (e.g. DeMets *et al.*, 1994). Great earthquakes such as the June 23 event are typical of so-called "Chilean-type" subduction zones (Uyeda, 1982), in which the subduction interface is strongly coupled (locked) due to the shallow angle and high friction between the two plates, and also because of the rapid convergence rate between the plates. The earthquake produced damaging shaking, ground deformation, liquefaction and tsunami inundation in a c. 300 km long zone in the Arequipa area (Fig. 1).

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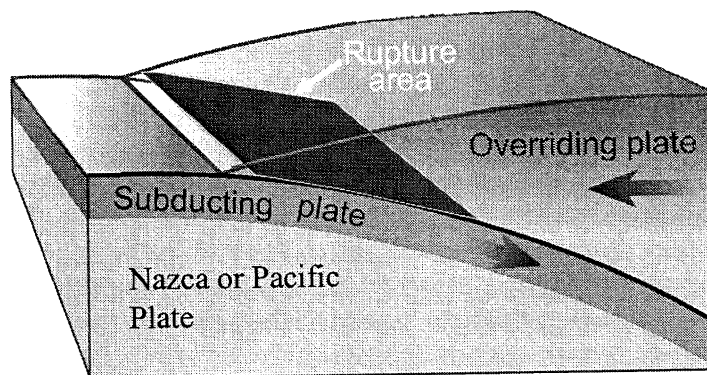
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a.

South American or Australian
Plate



b.

Figure 1. Plate tectonic setting of Peru and New Zealand, comparing the subduction zone setting of the eastern North Island to that of Peru (a); and a cartoon cross section of a subduction zone (b). In Peru the overriding plate is the South American continental plate and the subducting plate is the oceanic Nazca Plate. In the eastern North Island, the continental Australian Plate overrides the oceanic Pacific Plate. The southern Peru earthquake was centred just north of Arequipa on the Peruvian map. The subduction interface is the locked zone of contact between the two plates (marked "rupture area" on the figure) and great earthquakes are produced when then two plates release many years of accumulated strain.

At M_w 8.3, the southern Peru earthquake is the largest to occur in the world in the last 25 years. The maximum strength of shaking during the earthquake was Modified Mercalli Intensity (MM) 8 (L. Ocola pers comm.; Fig 2a), which was a moderately strong level of shaking. The duration of shaking was over a minute and the strongest (damaging) shaking lasted about 30 seconds. Many aftershocks have occurred since the earthquake, some larger than magnitude 7 (Fig. 2b).

The earthquake produced a 7 m high tsunami which hit the Camana coast (Fig. 3) about 14 minutes after the earthquake. The 130 fatalities from the earthquake were mainly due to the tsunami. Another 21,000 people were made homeless or otherwise affected by the earthquake. Nearly 15,000 dwellings were destroyed.

1.3 Purpose of Reconnaissance Trip

The purpose of the reconnaissance trip was to make first-hand observations of this natural hazard event, an event similar to one that could happen in New Zealand. We saw the great southern Peru earthquake as highly relevant to seismic and tsunami hazard assessment in New Zealand. It is the best example to occur in the world since the $M_{9.3}$, 1964 Good Friday, Alaska earthquake of the maximum-size earthquake expected on the Hikurangi subduction zone. The Hikurangi subduction zone in contrast has not produced any such earthquakes in the 160 year historical record. The South American and southern part of the Hikurangi subduction zones both appear to be strongly coupled or locked, and involve the rapid subduction of oceanic crust beneath continental crust (Fig. 1). As such, the Hikurangi subduction zone is similar to a "Chilean Type" of subduction zone (Uyeda, 1982). The occurrence of the great southern Peru earthquake and previous earthquakes in the much longer historical record of Peru (Becks and Ruff, 1989) shows that these subduction zones accommodate at least part of the plate boundary slip in large-to-great earthquakes. Given that these large-to-great subduction earthquakes typically occur at strongly coupled subduction zones we consider that the Hikurangi subduction zone may also produce these events over time. In this context the absence of large-to-great Hikurangi subduction earthquakes in the 160 year historical record of New Zealand would be due to the historical period being too short. The southern Peru event therefore presented us with a rare opportunity to see the onland effects of a great earthquake of the kinds that we might expect on the Hikurangi subduction zone, where the Pacific Plate thrusts underneath the Australian Plate at a long-term rate of 40 to 50mm/yr (e.g. DeMets *et al.*, 1994).

The main difference between the two subduction zones is that a larger portion of the locked part of the Hikurangi subduction zone is under land and at slightly shallower depths in the eastern North Island than is the case in southern Peru. It is therefore expected that a Hikurangi subduction zone earthquake will produce stronger shaking over a larger area of New Zealand than the southern Peru earthquake did in 2001, a consideration addressed later in this paper.

1.4 Objectives

This trip was focused on understanding the natural hazards associated with an earthquake of special relevance to New

Zealand. Since the built environment and procedures of emergency-management response in Peru are generally different to those of New Zealand, we knew that our observations of damage and response would have to be calibrated for New Zealand conditions. For example, we would have to assess what the damage to a poorly constructed building would equate to for a strongly constructed building in New Zealand. Similarly, we had to assess what the likely emergency management response would be to the earthquake and tsunami if a southern Peru-type event took place in New Zealand. The objectives of our four-person reconnaissance team (Fig. 4) were to observe and document five aspects of this great subduction earthquake:

1. the distribution, strength and duration of earthquake shaking.
2. the distribution and severity of ground failure (i.e. liquefaction and lateral spreading).
3. the tectonic effects (primarily coastal uplift and subsidence).
4. the distribution and severity of tsunami inundation.
5. the tsunami deposits produced by the tsunami to aid identification of paleotsunami deposits in New Zealand.

2.0 OBSERVATIONS

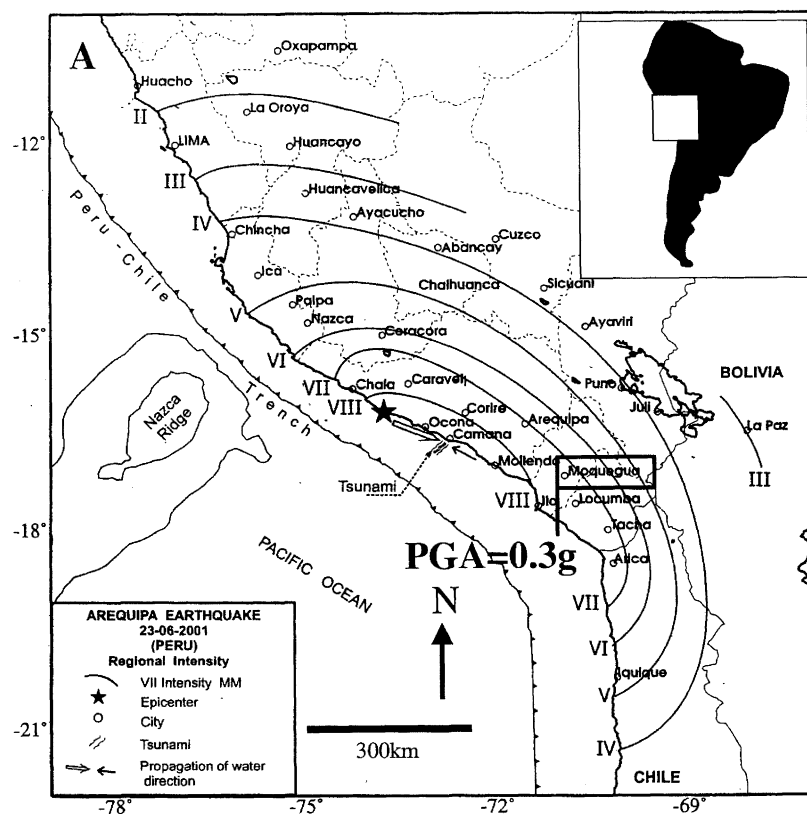
The areas visited along the 300 km-long earthquake area in chronological order were Arequipa (the second largest city in Peru), Los Cuevas-Camana-Pucchun, Chala, Ocona, Mollendo, Punta de Bombon, and Moquegua (Fig. 3). In the following sections we describe our observations according to the two categories of: (1) earthquake shaking, and associated ground and building damage, and; (2) tsunami and other coastal effects.

2.1 Earthquake-Shaking and Damage

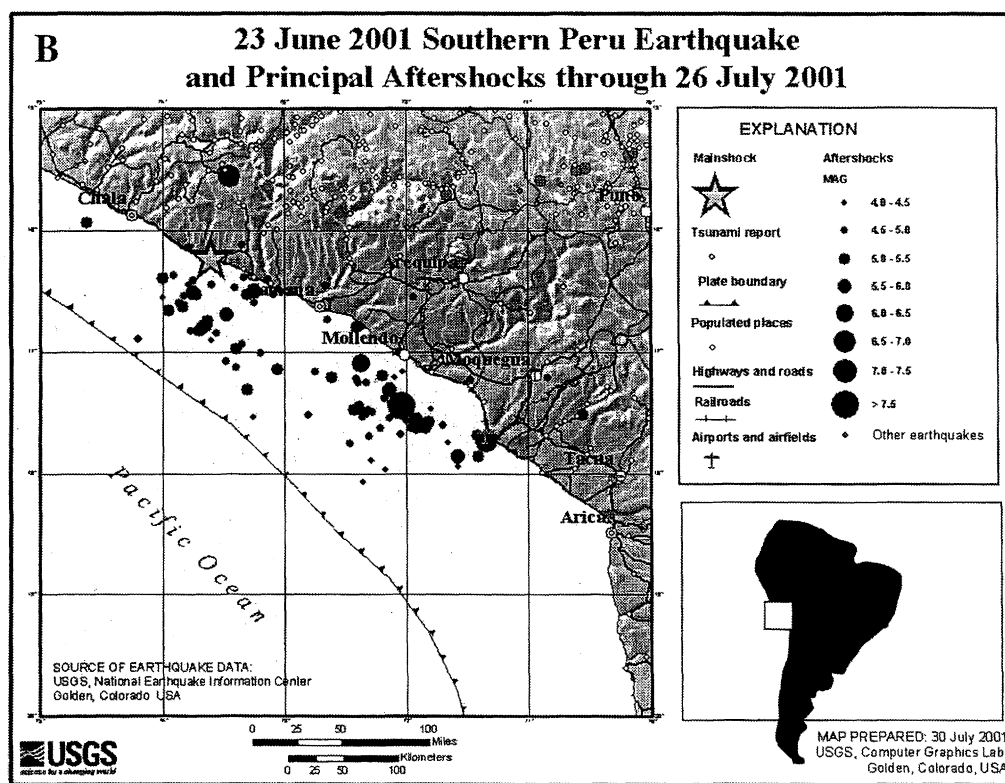
2.1.1 Earthquake-shaking effects

The city of Arequipa was almost 100 km away from the rupture zone. From our collection of first-hand accounts and our survey of the city we conclude that the shaking damage was relatively minor and confined mainly to areas of soft ground, where amplification of ground motions occurred. During the earthquake, the cathedral in the main centre of Arequipa lost one tower (Figs. 4 and 5). Similar damage apparently occurred to the other tower during an earthquake of estimated magnitude 9 in 1868. Other than the cathedral, the buildings damaged were mainly those with reinforced concrete framework and unreinforced brick infill, situated on very soft and poorly drained ground. Some modern buildings sustained significant damage in Arequipa, probably due to poor site conditions. Some of the large aftershocks of the southern Peru earthquake (Fig. 6) also produced damage in the general earthquake area. The top floor of the 1971-vintage military mess hall at the Arequipa military base (Fig. 7) was severely damaged. The building is not unlike some buildings of similar age in New Zealand.

Hill slope subsidence and slope failure damaged the Pan American highway and other main highways within the 300 km long earthquake zone. We show typical damage to a highway in Figure 8.



a.



b.

Figure 2. *Isoseismal map of Modified Mercalli (MM) intensity produced by the southern Peru earthquake (a), and aftershocks recorded in the month following the earthquake (b). The sources of the maps are Tavera et al. (2002) and the US Geological Survey (www.usgs.gov), respectively.*

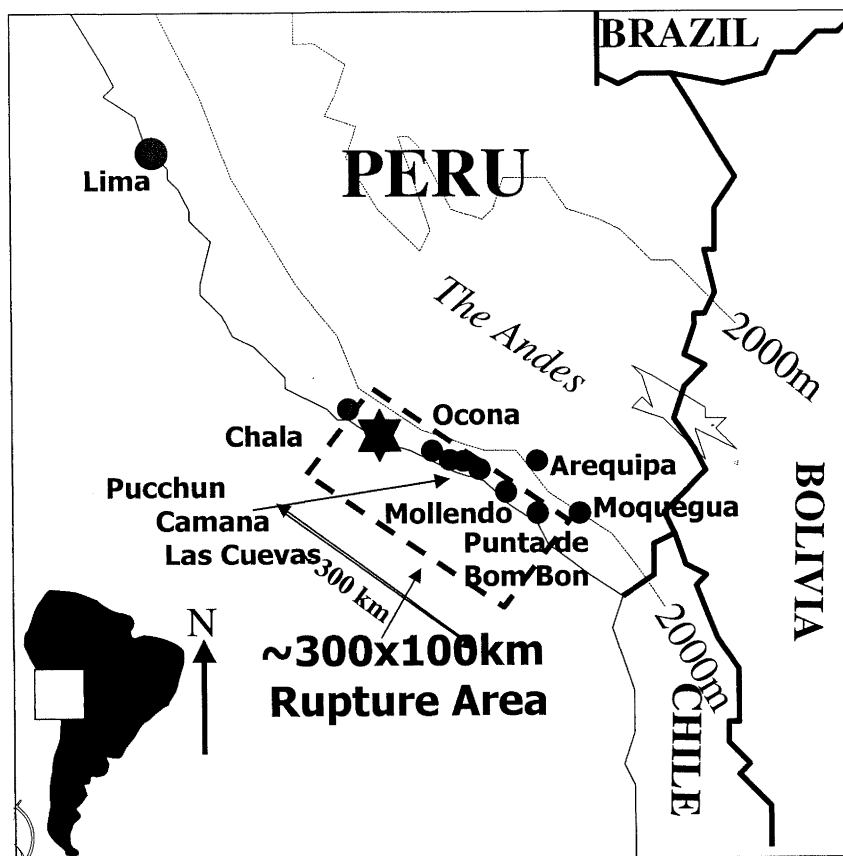


Figure 3. Locations visited during our reconnaissance trip. The solid rectangle shows the surface projection of the 300 x 100 km long zone of the subduction interface that is thought to have ruptured during the earthquake.



Figure 4. Reconnaissance team members. From left: Hector (Coco) Aleman (geophysicist), Robert Langridge (earthquake geologist), Mark Stirling (trip leader and seismic hazards scientist), and Rafael Benites (seismologist). The photograph also shows the damaged Arequipa cathedral in the background.



Figure 5. The Arequipa cathedral during the actual earthquake shaking, moments before the left-hand spire fell through the cathedral ceiling (the picture is from the tourist brochure "Terremoto" which was being sold on the streets of Arequipa at the time of our visit).

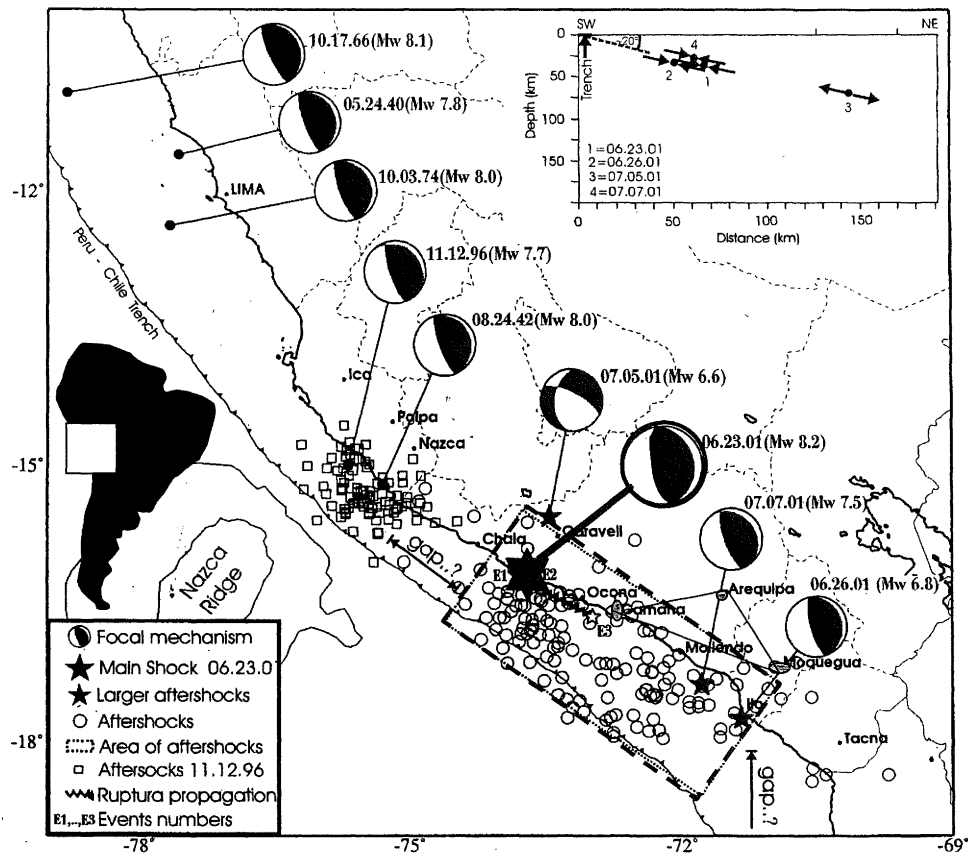


Figure 6. Historical subduction interface earthquakes in southern Peru since AD 1940. Focal mechanisms are lower hemisphere-equal area projections. The source of the map is Tavera et al. (2002). The surface projection of the rupture area of the earthquake is shown by the dotted rectangle. Several of the focal mechanisms shown on the figure are aftershocks of the of the southern Peru earthquake.

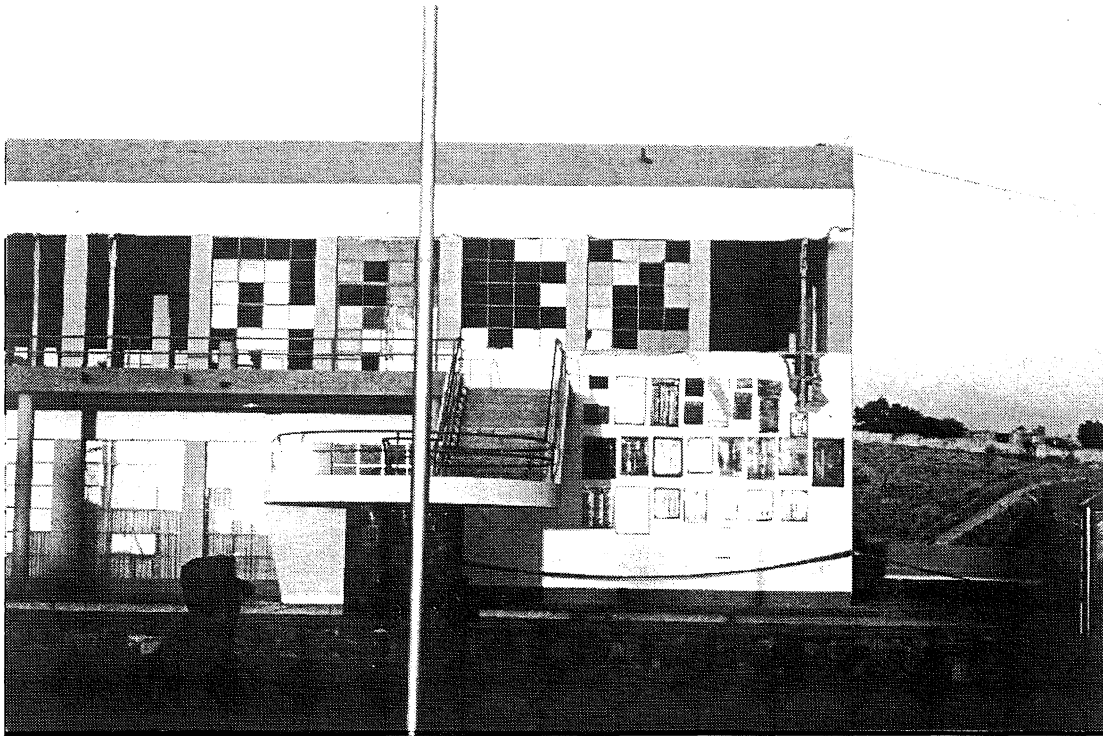


Figure 7. Damage to the top floor of the 1971-vintage Arequipa military mess. The broken glass and cracked pillars show that the building was not designed well enough to withstand the shaking, despite the relatively young age of the building.



Figure 8. Damage to the Pan American highway from failure of the slopes beneath the highway. Damage like this was widespread on the highways along the 300km long earthquake rupture zone, creating some considerable traffic hazards.

The only strong motion accelerograph record of the southern Peru earthquake came from the city of Moquegua (Fig. 3). This city sustained the most significant earthquake shaking damage of all the cities we saw because of the widespread "soft soil" (gravel alluvium) beneath the city. The accelerograph showed that a peak ground acceleration (PGA) of 0.3g had occurred in the city (Fig. 2), which we consider to be compatible with the level of damage observed in the city. The measured PGA of 0.3g is therefore likely to represent the maximum PGA produced by the earthquake, based on the fact that we did not see any other damage as extensive along the whole 300 km extent of the earthquake zone. This includes the epicentral area, where the strongest MM Intensity (8) was felt (Fig. 2a). A large proportion of the buildings were of adobe construction, and so the damage to the city was extensive (Fig. 9). Damage to younger and better constructed buildings was also significant, such as to the school building shown in Figure 10. This building appeared to be constructed to a similar standard to some buildings in New Zealand. Incidentally, our visit to Moquegua coincided with a visit by President Toledo to observe the earthquake damage. We were fortunate enough to meet the President during the course of our survey of the city.

In contrast to Moquegua, the city of Mollendo showed very little earthquake damage, despite being closer to the ruptured subduction interface. This city is on granite, or "hard rock" in engineering terms. This site condition was such that shaking damage was light. Few buildings including those of adobe construction were damaged (Fig. 11).

There were several places in the earthquake zone where seemingly well-constructed bridges were damaged. We show the one bridge we visited near Punta De Bom Bon in Figure 12, which shows the bridge broken in several places where the foundations have failed significantly. The bridge appeared to be of similar construction to many New Zealand bridges.

Along the entire earthquake zone many buildings were lightly damaged but still being used. We stayed in a number of hotels and ate in a number of restaurants with cracked walls and ceilings. We also saw much relief effort going on in the earthquake area, although it was some 5 weeks after the earthquake. Various relief organisations from around the world (eg. Red Cross) were active along the earthquake zone.

2.1.2 Earthquake-Induced Landslides and Liquefaction

There was very little earthquake-induced landsliding from the southern Peru earthquake. We saw one 100m high rock slide near the epicentre of the earthquake (Fig. 13). This was also where we saw one of only two areas of liquefaction. The other area of liquefaction was near the southern end of the earthquake zone, in a farm paddock near Punta de Bom Bon. Surprisingly these were the only areas of liquefaction seen, despite the great size of the earthquake and abundance of suitable conditions for liquefaction (coastal plains with sandy sediments and a high water table). It is possible that tsunami inundation in the Camana area destroyed liquefaction features, but the overall impression based on our survey of the 300 km long earthquake zone is that liquefaction was minor during the earthquake.

2.2 Impact of Tsunami and Inland Shift of Coastline

A large tsunami accompanied the southern Peru earthquake, and struck the coast at the central part of the earthquake zone (e.g. Camana area; Fig. 3) about 14 minutes after the earthquake. Eye witnesses described it as a 7 m high wall of black (sand-laden) water.

The tsunami was devastating to life and property due to the rapid advance and retreat of the water, and the abrupt inland shift of the coastline by about 100 m. The tsunami was the cause of most of the deaths in the earthquake, and had a large impact on the economy of southern Peru. It inundated large areas of cropland in the Pucchun-south Camana area, and also devastated the coastal tourist town of Las Cuevas and northern Camana (Fig. 3).

2.2.1 Damage to Coastal Towns: Las Cuevas and Camana

On our first arriving at Las Cuevas, we found it hard to imagine that the near total devastation of the coastal town was due to tsunami (Fig. 15). Instead, our impressions of the damage were that it was due to earthquake shaking. However, it was clear from the line of water-transported debris at the edge of the cliff (Fig. 15) and the distribution of debris throughout the ruins that the tsunami had violently impacted on the area. The tsunami swept several hundred metres in from the sea to the base of the cliff, smashing buildings and walls above high tide level, and depositing a layer of sand (up to 100 mm thick) and debris across the entire area.

In the Las Cuevas-south Camana area, eye-witness accounts of the tsunami impact allowed us to differentiate between earthquake versus tsunami damage. People felt the earthquake shaking but report no damage associated with the earthquake. It was the impact of the black wall of water that produced the near-total damage to the coastal part of the town. For example, the tsunami was observed to have come over the top of a two-storey discotheque, smashing through the roof and blowing out the windows (Fig. 16).

In our reconnaissance of the Las Cuevas-south Camana area, we were initially surprised at how close the holiday settlements were to the shore. However, after talking with the local residents we found that the settlements had been built well back from the shore and that the earthquake had caused the coastline to shift inland by about 100 m (Fig. 17a). A severely damaged coastal promenade (Fig. 17b) was well above the high water mark prior to the tsunami. According to residents, the shift of the coastline allowed the sea to progressively damage and breach the promenade over the following 5 weeks, and also led to the development of lagoons and the deposition of sands and gravels inland. We interpret the movement of the coastline to be due to the effect of coseismic subsidence and/or erosion of sand by the advancing and retreating tsunami. The tsunami had great capacity to remove sand from the beachfront when the water flowed back to the sea. Damage to buildings from the tsunami was worst on the northwest side of buildings (Fig. 17a). The tsunami therefore appears to have arrived from the northwest, consistent with the earthquake epicentre and area of maximum seabed deformation being to the north. The process by which the tsunami was produced by the southern Peru earthquake is shown by the sequence of cartoons in

Figure 18.

All around the Las Cuevas-south Camana area, we saw severe damage to man-made structures in the path of the tsunami. Concrete and cement block structures were smashed

and moved about as if they presented no barrier to the waves. Much sand was deposited by the seawater. The ponded seawater lasted for days on the streets of the ruined settlements after the tsunami (Fig 14).



Figure 9. Severe damage to buildings on the steep hillslopes of Moquegua. These hillslopes, along with the valley bottoms, are underlain by alluvial sediments which would have amplified the shaking from the earthquake. In this photograph nearly all adobe buildings have been destroyed, with considerably less damage to the more substantially constructed buildings.

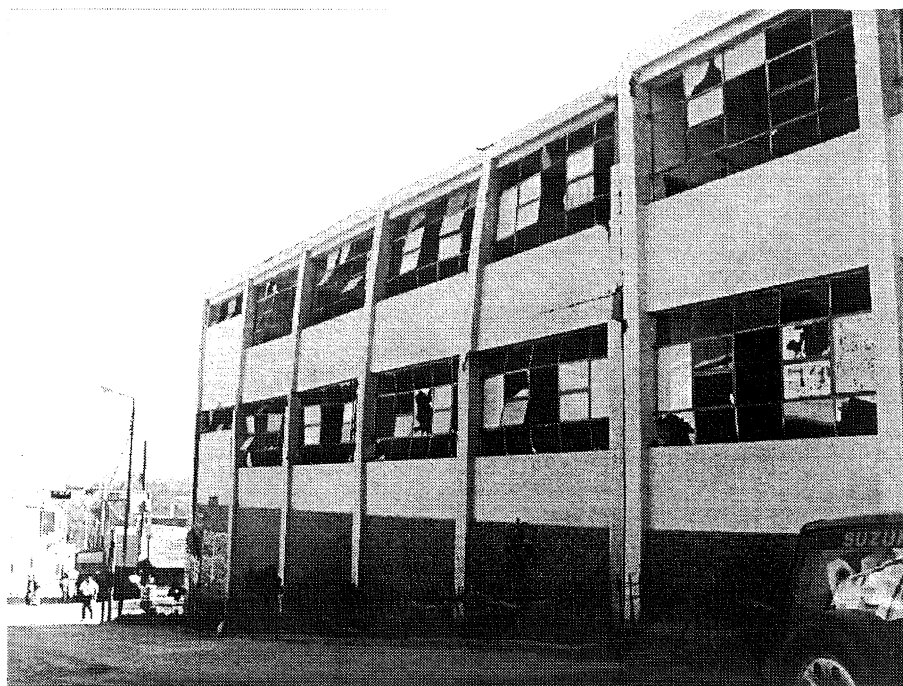


Figure 10. Damage to the Moquegua College, a building probably of similar age to the Arequipa military mess building in Figure 7.

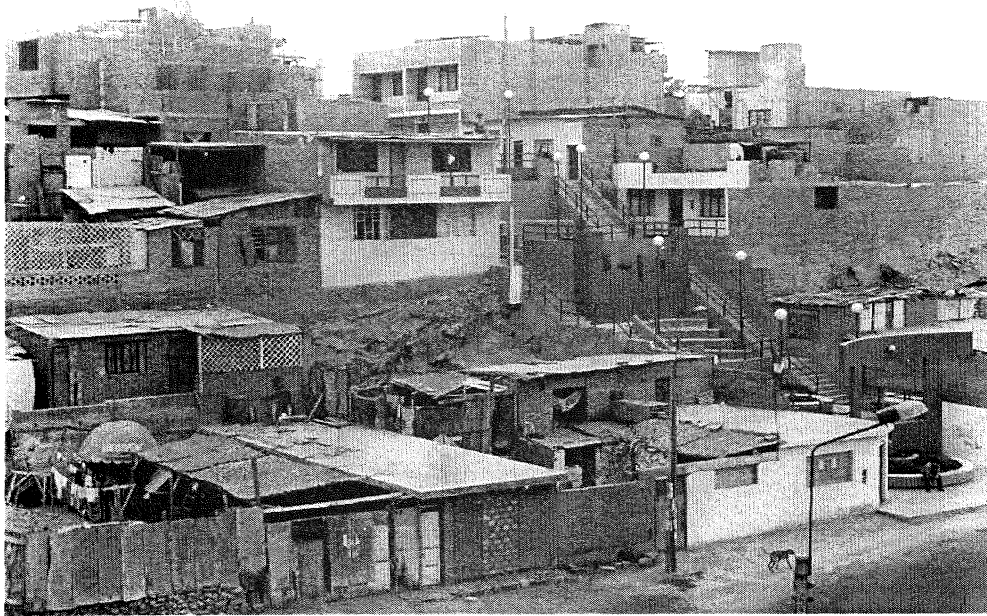


Figure 11. Undamaged buildings on granite rock in Mollendo. No damage was observed in the city, even in the case of adobe buildings (as can be seen in the lower centre of the photograph).



Figure 12. Damage to the bridge serving the township of Punta De Bom Bon.



Figure 13. Rockfall of c.100 m height in Ocona area.

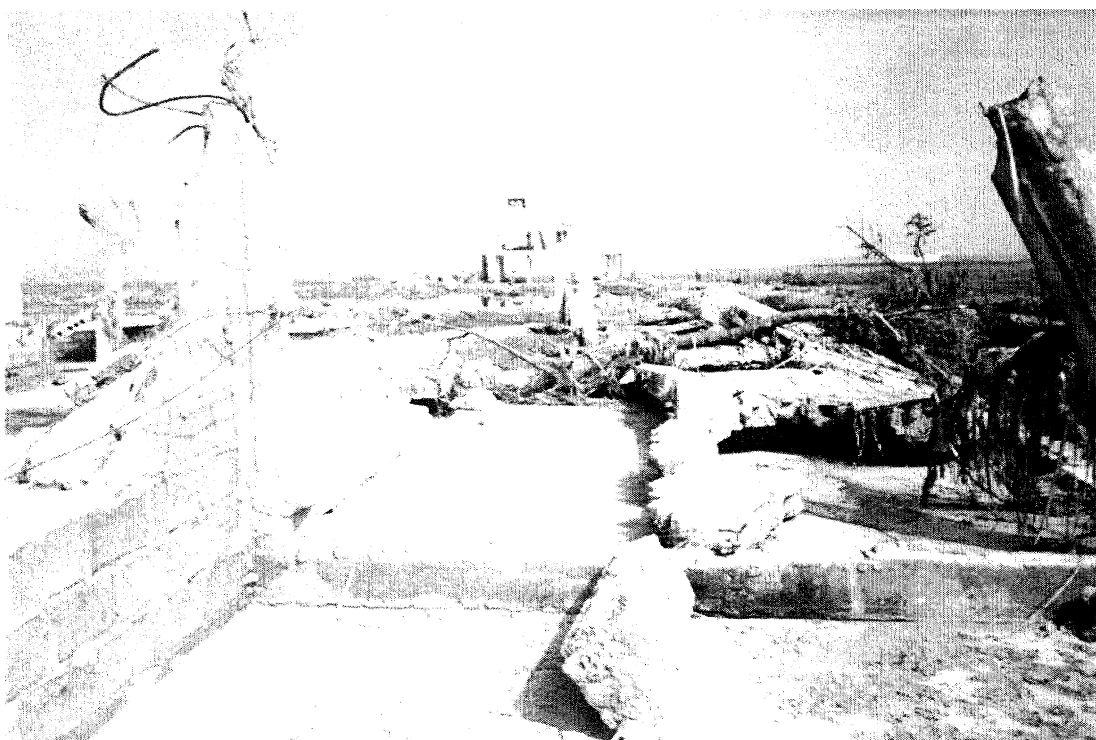


Figure 14. Devastation in the coastal resort town of Camana due to the tsunami.



Figure 15. The settlement of Las Cuevas (southeastern continuation of Camana) as we saw it some five weeks after it was destroyed by the tsunami. Arrow points to a darkish line of water-washed debris at the base of the hill, which marks the maximum inland extent of the tsunami.

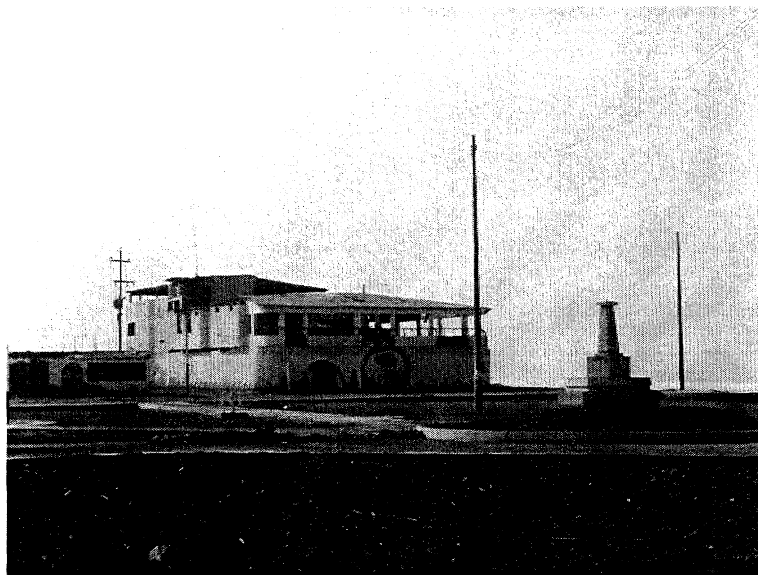
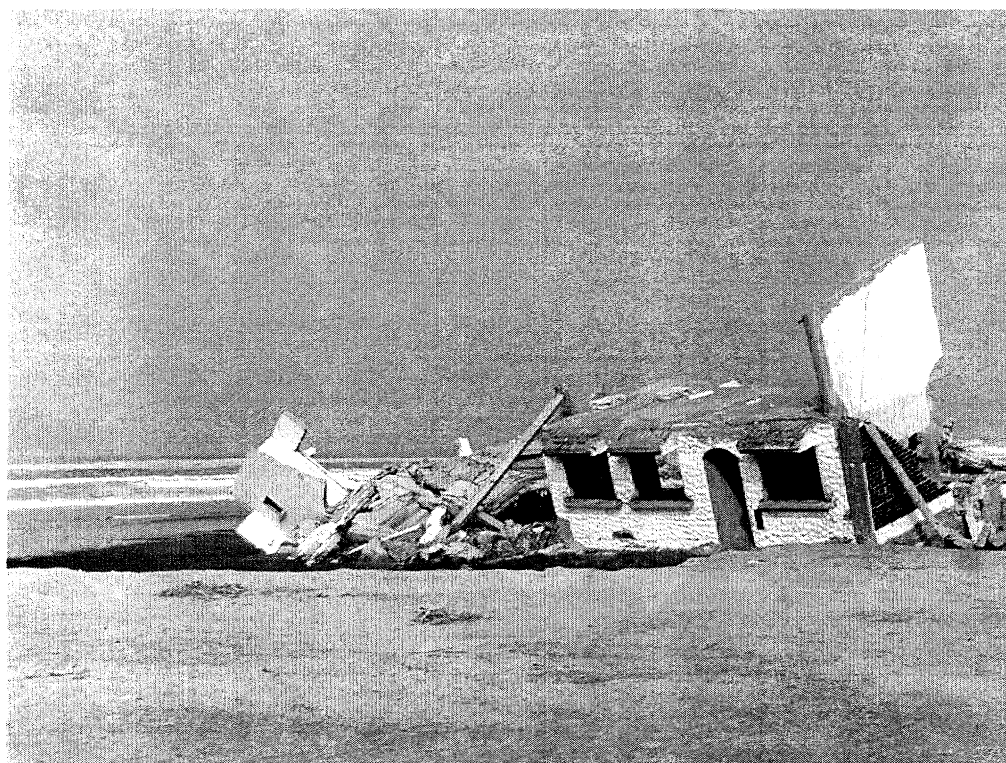
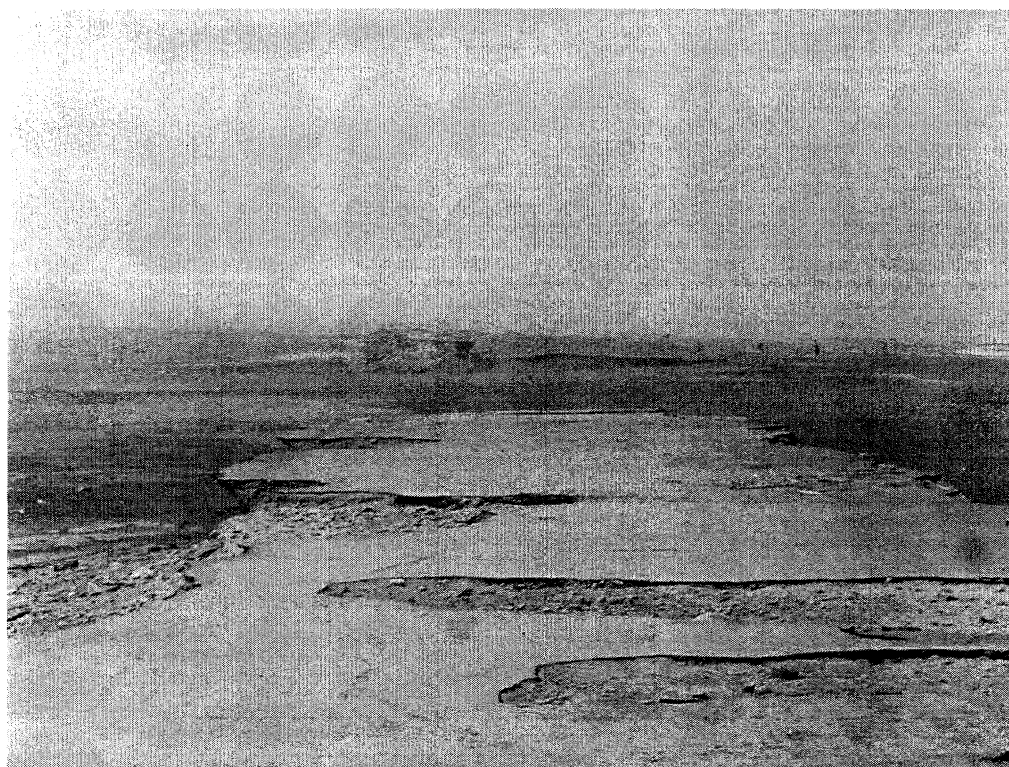


Figure 16. Witness accounts reported that the tsunami wave smashed through the roof of this disco and blew out the windows. The wave would therefore have been at least 7 m high, a height confirmed by the damage to the lamps of some tall lamp posts in the same area.



a.



b.

Figure 17. Possible evidence for coastal subsidence in Camana. The active beachfront was once 100 m seaward of the ruined building shown in this photograph (a) but is now adjacent to the building. This could be due to subsidence and the erosion of sand by the tsunami. The severe damage and southward lean to the building is likely to be due to scouring of the sand around the building and the severity and obliquity of tsunami impact. The coastal promenade in (b) was once well back from the active beach front, but is now at the active beachfront. In the 5 weeks following the earthquake it has been eroded and breached by the sea. This change in position of the active beachfront may be the result of coastal subsidence, and sand removal by the advance and retreat of the tsunami.

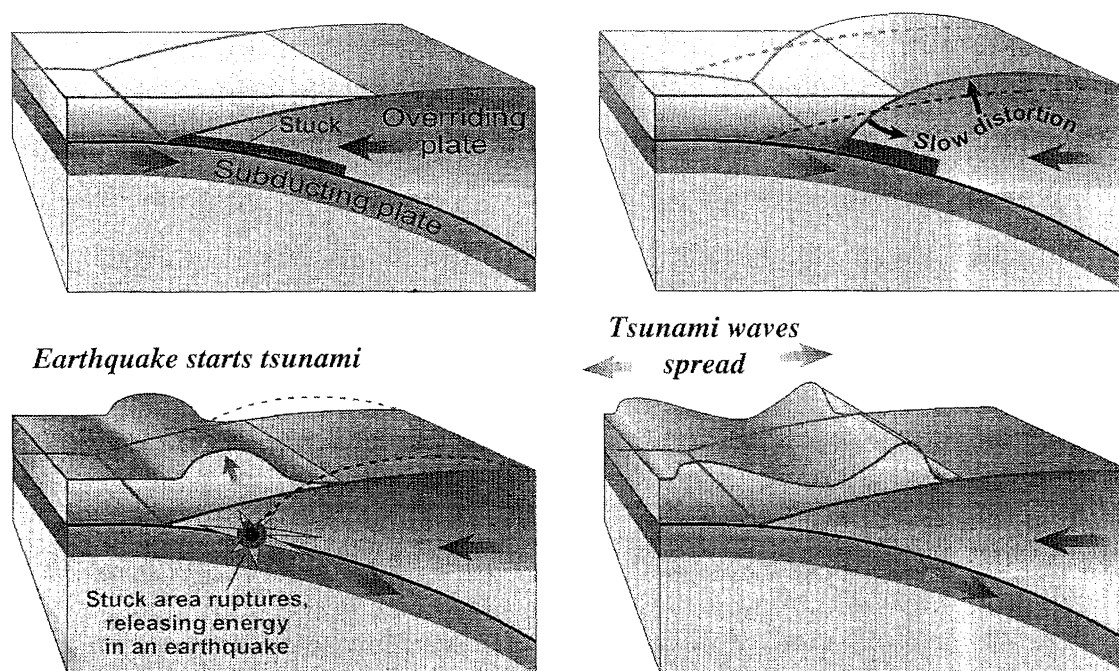


Figure 18. A four step cartoon showing the earthquake cycle of a subduction zone and how a tsunami is generated during a great earthquake. In the case of the southern Peru earthquake the overriding South American plate is to the right (east) and the subducting Pacific plate is to the left (west).

Such effects as homelessness, loss of family members, having to deal with the tainted water supply, and the threat of disease from bad water and decay were observed at the time of our visit, some five weeks after the tsunami. The Peruvians were fortunate that this earthquake occurred in winter. Camana is a summer resort town, and thousands of people from Arequipa spend part of summer on the coast. If the earthquake had happened in the summer then there would have been many more casualties from the tsunami.

2.2.2 Damage to Farmland: Pucchun

Considerable damage to farmland occurred in the Pucchun area just north of Camana (Fig. 3). Pucchun is a 2km wide irrigated coastal strip of flat land. The up-to-1km inland extent of the tsunami can be clearly seen as a colour contrast in Figure 19. The light gray fields are covered in sand (10 to 200 mm thick; Fig. 19) from the tsunami inundation, whereas the darker fields escaped tsunami inundation. Localised earthquake shaking-related ground damage was also seen at a pumping station in the middle of the farmland (the vegetated drainage channel can be seen to the right of centre of Fig. 19). A high gravel bar was breached in several places along the coast, and coarse gravels were deposited in a large tongue inland from the breach (Fig. 20). Witnesses described the tsunami as a large black wave ("una ola negra") overtopping and breaching the bar. The witnesses were lucky to escape the tsunami alive on foot, whereas many others perished. Bodies were still being recovered from the farmlands at the time of our visit.

The main effects of the tsunami in Pucchun were that the tsunami was erosive, seawater was left behind, salination of

the soil occurred over the zone of inundation, and a layer of sand was deposited over the rich topsoil (Figs. 21 and 22). Sand was also laid down inside many buildings in the area, with the added problem of being highly erosive before deposition. In a church in Las Cuevas the sand-laden waters eroded the cement-veneered walls of the church enough to expose the underlying bricks (Fig. 21b).

3.0 IMPLICATIONS FOR NEW ZEALAND

The southern Peru earthquake has provided us with the best opportunity in the last three decades to see the effects of the type of earthquake expected on the Hikurangi subduction zone in New Zealand. Our observations relevant to New Zealand are given in the following paragraphs.

The earthquake shaking was "moderately strong" in areas of "soft ground" (0.3g on alluvium in Moquegua, the only recorded PGA for the earthquake) and considerably less in areas of hard rock (e.g. Mollendo). We consider that shaking during a Hikurangi subduction zone earthquake may be of similar levels, and the influence of site conditions will be significant. The most serious damage would occur in areas of "soft ground" (e.g. Napier/Hastings, Gisborne, Wairoa and numerous parts of greater Wellington), whereas areas of hard rock would experience less damage. It is likely that the earthquake would not be as hazardous to these cities than earthquakes on the nearby crustal active faults (e.g. a M-7.5 event on the Wellington Fault), which would rupture the ground surface instead of rupturing about 20 km beneath the city as in the case of a great Hikurangi subduction zone earthquake. The shaking from the subduction zone

earthquake would therefore be more attenuated at the ground surface than the shaking from an earthquake on a crustal fault. A crustal active fault event may also produce considerably stronger shaking at the short spectral periods most damaging to one to two-storey buildings than the subduction zone earthquake (i.e. a PGA of about 1g for the

former versus the 0.3g measured in Moquegua). Great subduction zone earthquakes tend to be much richer in long-period energy than short-period energy, which could explain the relatively low levels of earthquake damage in the southern Peru event.

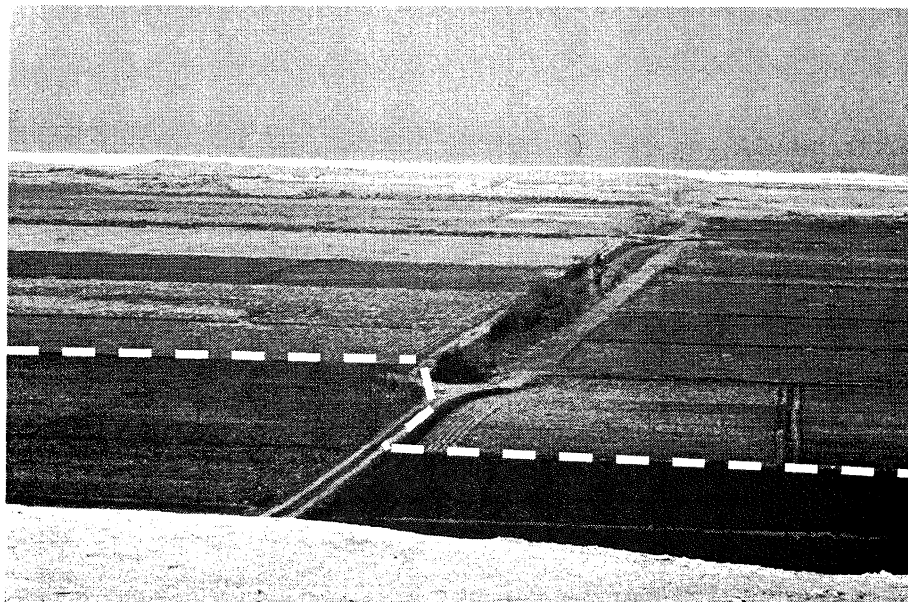


Figure 19. The Pucchun croplands showing the up-to-1km inland extent of tsunami inundation. The light gray farmlands in the photograph are covered with tsunami sand and lack vegetation, whereas the dark (crop-covered) fields escaped inundation. This boundary is marked by a dashed line.



Figure 20. Cobble gravel deposit formed by breaching of the natural beachfront bar during the tsunami inundation. Note also the extensive deposits of sand in the background.



a.



b.

Figure 21. Tsunami deposits. In (a), vegetation has flattened in the direction of wave motion (i.e. left to right) and buried by about 2cm of sand (see pocket-knife excavation to the right of the photograph) and the light colour on the surface of the deposit is a salt crust left behind after evaporation of the seawater. Tsunami deposits were left inside many buildings in the Las Cuevas-Camana area. The sand-laden water was also highly erosive. In this church building in Las Cuevas (b) the sand-laden waters eroded the cement-veneered walls of the church enough to expose the underlying bricks.

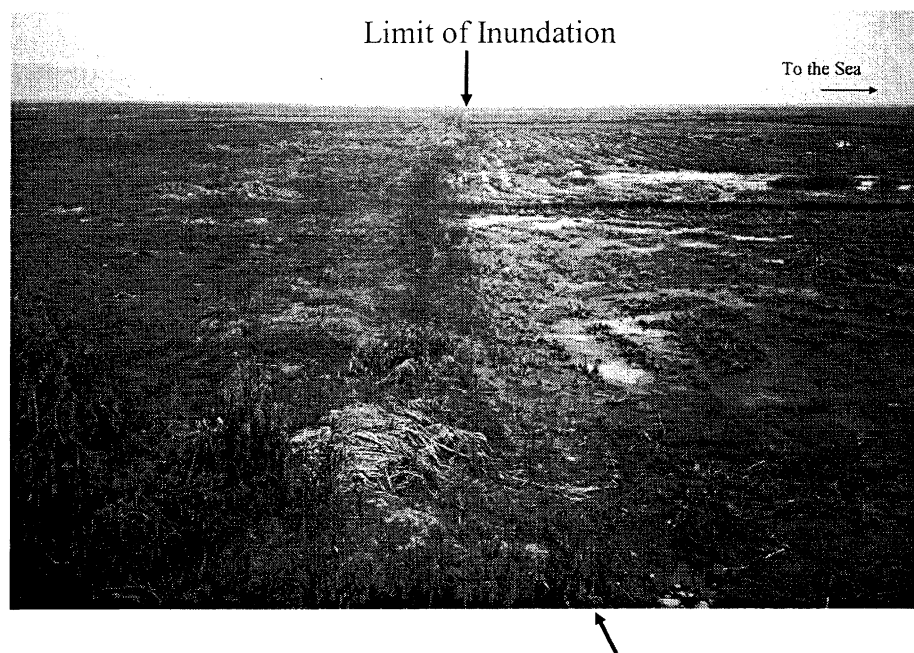


Figure 22. Distal edge of the tsunami inundation at Puccun, about 1km inland. The inundation zone experienced crop loss, sand and gravel deposition, ponded seawater and salinisation.

The southern Peru earthquake rupture zone was 300 km long, which in the eastern North Island would stretch from southern Wairarapa to Hawkes Bay. A southern Peru-sized earthquake on the Hikurangi subduction earthquake would therefore affect all of the southern North Island (or more), so it is possible that the impact of this earthquake would be more significant in a national context than an earthquake on a crustal fault. The regional extent could be further enhanced by the locked part of the Hikurangi subduction zone being largely under land in the Eastern North Island, which brings the source of earthquake shaking closer to the ground surface than the case of southern Peru.

The southern Peru earthquake produced a major tsunami in the central part of the earthquake zone. We expect a similar tsunami to accompany a Hikurangi subduction zone earthquake, and thus consider tsunami hazards to be very serious for centres such as Gisborne, Napier, Wairoa and greater Wellington. Loss of life, near-total destruction of nearshore buildings, subsidence, salinisation and tainted water supplies will result from a tsunami when it impacts any of these areas.

We have drawn many parallels between the southern Peru earthquake and those expected on the Hikurangi subduction zone, but express some caution. We acknowledge that the two subduction zones are not identical, in that the locked area of subduction zone is mostly beneath the seabed in southern Peru, whereas it is mostly under land and therefore shallower overall beneath the eastern North Island. We therefore think

that the strength of shaking might be slightly stronger in the eastern North Island as compared to southern Peru during great subduction interface earthquakes. However this difference might not be great, since the well-known subduction interface attenuation relationship of Youngs *et al* (1997) shows that the ground motions from these earthquakes increase only slightly with decreasing depth to the interface (e.g Fig. 23 shows a less than 0.05g increase in PGA for a source distance decrease of 30 km) There is also a question of how typical was the southern Peru earthquake of great subduction-interface events in general. With this question in mind we have plotted the 0.3g acceleration recorded for the earthquake at Moquegua on the Youngs *et al* subduction interface attenuation curves for median PGA (Fig. 23). The 70km distance used to plot the Moquegua record is an estimate of the closest distance to the subduction interface from Moquegua. On the basis of the Moquegua record it appears that the accelerations from the southern Peru earthquake were typical of subduction-interface earthquakes. The Moquegua peak ground accelerations appear to lie slightly above the soil curve, which amounts to an insignificant difference.

4.0 FUTURE WORK

During the course of our reconnaissance, we identified several avenues for future research that will improve the understanding of earthquake and tsunami hazards in New Zealand:

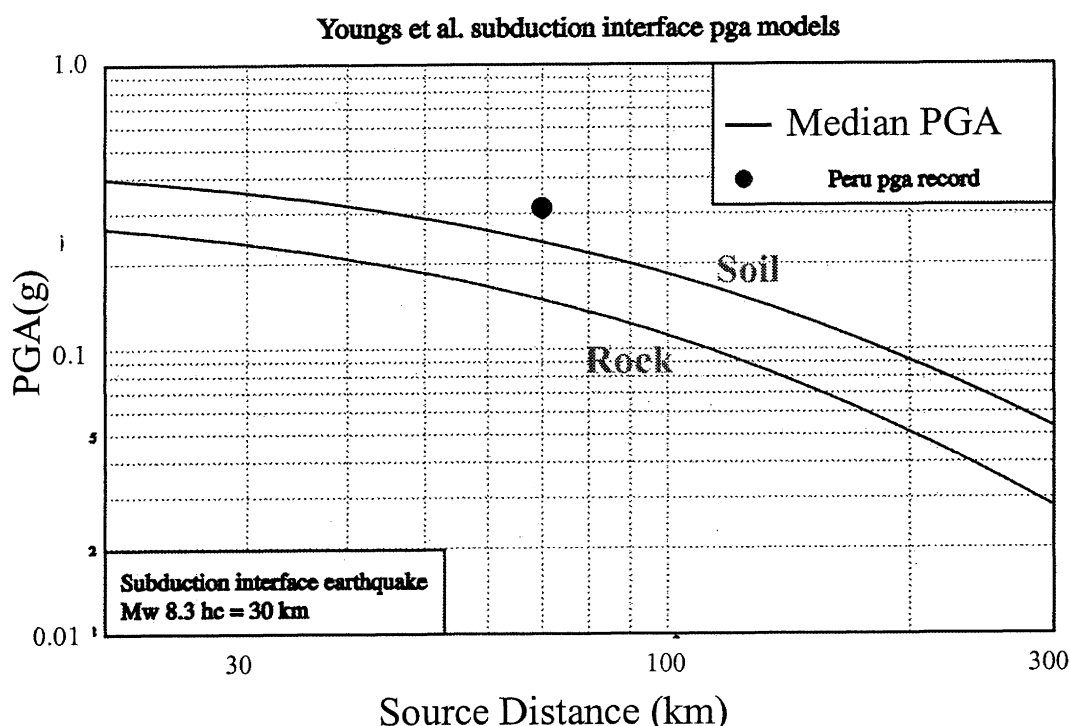


Figure 23. The Moquegua peak ground acceleration (soil site conditions) plotted on the graph of median ground motions predicted for the same size of earthquake from the Youngs et al (1997) subduction interface attenuation relationship.

- Establish the extent to which the ground motions of the southern Peru earthquake are typical of subduction-interface earthquakes on the Chile-Peru subduction zone and elsewhere in the world. The earthquake produced only “moderately strong” levels of shaking (PGA 0.3g on alluvium and considerably less on rock) which appear to be typical of the shaking levels measured in other subduction zone interface earthquakes. However, we recommend that this comparison should be the focus of further critical examination before the earthquake is formally used as a basis for hazard assessment in New Zealand. Analysis of the felt reports from other subduction zone earthquakes in similar settings to the southern Peru earthquake would be of considerable value in understanding the range of effects that could be produced in a future great Hikurangi subduction-zone earthquake.
- Model the tsunami wave heights and runup along the East Coast that might be produced by a great Hikurangi subduction zone earthquake. Observations of tsunami effects from the southern Peru earthquake and from other great subduction earthquakes could be used as a reality check for the output of the models.

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