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THE PERU EARTHQUAKE OF MAY 31, 1970: SOME PRELIMINARY SEISMOLOGICAL RESULTS

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Abstract

The 1970 Peru earthquake was a multiple shock. The first widely-recorded shock had a magnitude of about 5; within 20 sec there were at least four larger earthquakes, at least two of which exceeded magnitude 7. Focal mechanisms appear to be complicated, with at least one major shock yielding compressions at distances of 25° to 30° to the northeast. Most aftershocks occur at depths of 40 to 70 km; their first motions are sometimes reversed with respect to the main shocks. The seismic history of the region includes one comparable earthquake in 1725 but no events of similar magnitude thereafter. The town of Ranrahirca was not destroyed by the 1970 mud flow but by an earlier event in 1962.

Introduction

The South American continental border fronting on the Nazca Plate is one of the world's most active seismic regions. In spite of its dimensions, it was classed as a single region by Gutenberg and Richter (1954). Major earthquakes occur between the trench and the coast, at depths of 30 to 60 km. They are frequently associated with tsunamis and with large-scale geodetic changes. Wyss (1970) has shown that the region of intermediate earthquakes in Peru and Chile is subject to higher tectonic stresses than either the shallow zone or the deep zone. Thus, apparent stresses computed for two shocks off the coast of Central Peru at depths of 60 and 80 km reached values of 132 and 470 bars.

This preliminary paper is intended as a compilation of basic materials for future research. The Peru earthquake of May 31, 1970 appears to have been a complex event, consisting of several closely-spaced shocks at different depths, and perhaps with different focal mechanisms. A more complete geophysical picture will emerge from a detailed study of seismograms written at more than 100 stations. This study is now in progress.

Epicentral Locations and Origin Times

Table 1 summarizes the relevant parameters for three epicentral solutions obtained by courtesy of the National Ocean Survey of NOAA, using identical computational techniques. Solution A was obtained on the basis of 288 reported readings, without any selection or discrimination. Solution B was picked among a sequence of trial runs, using different computer options and subsets of stations. The preferred solution used *P* readings reported by 61 stations, including nine *PKP* readings. The focal depth parameter was free in both A and B. However, these solutions included only three readings at distances of less than 100 km: Ñaña, Huancayo, and Quito.

Solution C was obtained on the basis of readings of the seismograms carried out in Mexico. An effort was made to include readings at azimuths which had been poorly represented in the previous solutions. The readings at Ica, Peru and on the Tahiti array were particularly valuable. Table 2 lists the readings used for solution C.

From study of the seismograms it became obvious that groups of stations were

TABLE 1

SUMMARY OF RELEVANT PARAMETERS FOR THREE EPICENTRAL SOLUTIONS OBTAINED BY COURTESY OF NATIONAL OCEAN SURVEY*

Solution	Epicenter	Depth (Km)	Origin Time
A	9.2°S 78.8°W	43	20:23:27.3
B	9.2°S 78.8°W	47	20:23:28.9
C	9.2°S 78.6°W	35	20:23:26

* Identical computational techniques were used.

TABLE 2

READINGS USED FOR SOLUTION C*

Station	*P*-arrival time			Distance (deg)	Residual
NNA	20	24	20.5	3.5	2.9
HUA	20	24	38.4	4.7	5.4
ICA	20	24	49.4	5.9	−1.5
QUI†	20	25	42.5	9.0	5.8
ARE	20	25	54.0	10.4	1.3
LPB	20	26	29.1	13.0	1.3
BOG	20	26	56.1	14.6	4.5
MIC†	20	27	07.6	15.9	1.0
ANT	20	27	16.9	16.6	0.5
PEL	20	28	48.0	25.0	0.0
TRN	20	29	02.1	26.4	2.4
CON	20	29	17.0	28.0	1.0
BAE	20	29	42.1	31.2	0.0
CPO	20	31	40.0	45.0	0.0
GEO	20	32	03.2	47.9	0.5
WSC	20	32	03.7	48.1	−0.1
SLM	20	32	09.7	48.8	0.0
TUC	20	32	29.6	51.3	−0.1
TFO	20	32	42.9	53.1	0.0
RKT	20	33	00.0	55.1	0.0
JAS	20	33	37.7	60.8	−0.5
PPT	20	34	32.8	68.8	1.1
BY1	20	34	55.3	73.3	−0.1
BY2	20	34	56.3	73.4	−0.1
RBA	20	35	35.9	80.6	0.1
ESK	20	36	20.4	89.5	0.0
UPP	20	37	13.6	101.2	0.2
NUR	20	37	29.3	104.7	0.4
NOU	20	37	50.0	108.7	0.2

* Proposed epicentral location: latitude, 9.2°S; longitude, 78.6°W; depth 35 km.

† Times at QUI and MIC are doubtful. The systematic delays of 3 to 6 sec at Peruvian stations from offshore epicenters were first noted by Lomnitz and Cabré (1968). The final adjustment of the computer solution was done graphically, using the Gutenberg method.

reporting different P-arrivals. The initial event was quite small, and was clearly readable only on a few South American stations, which went off-scale a few seconds later. The strong-motion accelerogram at Lima unfortunately lost the entire portion of the P signal of interest. Hence, it seems likely that some remanent uncertainty in the epicentral parameters will be due to the complexity of the event; this uncertainty introduces an additional probable error of order ± 2 to 3 sec into individual station arrival times.

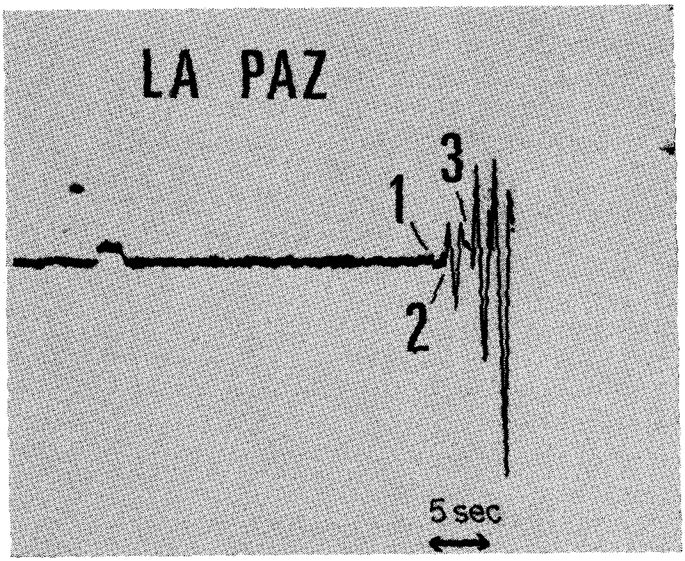

FIG. 1. Short-period vertical record at La Paz, Bolivia showing three separate first arrivals before the onset of the large impulse which threw the instrument off scale.

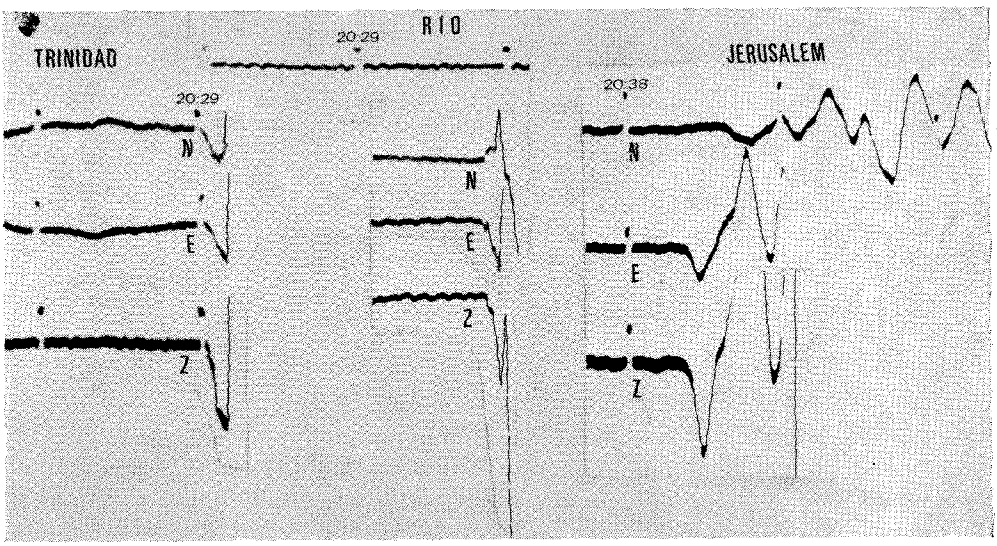

FIG. 2. Some examples of multiple arrivals on long-period, worldwide standard instruments. On Trinidad and Rio de Janeiro, note the distinct shocks at 2.5 sec and 7 sec after the initial event; the impulse at 7 sec looks like a compression. On the north component at *Jerusalem*, there is a delay of 18 sec corresponding to a major earthquake with an initial dilatation (indicated by arrested motion on the upswing for the E and Z components.)

Multiple Events

Mechanism. Short-period seismograms show considerable complexity due to successive arrivals. The "initial" earthquake, $M = 5$ (number 2, Figure 1) was preceded by a smaller earthquake, which was barely recorded on the four nearest stations. About 2.5 sec after the "initial" shock, there was a larger earthquake, followed by at least one medium-sized shock. The first major shock, which appeared to be a phase reversal at distances of 25° to 30° came 7 or 8 sec after the "initial" event (see long-period records at Trinidad and Rio de Janeiro in Figure 2). The total effect at large distances is a single dilatational pulse with a period of about 10 sec. Another larger event appeared at distant stations about 18 sec after the first arrival (Figure 2). This event has

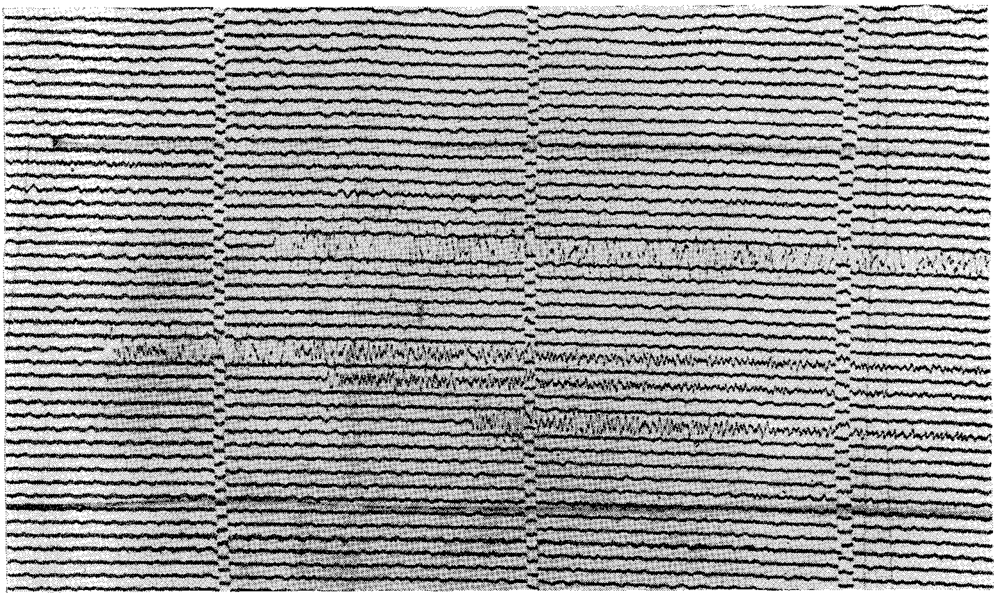

Fig. 3. At stations which record predominantly dilatations for the Peru events, one finds groups of aftershocks (like the above, recorded at Fayetteville), which show a clear compressional onset. The fourth event is shallower and happens to be dilatational.

perhaps been interpreted as *pP* by some stations; actually, it is quite difficult to distinguish the *pP* phases belonging to these various successive events.

The mechanism of most of these shocks appears to be compatible with high-angle normal faulting, but, in other cases, low-angle underthrusting of the continent by the ocean may occur. Because of the slow procedure of identifying each of the events at all stations, no fault-plane solution is proposed at this stage.

Aftershocks. Temporary stations were run at Casma, Chimbote, Trujillo, Huaraz, and Santiago de Chuco during the week of June 15, 1970. The records show that all of the aftershock activity was confined to the continental shelf. There is no evidence of any tectonic activity inland, in connection with the 1970 earthquake. High intensities observed in the Santa Valley (Callejón de Huaylas) must be connected with the local geology rather than with activation of the range faults which exist in that region.

The focal depth of the aftershocks varies between 30 and 70 km. Most of the after-

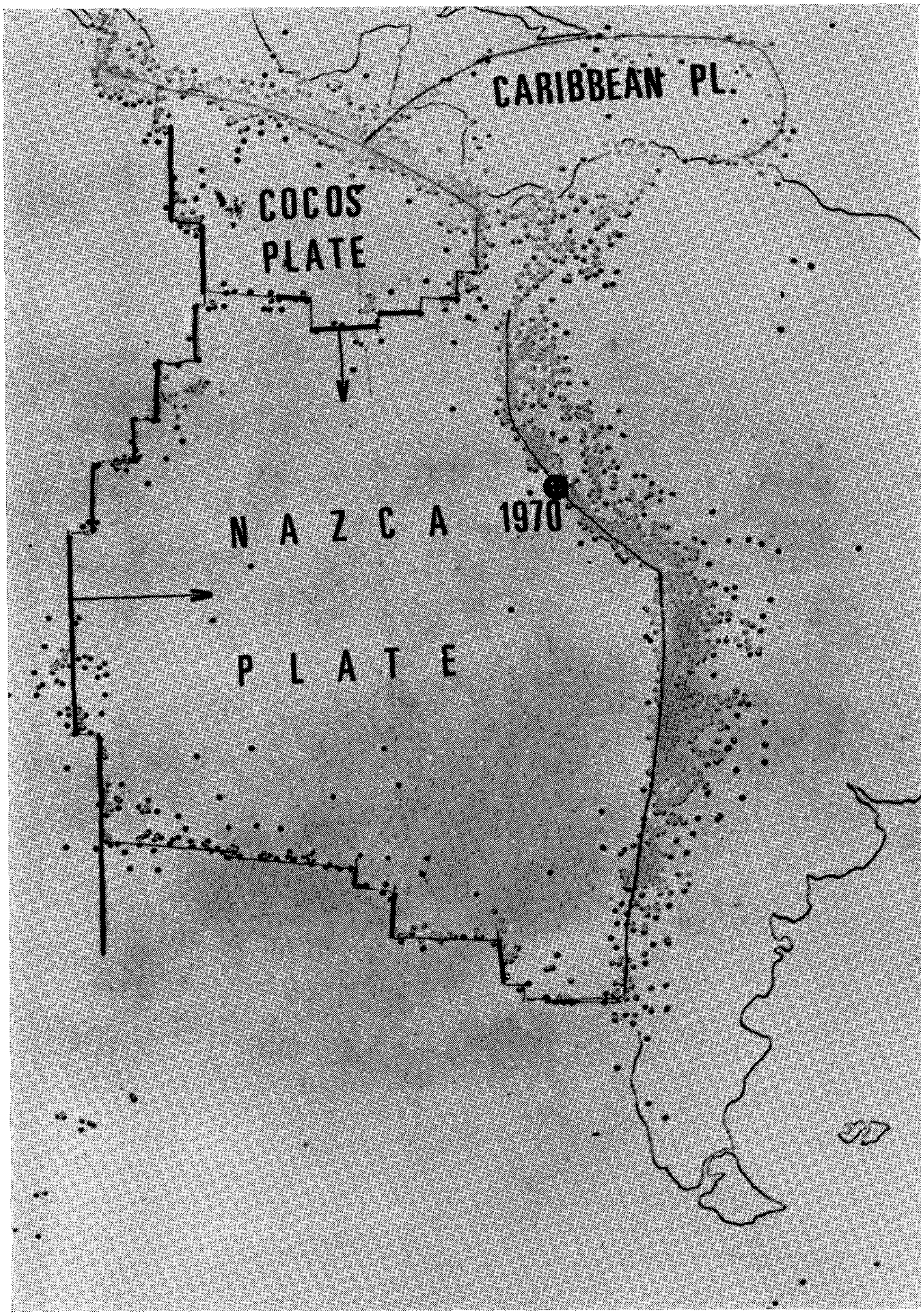

FIG. 4. The Nazca Plate in its relationship with the epicenter of the 1970 Peru earthquake. The plate is assumed to move normally against and under the Chilean Coast; this implies an angle of almost 45° between the direction of spreading and the coast of Peru. The heavy segments indicate spreading ridge sections (seismicity after Barazangi and Dorman, 1969).

shocks are consistent with the initial earthquake in their directions of first motion; however, at certain times, the aftershock activity reverses its polarity (Figure 3). The reason for this behavior is unknown.

Magnitude. The magnitude of a multiple event is difficult to define in practice. The initial shock had a body-wave magnitude of 5.6, or M_s about 5. A larger shock which followed about 2.5 sec later had a Richter magnitude of around 7. Several larger shocks occurred within the next 20 sec. Richter magnitudes computed from various portions of the P signal range from 7.3 to 8+. Pasadena reported 7.6, Berkeley gave $7\frac{1}{4}$ to $7\frac{1}{2}$, and Uppsala reported 7.9. Surface-wave magnitudes tended to be low and erratic, as might be expected because of the focal depth.

As compared to the Peru earthquake of October 17, 1966, $M = 7.5$ (Lomnitz and Cabré, 1968), the 1970 earthquake was more intense and was felt over a wider area. An unusual felt report was obtained by the author in the Altamira section of Caracas, Venezuela, indicating a Mercalli intensity of II.

Tectonics and Seismic History

Figure 4 shows the general tectonic setting of the coast of Peru, in relation to the Nazca Plate. Sea-floor spreading rates along the eastern Pacific rise vary between 4.6 to 6 cm per year. The contribution from the spreading ridge segments of the Galápagos and Chile rises is insufficiently known but probably does not exceed 2 cm per year.

The direction of motion of the Nazca Plate relative to the Americas Plate may be assumed to be approximately normal to the coast of Chile. Thus, while the Chilean coast is underthrust frontally, the coast of Peru is subjected to underthrusting at a strike angle of 30° to 45°. The transition region near the corner between Chile and Peru lacks deep-focus activity, and its earthquakes typically have low stresses (Wyss, 1970).

The problem of an oceanic plate impinging on a coast at an angle of about 45° cannot be treated here. The main result of such a configuration is a component of normal faulting associated with the underthrusting; this component would be expected to increase northward. It may be connected with large-scale inland rifting and normal faulting which occurs in Northern Peru, associated with the Huaylas and Marañón tectonic provinces (Wilson *et al.*, 1967).

The range fault along the western foot of the Cordillera Blanca shows evidence of Holocene and Recent vertical displacements (Kaizuka, 1971). No major earthquakes are known to have occurred on this structure in historic times. On the other hand, the earthquake of November 10, 1946 on the western flank of the Marañón graben, produced a 3.5 m high vertical fault scarp. Although the epicenter was only some 100 km north of Yungay, it caused no damage in the Santa Valley (Silgado, 1951).

The seismic history of the area is not very detailed. Earliest mention is of a destructive earthquake which occurred on February 14 or 16, 1619 —an event reported to have destroyed coastal and inland towns from Piura in the north to Santa in the south. The shock was particularly destructive in Trujillo and caused landslides in the interior mountains ranges (Silgado, 1968).

Another large earthquake damaged Trujillo on January 6, 1725. This shock was strongly felt in Lima. It triggered an avalanche of ice and mud which buried the town of Ancash, near Yungay, killing 1500. From available descriptions, we may assume that this event was comparable in epicentral location and magnitude with the 1970 event. No further earthquake of this size occurred in the present epicentral region between 1725 and 1970.

Additional Field Observation

In a previous short report (Lomnitz, 1970), it was stated that an avalanche of mud and ice originating from Mt. Huascarán had buried the towns of Yungay (population 19,000) and Ranrahirca (population 1,800). It appears, however, that Ranrahirca was

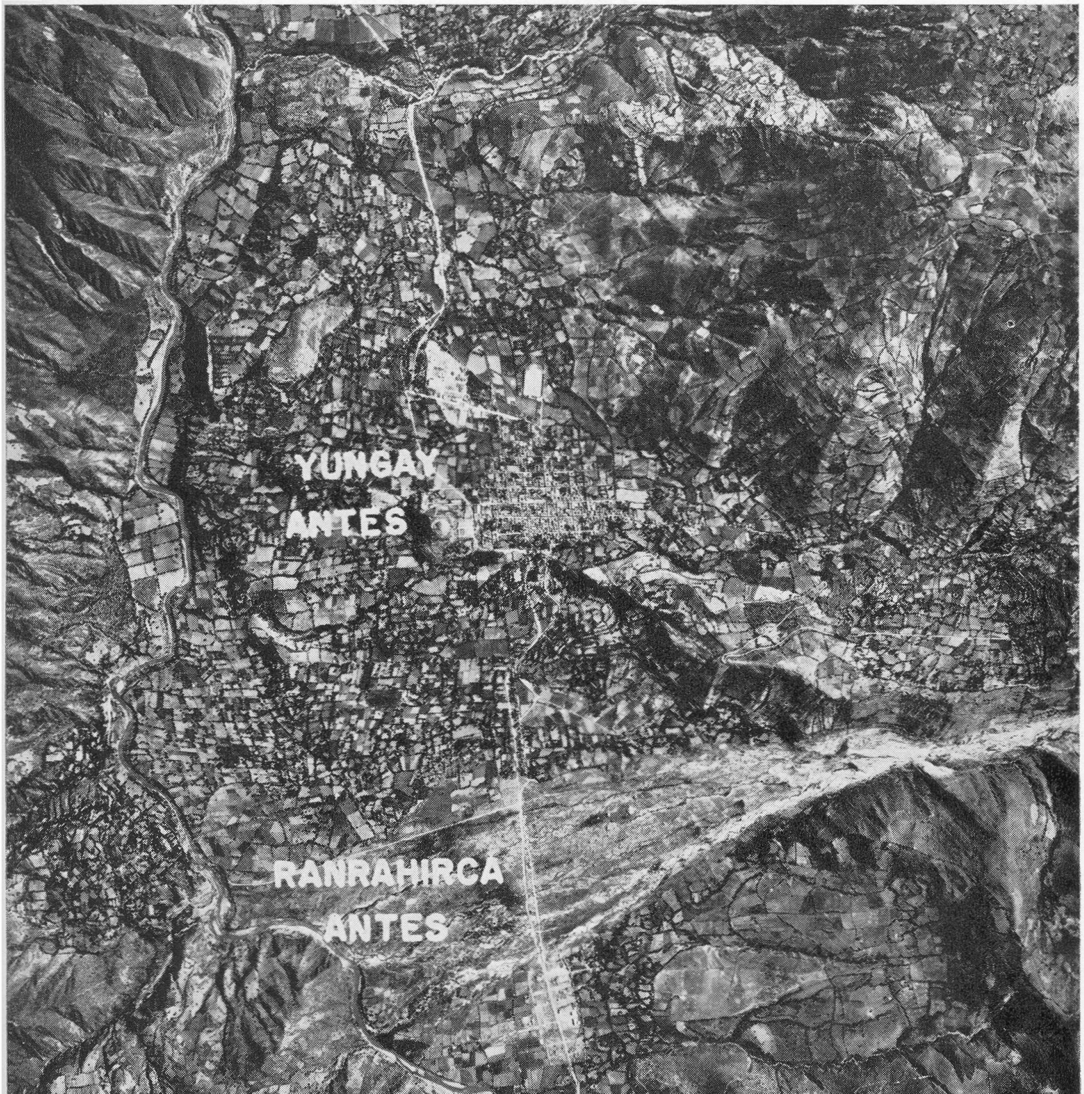

Fig. 5. Aerial photograph showing the site of Ranrahirca and the town of Yungay on July 2, 1967 (courtesy Servicio Aerofotográfico Nacional, Perú).

never rebuilt after it was destroyed by an earlier mud flow on January 10, 1962. This is evidenced by an aerial photograph dated 1967 (Figure 5), and confirmed by anthropologists who have done field work in the area. Thus, it would seem that Ranrahirca was *not* razed by an avalanche in 1970, other reports notwithstanding.

Conclusions

The 1970 Peru earthquake was a complex multiple event, probably associated with combined normal faulting and underthrusting to depths of 70 km under the continental shelf. The nature of the seismic mechanism may be consistent with the tectonics of this geological province of Peru, the only area in western South America where active rifting with surface-fault displacement is known to occur.

If the inferences of Wyss (1970) about high tectonic stresses at intermediate depth in this region are correct, then an earthquake of magnitude $7\frac{3}{4}$ might be released by a fault as small as 20 km. This fact has some implications for the analysis of the sequence of events in the 1970 Peru earthquake (Lomnitz, 1971).

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