REVISTA GEOLOGICA DE AMERICA CENTRAL

THE PUERTO ARMUELLES EARTHQUAKE OF JULY 18, 1934

On July 18, 1934 at 01h 36m 29s UTC, a very strong earthquake (Ms = 7.6) hit the Gulf of Chiriquí region. The epicenter reported by the 1934 ISC Bulletin is 8.2°N, 82.6° W. GUTENBERG & RICHTER (1958) report an epicenter with coordinates 8.00 N, 82.5° W.

This event caused very local damage mainly in the south western Panama region (VIQUEZ & TORAL, 1987). It was strong enough to trigger a Wenner Balboa Heights Panama (BHP) in the Panama Canal Zone, 340 km away, that recorded a maximum horizontal acceleration of 7 cm/s2 at 0.6 s (NEWMANN, 1936). This earthquake was also felt in Panama City and in San Jose, Costa Rica at 350 and 300 km from the epicenter, respectively with a M.M. intensity of V. It has been suggested that the Panama Fracture Zone works as an elastic wave buffer zone so that earthquakes to the west of it cause more destruction in Costa Rica and those to the east produce most of the damage in Panama (GUENDEL, writtencomm., 1989). This phenomenon could possibly be explained by the findings by DETRICK et al. (1986) of a seismically anomalous crust within large oceanic fracture zones, which presents low compressional wave velocities especially in the shallow crust, and very high velocity gradients.

CAMACHO: Puerto Armuelles Earthquake, Panama

The Puerto Armuelles Earthquake also generated a smallloca1 tsunami (LOCKRIDGE & SMITH, 1984). The tsunami was recorded in Bahia Ronda, in the eastern shore of the Gulf of Chiriqui, by a tide gage aboard the U.S.S. Hannibal. The peak to through amplitude was 0.6 m, and the duration of the wave train in Bahia Honda was five hours eighteen minutes. This tsunami only caused minor damage along the western shores of the gulf. CRUZ & WYSS (1983), have found that the tsunamis along the Pacific coast of Mexico and Central America just cause local damage. Large tsunamis like those of Chile and Japan are not characteristic of this region.

The main earthquake was followed by four strong aftershocks on the same day: at 04hOOm, Ms = 6.5; at 06h35m, Ms=6.5; at l6hl0m, Ms = 6.0; and at 17hOOm, Ms=6.9 (ACRES, 1982). The fourth aftershock was also strong enough to trigger the BHP accelerograph again. On July 21 at 10h49m another aftershock occurred, that registered a magnitude Ms = 6.75 (ACRES, 1982). Balboa Heigths Panama (BHP), located 350 km, away recorded fifty aftershocks between July 18 and July 26. Due to the July 21 event, cracks, several inches wide, appeared near the village of Progreso, extending across the Panama-Costa Rica border, with a NWW-SEE trend (LEEDS, 1978). This last strong aftershock was the one caused more damage, mostly in areas with extensive alluvium material. This was made worse by the fact that its epicenter was located on land, and that the buildings were already weakened after all these severe aftershocks. Most of the well constructed building just underwent minor damage (LEEDS, 1978; VIQUEZ & TORAL, 1988). Altogether, this group of events caused around two million 1934 U.S. dollars of damage.

PREVIOUS HYPOCENTRAL RELOCATION AND FOCAL PLANE SOLUTION

The epicenters of the July 18, 1934 Puerto Armuelles Earthquake and aftershocks were relocated for the first time by KELLEHER et al. (1973) using a single event location computer program they obtained the results shown on table 1. A plot of the-epicenters relocated by Kelleher erated a small local tsunami (LOCKRIDGE & in 1973 is on figure 2. It has been found by PLAFKER(1973),AL- GERMISSEN et al. (1974), PONCE et al. (1979), GETIRUT et al (1980), MIY AMURA (1980) MORALES (1984), and SINGH & LERMO, that for events in the Pacific of Mexico and Central America the epicenters located teleseismically, with unadjusted travel times, lie tens of kilometers northeast of the true epicenter . Due to this shift to the northeast the events are usually located inland or very close to the coast when in reality they have an offshore location. Moreover. CRUZ & WYSS (1983) have studied tsunamogenic earthquakes along the Pacific coast of Mexico and Central America, and found that their teleseismic plot 50 to 100Km inland from the coast. Like the other researchers mentioned before, they propose too, that these locations are biased by at least 75 km to the northeast and their depths are overestimated by approximately 20 km. According to them this has to be so, because major portions of the rupture areas must have been located at shallow depths under water so that tsunamis could have been generated.

Table 1
The July 18, 1934 Puerto Armuelles Earthquake - and Aftershocks as relocated by KELLEHER et al. (1973)

Event #	Date	OT.	Lat. (N)	Long. (W)	Md (PAS)
1	7/18	013623.2	8.14	82.38	7.6
2	7/18	040037.1	7.89	82.88	6.5
3	7/18	063533.0	8.31	82.37	6.0
4	7/18	160949.4	7.91	82.26	6.0
5	7/18	165938.8	7.81	82.15	6.9
6	7/21	103908.6	8.48	82.42	6.75
7	7/21	13191 8.3	82.87	6.0	

* The magnitude of this first event was estimated by Abe (1981).

The focal mechanism of the main event has been previously estimated by MÜHLHAUSER (1956). From twenty there P wave first motion readings he obtained a north south trending right lateral strike slip focal plane solution. It is important to note that five of the polarities employed by Miihlhauser are from stations located at more than 100 from the epicenter. Polarities from P wave first arrivals generally are not too reliable at these distances because the rays hit the earth's core (STEIN, 1987). Furthermore one of the polarities used in his determination, SCO is listed in the station bulletin and in the International Seismological Summary with the opposite sign. Unfortunately the historical seismogram is no longer available. Another station GEO is very unlikely to be compressive, because historical seismograms from three Canadian stations: OTT, SHF, and SAF with almost the same azimuth show clear dilatations.

An almost similar fault plane solution was obtained by WIECKENS & HODGSON (1967), employing a computer program to process the same data used before by Miihlhauser

DATA AND ANALYSIS.

In this study we have applied modem techniques to relocate the hypocenters of the main event and its aftershocks and determine its focal plane solution.

Hypocenter Relocation

To relocate the main event and its aftershock we have used first arrivals times as listed in the 1934 International Seismological Summary, the Bulletin du Bureau Central Seismologuique, the United States Coast and Geodetic Survey Earthquake Report, and bulletins from several Mexican and South American stations.

With these data we fed a Joint Hypocenter Determination (DOUGLAS, 1967; DEWEY, 1971) computer program: JHD89 kindly provided by J. Dewey. This method has proved to be very successful in reducing within group errors in studies with regional and teleseismic phases (DEWEY & ALGERMISSEN, 1974; VIRET, 1984).

We preferred a joint hypocenter determination (JHD) over a master event technique, even though the last one is easier to use, because many of the stations that recorded the 1934 events are no longer in operation. For either of these two techniques, the effect of travel time anomalies is minimized.

As calibration event we used the 1979 Puerto Annuelles Earthquake which was clearly and widely recorded at teleseismic distances. The International Seismological Centre Summary reports for this event the following parameters: OT 20h34m21 s, 8.342° N, 82.980° W, and a focal depth of 30 km. Instead of using this depth we used the one determined by ADAMEK (1986). U sing waveform modelling he determined a focal depth of 12 km for this event DZIEWONSKI (1987) estimated for the same event a depth of 10 km.

We calculated the depth of the main event from four pP -P time intervals from historical seismograms. These readings correspond to the following stations: on, EDI, ucc, PAS, and SLM. Using the J-B travel times we obtained a depth of 24.~ 2.6 kID, which may be a bit overestimated. In oceanic events due to the water layer the depth phases can be misidentified with water reberberations such as pwP or swP (MENDIGUREN, 1971; HERRMANN, 1976). Fortunately the bathymetry in this region is very shallow and the water layer does not affect the depth determination considerably. Moreover, the fact that this event caused a small tsunami and that these are generated by changes in the ocean floor following a shallow earthquake (MURTY, 1977) indicates that this event was shallow.

For the rest of the events we assigned "dummy" depths, based on what it is known for depths in this region from recent studies by WOLTERS (1983) and ADAMEK et al. (1988). The events located in the gulf were assigned a depth of 15 kID, and those located inland were assigned a depth of 25 kID. As has been stressed by DEWEY (1979) the effect of an uncertainty of approximately 15 km in depth, has a minimal effect on the teleseismically determined epicenter. Because of this it is better to use geophysical and tectonically reasonable estimates of depth, than try to compute it from inadequate data.

In this study instead of relocating the best re- corded events using JHD and then recomputing the remainings events with a single event teleseismic location program, using stations delays and variances computed in the JHD, we relocated the whole set of seven events using JHD.

Table 2.
The July 18, 1934 Puerto Armuelles Earthquake and its aftershock as relocated in this work using JHD89

Event #	Date	OT	Lat	Long	Ms	Depth
1	7/18	01h36m28.3s	8.12	82.61	7.7	25
2	7/18	04hOOm40.4s	8.03	82.95	6.5	15
3	7/18	06h35m39.1s	8.38	82.50	6.5	25
4	7/18	16h09mS4.5s	8.06	82.36	6.0	15
5	7/18	16h59m43.2s	7.91	82.26	6.9	15
6	7/21	10h39m14.7s	8.56	82.72	6.75	25
7	7/21	13h19m23.6s	8.18	82.90	6.0	15

A plot showing the location of the relocated epicenters with respect to the tectonic structures of the region is on figure 2. In this plot can be notice that the main event and the majority of its aftershocks have shifted to the southwest, and they are located in or within few kilometers of mapped faults.

The main event, number 1 in the map is at less than 10 km from the Balboa Fracture Zone. Events 2 and 7 are close to the Burica Medial Fault Zone, a north trending rigth lateral strike slip fault system, almost coincident with the Panama-Costa Rica border, which was inferred by CORRIGAN (19 86) based on stratigraphic evidence. The relocation of the sixth event lies close to the Chiriqui Regional Fault that extends north of the city of David, but this event could have also been caused by the Balboa Fracture Zone. The lack of a focal mechanism makes difficult to determine which of the two structures caused this event. Reports of cracks, with a NW - SW trend, near the town of Progreso (NEWMAN, 1936) would favour the Balboa Fracture Zone.

As The epicenters relocated using joint hypocenter determination are on table 2 the source fault for event 6. Three events: 3, 4, and 5, even though they do not copulate with any known tectonic structure, they show an alignment that parallels the trace of the Panama and Balboa Fracture Zone inland as occurs with the two other fracture zones.

Focal Plane Solution

To determine the focal plane solution of the main event, we read the polarity of the first arrivals of twenty five historical seismograms from stations distributed in the four quadrants, with epicentral distances in the range between 19° and 98°. The great majority of the recording stations are located in Europe. Angles of incidence were determined from standard tables (pRO & BIHE, 1972).

The whole focal mechanism determination procedure can be found in HERRMANN (1975). The azimuths, epicentral distance, angles and polarities corresponding to each of the twenty five station used in this study are on table 3.

Table 3

Stations used for the focal Plane Solution of the Puerto Armuelles Earthquake July 18, 1934.

Station ED(°)	Azimuth	(o)	Ih	Polarity
SJP	19.9	56.0	50.0	D
CSC	25.8	3.0	38.7	D
LPB	28.6	149.0	36.7	C
SLM	31.2	350.0	36.3	D
OTT	37.6	8.0	34.5	D
SHF	39.3	10.6	33.9	D
SFA	40.2	12.4	33.7	D
PAS	41.7	314.0	33.3	C
BZM	44.8	332.0	32.1	C
MHC	46.3	316.0	31.6	C
BKS	46.4	316.0	31.5	C
UKI	47.7	317.0	31.3	C
SAS	48.1	340.0	31.1	C
LPA	49.0	153.0	30.8	D
SIT	63.6	331.0	26.3	C
HON	73.3	290.0	23.2	C
TOL	76.0	51.0	22.5	C
EDI	77.3	34.0	22.0	D
All	78.7	52.0	21.6	C
KEW	79.1	39.0	21.5	C
UCC	81.7	39.0	20.7	C
BN	82.2	38.0	20.5	C
TU	84.9	41.0	19.4	C
UPP	88.0	30.0	18.7	C
API	91.8	256.0	18.2	D
PUL	94.0	27.0	18.1	C
CIZ	98.5	225.0	18.0	D

P **wave first motion** is **indicated by** C (compression) D **(dilatation)**

From these data we obtained a focal plane Solution, that indicates a right lateral strike slip faulting with a normal component. The nodal planes are on table 4, and the focal plot is on Figure 3. As fault plane we have chosen plane A from table 4, because it correlates extremely well with the trend of the relocated aftershocks, and the bearing of the strike slip faults of the area under study. It is also worth of note that for stations SLM and PB, located very near plane A, the amplitude of the S wave in the E- W component is much greater than in the N-S component.

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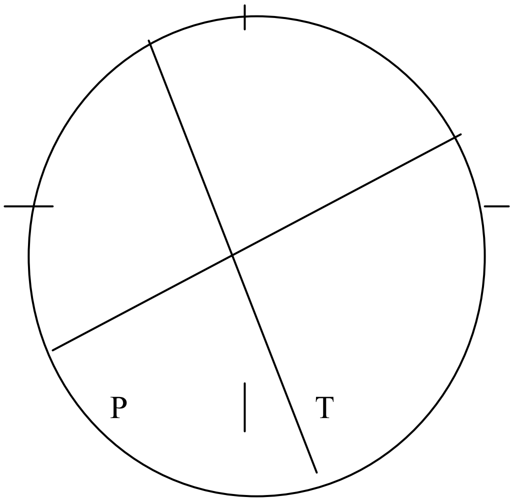

Fig. 3: p wave focal mechanism solution of the July 18, 1934 Puerto Armuelles earthquake. This diagram is an equal area projection of the lower hemisphere of the focal sphere. Solid triangles denote compressions and open triangles dilatation.

Table 4.
Fault Plane Solution of the Puerto Armuelles Earthquake of July 18, 1934.

Strike **(o)**	dip **(o)**	slip **(o)**	Trend **(o)**	Plunge **(o)**
Plane A	341	86	-	168
Plane B	250	78	-	04
Paxis	206	11		
T axis	115	06		

A strike slip focal mechanism does not contradict the fact that a local tsunami was generated by this event. Large earthquakes along major strike slip faults near the coasts of southeastern Alaska and British Columbia have generated tsunamis that were not observables at distances greater than about 100km (ISAAKS etal., 1968; MURTY,1977).

As can be notice from the focal plot on figure 3, dte fault plane A correlates exceptionally well width dte trace of Balboa Fracture Zone.

CONCLUSIONS

After relocating the hypocenter of the July 18, 1934 Puerto Armuelles Earthquake and its aftershocks, and having determined the focal mechanism of the main event we may conclude the following:

1-. The dextral strike slip focal mechanism of the main earthquake, which occurred at less than 30 km from the coast, seems to rule out the possibility that the Fracture Zones are subducting in the southwestern Panama continental shelf.

2. At least, the Panama Fracture Zone and the Balboa Fracture Zone can be extrapolated northward into the Panama southwestern continental margin were they curve into a northwest trending direction. Once inland they merge with a braided systems of faults, which run parallel to the southern margins of Western Panama and Costa Rica, as stated by BERRANGE & THORPE (1988).

3. The alignment of three of the aftershocks: 3, 4 and 5 in a northwest trending pattern, which parallels that of the Panama and Balboa Fracture Zones may indicate the extension of the Mykland fault through the continental shelf, up to connect with the regional Chiriqui fault, that runs to the north of the city of David.

4. The northern terminus of the braided Panama-Coiba Fracture Zone is seismically active and capable of generate events with magnitudes greater than Ms = 7.0.

5. The aftershock pattern of the 1934 Puerto Armuelles Earthquake may indicate that these parallel north trending right lateral strike-slip faults interact, at least, for large events.

6- Even though, the earthquakes in the continental shelf of southwestern Panama do not occur very often, as in other parts of the Middle American Arc, they pose a high risk to this whole region due to their magnitude and proximity to highly populated areas with many important infrastructures.

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REFERENCES

ABE, K., 1981: Magnitude of large shallow earth- quakes from 1904 to 1980. -Phys. Earth Planet. Inter., 21: 72-92.

ACRES INTERNATIONAL LIMlTED, 1981: Evaluación sísmica del proyecto hidroeléctrico Tabasará. -53 págs.

ADAMEK, S.H., 1986: Earthquake studies in the Panama-Costa Rica region. -211 pags. Universidad de Texas at Austin (tesis inédita).

ADAMEK, S.H., TAJIMA, F. & WIENS, D., 1987: Seismic rupture associated with subduction of the Cocas ridge. -Tectonics, 6: 757- 774.

ADAMEK, S.H., FROHUCH, S. & PENNINGTON, W., 1988: Seismicity of the Caribbean-Nazca boundary: Constrains on microplate tectonics of the Panama region. -I. Geophysics. Res., 93.: 2053- 2075.

ALGERMISSEN, S.T., DEWEY, J.W., LANGER, W.&DILLINGER,W.H.,1974: TheManagua, Nicaragua Earthquake of December 23, 1972: location, focal mechanism and intensity distribution. -Bull. Seism. Soc. Am., 64: 993-1004.

BARRIT, S. & BERRANGE, J.P., 1987: An interpretation of a gravity survey of the Osa Peninsula and enviroments, Southern Costa Rica. -Overseas Gol. Mineral Res., 64: 2356.

SPRECHMANN, P., 1984: Manual de Geologia de Costa Rica. Vol I: Estratigrafia. -320 pags.; Editorial de la Universidad de Costa Rica, San Jose.

STEIN, S., 1987: Introduction to seismology, earth- quakes and earth structure. -520 pags.; Blackwell Scientific Publications, London.

TERRY,R.A**.,** 1941: Notes on submarine valleys off the Panamanian coast -The Geographical Review, 31: 377-384

VERGARA, A., 1988: Tectonic patterns of the Panama Block deduced from seismicity, gravitational data and earthquake mechanism: Implications to the seismic hazard. -Tectonics, 154.: 253-267.

VIQUEZ, V. & TORAL,J.,   1988: Sismicidad histórica sentida en el Istmo de Panama. –Rev. .Geofísica, 27: 26- 70.

VIRET, M., BOLLINGER, G.A., SNOKE, J.A. & DEWEY,J.W.,1984: Joint hypocenter relocation studies with sparse data sets -A case history: Virginia Earthquakes. -Bull.Seism.Soc.Am.. 74: 2297-2311.

WEYL, R., 1980: The Geology of Central America. - 371 págs.; Gebrüder Borntraeger, Berlin.

WICKENS, A.J. & HODGSON, J .H., 1967: Computer reevaluation of earthquake mechanism solutions 1922-1962. -230 págs., Crescent Observatory Contrib. No.103.

WOLTERS,B.,1983: Seismicity and earthquake focal mechanisms .and their tectonic implications in southern Central America and northwestern South America:- 89 págs.; University of Stanford (thesis).

WOLTERS. B.. 1986: Seismicity and tectonics of southern Central America and adjacent regions with special attention to the surroundings of Panama -Tectonophysics. 128: 21-46.