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INSTITUTO DE GEOFISICA
CIUDAD UNIVERSITARIA
MEXICO 20, D. F. MEXICO

March 6, 1979

Prof. Andrew F. Nagy
Department of Atmospheric and
Oceanic Science
The University of Michigan
Ann Arbor, Michigan 48109

Dear Prof. Nagy:

I am enclosing three copies of "Secular Variation of Gravity in Mexico?" which we submit for possible publication in Geophys. Res. Lett. Names, addresses and telephone numbers of six potential referees are given in the attached sheet.

Kind regards.

Sincerely yours,

Shri Krishna Singh

SKS*eoc.

Timeliness of the Paper "Secular Variation of Gravity in Mexico?"

The results on the secular variation of gravity in Mexico was published by Woollard et al about 10 years ago. These variations are certainly one of the largest reported anywhere in the world. The implication of these results in terms of tectonics and earthquakes in Mexico has been a source of worry and some doubt in the geophysical community in Mexico and elsewhere. Our new results, which are presented in this paper, do not confirm the variations reported in the past. Although we can not be certain we suspect that the past data may have been unreliable. We believe that our findings are timely and would serve the geophysical community at large.

POTENTIAL REFEREES

1. Dr. R.C. Jachens
   Regional Geophysics Branch
   U.S. Geological Survey
   345 Middlefield Road
   Menlo Park, Calif. 94205
   Phone: (415) 323-8111 (Ext. 2168)

2. Dr. Anthony Lambert
   Earth Physics Branch
   1 Observatory Crescent,
   Ottawa, K1A OY3, CANADA
   Phone: (613) 994-5165

3. Dr. W.E. Strange
   National Geodetic Survey NOAA
   Rockville, Maryland 20852
   Phone: (301) 443-8528

4. Prof. G.P. Woollard
   Hawaii Institute of Geophysics
   University of Hawaii at Manoa
   2525 Correa Road, Honolulu, Hawaii 96822
   Phone: (808) 948-8760

5. Prof. J.N. Brune
   Institute of Geophysics & Planetary Physics
   Scripps Institution of Oceanography
   University of California, San Diego
   La Jolla, Calif. 92093
   Phone: (714) 452-2890

6. Prof. R.P. Meyer
   Dept. of Geology and Geophysics
   University of Wisconsin
   1215 W. Dayton St., Madison, Wisconsin 53706
   Phone:(608) 262-1698

SECULAR VARIATION OF GRAVITY IN MEXICO?

S. K. Singh, M. Mena, and J. Monges

Instituto de Geofísica, Universidad Nacional
Autónoma de México, C.U., México 20, D.F.

Abstract. Based on data obtained during the period 1949-1967, Woollard and others reported large secular variation of gravity in Mexico. Data obtained since 1971, using LaCoste-Romberg gravimeters, indicate that no significant variation is occurring between Mexico City and Acapulco and Monterrey and Mexico City at present. Local secular variation of gravity reported for Mexico City is continuing and is well correlated with the sinking (due to water withdrawal) of the city.

Introduction

Woollard et al. (1969) and Woollard and Monges (1970) reported large secular variation of gravity in Mexico. The variation was found by these authors when all the pendulum data from 1953 to 1966 over the North American standardization range was reworked in 1967. Although the secular variation of gravity reported by these authors will be taken up later, we summarize the result in the following:

(a) Whereas Monterrey (Fig. 1) appeared stable with respect to Madison, Wisconsin base station, the value of gravity at the University base in Mexico City was found to be

decreasing at a rate of 0.037 mgal/yr with respect to Monterrey. Thus the crustal block south of Monterrey appeared to be rising relative to the crustal block to the north.

(b) To check if the above mentioned relative movement extended to the south, the Mexico City-Acapulco traverse (Fig. 1), originally established in 1949, with a tie made between Mexico City and the Acapulco airport in 1961, was repeated by Woollard and Monges in 1967. The result showed an increase in gravity at Acapulco of 0.071 mgal/yr between 1947 to 1961. Between 1961 and 1967 a jump in the gravity at Acapulco, perhaps related to local earthquakes, was found. Much of the variation of gravity in the Mexico City-Acapulco traverse was between Chilpancingo and Acapulco.

(c) A local secular variation of gravity in Mexico City was reported. The gravity near the center of the city (Hotel Geneve) was increasing 0.06 mgal/yr with respect to Tacubaya. Tacubaya is on bedrock whereas most of the city is on lake sediments. Since the installations of a closed sewer system, the recharge to the water table has been partially shut off. This, coupled with pumping, has resulted in the sinking of a large part of the city.

Except for (c), the secular variation of gravity mentioned in (a) and (b), which are related to tectonic phenomena, are certainly one of the largest reported anywhere.

In this paper we discuss the secular variation since 1971 from the data obtained by using LaCoste-Romberg gravimeters.

Data

Most of the data collection since 1971 has been done using LRG 247 and LRG 143 gravimeters. Although two other gravimeters (LRG 193 and LRG 486) were also used occasionally, we do not report the data obtained by these meters since no independent calibration, other than that provided by the manufacturers, is available to us. LRG 247 is known to be a reliable meter while LRG 143 sometimes has erratic behaviour. These two gravimeters were calibrated in 1976 over Mt. Hamilton and Skeggs calibration range (Barnes et al., 1969). The calibration factors for LRG 247 and LRG 143 were found to be 1.00053 and 1.00027, respectively. In view of the known erratic behaviour of LRG 143, we report on the data from LRG 247 and LRG 143 separately. Since lesser number of observations are available for LRG 143 than for LRG 247, we shall plot only the LRG 247 values in the figures. All data have been corrected for the drift, the earth tides, and the calibration factor.

Mexico City-Acapulco Traverse

The data on the gravity difference, Δg, for the Mexico City-Acapulco traverse are given in Table 1. In 1961 and 1971-onwards the measurements in Mexico City were made at the University auxiliary base station (Mexico F). Δg

between Tacubaya (Mexico D) and University auxiliary base station, which was found to be -0.54 mgal in 1955, was determined as -0.46 mgal in 1967 (Woollard et al., 1969) and -0.466 mgal in 1978. International Gravity Standard Network of 1971 (IGSN71) gives a Δg of -0.46 mgal. We have referred all the values in Table 1 to Tacubaya by taking a Δg = -0.46 mgal between Tacubaya and the University including the 1961 values which were reported by Woollard et al. (1969) with Δg = -0.54 mgal. Iguala and Chilpancingo stations before 1971 and beginning 1971 are not the same. Acapulco J (the old airport site) and Acapulco Federal Palace stations have been destroyed.

In Fig. 2 the change in gravity difference, $\delta(\Delta g)$, between Acapulco and Tacubaya is plotted against time. Note that the values before 1971 are for Acapulco J (old airport) station. Since this station has been lost and its location now is only approximately known, the values beginning 1971, which are for LRG 247, refer to Acapulco Heros Monument station. The values after 1971 are plotted with respect to the 1971 value. $\delta(\Delta g)$ = 0.078 mgal/yr up to 1967 with a step-like change of about 1.1 mgal between 1961 and 1967, as reported by Woollard et al. (1969), is shown in Fig. 2 along with large earthquakes ($M_s \geq 7.0$) which occurred within 100 km of the traverse in the same period. Beginning 1971 $\delta(\Delta g)$ values may be taken as zero since they are within the range of the errors of our measurements. The Fig. 3, modified from Woollard et al. (1969) shows $\delta(\Delta g)$ along the traverse for

1949-1967 and 1971-1978, together with the geologic profile. For 1949-1967, stations from Mexico City to Chilpancingo show slightly negative $\delta(\Delta g)$ but $\delta(\Delta g) = 2.70$ mgal is observed between Chilpancingo and Acapulco. For 1971-1978 no significant $\delta(\Delta g)$ is found for the entire traverse (note the scale on the right-hand side for 1971-1978 in Fig. 3).

Was the secular variation of gravity detected between 1947 to 1967 real? If 1 m of change in elevation is taken to correspond .2 mgal change of gravity, a change in elevation of about 13.5 m between Chilpancingo and Acapulco for 1947 to 1967 is indicated. Woollard et al. (1969) attributed the change in gravity to crustal adjustment between the plateau of Mexico and coastal regions along faults near Chilpancingo (FF' in Fig. 3). At present, no geologic evidence is available to support the existence of faults that would show recent vertical movements (de Cserna, 1965; de cserna, personal communication, 1978). Rough estimates of the areas of rupture and average dislocations associated with the three large earthquakes (M_s = 7.9, 7.2, 7.0), which occurred in the area during the period of interest, were made using relations given by Geller (1976). As expected intuitively, the vertical relative displacement implied by the gravity data could not, even in the most favorable conditions, be reconciled with the displacements computed from earthquake dislocation models. It should be pointed that local levelling in Acapulco, following the 1962 earthquakes (M_s = 7.2, 7.0), revealed changes of about 0.3 m in elevation (Woollard and Monges, 1970).

In the upper part of Table 1 the gravity differences between Mexico City and Acapulco given in Table 1 are compared with the corresponding difference obtained from the IGSN71 values. Beginning 1971, Δg values are close to the IGSN71 value whereas 1961 and 1967 values are too high. Gravity calibration for 1967 appears to be 2.99 mgal/1000 higher than IGSN71 standard. It seems safe to conclude that the large Δg between Mexico City and Acapulco for 1967 was due to the calibration problem since 2.99 mgal/1000 "over calibration" also explains, although approximately, the difference between the Δg for Cuernavaca for 1967 and for values beginning 1971 (Table 1). The calibration for 1961 appears to be 0.35 mgal/1000 higher than IGSN71 value. Assuming that $\delta(\Delta g)$ values for 1961 and 1967 relative to IGSN71 value were due to calibration problems, $\delta(\Delta g)$ between 1949 and 1961 and/or 1967 becomes about 0.74 mgal. The 1949 Δg values (Table 1) upto Chilpancingo, like the 1967 Δg values, suggest an "over calibration" of about 3 mgal/1000 relative to IGSN71 standard although the calibration for this Worden gravimeter is supposed to have been better than 0.5 mgal/1000 (Woollard and Monges, 1970). If, however, an "over calibration" of 3 mgal/1000 for 1949 measurements is accepted then we again obtain a $\delta(\Delta g)$ of about 2.7 mgal between Chilpancingo and Acapulco for the period 1949-1967. The known erratic behaviour of the Worden gravimeter (Woollard and Monges, 1970) and the fact that the traverse in 1949 was not closed in Mexico City may explain this

large anomaly. Unfortunately, since the original data sheets for 1949 and 1967 seen to have been lost, we are unable to confirm this. One additional point to be noted is that the Acapulco Federal Palace site of 1949 could only be located approximately in 1967. Woollard et al. (1969) estimate an error of 0.1 mgal due to this mislocation.

Since (a) no geologic field evidence of an active fault accomodating aseismic and seismic slip between Chilpancingo and Acapulco exists, (b) the large earthquakes are not sufficient to explain implied vertical displacement from the gravity data for 1947-1967 period, and (c) no significant secular variation of gravity is found for 1971-1978 period, we believe that the data for 1947 to 1967 may not be reliable. If, on the other hand, the secular variation of gravity was real, we are unable to offer an adequate physical mechanism to explain it.

Secular Variation of Gravity between Mexico City and Monterrey

Table 2 gives the Δg data between Monterrey and Mexico City. Change in gravity difference, $\delta(\Delta g)$, as a function of time is plotted in Fig. 4. In the figure the data for 1972-onwards is for LRG 247. It is clear from Fig. 4 that the secular variation of -0.037 mgal/yr reported by Woollard et al. (1969) from data up to 1964 is not supported by measurements for the period 1972-1978. In the bottom part of Table 3, the

gravity differences taken from Table 2 are compared with the corresponding IGSN71 values. The Δg values for 1961 and 1972-onwards are close to the Δg value for IGSN71. It is not possible for us to evaluate the quality of the past data which were obtained from the Gulf pendulums. Here we only assert that if the reported secular variation was real, it is not continuing since 1972 to the present.

Secular Variation of Gravity in Mexico City

Change in gravity difference, $\delta(\Delta g)$, and elevation difference, $\delta(\Delta h)$, between Tacubaya (Mexico D, located on bed rock) and Hotel Geneve (located on lake deposits near the center of the City) is shown in Fig. 5. Data up to 1967 (Woollard et al., 1969) show an increase of 0.06 mgal/yr at Hotel Geneve with respect to Tacubaya. $\delta(\Delta g)$ value for 1978 gives a lesser rate of change of the gravity difference. The data on $\delta(\Delta h)$, obtained from levelling carried out by the Water Commission of the Valley of Mexico (Anonymous, 1975), give an average sinking of 7.3 cm/yr for the period 1953-1973. If the $\delta(\Delta g)$ values beginning 1967 are considered reliable and the sinking rate is considered constant since 1963, then $\delta(\Delta g)/\delta(\Delta h) = 2.8$ μgal/cm is obtained. Although the past rate of $\delta(\Delta g)$ appears high, secular variation of gravity in Mexico City is real and well correlated with the sinking of the city due to the pumping of water.

Conclusion

Large secular variations of gravity reported in the past between Mexico City and Acapulco and Mexico City and Monterrey are not confirmed by recent data covering the period 1971-1978. Although we cannot be certain, we believe that the past data may have been unreliable. In this context we quote Boulanger (1978) "the analysis of world literature shows that the higher the precision and the more improved the technique of measurement, the lesser are the recorded variations (of non-tidal gravity)". Although our observations were poor in comparison with the present state of high precision gravity work, they were of sufficient quality to detect the large variation reported in the past, if they were still continuing. The reported gravity change for Mexico City is real and is related to the sinking of the city due to water withdrawal and resulting soil compaction.

A large network of gravity stations in Mexico City and Mexico City-Acapulco traverse is presently being planned for future high precision gravimetric work.

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Table 1. Gravity difference for stations on Mexico City-Acapulco traverse in mgals. Number in brackets refers to the Lacoste-Romberg gravimeter that was used.

	1949 Δg	1961[b] Δg	1967 Δg	1971[b] Δg (G247)	1972[b], Δg (G247)	1972[b], Δg (G143)	1973[b] Δg (G247)	1978[b], Δg (G247)	1978[b], Δg (G143)
Univ. Aux. (Mexico F)	---	-0.46	---	-0.46	-0.46	-0.46	-0.46	-0.46	-0.46
Tacubaya (Mexico D)	0	0	0	0	0	0	0	0	0
Cuernavaca	173.2		173.17	172.723				172.772	
Iguala[a]	318.4		318.26	316.005				315.996	315.826
Chilpancingo[a]	223.7		223.49	223.518				223.550	223.443
Rio Papagayo	485.1			485.836				485.866	485.806
Acapulco J (Old Airport)	573.9[d]	574.84	576.36	574.690	574.691	574.668		574.699[c]	574.729[c]
Acapulco K (New Airport)					574.443	574.435	574.520	574.545	574.495
Acapulco Fed. Palace	582.0		584.49						
Acapulco Heros Monument				582.570	582.528	583.555	582.545	582.555	582.544

[a] Iguala and Chilpancingo stations beginning 1971 are at different locations.

[b] These measurements were made at Univ. Aux. station. The values are referred to Tacubaya by substracting 0.46 mgal.

[c] Approximate location.

[d] Inferred value from 1967 measurements.

Table 2. Gravity differences between Mexico City and Monterrey in mgals. Values with square brackets are inferred values taking Tacubaya-Univ. Aux. Δg of +0.46 mgal.

	1953 Δg	1961 Δg	1964 Δg	1972,Δg		1973,Δg	1975,Δg		1978,Δg
				(G247)	(G143)	(G247)	(G247)	(G143)	(G247)
Monterrey A	0	0	0	0	0	0	0	0	0
Tacubaya (Mexico D)	-863.31	[-863.60]	[-863.80]	[-863.555]	[-863.470]	[-863.523]	[-863.512]	[-863.523]	[-863.593]
Univ. Aux. (Mexico F)	[-863.77]	-864.06	-864.26	-864.015	-863.930	-863.983	-863.972	-863.983	-864.053

Table 3. Comparison of gravity differences obtained from Tables 1 and 2 and IGSN 1971 values.

	(1)	(2)	Difference between Δg from Table 1 and (2)							
	IGSN71	Δg	1961	1967	1971 (G247)	1972 (G247)	1972 (G143)	1973 (G247)	1978 (G247)	1978 (G143)
Tacubaya (Mexico D)	977,927.15	0	0	0	0	0	0	0	0	0
Acapulco J (Old Airport)	978,501.79	574.64	+0.20	+1.72	+0.050	+0.051	+0.028	-	-0.059	+0.089
Acapulco K (New Airport)	978,501.62	574.47	-	-	-	+0.027	-0.035	+0.05	+0.075	+0.091

	(1)	(2)	Difference between Δg from Table 2 and (2)								
	IGSN71	Δg	1953	1961	1964	1972 (G247)	1972 (G143)	1973 (G247)	1975 (G247)	1975 (G143)	1978 (G147)
Monterrey A	978,790.69	0	0	0	0	0	0	0	0	0	0
Tacubaya (Mexico D)	977,927.15	-863.54	+0.23	-0.06	-0.26	-0.015	+0.07	+0.017	+0.028	+0.017	-0.053

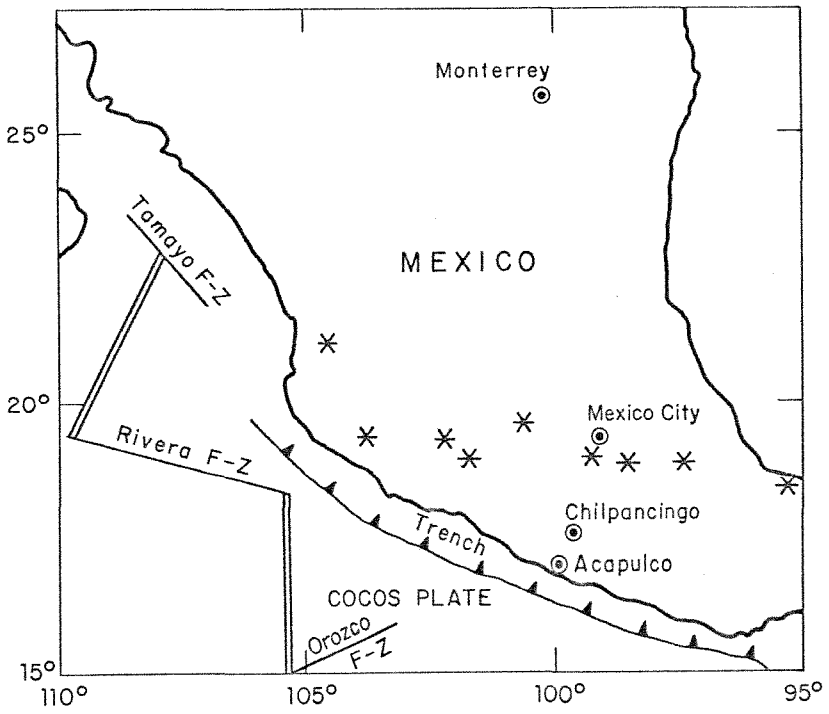

Fig.1. Location and tectonic map. Quaternary volcanos in Mexico are shown by stars.

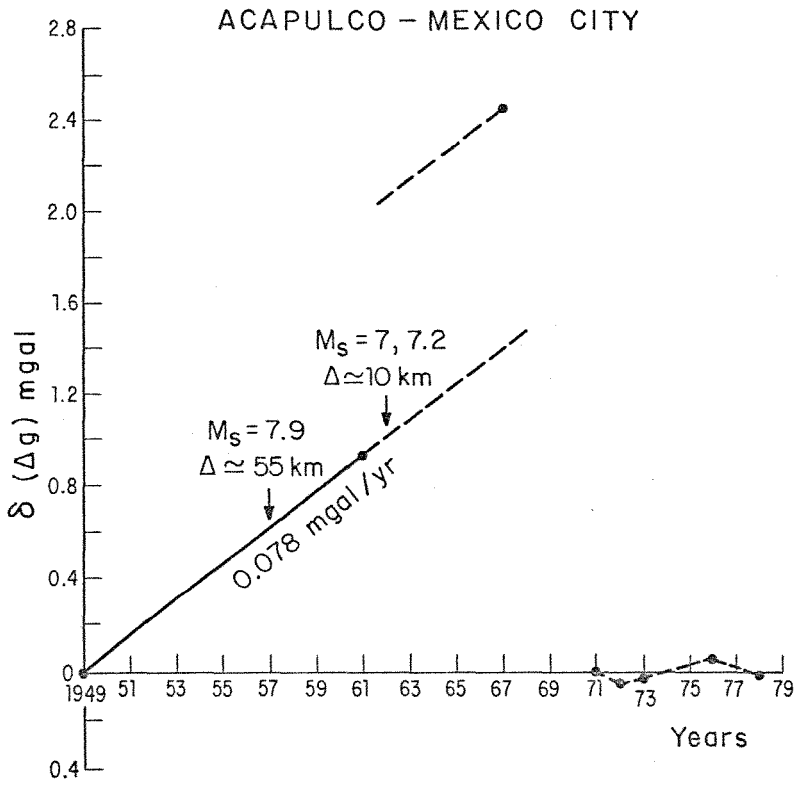

Fig.2. Change in gravity difference, $\delta(\Delta g)$, between Acapulco and Mexico City as a function of time. Value for 1971 has been reset to zero (due to change in base station at Acapulco, see text) and values for later years are with respect to the 1971 value. Large earthquakes and their epicentral distance from the traverse are shown.

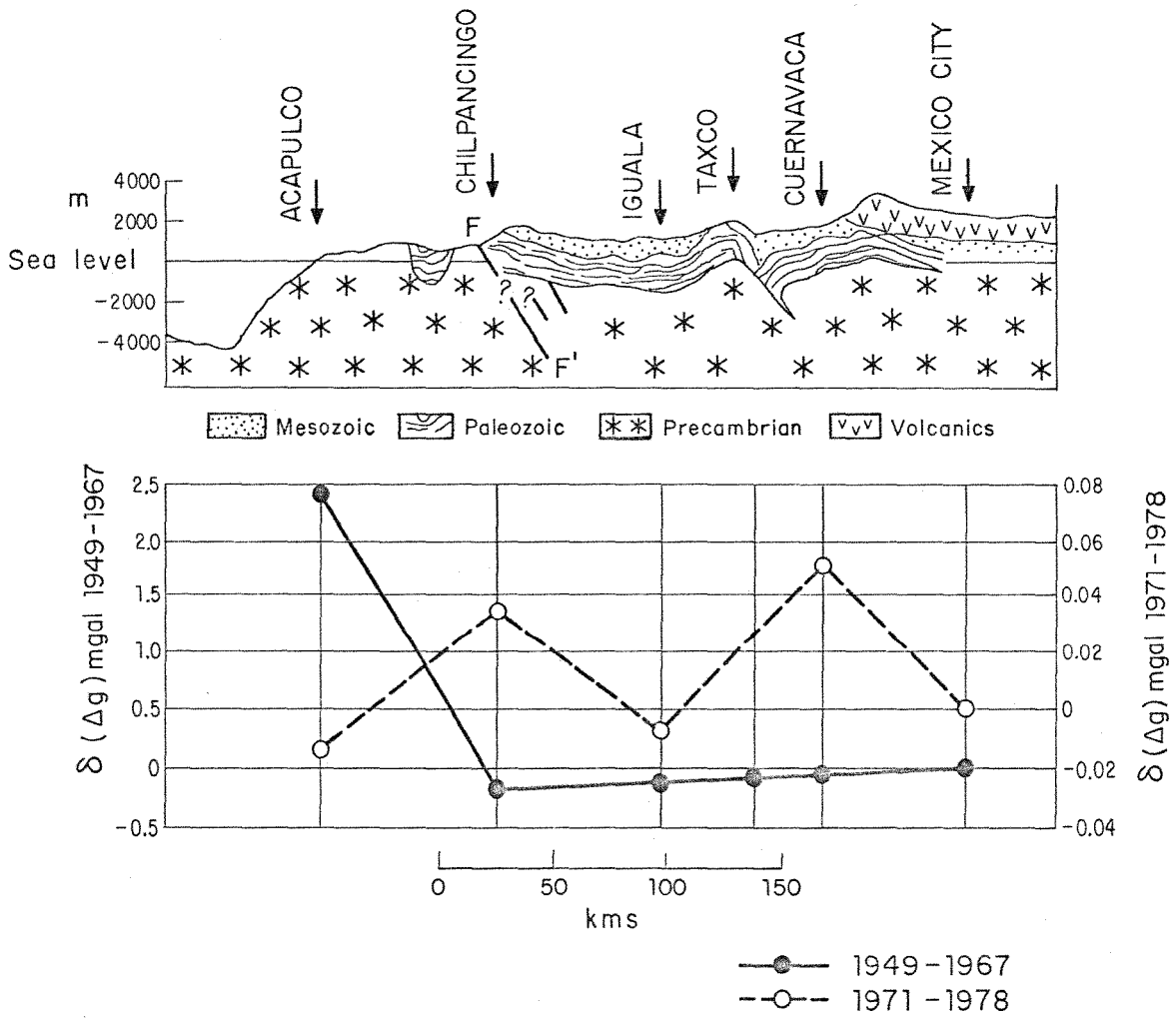

Fig.3. Top: Geologic section along the traverse Mexico City-Acapulco. No field evidence of recent aseismic or seismic slip on the faults FF' exists. Bottom: Change in gravity difference along the traverse in the time intervals 1949-1967 (scale on the left) and 1971-1978 (scale on the right).

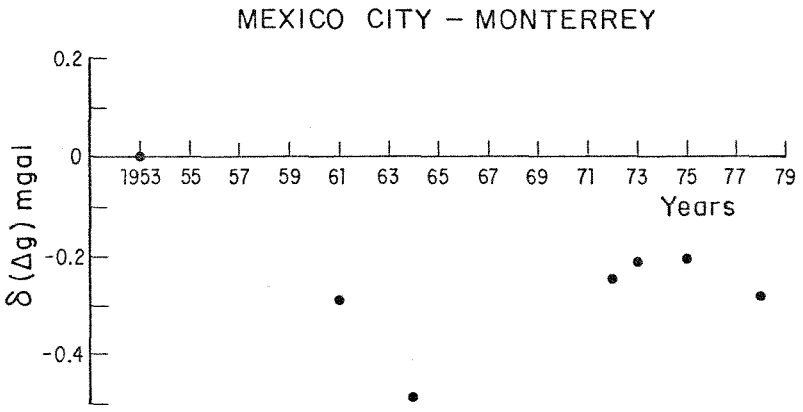

Fig.4. Change in gravity difference, $\delta(\Delta g)$, between Mexico City and Monterrey as a function of time.

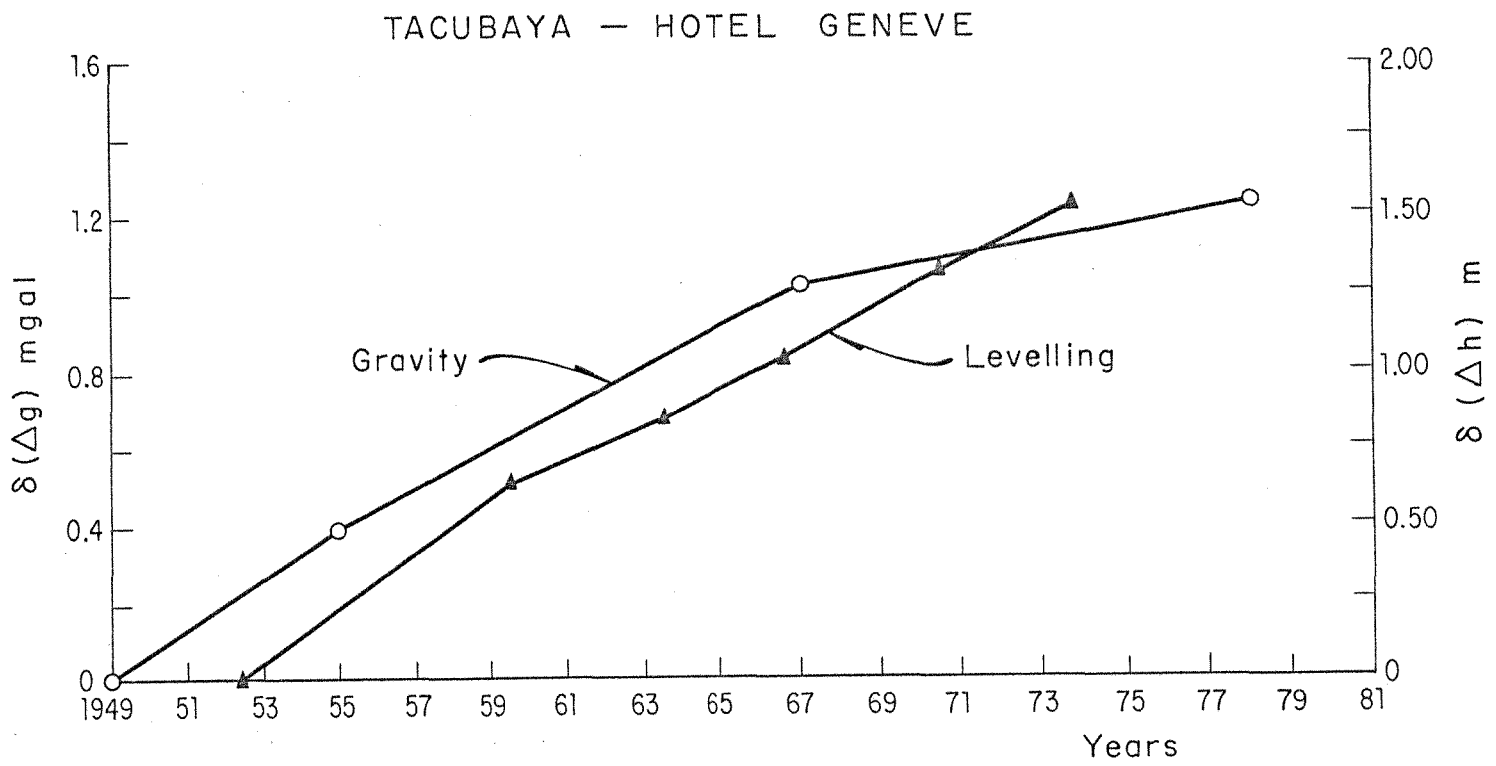

Fig.5. Change in gravity difference, $\delta(\Delta g)$, and elevation difference, $\delta(\Delta h)$, between Tacubaya and Hotel Geneve for the period 1949-1978.