POSTSEISMIC LAND MOVEMENTS IN SOUTH-CENTRAL CHILE

Sergio E. Barrientos

Dept. of Geology and Geophysics
University of Chile
Casilla 2777
Santiago, Chile
BITNET address: SBARRIEN@UCHCECVM

Resume

Tide gage records at Puerto Montt, referenced to Talcahuano, indicate a large (1 m) postseismic uplift of the region. Field observations in 1989 carried out at the same locations of previous measurements in 1968 [Plafker, 1970] are consistent with tide gage records. The postseismic elevation changes are modeled as the product of a propagating creep on the down dip extension of the fault. For a 35° E fault dip, minimum root mean square error indicate a creep velocity of 3-5 km/yr and slip amplitude of 4-6 m.

Resumen

Registros de mareógrafos en Puerto Montt, con respecto a los registros en Talcahuano, indican un levantamiento de al menos 1 m en la región. Observaciones directas de levantamiento de la costa efectuadas en 1989 en las mismas localidades que fueron medidas en 1968 [Plafker, 1970] son consistentes con los registros de mareas. Los cambios de elevación son modelados como producto de un deslizamiento asísmico en la continuación en profundidad de la falla que acomodó movimiento cosismico. Para una falla de manteo de 35°E, la suma de errores al cuadrado es mínima cuando la velocidad y amplitud de deslizamiento varían entre 3-5 km/año y 4-6 m respectivamente.

Introduction

The great Chilean earthquake sequence of May 21-22, 1960, with a moment magnitude of 9.5, has been the largest event recorded in this century [Kanamori, 1977; Cifuentes, 1989]. Remarkable changes in land levels were observed in a region 1000-km long by 200-km wide stretching southward from Arauco Peninsula. Extreme co-seismic sea level changes ranged from 5.7 m of uplift in Guamblin Island to 2.7 m of subsidence in the city of Valdivia. These values are based on measurements of sea level change made by G. Plafker who visited the site in 1968, eight years after the earthquake. The sea level observations are complemented by geodetic measurements along two survey lines carried out by the Instituto Geográfico Militar [IGM, 1965]: A 150-km leveling line from the coastal city of Concepción to Parral and a 600-km line extending southward to Puerto Montt.

Plafker and Savage [1970] analyzed the static deformation data and presented teleseismic surface wave evidence to support their preferred uniform slip dislocation model that involves between 20 and 40 m of dip slip on a fault 1000 km long and at least 60 km wide. Plafker [1972] re-analyzed the static deformation and deduced a model involving a fault 120 km wide by 1000 km long dipping 20° E with 20 m of slip. Barrientos and Ward [1990], inverting the elevation change data for a variable slip model, inferred that most of the slip is concentrated on a 900 km long by 150 km wide band parallel to the coast. Several patches of moment, isolated from the main body of moment release, are found at 80 to 110 km depth, presumably indicating aseismic slip. Due to the size of the coseismic displacement, large postseismic readjustments are expected. This paper investigates the evidence of postseismic movements and establishes the bounds on creep velocity as indicated by the records of the Puerto Montt and Talcahuano tide gages.

Data

The Puerto Montt and Talcahuano tide gage records form the basis of our analysis. The Talcahuano tide gage -located just outside of the 1960 deformation zone- has recorded the sea level almost continuously since 1949. The longest period lacking information extends for approximately a year -from September, 1953 until October 1954. Seven interruptions of two months or less also conspire against the continuity of the data. Monthly mean values of the sea level are obtained by averaging hourly readings. Sea level remains stable for most part of the total interval slightly increasing after 1976. Most of the signal shows a uniform standard deviation (s.d.) of approximately 37 cm, some anomalously low s. d. values are found during periods of incomplete record.

The Puerto Montt tide gage record is less complete. This record can be divided in four periods: i) from Feb. 1945 to Dec. 1952, ii) from Nov. 1957 to March 1960, iii) from June 1964 to Nov. 1972, and iv) from Apr. 1980 to Dec. 1984. All of these periods are referred to a different reference system except for periods ii) and iii) which include year 1960. The standard deviation of this signal is about 150 cm, about 3.5 times the s.d. of the Talcahuano tide gage, reflecting the different environmental conditions of marine currents.

The trends along all periods in the Puerto Montt tida gage show different tendencies. Prior to 1960, both periods of observation show a stable sea level. This situation changed sometime between 1960 and 1964 evidenced by the continuous decrease of the sea level between 1964 and 1972. The sea level decrease is not apparent during the interval 1980-1984.

To eliminate the eustatic sea level changes -and also high frequency signals exhibited in the records- it is desirable to analyze the difference of the signals, i.e. Puerto Montt minus Talcahuano amplitudes.

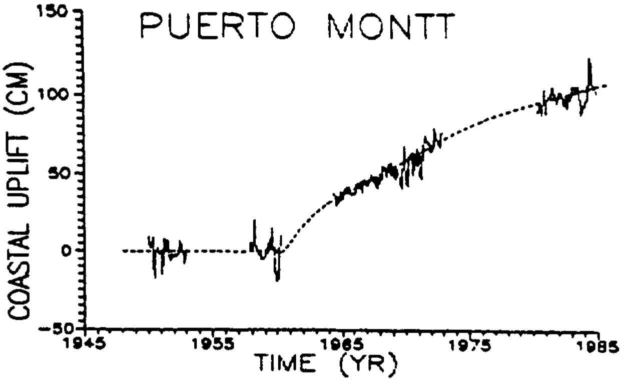

Fig. 1. Elevation change at the Puerto Montt tide gage as a function of time. The dashed line, which is the interpretation of coastal uplift, indicates a postseismic change of more than 1 m.

This procedure was suggested by Wyss [1976] when analyzing the possible variations of sea level as premonitory phenomena of large earthquakes. This procedure gives a better estimation of the coastal uplift rate at Puerto Montt. Figure 1 shows the difference of the signals recorded at both tide gages. The dashed line joins the different observation samples and it is interpretative for the 1953-1958 and 1973-1980 periods. A straight horizontal line was assumed for the pre-1960 epoch. We have assumed that for the period 1960-1964 no elevation change took place during the co-seismic stage, hence all movement is postseismic (another possibility is that 18 cm of uplift took place co-seismically and then a continuous uplift rate -4.5 cm/yr- coincident with observations for the 1964-1972 interval). Lastly, the uplift rate between 1973 and 1980 is shown as the continuous second-degree curve that is coincident with the slopes at the two ends (4.5 cm/yr and 2.2 cm/yr) where data is available.

Discussion

The post-seismic movements can be interpreted in terms of two generally accepted models. Visco-elastic readjustments of astenospheric material and retarded slip along the fault. In subduction zones, visco-elastic models have been proposed by Nur and Mavko [1974], Thatcher and Rundle [1979] to explain post-seismic deformation landward of oceanic trenches mainly associated with Japanese earthquakes. Fitch and Scholz [1971] modeled the post-seismic deformation following the 1946 Nankaido (Japan) earthquake with additional forward slip on the down-dip extension of the fault plane. Kasahara [1975] has discussed the possibility of aseismic faulting following the 1973 Nemuro-Oki earthquake (Japan) based upon leveling lines and tide gage records. Along the ideas stated by Kasahara [1975] is the possiblity of retarded faulting due to aseismic propagation of the fault.

The coastal uplift at Puerto Montt has been interpreted as the product of creep propagating along the down-dip extension of the fault which ruptured during the 1960 sequence, although viscoelastic rebound cannot be ruled out. Since Puerto Montt lies in the center of the 1000-km long rupture region, edge effects can be neglected allowing for a two-dimensional fault representation. The propagating pulse is modeled as several line sources activated according to a prescribed velocity. The fault model inputs are: dip angle, velocity, and starting point of the propagating pulse. For a given combination of these parameters, slip amplitude is inverted through a linear regression. The data used in the inversion correspond to the dashed line in Figure 1 (with no co-seismic movement) sampled every 0.5 yr. Fixing the dip angle at 35°E [Kadinsky-Cade, 1985] minimum root mean square error (RMSE) produce velocities and slip amplitudes varying between 3-5 km/yr and 4-6 m respectively.

These observations were corroborated during the austral summer of 1989, when re-determinations of sea level at several locations in the Puerto Montt area were consistently lower (up to 50 cm) than those observed by Plafker in 1968 at the same locations. Values of this amount are predicted by the model.

References

Barrientos, S. E. and S. N. Ward, The 1960 Chile earthquake: Inversion for slip distribution from surface deformation, submitted for publication in Geophys. J. Int.

Cifuentes, I., 1989. The 1960 Chilean earthquakes, J. Geophys. Res., 94, 665-680.

Fitch, T. and C. Scholz, 1971. Mechanism of underthrusting in southwest Japan: a model of convergent plate interactions, J. Geophys. Res., 80, 1444-1447.

IGM, 1965. Anuario N°9, Instituto Geográfico Militar, 1960-1965. Santiago, Chile.

Kadinsky-Cade, K. A., 1985. Seismotectonics of the Chile margin and the 1977 Caucete earthquake of western Argentina, Ph. D. Thesis, Cornell University.

Kanamori, H., 1977. The energy release in great earthquakes, J. Geophys. Res. 82, 2981-2987.

Kasahara, K., 1975. Aseismic faulting following the 1973 Nemuro-Oki earthquake, Hokkaido, Japan (a possibility), Pegeoph,113, 127-139.

Nur, A. and G. Mavko, 1974. Post-seismic visco-elastic rebound, Science, 183, 204-206.

Plafker, G. and J. C. Savage, 1970. Mechanism of the Chilean earthquakes of May 21 and 22, 1960. Geol. Soc. Am. Bull.,81, 1001-1030.

Plafker, G., 1972. Alaskan earthquake of 1964 and Chilean earthquake of 1960: Implications for arc tectonics. J. Geophys. Res. 77, 901-925.

Thatcher, W. and J. Rundle, 1979. A model for the earthquake cycle in the underthrust zone, J. Geophys. Res. 84, 5540-5556.

Wyss, M., 1976. Local changes of sea level before large earthquakes in South America. Bull. Seis. Soc. Am., 66, 903-914.