NOTA GEOLOGICA

LIKELY OCCURRENCE OF A MEGA-TSUNAMI IN THE MIDDLE PLEISTOCENE, NEAR COQUIMBO, CHILE

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RESUMEN

En los alrededores de la Bahía Herradura, en Chile (29°59'S), enormes bloques, incluidos en los depósitos de playa de una terraza marina del Pleistoceno medio, indican la ocurrencia de un maremoto de amplitud excepcional. Fue un acontecimiento fuera de lo común que se produjo una sola vez en todo el transcurso del Plio-Cuaternario.

Palabras claves: Maremoto, Terraza marina pleistocena, Depósito de playa, Chile.

INTRODUCTION

Rare natural events, characterized by a very high magnitude and a low frequency, may be recorded in geological deposits associated with specific landforms. This paper reports the occurrence of a likely tsunami of exceptional magnitude which occurred in the Middle Pleistocene and left stratigraphic evidence near Coquimbo, Chile.

REGIONAL SETTING

Just south-west of Coquimbo, Herradura Bay (29°59'S) is bordered by a set of five uplifted marine terraces which rise from the present sea level to an elevation of about 85m (Fig. 1). They were cut into Upper Miocene soft sandstones pertaining to the so-called Coquimbo Formation (Paskoff, 1970; Martínez, 1979). Surficial shelly beach sediments lying on the terraces are separated from the sandstones by an erosional unconformity (Fig. 2). The sediments were deposited by Plio-Quaternary marine transgressions and regressions of glacio-eustatic origin, which, superimposed on a general upward movement of the continental margin, were responsible for the genesis of the terraces (Paskoff, 1970; 1977;1989). The elevation of the last interglacial terrace, which barely reaches 20 m, points to a slow long-term uplift rate of about 0.11 to 0.16 m/10^3 years. Such an uplift rate is low for an area of plate convergence and is probably related to an anomalously low dip segment of the subducted Nazca plate in the Coquimbo area (Leonard *et al.* 1984).

THE BOULDER PROBLEM

The surface of the third marine terrace (30- 40 m) above the modern beach -the so-called Herradura I terrace (Herm and Paskoff, 1967)- is notable because of the occurrence of scattered large boulders which are embedded in the shelly beach deposits associated with the abrasion platform. According to amino acid epimerization studies, as well as U-series and Electron Spin Resonance (ESR) datings on shells (Radtke, 1989), this terrace is older than the last interglacial period (isotope stage 5e, corresponding to Herradura II) and may be on the order of 300.000 years in age (stage 9). The above mentioned boul-

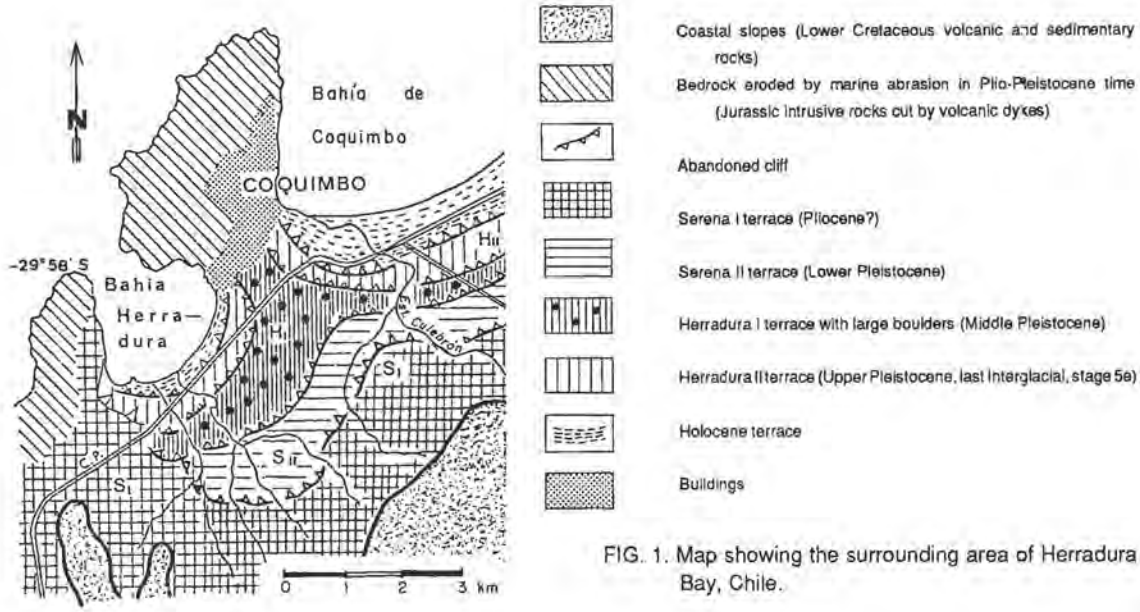

FIG. 1. Map showing the surrounding area of Herradura Bay, Chile.

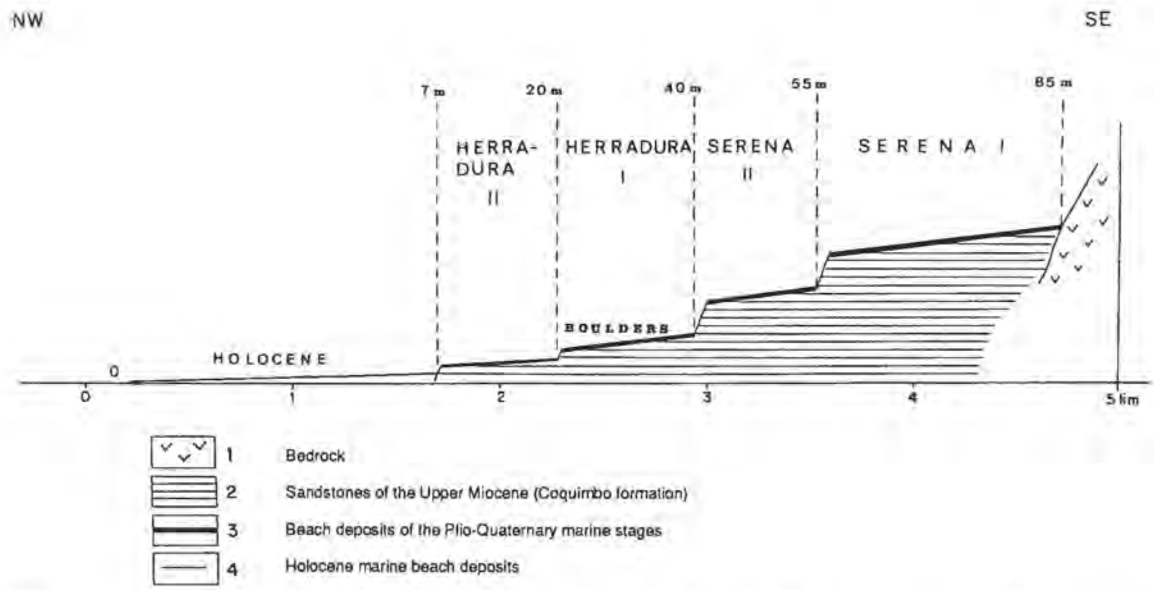

FIG. 2. Cross-section showing the Plio-Quaternary marine terraces in the surrounding area of Herradura Bay, Chile.

ders are not found on the surface of the other terraces.

The source of the boulders is known on the basis of their geographical distribution and their petrographic nature. They came from the Coquimbo peninsula. Some are of medium to fine grained monzonite or tonalite. Others are of andesite or diabase. Such kinds of rocks are not found on the coastal slopes which limit Herradura Bay inland. They cutcrop in the Coquimbo peninsula which is characterizad from a geological point of view by a Jurassic granitic intrusion cut by thick volcanic dykes.

FIG. 3. Large boulder protruding on the surface of the Herradura I terrace (Middle Pleistocene), near the Coquimbo railway station (Photo: R. Paskoff, September 25, 1989).

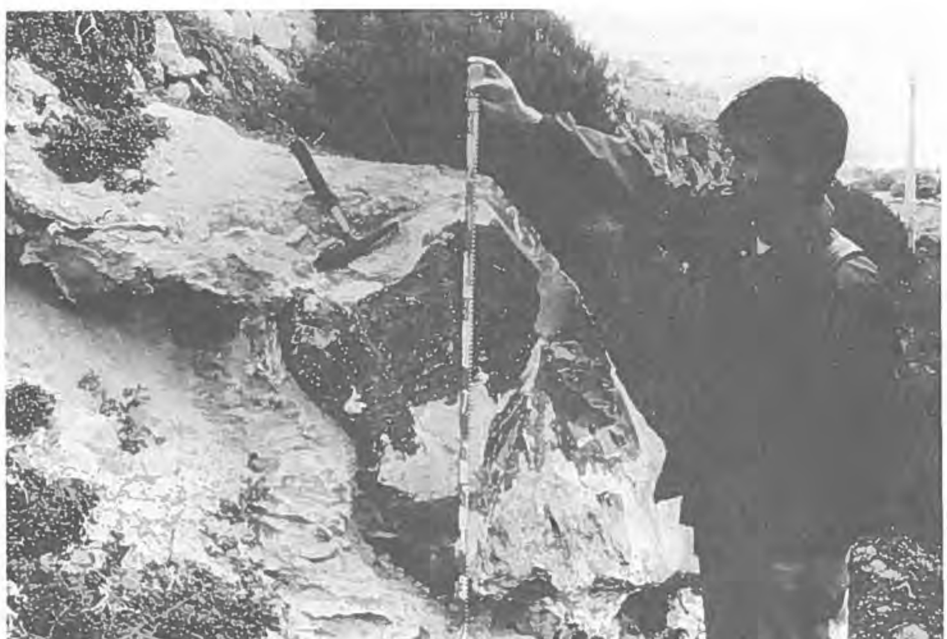

FIG. 4. Large boulder buried in the beach deposits of the Herradura I terrace (Middle Pleistocene), near Cantera Alta (Photo: R. Paskoff, September 25, 1989).

The boulders, which can be more than 2 m in length (Fig. 3), present a problem. They were transported over long distances, sometimes exceeding 2 km, from the rocky Coquimbo peninsula that was still an island when the Herradura I terrace developed. They were deposited under marine coastal waters, they are included in stratified beach deposits (Fig. 4), they are covered by shells, and in some cases they have barnacles adhering to them. Therefore, they constitute integral elements of the terrace deposits. It is puzzling to think how boulders of such size could have been transported and dropped where they now lie. The boulders are beyond the power of normal waves or current to carry them over a long distance from their source on the slopes of the former Coquimbo island.

It must also be pointed out that the episode of boulder deposition was unique since their occurrence in the area is limited to a single terrace. A few boulders of similar size and composition found on the surface of the Herradura II terrace must be considered as lag boulders. Exceeding the competency of normal waves, they remained in *situ,* but at a lower elevation, during the last interglacial period when the sea cut a new platform at the expense of the previous one. The phenomenon of boulder deposition was never repeated. Therefore it must be considered as an exceptional event which resulted from very rare and unusual conditions.

ERRATIC BOULDERS

Willis (1929), who was the first to recognize these boulders and the impossibility of their transportation by ordinary waves and currents, suggested that they were floated. Two agents for this peculiar mode of transport, which could account for the distribution of boulders, may be imagined. One consists of rafts of tree trunks carrying large rocks in their roots. The other is ice. No field evidence for either has been found. Willis discarded as highly improbable the existence in the area of trees sufficiently large to transport such boulders. He also thought that it would be unreasonable to postulate any development of huge masses of ice in a subtropical latitude, even during a glacial period of the Pleistocene. However, he presumed that, at the time of formation of the terrace on which the boulders are scattered, the local climate could have been severe enough to permit some coastal ice to form in shady areas of limited extension and in sufficient volume to afford local transportation of the large blocks. He also assumed that they were derived from a rock gorge cut into the pre-Tertiary basement by a small coastal stream, the Estero Culebrón. This point of view is hard to accept since the marine terrace bearing the boulders developed during a phase of high sea level, thus corresponding to an interglacial period, by no means propitious to ice formation in a latitude of 30°

THE MEGA-TSUNAMI HYPOTHESIS

An alternative explanation which does not demand an unrealistic assumption is herein proposed. Since the Pacific coast of South America is today episodically affected by tsunamis (Lomnitz, 1970), it is most probable that the large boulders were displaced by powerful waves generated by an earthquake of exceptional magnitude. Their distribution points to waves which came from the north-west. They moved large blocks when passing over the rocky island of Coquimbo and spread them over the nearshore zone of that time. This unusual tsunami was a unique event since, as evidenced by the occurrence of boulders on a single terrace, it happened only once in Plio-Quaternary time, probably around 300.000 years ago. It also affected Guanaquero Bay (30°08'S), about 25 km south-west of Herradura Bay, where the Herradura I marine terrace similarly is strewn with large boulders which were likely transported by huge waves coming from the north-west across the Guanaquero peninsula. However, farther south, around Tongoy Bay (30°15'S), no evidence supporting the occurrence of the Middle Pleistocene mega-tsunami has been found in the

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