EVIDENCE OF SUCCESSIVE IMPACTS OF THE NAZCA RIDGE UPON THE CONTINENTAL MARGIN OF CENTRAL-SOUTHERN PERU AS SUGGESTED BY SAR ERS-1 IMAGERY

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KEY WORDS: Central Andes, Southern Peru, Neotectonics, Radar imagery, Subducting Aseismic Ridge, Oblique indentation.

INTRODUCTION

Since the discovery of the Nazca Ridge offshore of Central-Southern Peru by 16°S latitude (SCHWEIGGER 1947), many are the authors which have been interested on the possible tectonic effects on the overriding forearc of the shallow subduction of that major oceanic high.

RUEGG (1952) was the first to notice the existence of an abnormaly elevated sector in the Coast Range, culminating near 1800 m at Cerro Huaricangana, just facing that aseismic ridge.and to suggest a possible relation between them. While it falls to TEVES (1975) to have drawn attention on the magnitude of the coastal uplift near San Juan de Marcona as testified by the exceptionnaly high number of marine terraces developped there (BROGGI 1947; LEGAULT 1963), and on the striking deflexion of the hydro graphic system about Ica and Nazca sectors.

Since then, detailed studies about marine terraces height variations and stratigraphy along the coast between Paracas (13.5°S) and Lomas (15.6°S) (MACHARÉ 1987; MACHARÉ & ORTLIEB 1992; HSU 1988, 1992) have revealed a striking quaternary longitudinal deformation of the coastal area. The pattern of deformation displays indeed an asymmetrical curviplanar dome-shaped curve, very similar to the bathymetric cross-section of the Nazca Ridge but with a maximum altitude of around +900 m for the highest terrace (upper Pliocene) which apex is clearly displaced southeastward above the southern flank of the ridge as a predictable consequence of oblique ridge subduction. In the present geodynamic context (Fig. 1) i.e. a plate convergence direction about N080° at a rate of 78 mm/a (DE METS *et al.* 1990) and a trench axis trending approximately N315°, the orientation of the long axis of the ridge about N040° implies that during the last million years the ridge in the course of its oblique consumption has been scanning the continental margin southeastward at the rate of about 50 km/Ma (MACHARÉ 1987). Founded on old rates of convergence and a simplified trigonometric calculus an overestimated scanning of 71 km/Ma has been set up by HSU (1992), but revised with the more recent estimates of plate motions (DE METS *et al.*1990,1994) it shows to be very nearest to the previous value.

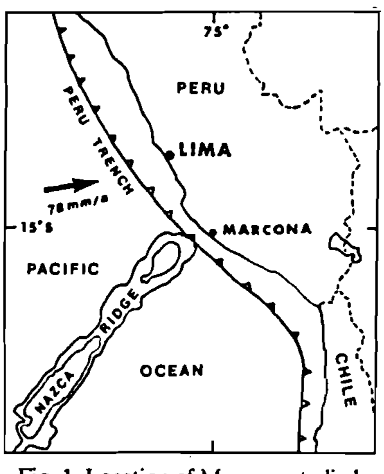

Fig. 1. Location of Marcona studied area and its geodynamic context.

Attemps of modelling the coastal uplift as induced by the geometry and kinematics of the subducting Nazca Ridge have been proposed (MORETTI 1982; HSU 1988, 1992), but concerned exclusively by the vertical effects. In a word, any of the proposed models have considered the possible horizontal compressive effect the system may produce. That derives from the fact that according to SÉBRIER *et al.*. 1985) the onshore geology along the Pacific coast opposite the Nazca Ridge reveals a preferential quaternary and recent extensional regime manifested by a normal faulting with metric throws. Whence the emphasis put by HSU (1992) on the lack of compressional tectonics and by MACHARÉ & ORTLIEB (1992) on the idea the ridge does note collide with the South American Margin.

EVIDENCE OF COMPRESSIONAL NEOTECTONICS

However, consequential evidences of early Quaternary compressional deformations affecting the Pliocene marine beds between Pisco and Nazca have been reported by MACHARÉ (1987). The structures are specially obvious at the boundary between the Coast Range and the Piedmont Depression of Ica-Nazca and result in impressive flexures with kilometric throws apparently induced by reverse faulting with NE vergence.in the basement.

From that point of view, one of the most privileged site of observation of that kind of structures is decidetly the Huaricangana periphery from Río Grande to Lomas. Furthermore it focused the main MACHARÉ's observations evidencing particularly the Rio Nazca Flexure which accounts for the northwestward deflexion of the stream and the significant folding of the Pliocene. Noteworthy too is the size of the area involved by compressional deformations since it seems to extend as far north as 30 km from the front of the massif. As regards the punctual measurements of microstructures, they give variable directions of shortening from NNW-SSE to NE-SW (MACHARÉ 1987) which fit the very shape of the massif.

However, the standart mapping (CALDAS 1978) having evidenced a major NW-SE trending fault bounding the northeastern edge of the Huaricangana (Tunga Fault), the Rio Nazca Flexure is interpreted as its extension. Beyong, an eventual connexion with the western fault of Ica is also considered (MONTOYA, GARCIA & CALDAS 1993).

RADAR IMAGERY AND NEOTECTONIC PATTERN

With the aim to specify the accurate neotectonic pattern of the area we turned to a SAR ERS-1 image. Radar imagery has proved to be particularly convenient for neotectonic studies because it enhances topographic features, specialy scarps and thalwegs, more than optical imagery and permits extensive observations at regional scale (CHOROWICZ *et al.* 1995). We used a scene centred upon Marcona, active illumination is from the ENE on descending orbits. The image covers an area 100x100 km, it was produced at 1/250 000 scale and inversed (Fig. 2). This type of presentation of the image has the advantage to display in dark the bright slope facing the radar and affected by shortening and layover effects,

Fig. 2. Reverse print of ERS-1 SAR Marcona scene.

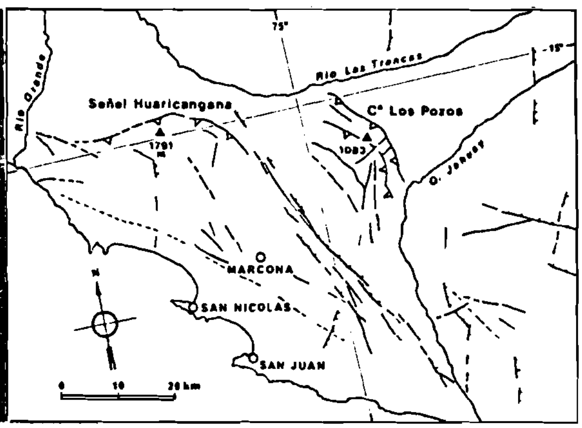

Fig. 3. Structural interpretation of the Marcona scene.

giving the impression of shadow. Slopes backing the radar are then clear and give the impression to be illuminated. They are rich in information because generally stretched. More-over, the image was pre-processed with the *Connected Center Filter* β_C (MERING & PARROT 1994) to reduce the speckle while preserving the connectivity of the lineaments. On the filtered image, light continuous lines are interpreted as recent faults and therefore extracted by mean of an upper thresholding of the grey tones.

Visual analysis of the SAR scene shows immediatly the striking symmetry in the deflexion of the hydrographic system seeing that the Rio Las Trancas swerves to the NW and the Q. Jahuay to the SSE. The other outstanding stroke is the clear scarp facing northeastward girdling the C° Huaricangana from the mouth of the Rio Grande to Lomas. By its continuity and convexity we interpret this feature as product of a major reverse fault involving a global thrust of the massif to the NNW. (Fig. 3). The extraction of the fault line merely confirms the continuity and sweep of the fault and therefore the geometry suggested (Fig. 4). The third feature to mention deals with the structures revealed by the small massif of C° Los Pozos isolated at the mouth of the funnel-shaped interstream between Las Trancas and Jahuay rivers. It appears to be cut indeed by a set of faults slightly curved with convexity and scarps facing to the ENE we interpret, there again, as reverse faults.

Fig. 4. Extraction of the Huaricangana fault line by mean of an upper thresholding of the SAR image.

CONCLUSIONS

This remarkable neotectonic pattern with its rather astonishing symmetry proves indisputably the area has undergone horizontal compressional forces oriented mainly towards the NE which appears consistent with the direction of convergence and so can be considered as tectonic effects of the subducting Nazca Ridge. However, since the symmetry is not perfect (the axis of curvature of the Huaricangana Fault doesn't fall in the one of C° Los Pozos), the relation seems more complex and may imply some rotations during the time in consequence of the oblique subduction. In short, much would be to learnt from a modelisation at lithospheric scale seeing that we are confronted with a complicated case of oblique indentation by a trapezoidal-shaped wedge, apparently not yet investigated by the literature.

At last, considering the tectonic signification of the hydrographic deflexions just discussed and the striking analogy between the pattern observed at Marcona and the one shown at Ica with the Rio Pisco turned to the W and the Rio Ica to the SSE, this leads to believe the subducting Nazca Ridge has produced two major successive impacts upon the continental margin of central-southern Peru (Fig. 5). This militates for a morphology of the ridge axialy rather irregular and discontinuous for the recently subducted part e.i.. fairly comparable with the one developped offward (MAMMERICKX & SMITH 1978). This irregular morphology could explain the apparent contradiction between the compressive neotectonics preserved onshore and the actual offshore evidences for a very minor compressional deformation in the lower forearc (HAGEN & MOBERLY 1994). In short, the "big bone" should have passed. This recalls, at a greater, scale the general model of subduction of a seamount proposed by VON HUENE & LALLEMAND (1990). So, the dynamic morphotectonic reply of the forearc to subduction of asperities should be quicker than usually accepted.

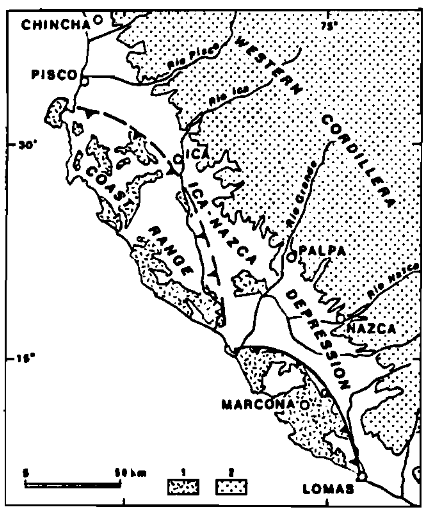

Fig. 5. Tectonic interpretation of the Coast Range of Central-Southern Peru as the result of two successive impacts of the Nazca Ridge upon the continental margin. *Pre-Cenozoic bedrocks of the Coast Range (1) and the Western Cordillera.(2)*

Finally, one should not be surprised by such an inland extent of horizontal convergent structures, Costa Rica neotec-tonics in consequence of the Cocos Ridge subduction provides an other example but in a normal convergent context (KOLARSKY *et al.* 1995) .

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