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ARCHAEOSHORELINE AND TECTONIC

Sites archéologiques de rivage et tectonique

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RESUME

La reconstitution des rivages anciens en vue d'une analyse des sites archéologiques côtiers implique nécessairement une prise en compte des mouvements tectoniques et ceci pas uniquement dans les seules zones séismiques. Aux îles Canaries, l'âge et la position des grès de plage supposent que, malgré une activité volcanique intense, un soulèvement très faible, voire nul se soit produit au cours de l'Holocène. A Timor, la datation radiométrique d'exemplaires de Tridacna *prélevés sur la barrière corallienne suggère une stabilité holocène après un soulèvement rapide au cours du Quaternaire.*

Dans le Sud du Chili, les plages fossiles indiquent une émersion progressive dans certains secteurs alors que la submersion prédomine dans d'autres. Les fluctuations du niveau de la mer ne se produisent donc pas uniformément dans un cadre tectonique stable. Dans certains cas, la tectonique peut être la clé d'une évolution au cours des temps de maints sites préhistoriques de rivage.

ABSTRACT

The reconstruction of palaeoshores for the analysis of coastal sites requires assessment of associated earth movements especially but not only in seismic areas. In the Canary Is., the age and position of beachrock implies slight or no tectonic Holocene emergence despite an active volcanic history. In Timor, radiometric dating of Tridacna *from reef platforms points to Holocene stability following a period of rapid Quaternary uplift. In southern Chile, fossil beaches show that successive earthquakes have led to cumulative emergence on some stretches of coast and submergence on others. Such findings demonstrate that sea-level fluctuations cannot be assumed to operate uniformly and within a static tectonic framework and that on occasion the tectonic effect may be the key to site history*

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INTRODUCTION

The search for coastal sites and the interpretation of their location evidently call for information on shifts in the shoreline. For most purposes it is immaterial whether the displacements were produced by erosion, deposition, a displacement of the land or an oscillation in global sea level. In Qatar, for example, Danish archaeologists searching for prehistoric sites found it helpful to postulate that sea level - for whatever reason - had formerly lain about 3 m above its present position (BIBBY, 1970). Again, the detailed coastal maps computed by LAMBEEK (1996) for the Aegean on the basis of glacioisostatic modelling are of interest to Classical archaeologist primarily because they track the shifting links between the islands and mainland Greece.

For certain purposes, however, we wish to know the timing and causes of shoreline shift in some detail. A port may have been abandoned before rather because of silting; progressive cliff retreat and instantaneous downfaulting have dissimilar impacts on coastal sites (e.g. MOUYARIS *et al.*, 1992). Indeed, the destruction of major cities by earthquakes, and the devastation produced by seismic seawaves or tsunamis, vies with invasion as an explanation that is often difficult to test. By the same token the efforts by geologists to profit from the human record in their search for detailed earthquake chronologies is all too often hampered by the difficulty of distinguishing between human and seismic damage or assessing the economic impact of natural disasters.

This paper discusses recent field studies in three areas whose archaeological record is poorly understood. In all three the focus is on the tectonic component in an attempt to show that the results can be of value to environmental reconstruction provided their limitations are clearly stated. The primary aim of the first study was to discover how far the volcanic origin of the Canaries archipelago was matched by tectonic instability and, more specifically, whether reports of elevated Pleistocene fossil beaches implied continuing uplift. The Timor study was designed to test the hypothesis that convergence between the Indian lithospheric plate and that of SE Asia had led to rupture of the Indian plate and rapid upward rebound of the continental margin. The discussion briefly considers the physiographic effects of earth movements on the coast of south-central Chile.

CANARY ISLANDS

Beachrock is a littoral deposit which is seductively crisp and whose relationship to sea level appears unambiguous especially in areas where the tidal range is narrowly defined. Yet beachrock cementation through the agency of splash can occur well above the high water mark (KELLETAT, 1988) and will not always be betrayed by microscopic evidence of recrystallisation or by ^{13}C measurements that point to a contribution by meteoric waters. Similarly, beachrock erosion may he promoted by storm action as well as by a fall in sea level (GREENSMITH, 1994); what is more, the maximum depth at which it may have formed is not clearly understood.

Armed with these gloomy facts a study of sea level change in the Canaries was made in the easternmost islands of Lanzarote and Fuerteventura supplemented by a brief reconnaissance visit to La Palma (Fig. 1).

Fig. 1. - Location of Canary Islands.

The literature contained some information on the coastal evolution of all three islands but their chronology was uncertain. For example, fossiliferous conglomerates and sandstones had been reported by HAUSEN (1968) on the leeward coast of Fuerteventura overlying an abrasion platform which had formed close to the present upper tide level in the Quaternary. The fossils included *Patella* and other molluscs. HAUSEN also found a thin horizon of littoral conglomerates at the base of a foraminiferal limestone on the windward coast at a height of about 15m. On Lanzarote, FUSTER *et al.* (1968) confirmed the existence of fossiliferous marine terraces at 50, 20, 10, 5 and I m, particularly in the Montaña Roja at the southern end of the island. The terraces were thought to be associated with successive basalt series (ROTHE, 1986) but their age remained obscure. The 50 m terrace contains the gastropod *Strombus bubonius* (HERNANDEZ-PACHECO, 1968, quoted by FUSTER *et al.*, 1968) whose chronological range, as in the Mediterranean basin, is not known.

Fossiliferous beaches had been found at elevations of up to 55 m on Lanzarote and Fuerteventura (LECOINTRE *et al.*, 1967) but many of them are now attributed to the Pliocene (MECO & STEARNS, 1981). Well attested Late Quaternary deposits, with Uranium-series ages of 106 ± 7 and 112 ± 7 x 10^3 years, were reported at a maximum of 4 m on both islands (ZAZO *et al.*, 1993). As the level generally accepted for the 5e eustatic highstand of 120 x 10^3 yr BP is about 6 m this was *prima facie* evidence for tectonic stability.

Beachrock, though widespread, was rarely found more than 1-2 m above High Water in all three islands (Fig. 2., Tab. I). The limited range of elevations could be taken to reinforce the case for stability. Indeed the fact that the ^{14}C ages in the 0-2000 yr range are all found 0-0.7m above High Water may stem from the slight emergence since 3000 yr BP indicated by the theoretical model of CLARK (1980). Yet the attribution to beachrock well above this level of several non-finite determinations (including LZ IV, which is at the limit of the method) does not rule out some uplift. Indeed uplift at a rate slower than that of the Holocene transgression, an average of 4.7 mm yr^{-1} in the scheme of CLARK (1980), would not be detected.

Until further geochemical tests remove some of the ambiguities the unsatisfactory conclusion must be that the beachrock appears to exclude submergence but does not rule out some light emergence in the late Pleistocene.

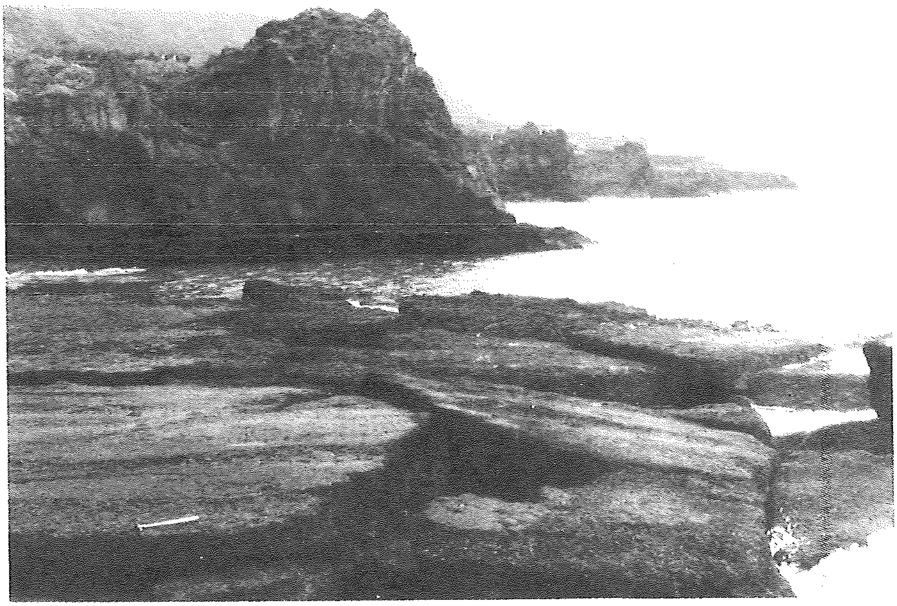

Fig.2. - Tabular beachrock undermind by wave action.

TAB.I. - ^{14}C ages for the Canary Is.

Site	Elev. (nl)	age (yr BP)	Lab. rio.	Cal. age (yr BP)+	corr. clev (M)*
Lanzarote					
LZ I	0	1930 ± 110	UCL-350	1480 ± 140	0.5
LZ III	0.7	1940 ± 240	UCL-351	1490 ± 280	0.2
LZ IV	2	>16,000 §	UCL-352	n.a.	n.a.
LZ V	0	>16,000 §	UCL-347	n.a.	n.a.
Fuerteventura					
Sot I	1.9	> 16,000 §	UCL-347	n.a.	n.a.
Sot II	1.7	> 16,000 §	UCL-348	n.a.	n.a.
Sot b	0	> 16,000 §	UCL-356	n.a.	n.a.
Guis	0.3	230 ± 80	UCL-349	n.a.	0.3
FV	1.0	>16,000 §	UCL-357	n.a.	n.a,
La Palma					
LP I	0	2100±90	UCL-354	1680 ± 130	-0.5

+ age calibration after STUIVER & REIMER (1993). First-order ages (UCL- numbers) after VITA-FINZI (1991). All the samples on *Patella* sp.

* based on graph for Zone III in CLARK (1980).

§ age at limit of first-order method.

TIMOR

Plots of earthquake hypocentres and analysis of the corresponding focal-plane solutions shed light on plate interaction only for the period spanned by the seismic records, and even then the dynamic patterns they reveal may be prejudiced by fault reactivation or by ambiguous solutions too deep to be resolved by surfact fault breaks. Some of the deficiencies can be made up by deformation chronologies which are long enough for major trends to override temporary or spurious patterns and which complement localised seismic data with direct evidence of ground deformation. The outcome may shed light on such matters as seismic hazard or cultural adaptation to former patterns of earthquake activity (VITA-FINZI, 1992).

The present study relies on fossil shorelines in West Timor, in eastern Indonesia (Fig. 3a), where the Indo-Australian Plate is being subducted under the Banda Arc at an average rate of about 70 mm yr^{-1}.

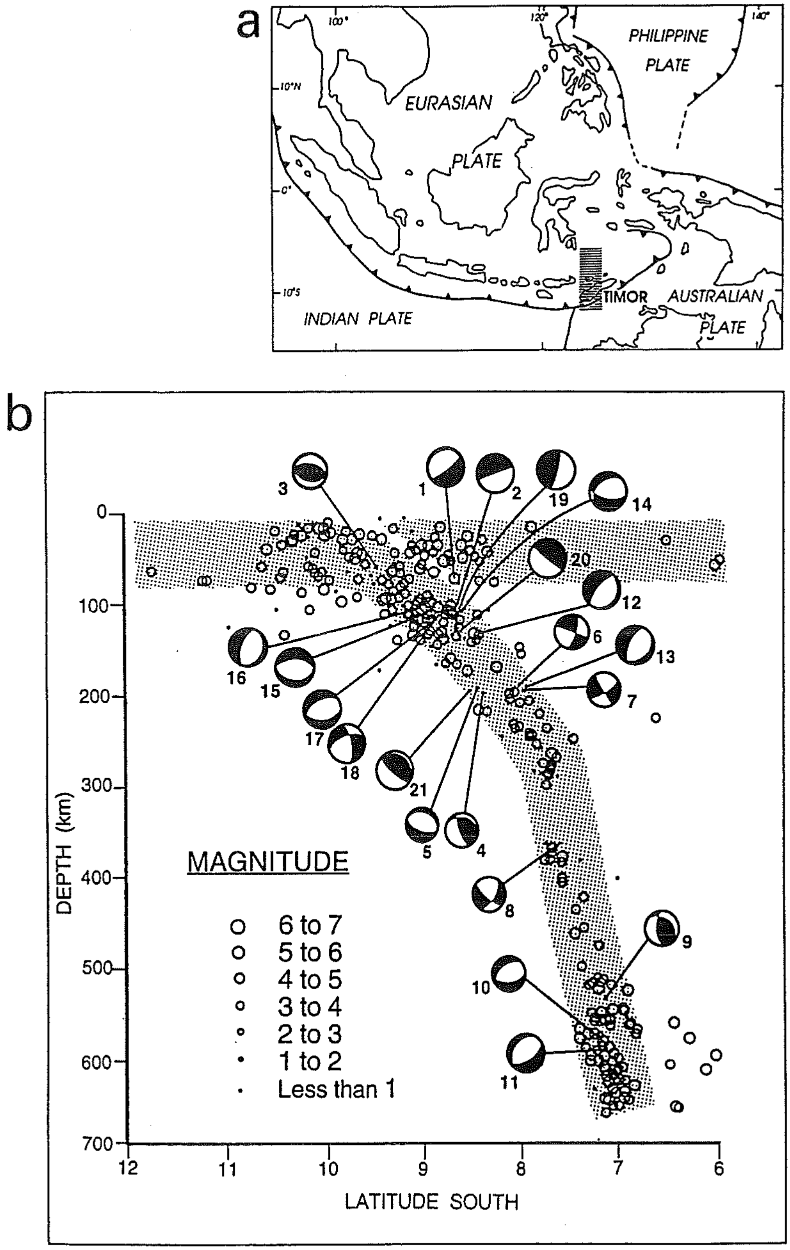

Fig.3 a. - Location of Timor.

b. - Magnitute and focal plane soutions for selected earthquakes in zone shown in fig.3a Note gap in seismicity at a depth of about 300-360 km close to point of inflection of inferred lithospheric slab.

Collision between Australia and this part of the Southeast Asian Plate is thought to have started 3.10^6 years ago, with the emergence of Timor as one of its consequences. Precisely how remains controversial (see for example CARDWELL & ISACKS 1978). According to PRICE & AUDLEY-CHARLES (1983), collision of the Australian Plate with the Eurasian Plate in the Early Pliocene led to its rupture, a process which was helped by hydraulic fracture and reverse faulting. The detached portion of the Australian lithospheric slab began to sink and the continental margin rebounded, carrying the island of Timor up with it.

Sudden changes in tectonic deformation in other subduction settings have been ascribed to slab rupture. For instance, CHATELAIN *et al.* (1992) explained the rapid uplift currently experienced by the Vanuatu Islands by the creation of a gap in the downgoing slab of the Australian lithosphere. Within the area under review, McCAFFREY *et al.* (1985) cited the results of a microearthquake survey to propose that the subducted lithosphere north of Timor was becoming detached at a depth of 50-100 km, leading to uplift of the upper slab as well as rapid sinking of the upper part of the detached portion.

The pattern of hypocentres falling within the relevant longitudinal belt (Fig. 3b) shows a gap at a depth of about 350 km combined with a marked change in slab dip (front about 45° to 75°) and a moderately high level of activity at 600 km. The distribution of shallow to deep hypocentres along the Banda Arc has been interpreted by CARDWELL & ISACKS (1978) as a laterally continuous slab, the seismic gap detected in its western part at depths of 300-500 km being dismissed as illusory on the grounds that it is absent further east. It is of course possible that the gap stems merely from a lack of events during the period of record. But the coincidence of the gap in the Timor plot with a steepening of the slab, and the absence of events of all magnitudes, suggest that the gap is real .

It has been known for over half a century that there are elevated reefs in the central part of West Timor which date from the Late Cainozoic (VAN BEMMELEN, 1949).

Micropalaeontological evidence indicates that outcrops now 3000 m above sea level were deposited at depths of 2000 m during the late Neogene (BARBER *et al.*, 1977). Uplift is thought to have proceeded at an average rate of 3 mm yr^{-1} which in due course declined to 1.5 mm yr^{-1} (AUDLEY-CHARLES, 1986) although some workers believe that uplift during the Quaternary attained 10 mm yr^{-1} (DE SMET *et al.*, 1989).

The first radiometric study of shoreline history in Timor was made by CHAPPELL & VEEH (19178) on the north coast of East Timor. Using stratigraphic and palaeoecological data calibrated with Th/U determinations on elevated reefs they obtained an uplift rate for the last 120,000 yr of 0.03 mm yr^{-1}. In western Timor, dating of uplifted coastal terraces gave an average rate of 0.3 mm yr^{-1} for the last 152,000 years (JOUANNIC *et al.*, 1988). Though higher than that for East

Timor this value is consistent with the presence of numerous large, modern reef platforms (JOUANNIC *et al.* 1988).

Radiocarbon dating of corals and *Tridacna* clams from Western Timor and the adjoining island of Semau points to an uplift rate of 0.4 mm yr^{-1} for the last 4000 years. The evidence for the north coast of Sumba Island is similar. PIRAZZOLI *et al.* (1993) concluded that their evidence fitted an average uplift rate of 0.49 mm yr^{-1} during the last million years. They also reported a ^{230}Th age of 6300 ± 200 yr BP and ^{14}C ages of 1920 ± 250 and 5070 ± 200 yr BP for a narrow terrace 1.5 ± 0.5 m above MSL and 3 m above low tide. As HANTORO *et al.* (1989) observe, the terrace is topped by high tide.

As all but three samples of the Timor and Semau ages exceeded the then 12,000 year limit of the first-order method, three were submitted for conventional assay at the Weizmann Institute. They were found to display activity indistinguishable from background (GOODFRIEND, pers. comm.). Amino acid analysis confirmed this finding, with D-alloisoleucine/L-isoleucine values of about 1.00 ± 5% (Tab. II).

TAB.II. - ^{14}C and amino acid ages for sites in SW Timor and Sumba.

sample	height (m)	first order ^{14}C age (yr BP)*	lab.n°	conventional ^{14}C age (yr BP)	lab.n° ***	A/I****
Timor						
37	1.3	4980 ± 330**	UCL-154			
39	1.3	4540 ± 310**	UCL-175			
9	2.0	>12,000	UCL-164	37,600 ± 900	RT-1555	1.11
1b	2.5	>12,000	UCL-153	n.d.		0.899
17b	3.0	>12,000	UCL-163	36,900 ± 3500	RT-1562	0.937
2	3.5	>12,000	UCL-161	42,200 ± 2070	RT-1533	n.d.
5b	5			37,800 ± 1000	RT-1554	1.02
20	12			n.d.		1.00
Sumba						
2	low tide	5615 ± 360	UCL-160			

* using procedure in VITA-FINZI 1991. For additional first-oder ages see VITA-FINZI & HIDAYAT, 1991

** Calibrated after STUIVER *et al.* 1986

*** RT-ages after GOODFRIEND (pers. comm. 1992)

**** A/I = D-alloisoleucine / L- isoleucine ratio

The complexities of sea-level and tectonic history rule out any simple correction for eustatic effects during the Quaternary. The Holocene is more tractable and here reference to global data such as that collected by FLINT (1971) indicates emergence by 0.7 ± 1.0 mm yr^{-1}. Though faster than the long-term results derived from U-series dating these values tally with the late Pleistocene rate proposed by AUDLEY-CHARLES (1986). Indeed the error bars associated with average uplift values may conceal slight, localised episodes of subsidence. The data in Table II also suggest that there has been no appreciable uplift in the last 5600 years, the age obtained for an intertidal beachrock on Sumba.

In an area where vertical movements are predominantly coseisimic the lack of definite evidence for late Holocene uplift could stem simply from the prevalence of long recurrence intervals. But NEWCOMB & McCANN (1987) infer from historical records and the age of the subducted oceanic crust that, in contrast with its northwestern portions near Sumatra, where uplift is predominantly spasmodic (VITA-FINZI & SITUMORANG 1989), the eastern Sunda Arc near Java deforms mainly in aseismic fashion. In any case, the four RT results (Tab. I) show that the Holocene averages hold good for at least 42 000 yr.

High uplift rates for inland Timor have been reconciled with slow coastal uplift by postulating regional arching of the island (DE SMET *et al.*, 1989., VAN BEMMELEN, 1949). The shoreline record in the Sunda Strait region has been interpreted (JOUANNIC *et al.*, 1985) as an isostatic effect produced by loading by glacial meltwaters or the volcanic complex of Krakatoa, and the elevated young coral reefs on the islands of the Banda outer-arc ridge as the product of rapid uplift resulting from the buoying effect of the light sediments stuffed under the arc (HAMILTON, 1979). None of these mechanisms accounts for the almost total cessation of uplift indicated by the palaeontological and dating evidence.

In short, the neotectonic record supports the view that the rate of Quaternary uplift in western Timor (and also in north Sumba) declined to a negligible level during the late Quaternary. The contrast with other parts of the archipelago such as the islands of Nias and Simeulue off Sumatra is striking (VITA-FINZI & SITUMORANG,1989); its cultural implications have still to be explored.

DISCUSSION

The above two examples refer to areas where the tectonic component is relatively uniform. Elsewhere (or perhaps wherever the investigation has been sufficiently thorough) the picture is more confused. An excellent example is south central Chile (Fig. 4).

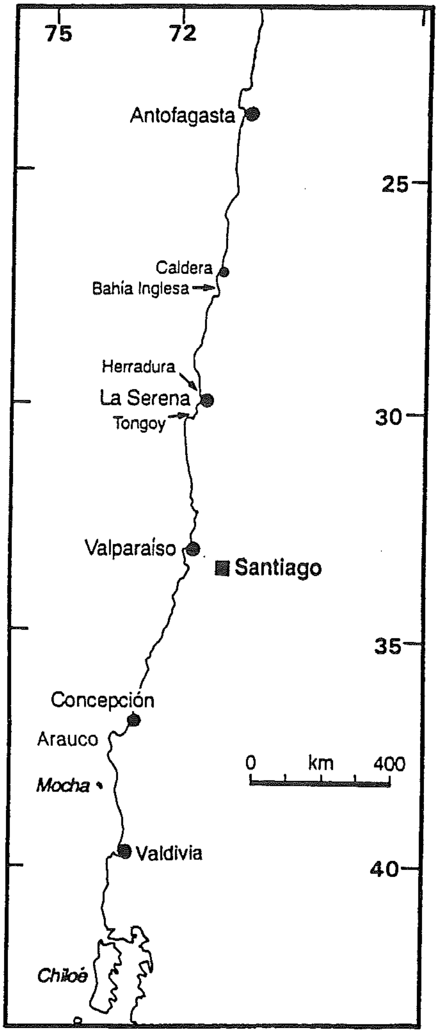

Fig.4. - Location of sites in Chile mentioned in text.

The 1960 Vaidivia earthquake left its topographic imprint on the coast of Chile between 35° and 47° S, with a western belt where uplift attained as much as 5.7m and an eastern belt affected by up to 2.3m of subsidence (PLAFKER & SAVAGE, 1970). Some accounts of the deformation invoked thin viscous sheet models; others favoured dislocation mechanisms. The scheme proposed by MANN & VITA-FINZI (1994) proposed elastic buckling of the South American plate; it successfully accounted for a second, eastern zone of uplift identified by the geodetic survey, and provided a simple explanation for the postseismic relaxation reported at various points along the coast.

The observations by PLAFKER & SAVAGE (1970) showed that, as in many other subduction earthquakes, the sign and amount of coseismic displacement depended on position; later studies demonstrated the importance of timing. A measure of relaxation had already taken place by the time, of the geodetic survey. At some locations the coseismic displacement may ultimately disappear; at others, for example on the island of Mocha southwest of the Arauco peninsula, the movement shows no sign of reversing even though it varies markedly in rate.

Nevertheless the general pattern of coastal types is consistent with that of the 1960 event, with a western band dominated by emergence and a central belt where subsidence is manifested by a drowned ria coast (see for example eastern Chiloe, Fig. 4) and by lake basins or broad valleys that lend themselves to damming for reservoirs (Fig. 5).

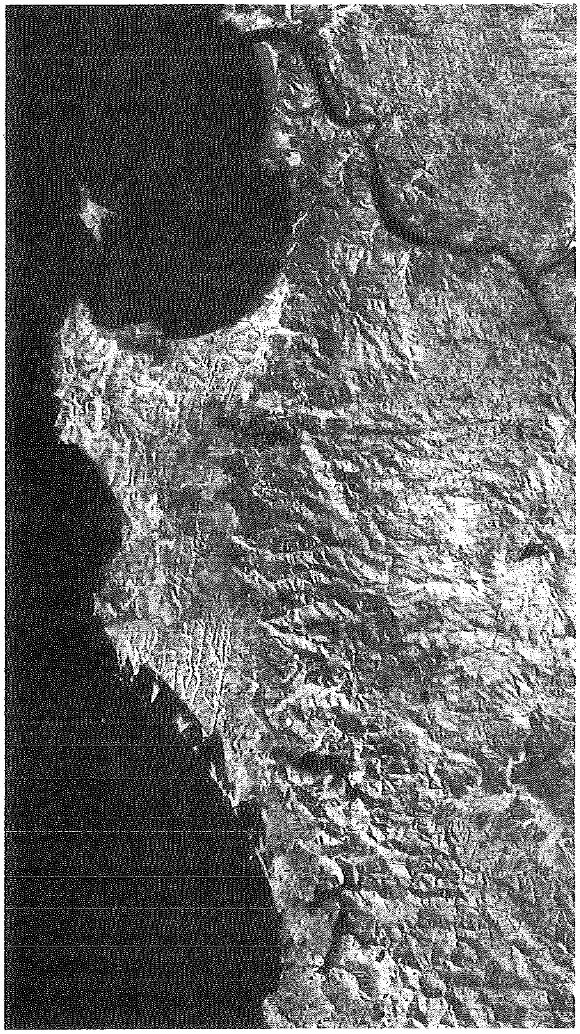

Fig.5. - Landsat image of Arauco area showing emergence near the coast and evidence of subsidence along a central belt (ria, lake basins).

The celebrated fossil beaches of the region, notably those at Tongoy, Herradura, Bahia Inglesa, Caldera and Antofagasta, confirm that movement is not unidirectional, as there is no simple relationship between height and age: indeed, most of them are beyond the range of ^{14}C dating where one would expect a rich Holocene record, and several sections show stratigraphic evidence of alternating uplift and subsidence.

Thus the nature of coastal change in this part of Chile depends on position within a broad framework of N-S up- and downwarps and on timing within the latest major earthquake cycle. In addition the length of time since the previous, deforming event may be of importance in determining how far postseismic relaxation has progressed and thus whether vertical displacement will be cumulative. There are obvious implications for seismic hazard assesment (VITA-FINZI, 1996) as well as for archaeology.

In short, the "correcting for sea-level change" may prove troublesome, but the geologist will profit from the outcome as much as the archaeologist.

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