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COASTAL FLOW MODIFICATION BY SUBMARINE CANYONS ALONG THE NE SPANISH COAST

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RESUMEN

La ausencia de vientos dominantes y la existencia de varios cañones submarinos perpendiculares a la estrecha plataforma continental, hace de la región norte de la costa Catalana una zona ideal para comprobar las hipótesis de modificación topográfica de un flujo costero. El análisis de datos hidrográficos obtenidos durante dos campañas oceanográficas en 1983, combinado con un estudio intensivo de imágenes de satélite (termografías NOAA y CZCS/Nimbus), indica que los cañones actúan como barreras que desvían la corriente que circula hacia el sur. El flujo es desviado hacia mar abierto al sobrepasar cada cañón, de acuerdo con la teoría simple de la circulación en aguas poco profundas.

Palabras clave: Flujo Costero, Cañón submarino, Aguas someras, Imágenes de satélite.

ABSTRACT

The lack of dominant winds and the almost complete bisecting of the narrow shelf by several canyons, make the region of the northeast Spanish coast an ideal area to test the hypothesis of topographic modification of the general coastal flow. Analysis of in situ data from two cruises in 1983, combined with an intense study of satellite imagery, indicates that the canyons act as deflecting barriers to the southward current. The flow is deflected offshore on the downstream side of each canyon, in accordance to simple shallow-water theory.

Key words: Coastal flow, Submarine canyon, Shallow water, Satellite imagery.

1. INTRODUCTION

Recent coastal interactions studies have shown that in these regions the entire water column is affected by topographic changes. Narimoussa and Maxworthy (1987) studied the effects of coastline perturbations on upwelling circulation and found that unstable baroclinic waves formed at the upwelled front upstream of a cape and drifted toward it. Preller and O'brien (1980) studied the effects of bottom topography on coastal currents and fronts and found that the upwelling maximum off Peru (40 km south of 15°S) was the result of a mesoscale topographic feature. It has been shown that submarine canyons exert significant influences on the surface flow and are the sites of preferential exchange between the shelf and slope, and consequently suport high levels of biomass (Huthnance, 1981; Denman and Powell, 1984).

More specifically, the deflection of shelf-edge or coastal currents by submarine canyons was studied by Kinsella, et al. (1987), who examined the interaction between a shelf-break jet (the Labrador Current) and a submarine canyon (Carson Canyon) located at the edge of the Grand Banks of Newfoundland. They found that the effects of this nonlinear interaction were influencing both the dynamics of the jet and the residual circulation in the canyon.

Off the northeast Spanish coast, the narrow continental shelf is bisected by four submarine canyons (figure 1). In the slope region, a density front is found throughout the year. Font et al (1988) found that geostrophic currents of approximately 30 cm/s, were associated with this shelf/slope front. This front in characterized by frequent salinity inversions that were found, in 1983 and 1986, to be associated with rapidly evolving mesoscale features (Wang et al. 1988; Tintore et al. 1989). Tintore et al (1989) showed the low salinity anticyclonic eddy observed in the shelf region off Barcelona in July 1983 was associated with a plume of cold water wich originated in the Gulf of Lions and was moving southward in the slope region. La Violete et al. (1989) found that this type of mesoscale filament or eddy is frequent off the Northeast Spanish coast and appears to be associated with a band of cold water present in the slope region.

Over the shelf, the flow is weak but mainly oriented to the southwest. In spring and early summer the strong buoyancy input of the Rhône River reinforces the horizontal density gradients, enhancing the southward baroclinic flow (Masó, 1989). During the stratified season, tongues of very low salinity water (31 psu) can be traced down to near cape Sant Sebastià (42°N) (Castellón et al. 1985)., In winter, the shelf water is well mixed, with little horizontal or vertical changes.

In this paper we study the modifications of the shelf flow induced by abrupt topographic canyons. The lack of dominant winds and a predominantly southestward flow suggests we have near ideal conditions to test the hypothesis of topographically modified coastal flow.

2. IN SITU MEASUREMENTS

Data used in this study were collected on-board the R/V García del Cid during two field experiments in 1983. CTD stations are shown in figure 1 (note that no in situ data are used in the study of Canyons 3 and 4. These two canyons will be examined only with satellite imagery).

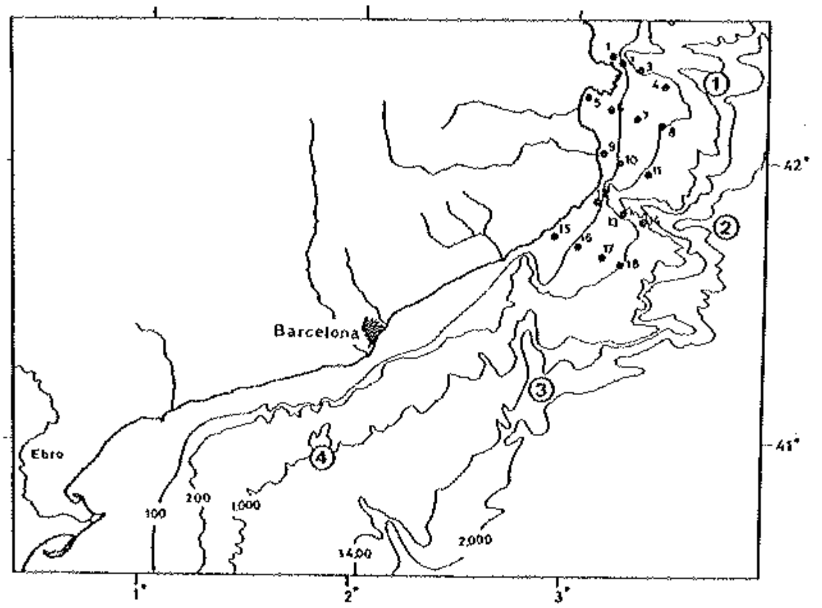

Figure 1.— Bathymetry (with canyons 1, 2, 3 and 4 shown) and CTD stations (June 1983).

3. SATELLITE IMAGERY

Cloud-freee satellite thermal sensor (NOAA Advanced Very High Resolution Radiometer (AVHRR)) and visible (Nimbus Coastal Zone Color Scanner (CZCS) imagery for the period January trhough December 1986, were examined to see if changes in the thermal and visible field could be used to infer deformations in the flow caused by the submarine canyons. Altogether, 105 infrared and 8 visible images were examined. All had been registered into Mercator projections. In addition, because of the very low contrast of the regional thermal data, the images in this spectral range were enhanced. The enhancement cosisted of Wallis convolution (space varying contrast stretch and level equalizing technique to normalize the image). As a result, the thermal images have undergone enhancement with variable weighting so that weak gradients fields are given higher weights than strong gradients. Thus, all of the thermal gradients are shown as equal and the total gradient field is displayed. See La Violette (1987) for the general details of the rationale and methodology used in the image processing. Examples of the visible and thermal imagery, that have been examined for the study, are shown in figure 2 a and b.

4. RESULTS AND DISCUSION

Shallow-water theory for a homogeneous, frictionless fluid shows that the adjustment over a topographic ridge or canyon is governed by the equation of conservation of potential vorticity (Pedlosky, 1979), i.e.

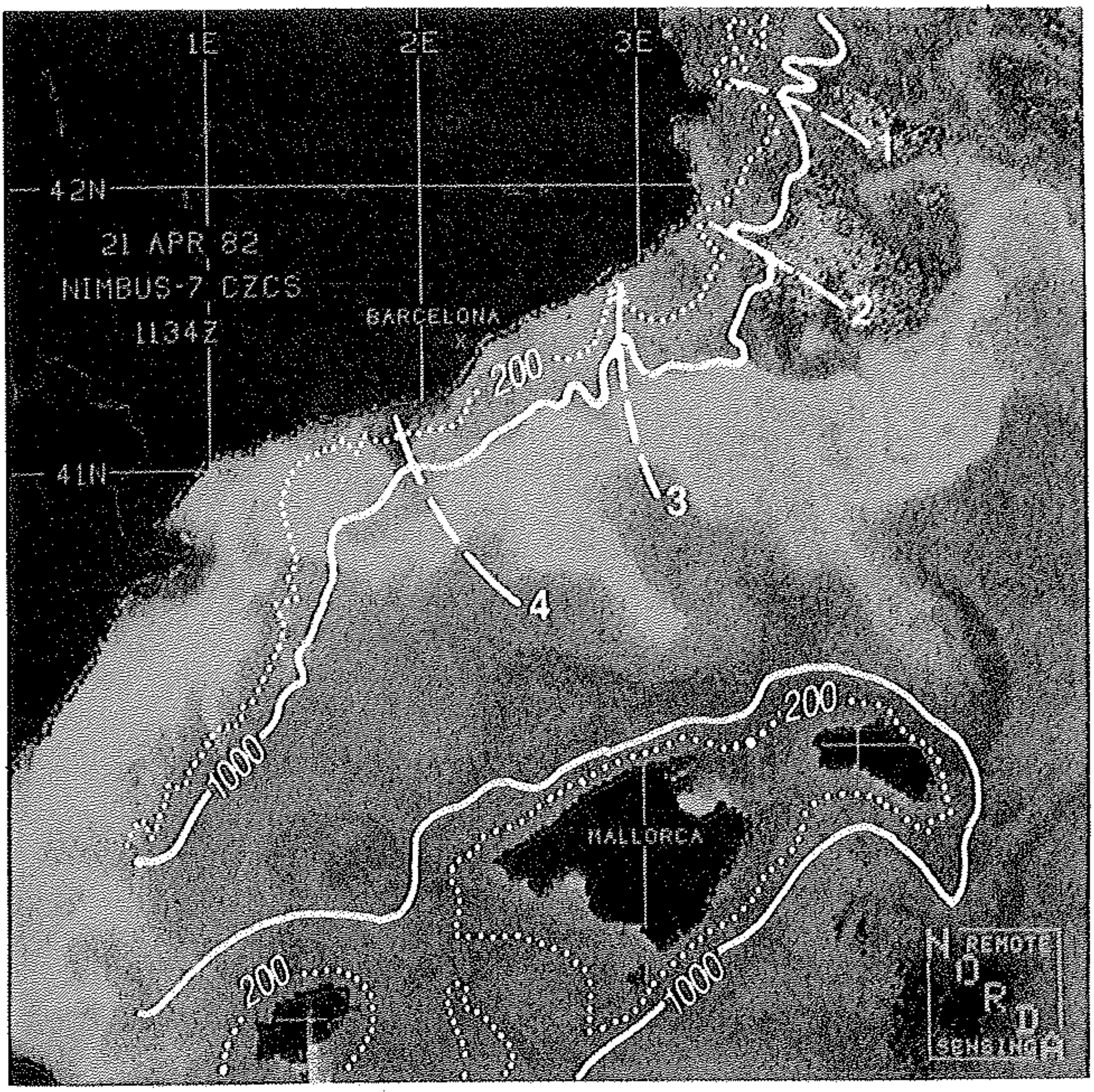

Figure 2.— (a). An example of the deformation of flow associated with the four canyons as seen in a Nimbus 7 CZCS visible image. This presentation of the chlorophyll distribution indicates that the deflections of the flow offshore associated with canyons 3 and 4 are more pronounced than those of canyons 1 and 2.

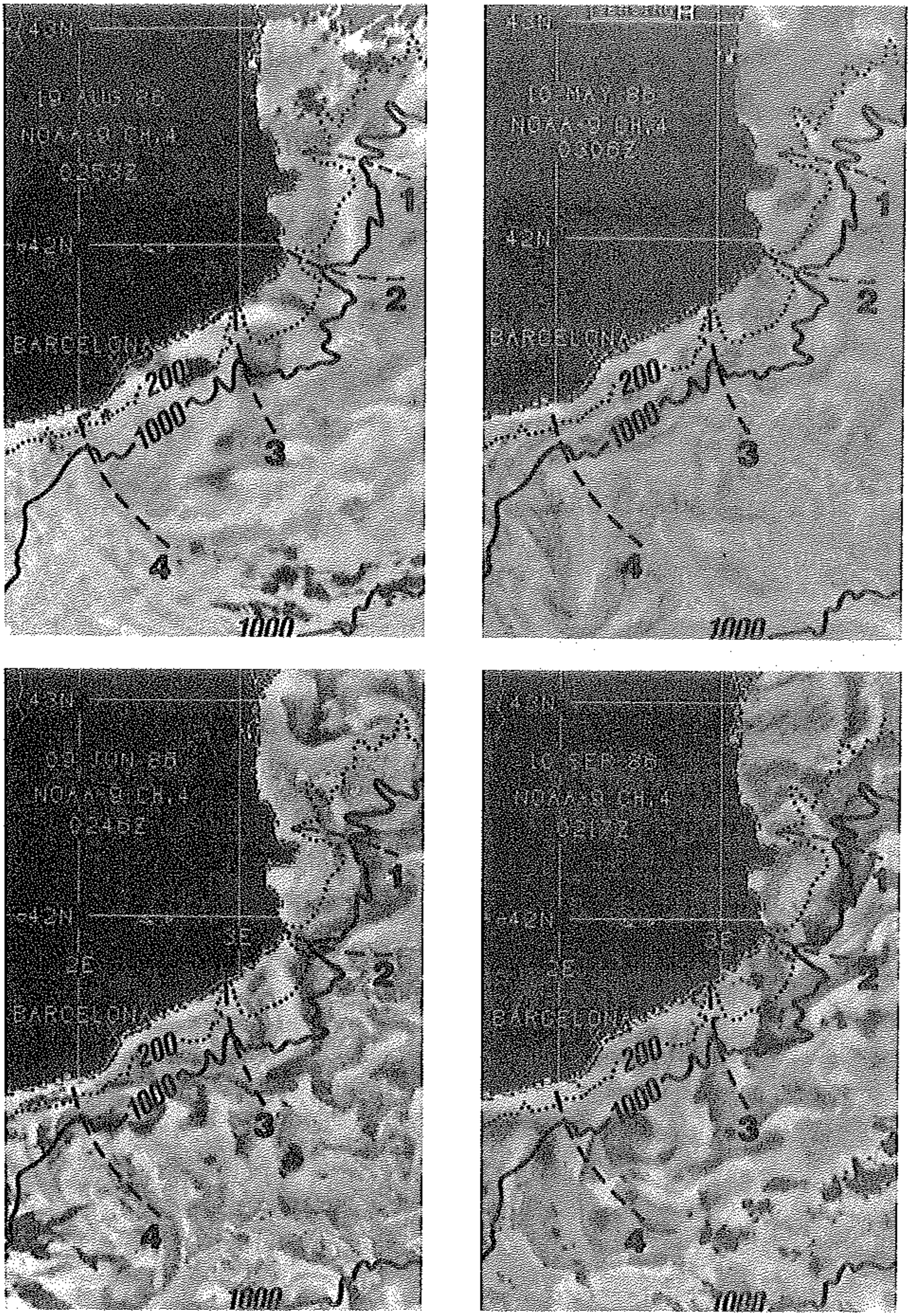

Figure 2.— (b). Four NOAA AVHRR thermal images of the submarine canyon region (in the images the darker the tone, the colder the water and, conversely, the lighter the tone, the warmer the water). The 200 and 1000 m isobaths have been superimposed to provide reference to the canyons locations. In the images, the southward flow deformation is best seen as an offshore deflection of cold water slightly dowstream of each canyon. In these examples the deformation associated with Canyon 1 is either not present or weakly displayed. (next page).

$$\pi = (\Gamma + f)/H = \text{constant}$$

where:

π = Is the potential vorticty.

Γ = Is the relative vorticity.

f = Is the planetary vorticity.

H = Is the depth of the fluid.

However, the adjustment is different for eastward or westward flows (Holton, 1979). A westward flow with zero initial relative vorticity has to "feel" the effects of bottom topography upstream of the canyon (or ridge) to preserve the initial potential vorticity. Otherwise, if the flow were modified at the canyon wall, the increase in depth would induce cyclonic (positive) vorticity, which would bring the fluid into deeper water. This depth increase in turn would increase the cyclonic vorticity to yield a reversal of the initial flow.Consequently, the flow is expected to veer to the right (toward shallow water) upstream of the canyon, creating negative relative vorticity that would be balanced by the decrease in depth. Over the canyon, the increase in depth will create cyclonic relative vorticity; therefore, an offshore displacement of shelf water should be expected.

Evidence of this type of modification ot the shelf flow can be seen in the in situ data and satellite images. The dynamic topography (figure 3) indicates the flow is approximately along isobaths. This coincidence of isobaths and streamlines suggests that, to lowest order, the shallow-water model is appropriate for the description of the shelf flow.

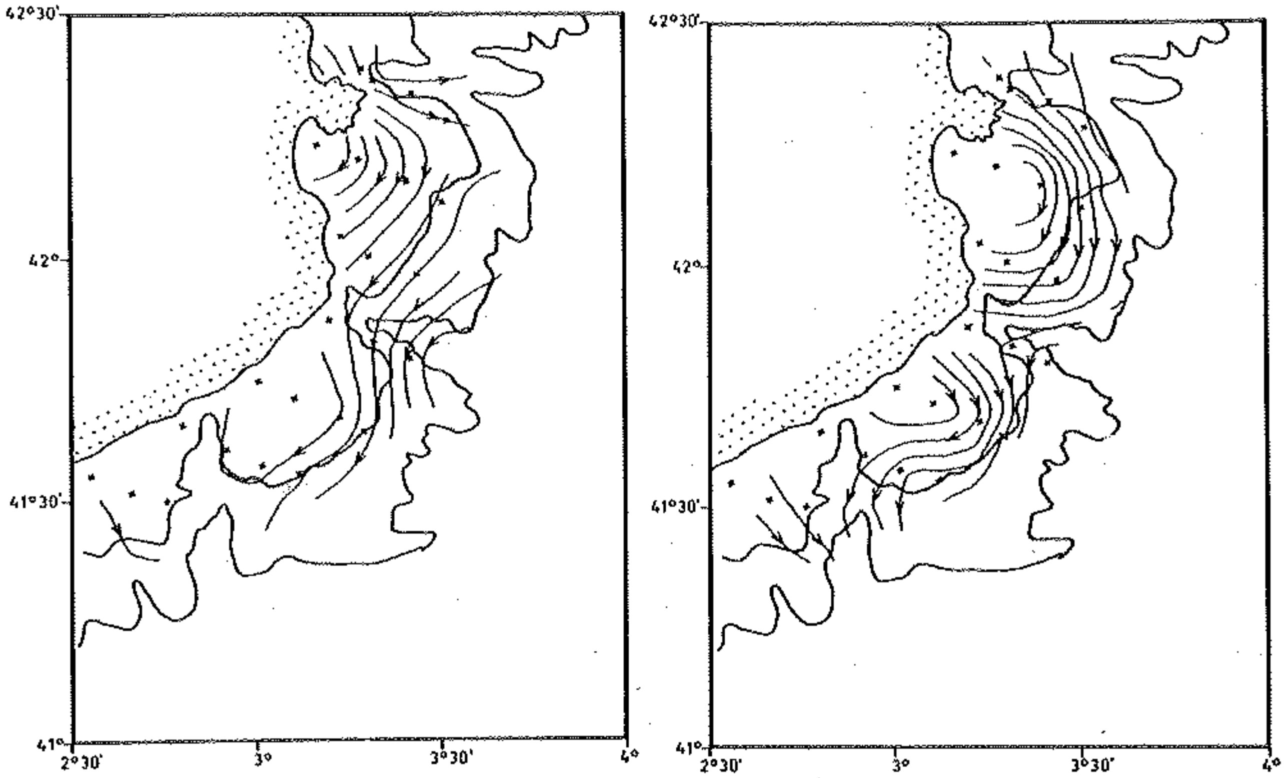

Figure 3.— Dynamic topography (ref. at 100 m, from June data): a) at 10 m contours every. .01 dyn. cm, b) at 50 m, contour every. .005. dyn. cm.

The dynamic topography and the salinity distribution at 20 m (figure 4) indicate that the flow veers to the right (toward the coast) before reaching the canyon. Because of the induced topographic change, the fluid will tend to adjust to a new equilibrium in a narrow region near the upstream wall of the canyon. This region is an inertial boundary layer whose thickness is giben by Pedlosky (1979):

$$\delta = [U/f\ (dH/dy)/Ho]^{1/2}$$

Where U is the flow speed and Ho is the depth of the fluid. In our case, a rough estimate (U = 10 cm/s, Ho = 100 m, dH/dy = 0.1) gives δ = 14 km which agrees with the distance the southward flow is deflected toward the coast before the canyon (figures 3 and 4). Over the canyon and downstream, figures 3 and 4 also show that the flow is deflected offshore as would be expected from our theoretical considerations. Furthermore, temperature/salinity diagrams for canyons 1 and 2 confirm this picture and indicate the vertical extent of the modified flow (figure 5). Similar features were observed under winter conditions. Surface salinity distribution (figure 6) depict the same type of flow modification shown in figure 4.

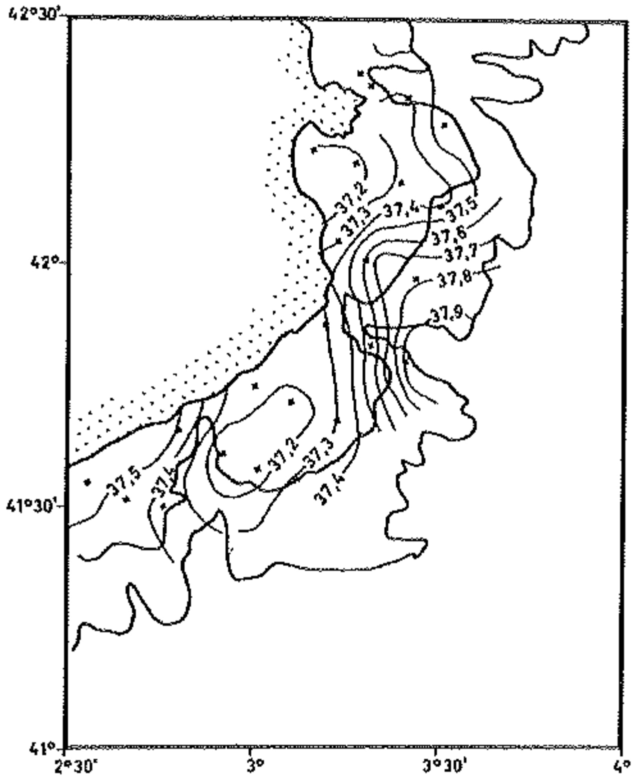

Figure 4.— Salinity distribution at 20 m (June data).

Our in situ data analysis indicates that the canyons off the northeast Spanish coast act as deflecting barriers to the southward current, inducing a shelfward deflection before the canyons and an offshore flow on the southern side of them. In their study of the Carson Canyon, Kinsella et al. (1987) also found a shelfward deflection of the dynamic topography. They found that the mean current was flowing acroos isobaths into the canyon on the upstream side but steering off-shelf on the downstream side.

Since this characteristic appears to be common, the resultant changes in the surface thermal field should be visible in the satellite thermal and visible imagery. Although in the imagery we examined these changes did not always occur, it occured frequently enough to confirm that the canyons did exert a strong control on the regional flow. The distribution of occurence of the modified flow in the infrared thermal imagery we examined is presented in Table 1. In the eight visible images,five were cloudy over canyons 1 and 2 but showed evidence of modifications over canyons 3 and 4. The remaining two were for 10 May 1986 (similar to the thermal image in figure 2a) and 21 April 1982 (figure 2b). Our examples in figure 2 are overlayed with the 200 and 1.000 m isobaths to show the relationship of the canyons' location with the modified flow. Note that the modifications over canyons 3 and 4 are well displayed in the examples. This was true of all the image showing deformation in this region. We believe these canyons are major contributors to the offshore transfer of coastal properties.

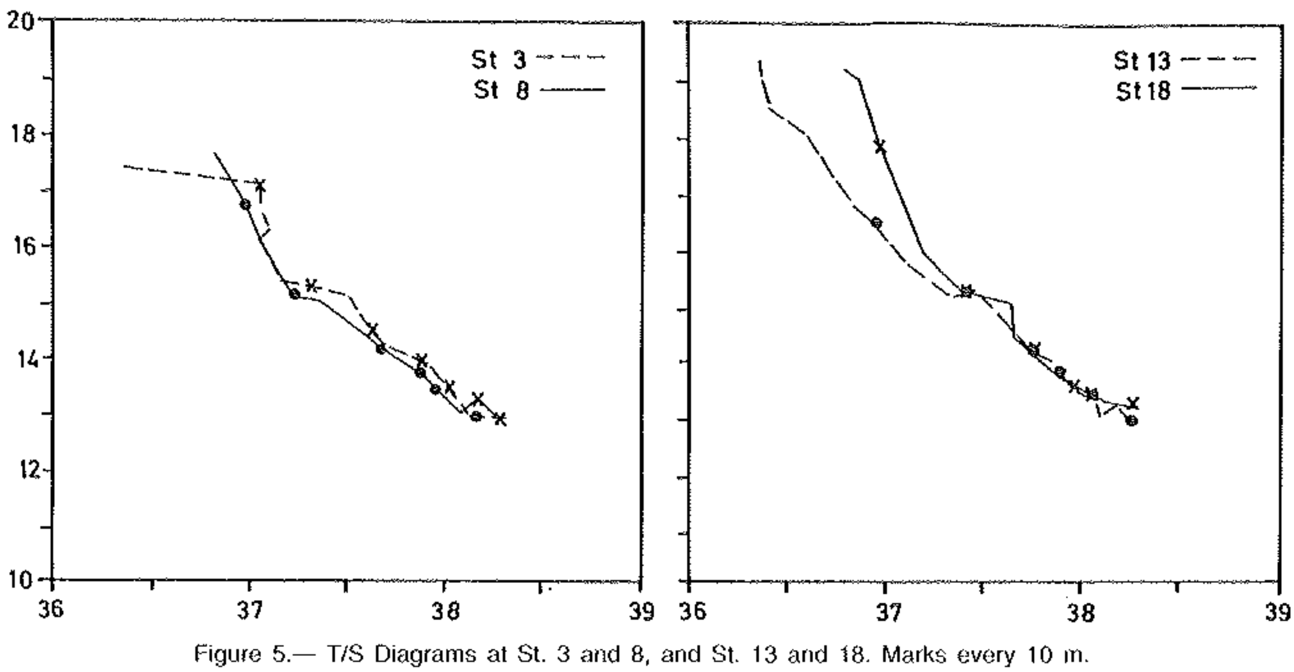

Figure 5.— T/S Diagrams at St. 3 and 8, and St. 13 and 18. Marks every 10 m.

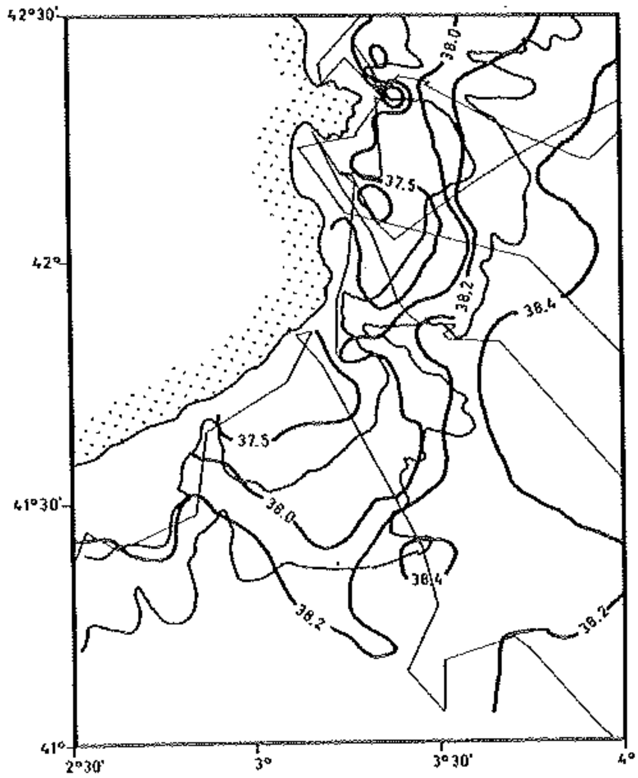

Figure 6.— Surface salinity (shipboard thermosalinograph) distribution in March 1983. The ship tracks are included in the figure to show the data distribution.

TABLA 1

Flow deformation occurrence from infrared satellite imagery

Canyon	1*	2	3	4
No. of images cloud-free	17	27	43	47
Deformed flow visible	10	19	28	38
No deformation	7	8	15	9

(*) Only 30 of the images included this canyon.

5. CONCLUSIONES

This preliminary study of the influence of bottom topography on the surface circulation has shown evidence of surface flow modification by submarine canyons off the northeast Spanish coast. Both hydrographic and satellite data indicate that the flow is deflectd shelfward upstream of the canyons and offshore on the downstream side. Canyons 3 and 4 appear to be especially modified according to the satellite imagery. Because of the implications to the transfer process of coastal properties, more study of these canyons are needed. Such studies should involve closely spaced in situ data to help fully understand the process.

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