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Morphology and sediment structures in Golfo Dulce, Costa Rica

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Abstract: Sediment echosounder records (18 KHz) of 14 profiles were made in the fjord-like embayment of Golfo Dulce, Pacific of Costa Rica, to investigate morphology and sediment structure. The NW-SW section includes an oriental fault that is the main internal tectonic characteristic of the Gulf; that has a very steep slope and reaches 170 m in height. Two parallel, but less prominent tectonic faults are also evident on the echographs. The sediments in the flat inner basin consist mainly of turbidites, which reach the deepest part of Golfo Dulce by channels, leaving most of the slope sediments unaffected.

Key words: Morphology, sediments, marine geology, Golfo Dulce, Costa Rica.

Golfo Dulce on the southern Pacific coast of Costa Rica (Fig. 1) is a fjord-like structure with a deep inner basin (>200 m) sheltered against the open Pacific by a shallow sill (60 m). Due to the morphology only a limited water exchange between Golfo Dulce and the ocean takes place, resulting in at least temporarily anoxic bottom waters in the inner basin (Richards *et al.* 1971), comparable to conditions in high-latitude fjords. Thus, as a "tropical fjord", Golfo Dulce is the only anoxic basin along the Pacific coast of the Americas.

During the individual legs of the the RV Victor Hensen cruise to Costa Rica in 1993/1994 Golfo Dulce was a main object for a wide range of investigations in all the marine sciences as physical and chemical oceanography, plankton, benthos and fish biology, microbial ecology, and marine geology. The broad interest in Golfo Dulce is based on its unique feature as being one of only four anoxic marine basins in the tropics (e.g. Richards 1965, Deuser 1975). However, before the RV Victor Hensen cruise Golfo Dulce has only sporadically been investigated, as e.g. by Richards *et al.* (1971) for its oceanography and by Cortés (1990, 1991, 1992) for the corals living there.

As the anoxic bottom waters with all their consequences for marine life, chemical oceanography and structure of the sediments are the main item of the scientific interest in Golfo Dulce, the reason for their generation, the morphology of Golfo Dulce, needs some analysis. In order to increase the knowledge about its morphology and the structure of the sediments, we ran 14 echosounder profiles through Golfo Dulce during leg 3 of the RV Victor Hensen cruise in January 1994 (Fig. 1). Here we present a map that shows the bottom topography along our profiles, which show i.e. that one of the major tectonic faults running through Golfo Dulce (Berrangé 1987) results in a very steep slope up to >100 m heigth along its northeastern slope. In addition, some echographs show a variety of sediment structures found in Golfo Dulce.

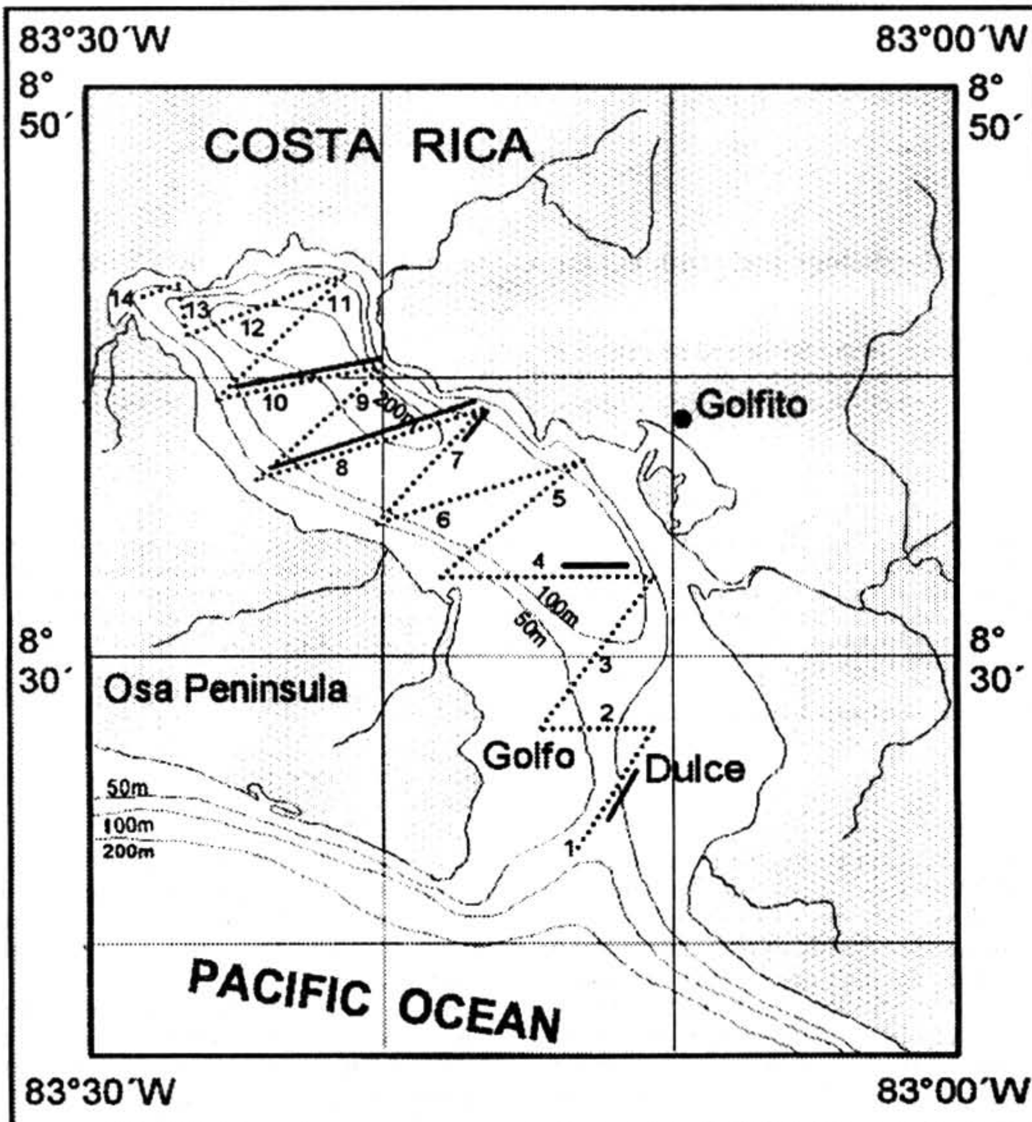

Fig. 1. Echosounder profiles (1 to 14) inside Golfo Dulce, run with an 18 kHz sediment echosounder mounted onboard RV Victor Hensen. The black bars indicate profile sections shown as original echographs in Fig. 5-9.

Due to the subduction of the oceanic Cocos and Nazca plates beneath the Caribbean and South American plates the Pacific coast of Costa Rica has been uplifted through the last 80 million years (Weyl 1980). Golfo Dulce is presently considered as a "pull-apart" basin, which opened about 1-2 million years ago by the displacement of the Burica peninsula to the south (Fig. 2) (Berrangé and Thorpe 1988). Although tectonic activity and uplifting is still going on (Fischer 1980), the inner (northern) part of Golfo Dulce is currently subsiding, due to local tectonic adjustment (Fischer 1980, Lews 1983). The subsidence of the inner part of Golfo Dulce and the relative stability of the sill region resulted in its fjord-like structure.

The tectonic activity in the whole region results in a complex tectonic pattern, where major tectonic faults can be traced as the

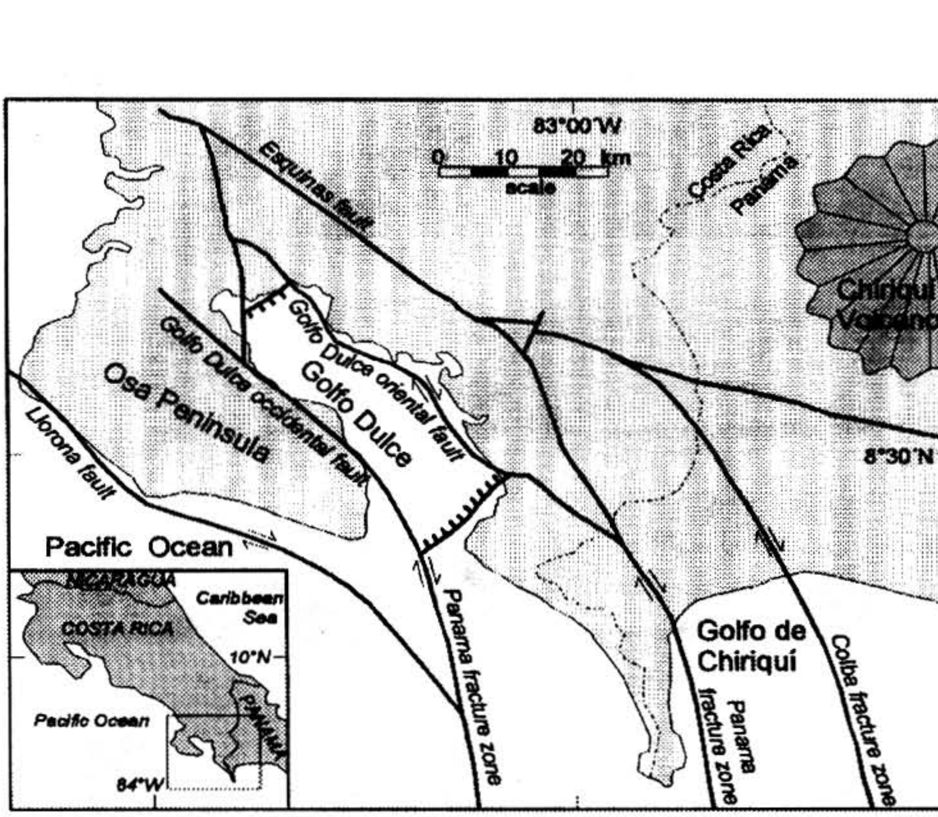

Fig. 2. Tectonic map from the Golfo Dulce region showing major tectonic fault systems (simplified from Berrangé 1989).

Panama fracture zone as far out as the East Pacific Rise (Berrangé 1989). The Panama fracture zone is connected to the two major faults that dominate the shape of Golfo Dulce, the Golfo Dulce oriental fault along its north-eastern slope and the Golfo Dulce occidental fault along its coastal lowlands in the southwest (Fig. 2). These two faults strongly dominate the morphology of the Golfo Dulce region.

MATERIAL AND METHODS

For the morphologic mapping of Golfo Dulce a shipmounted 18 kHz ELAC sediment echosounder has been used. Data have been obtained from 14 profiles runnig on a zick-zack line through Golfo Dulce (Fig. 1). Control about the ships position (by GPS) and control about its velocity (on average 8 kn) made it possible to put the echosounder records in the geographic context.

The original echographs have been put on a scanner Epson GT-6000 and scanned with 300 dpi on a greyscale. Light grey colours, partly occuring on top of the dark sea bottom reflector, represent only shadows generated by the scanning procedure and are no real bottom features. The echographs displayed in Fig. 5-9 show a strong exaggeration, as the horizontal lines indicate 10 m isobaths, while the total width of Fig. 5-9 varies between 2 km and 15 km.

RESULTS AND DISCUSSION

The general morphology of Golfo Dulce as deduced from the 14 echosounder profiles is shown in Fig. 3 and put in the geographic context in Fig. 4. The echographs of the outer part of Golfo Dulce, the sill area, show only the sea floor as a single reflector, indicating a hard bottom with no young sediments (Fig. 5). The sill area is marked by a central channel with a water depth of 60 m and by shallow banks (<20

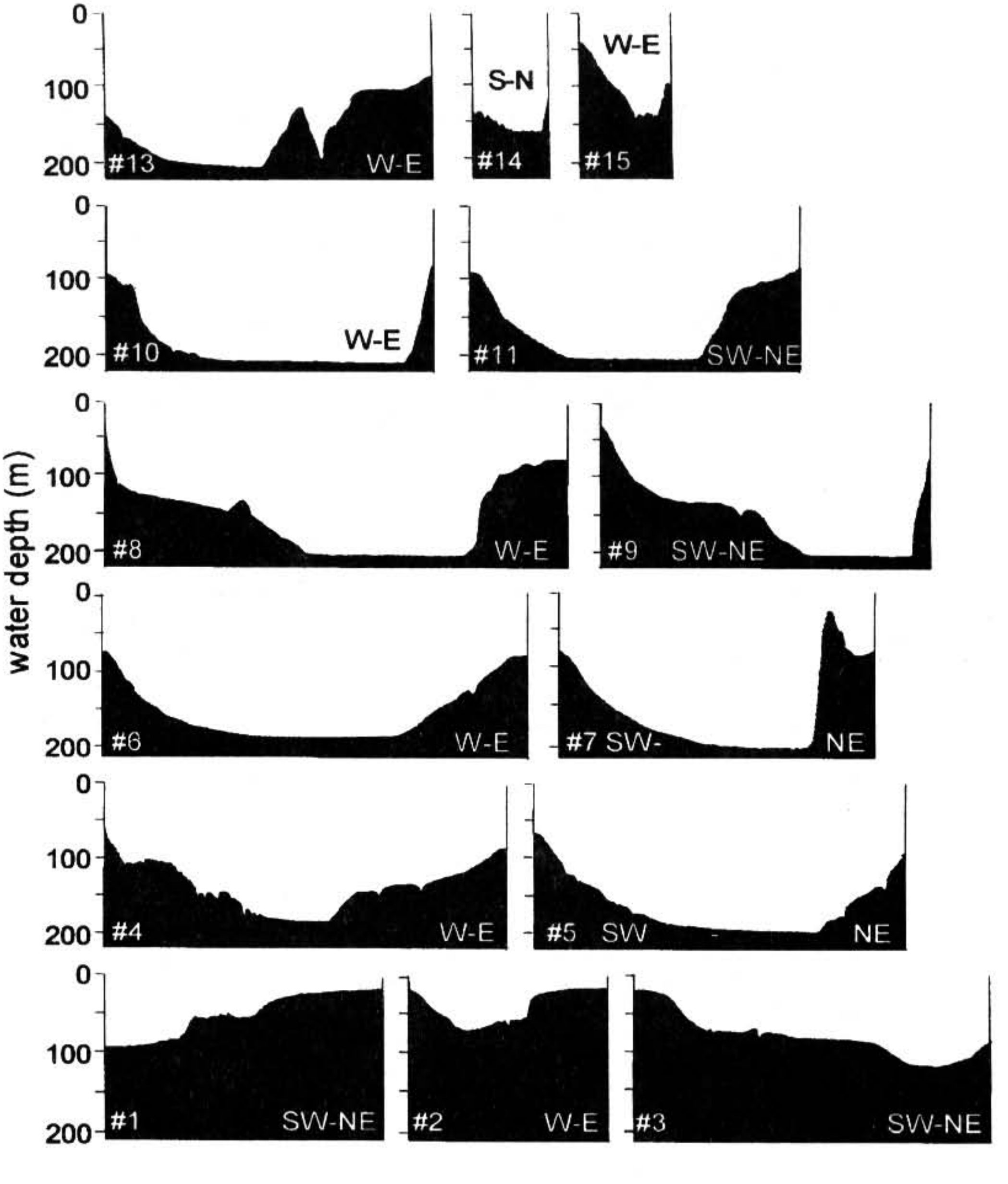

Fig. 3. Bathymetric profiles through Golfo Dulce. The profile numbers refer to Fig. 1.

m) to the east and the west. The missing sediment cover probably reflects the intensity of the tidal currents, which sweep the sill area during each tide.

Entering Golfo Dulce also the inner part of the sill appears as a hard bottom in the echographs. However, even this probably rocky material has been cut by a ~10 m channel (Fig. 3, profile 2), which are more common along the sediment covered slopes of the inner basin. North of 8°30´N the slope to the deep inner basin starts to be covered by young sediments. Southwest of Golfito the inner basin has an absolutely flat sediment surface in about 185

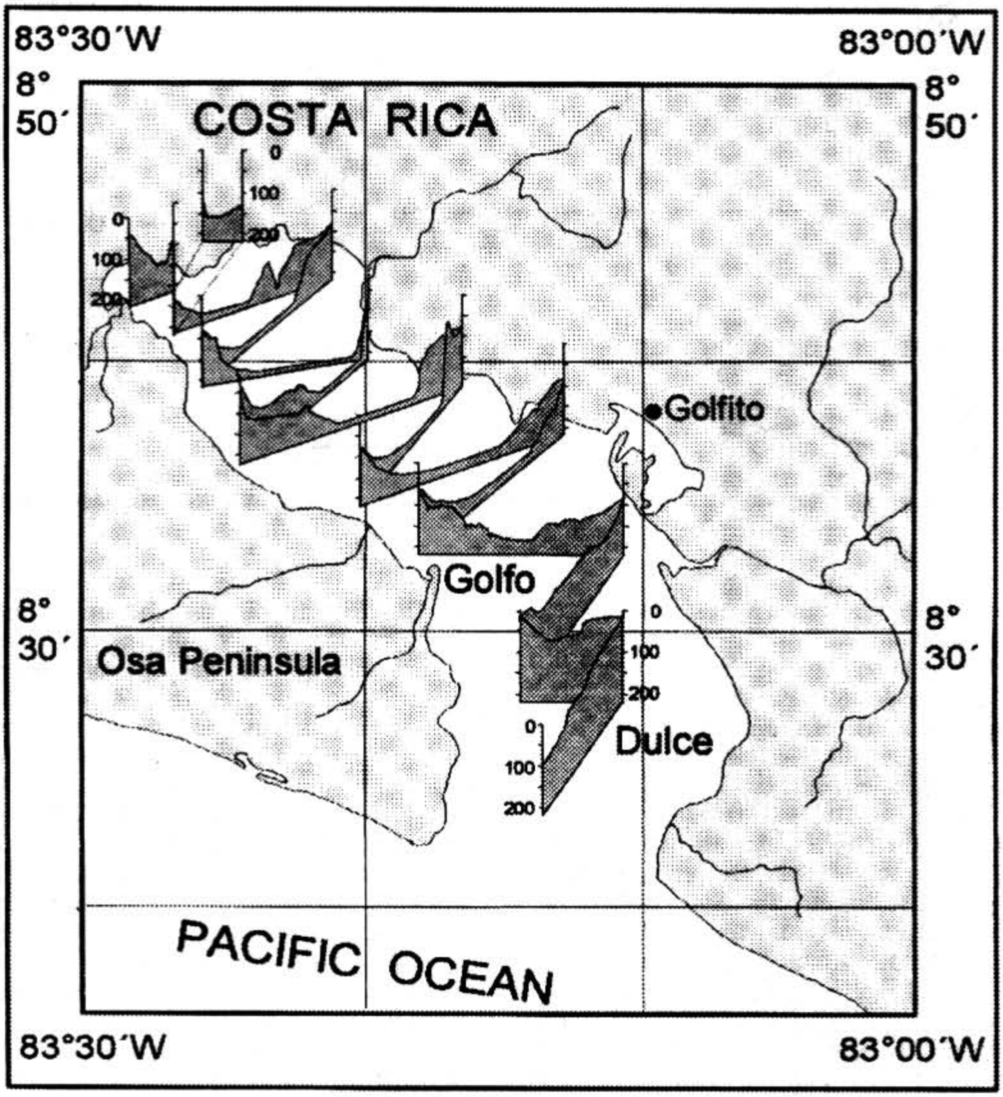

Fig. 4. Bathymetric profiles through Golfo Dulce put in the geographic context.

m water depth. From there the deep basin slightly dips with a flat sediment surface 15 nm to the northwest, to reach 210 m waterdepth in the northwesternmost part of the basin (Fig. 4, 6-8).

To the northeast the inner basin is bordered by a very steep slope up to >150 m high (Fig. 4, 6-8), which is almost free of sediments. This steep slope appears most pronounced in Fig. 7, where it rises 170 m within 300 m horizontal distance. According to Fig. 2 it represents the Golfo Dulce oriental fault (Berrangé 1989). A second escarpment closer to the coast (Fig. 7) indicates that this fault might be associated by some parallel, but smaller faults. Due to its size and location the Golfo Dulce oriental fault seems to be strongly involved into the development of the inner basin of Golfo Dulce. A second major fault involved in this development, the Golfo Dulce occidental fault, is located onshore in the lowlands along the southwestern coast (Fig. 2; Berrangé 1989).

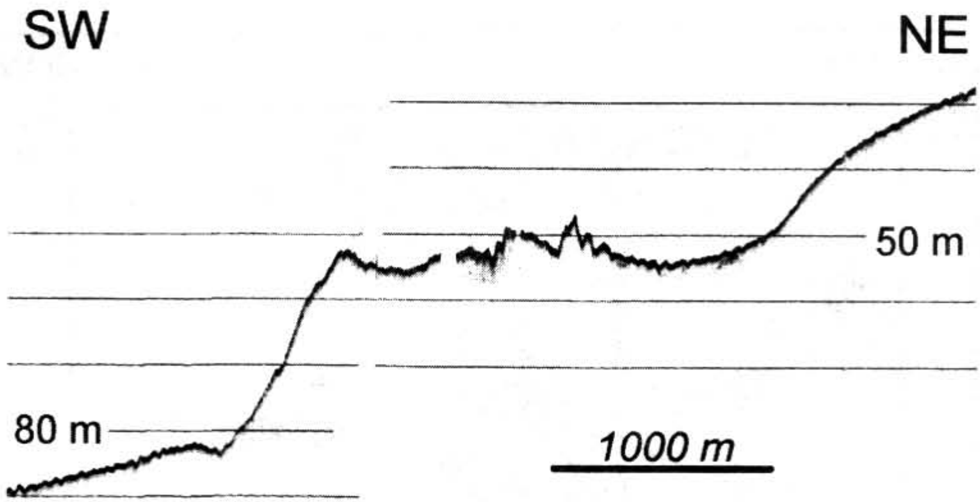

Fig. 5. Echograph of the hard sea floor without any hints of young, soft sediments in the sill area of Golfo Dulce (profile 1 in Fig. 1).

However, the echographs indicate another fault along the southwestern slope of the inner basin, which is most obvious as a bedrock outcrop in 140 m water depth in Fig. 6. This fault can be traced over most of the inner part of Golfo Dulce (profiles 8-11, Fig. 3 and 4). This combination of parallel faults is typical for a "pull-apart" basin.

Besides the Golfo Dulce oriental fault and the sill area most of Golfo Dulce is covered by young, soft sediments. The penetration of the echographs reaches a maximum just off the mouth of the Rio Esquinas in the northeasternmost part of Golfo Dulce, where a sediment layer of 15 m thickness is resolved in the echographs. However, the average penetration is between 5 m to 10 m. The actual thickness of the sediments is probably much higher.

In the inner basin up to ten meters of sediments with some strong reflectors are resolved in the echographs (Fig. 6-8). Analyses of sediment cores from the inner basin show that the sediments there consist mainly of turbidites, characterized by upward fining sequences and high amounts of wood and leaf fragments (Hebbeln 1994). The turbidites reach the deepest part of Golfo Dulce most likely by various channels, that cut in the slope sediments all around the basin. Fig. 9 shows an example of those channels. There, the channels cut ~10 m into the sediments, which are resolved by the echograph to a sub-bottom depth of 5 m to 10 m. The dipping of the reflectors along the slopes of the channels indicate, that these are longstanding features and not only shortterm erosional structures, in which case horizontal reflectors would have been cut by the channel wall. Keeping the exageration of the echographs in mind, the steep-walled channels from Fig. 9 appear in reality as ~200 m wide and 10 m deep depressions. This rather big size points to the efficiency of these depressions for channeling turbidites from somewhere close to the major rivers down to the deep inner basin. In contrast to the inner basin sediment cores, analysis of cores from the slopes indicate a continuous sequence of very fine sediments (silty clays) (Beese 1995), pointing also to some distinct conduits for transporting the turbidites downslope. The turbiditic structure of the basin sediments with strong variations in its sediment-acoustic behaviour is most likely the reason for the relatively low echosounder penetration in the basin compared to the slope.

Along the margins of the inner basin the intersection between the slope and the basin sediments shows some remarkable features. On either side of the basin the reflectors of the slope sediments are partly discordant overlain by the basin sediments (Fig. 6 and 8). Only the youngest slope sediments seem to continue as almost horizontal reflectors in the basin, however, with a greater thickness as along the slope

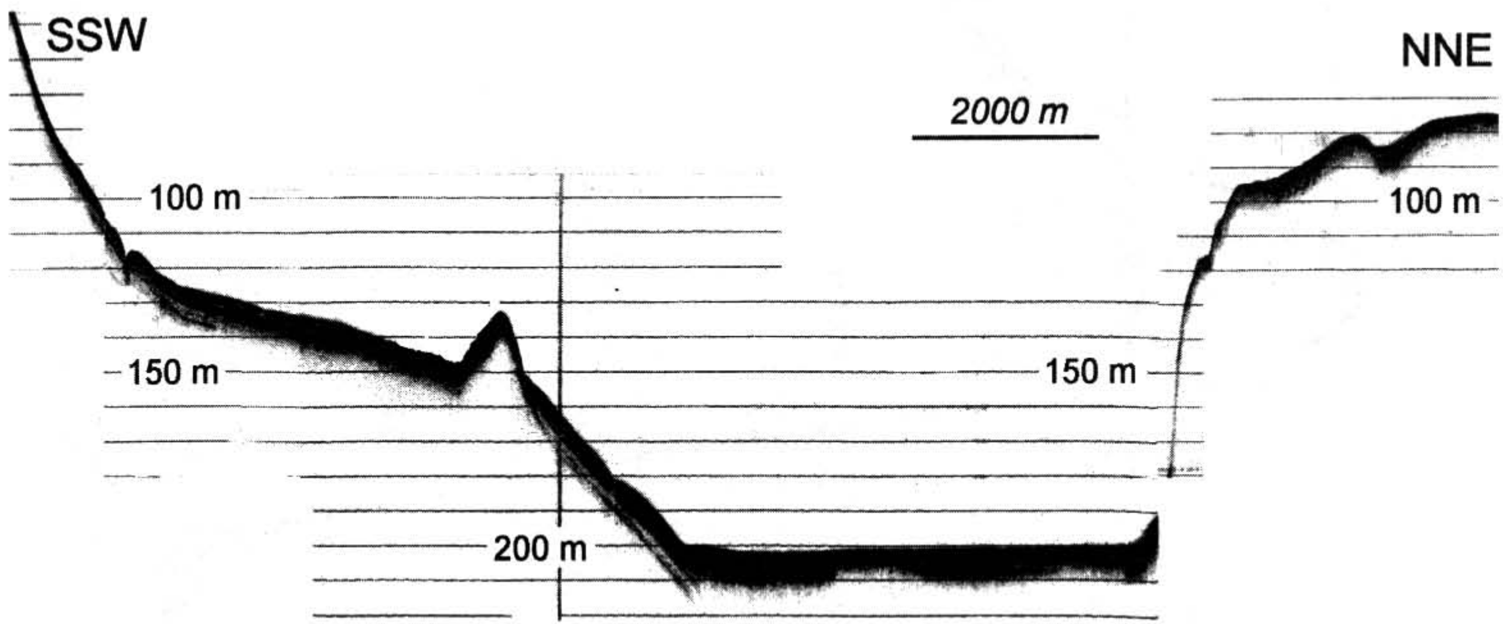

Fig. 6. Echograph of a whole cross-section through Golfo Dulce with the Golfo Dulce oriental fault at the norteastern margin of the basin and a second major fault, marked by the bedrock outcrop on the southwestern slope (profile 8 in Fig. 1).

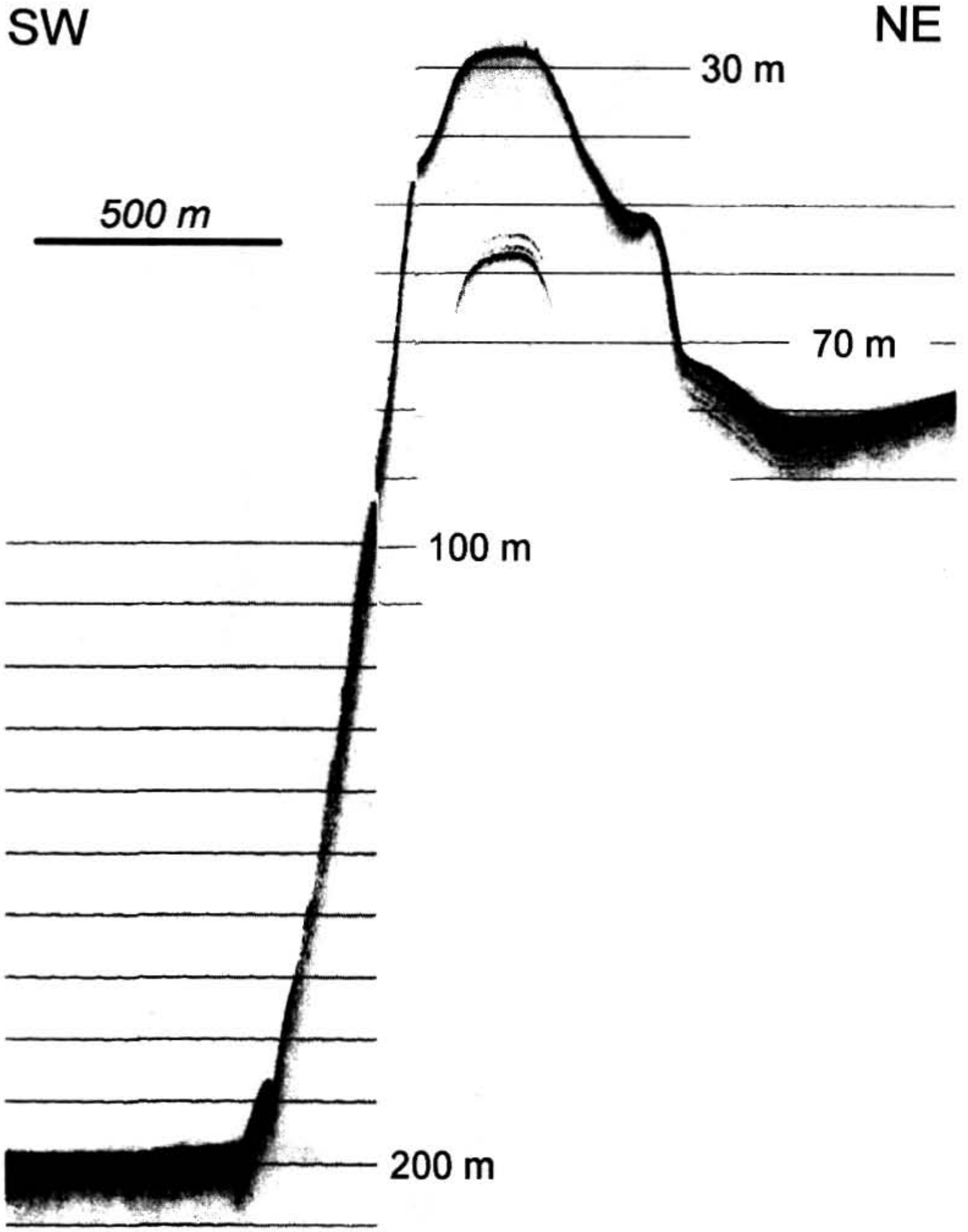

Fig. 7. Echograph of the very steep slope of the Golfo Dulce oriental fault associated with a bedrock outcrop bordered by a second fault towards the coast in the NE. A small near coastal basin with a water depth of ~80 m is located NE of the faults (profile 7 in Fig. 1).

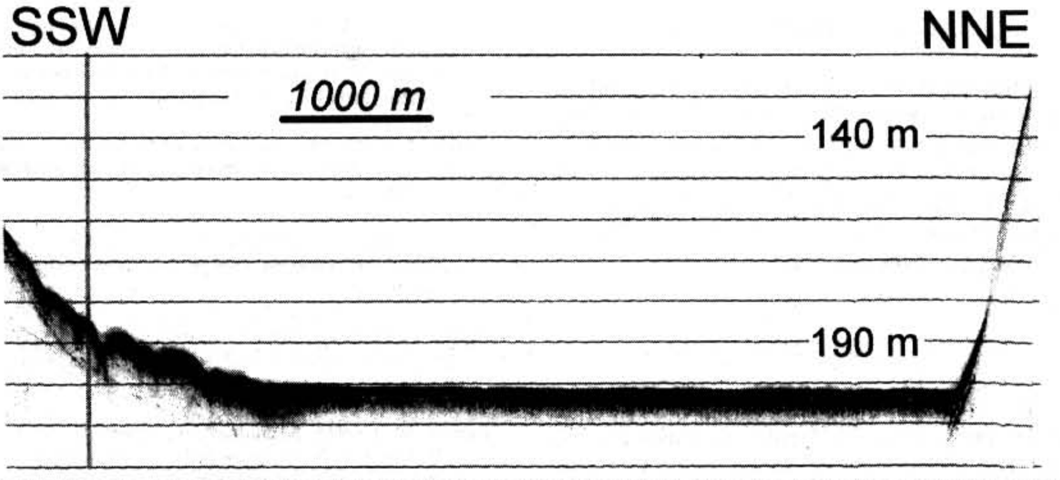

Fig. 8. Echograph a cross-section through the inner basin of Golfo Dulce with the steep slope in the NNE and with hummocky sea floor structures , indicating slump structures in the SW (profile 10 in Fig. 1).

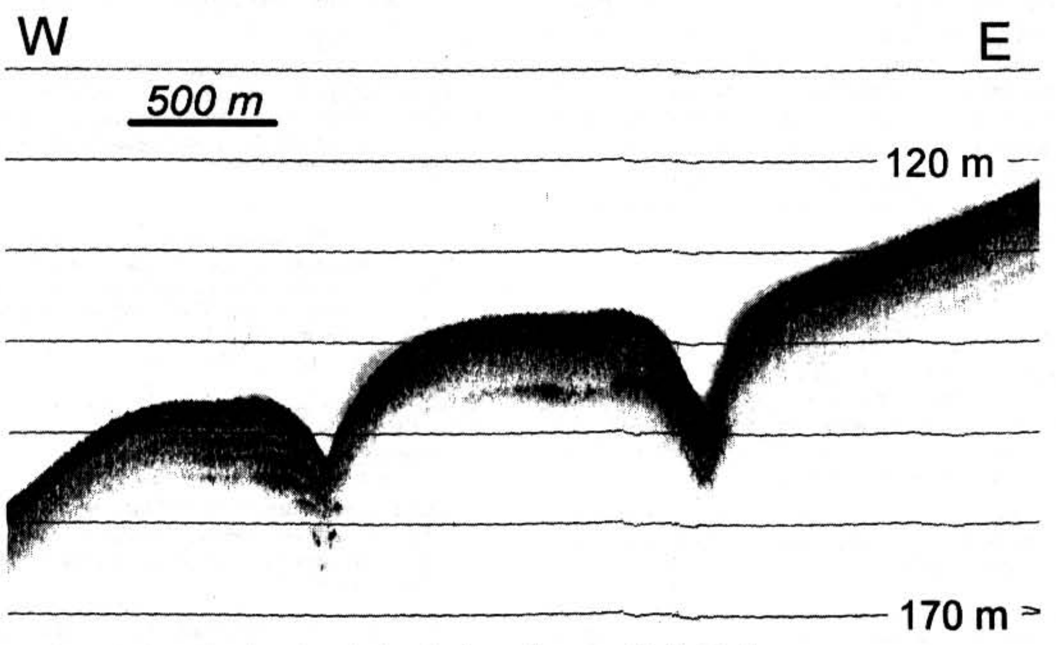

Fig. 9. Echograph of turbidite channels cutting into the slope sediments (profile 4 in Fig. 1).

(Fig. 6). This observation points to much higher accumulation rates in the basin compared to the slopes. As due to their proximity the hemipelagic accumulation rates should not differ very much between these two morphologic units, the turbidite impact on the basin sediments is assumed to account for the higher accumulation rates. An estimate of the turbidite content in the basin sediments of ~60% of the total sediment (Hebbeln 1994) points to an accumulation rate there more than twice as high as along the slopes.

Hummocky sea floor structures at the base of the slopes, as displayed in Fig. 8, represent slump bodies created by mass transport down the slopes. However, other similar structures, e.g. off Puerto Jimenez (Fig. 3 and 4, profile 4) and in the very innermost part of the basin (Fig. 3 and 4, profiles 13-14), are probably reflecting bedrock structures.

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RESUMEN

En 14 barridos del "fiordo tropical" Golfo Dulce en la costa del Pacífico de Costa Rica se hicieron registros de ecosonda de 18 kHz para evaluar la morfología y estructura sedimentaria. La sección NW-SE incluye una falla oriental del Golfo Dulce como principal característica tectónica interna, con una altura de 170 m y una cuesta muy empinada. También se detectaron dos fallas paralelas menos prominentes. Los sedimentos de la parte interna plana son principalmente turbiditas y alcanzan las partes más profundas del golfo mediante canales, sin afectar la mayoría de los sedimentos de la parte inclinada.

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