# The submarine "El Golfo" debris avalanche and the Canary debris flow, West Hierro Island:The last major slides in the Canary archipelago

*La avalancha de El Golfo y el "debris flow"de Canarias, Oeste de la isla de Hierro: Los ultimos grandes deslizamientos submarinos del archipiélago Canario*

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ABSTRACT

*Swath bathymetry and geophysical data of the island of Hierro show that the western flank of the island is affected, at least, by two major catastrophic slope failures. One of the two, called the El Golfo debris avalanche, led to the deposition of a sedimentary body of about 150 km³ of volcanic rock debris on the upper rise. The second major instability event, named the Canary debris flow, originated at the base-of-slope of the island of Hierro, and involved a larger amount of remobilized material. New evidences suggest that the Canary debris flow is the oldest in age. As a consequence of the Canary slide event, oversteeping and undermining of the lower island flanks occurred and subsequently triggered the El Golfo debris avalanche, whose deposits covered and obliterated the source area of the Canary debris flow. The triggering of El Golfo debris avalanche seems to be related also to the rift zones in the island of Hierro. From the establishment of the complex relationships between both slides, the El Golfo debris avalanche has been dated between 12.000 and 6.000 yBP.*

RESUMEN

*Nuevos datos de batimetría y geofísica marinas de la isla de Hierro demuestran que el flanco occidental de la isla está afectado por un deslizamiento que depositó 150 km³ de derrubios volcánicos en el glacis continental superior, la avalancha de El Golfo. Un segundo evento, llamado "debris flow" de Canarias, se originó en la base del talud de la isla del Hierro y movilizó unos 400 km³ de material. Nuevas evidencias sugieren que el "debris flow" de Canarias precedió a la avalancha de El Golfo. La avalancha de El Golfo pudo haberse originado a consecuencia de la socavación y sobreinclinación del talud asociadas a la cicatriz del «debris flow» de Canarias. Las zonas de rift en la isla del Hierro parecen haber tenido también un papel significativo en el desencadenamiento de la avalancha de El Golfo. El resultado fue el enmascaramiento del área fuente del "debris flow" de Canarias por los depositos de la avalancha. De la determinación de las complejas relaciones entre ambos flujos, se desprende que la avalancha de El Golfo ocurrió entre 12.000 y 6.000 años BP.*

**Key words:** *submarine landslide, debris avalanche, debris flow, swath bathymetry, bottom parametric source, Hierro, Canary Islands.*

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## Introduction

The phenomenon of landsliding in oceanic islands often takes the form of debris avalanches. These are mainly characterized by a well defined amphitheater of scarps at their head, hummocky terrain in their lower parts, and an overall gradient less than 3° (Moore *et al.*, 1989; Moore *et al.*, 1994). Debris avalanches are generated by catastrophic failures and flow rapidly in single events (Moore *et al.*, 1994). In the Canary Islands, as in other volcanic island chains, this is the typical mechanism affecting the subaerial/ submarine flanks and slopes adjacent to the islands. The products of these landslides are generally deposited in the submarine base-of-slope.

Debris flows also affect the continental rise and the base-of-slope of oceanic islands. Debris flows have, as well, amphitheaters at their heads, although with lower scarps, and a tail of deposited material longer and thinner than that of debris avalanches. Debris flows travel larger distances over slopes ranging between 0° and 2° (Masson *et al.*, 1992b).

The three-pointed star morphology of the island of Hierro reflects that the volcanic edifice has suffered three main slides as it was pointed out by Pellicer (1977) and Holcomb and Searle (1991): El Golfo, Las Playas and El Julan, the two first being particularly apparent onland (Fig.1).

The northwest facing El Golfo slide is the largest. It shows head scarps up to 1100 m high which quickly decrease in height towards the sea. These scarps, with slopes ranging from 22° to 58°, define a large amphitheater of 14.5 km in diameter. The headwalls of this amphitheater give place to a zone of flat smoothed relief dipping towards the sea. The amphitheater is clearly marked by a system of dykes and fractures with the same orientation of the slide headwall (Pellicer, 1977) (Fig.1). This relation between dykes and fractures, and landslides is present in other oceanic islands as the Hawaiian Ridge (Moore *et al.*, 1989).

Las Playas slide is headed by a southeast facing amphitheater, 4.5 km in diameter. The amphitheater is bounded by scarps up to 700 m high with slopes averaging 47°.

Only the submarine part of El Julan slide has been detected by means of GLORIA long-range side-scan images (Holcomb and Searle, 1991), as no headwalls are visible on the island. Masson (1996) points out that this is an old landslide, which possibly occurred between 300.000 and 500.000 years BP, as indicated by burial of the debris avalanche deposits beneath up to 20 m of later sediment. The El Julan slide scar is probably covered by 0,5-0,08 Ma old volcanic materials belonging to the Ancient series B of Hierro and by younger, less than 0,05 Ma old, materials of the intermediate volcanic series, which altogether crop out in the area immediately onshore of the submerged part of this slide (Fuster *et al.*, 1993).

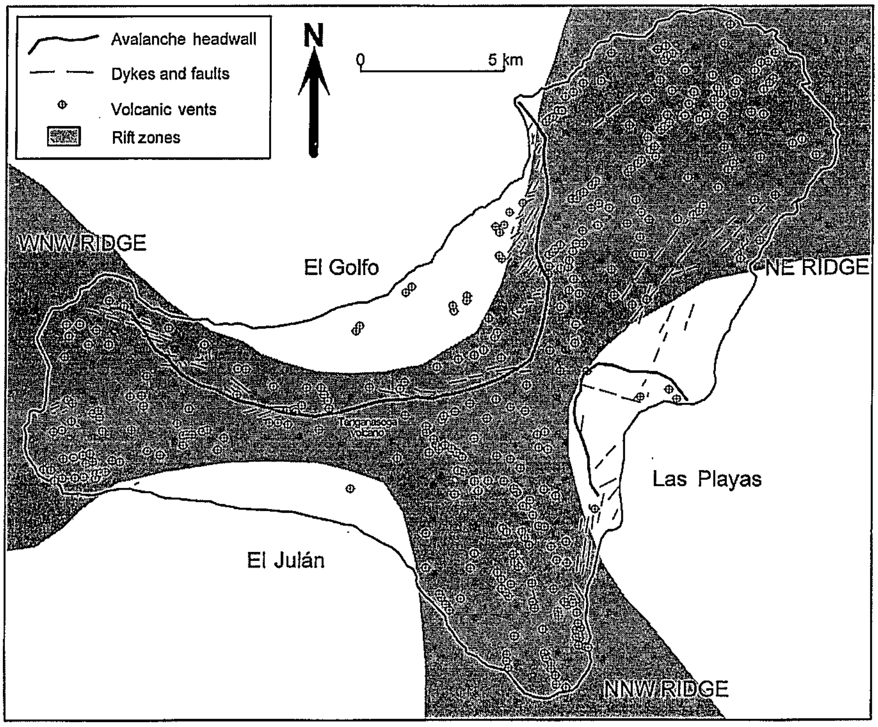


**Fig. 1.- The three rift zones of the Hierro Island as indicated by the topography and the concentration of eruptive vents, as well as for the orientation of the main dykes and faults (modified from Pellicer, 1977).**

*Fig. 1.- Las tres zonas de rift de la isla de Hierro a partir de la topografía y de la concentración de bocas eruptivas, asi como por la orientación de los principales diques y fallas (modificado de Pellicer, 1977).*

## Methods

The data on which the results presented in this paper are based, were acquired during a cruise carried out in December 1994 on board the Spanish R/V Hesperides. They include 2145 km of SIMRAD EM12S swath bathymetry tracks fully covering 9200 km$^2$ of the seafloor, 2145 km of very high resolution TOPAS Bottom Parametric Source (BPS) profiles, and 656 km of single-channel airgun seismic reflection profiles (Alonso *et al.*, 1994).

## Results

The studied data set allows to identify two large slides affecting the submarine western flank of the Hierro Island: The El Golfo debris avalanche and the Canary debris flow (Fig. 2).

El Golfo debris avalanche, as mentioned above, originated subaerially, and shows two segments with morpho-sedimentary significance (Fig. 2):

a) A proximal area of the avalanche characterized by subaerial scarps as high as 1100 m in the central part of the island. The bathymetry shows smooth reliefs dipping 5° north-westwards and levee-like features bounded by scarps in the submarine part of the source area. These scarps, which range between 150 and 200 m high, configure the offshore continuation of the El Golfo slide (Fig. 3).

b) A distal area covering 2600 km$^2$ characterized by hummocky terrain in the bathymetric chart (Fig. 3) and hyperbolic response in BPS records. The largest hummocks within this area are 80 m high and 1 km in diameter. Airgun seismic records show this zone to be dominated by transparent facies reaching an average thickness of 60 m and a maximum thickness of 200 m close to the mouth of the amphitheater (Fig.4). The calculated volume for the deposit is 150 km$^3$. The former characteristics together allows to interpret the hummocky zone as a debris avalanche according to the criteria of Moore *et al.*, (1994).

Acoustic mapping and morpho-bathymetric characters of the Canary debris flow show, as well, two segments:

a) A proximal area with a NE-SW scarp at a depth of 3200 m, 5600 m long and 150 - 200 m high, situated behind the hummocks of the avalanche (Fig. 2). This area appears to have been significantly covered by the former El Golfo debris avalanche. The orientation of the main scarp in this area clearly differentiates it from the NW-SE oriented scarps of the El Golfo avalanche headwall.

b) The distal area is bathymetrically characterized by a very smoothed relief only disrupted by several gentle highs with uneven morphologies (Figs. 2 and 3). These highs have elevations around 50-75 m above the surrounding ocean floor and diameters of 1 to 10 km. Airgun seismic records show these highs to be controlled by normal faults. In BPS records the Canary debris flow is mainly dominated by opaque facies evolving, with increasing distality, to transparent facies. Masson *et al.*, (1992a) have calculated that the Canary debris flow has a volume of about 400 km$^3$.

## Discussion

It is necessary to clarify the relationship between the Canary debris flow and El Golfo debris avalanche. The calculated volume for the subaerial and submarine scarps of El Golfo is 180 km$^3$ while the volume calculated after mapping of the avalanche deposit is on the order of 150 km$^3$. Since the Canary debris flow has a volume of 400 km$^3$

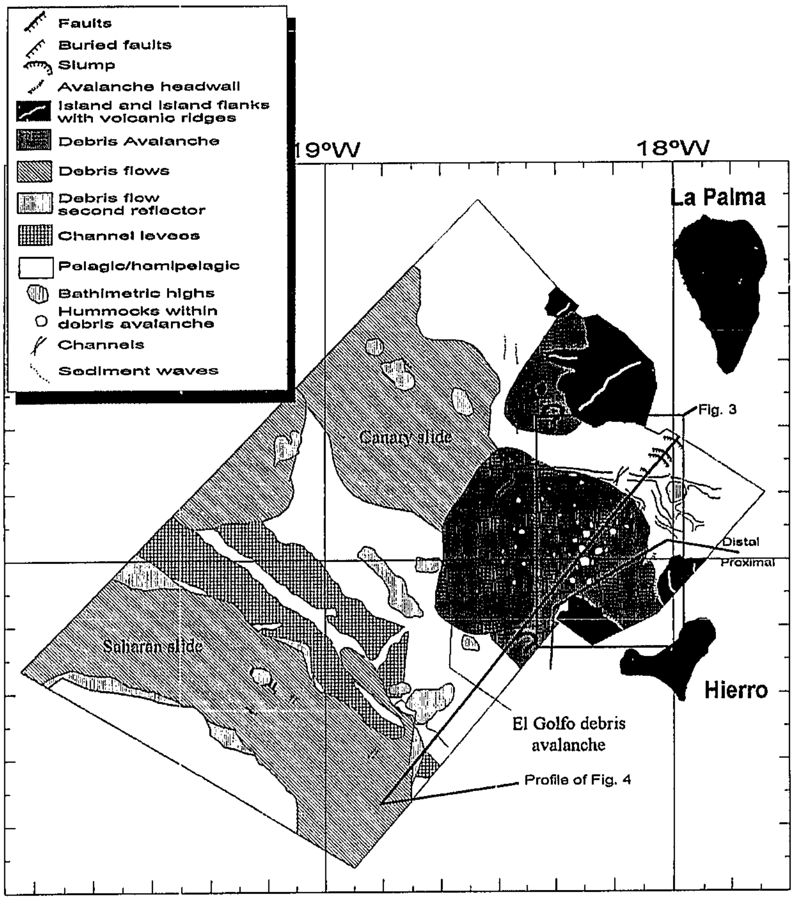


**Fig. 2.- Interpreted facies distribution map of the study area. The boundaries of debris flows are identified from BPS records, while the boundaries of the debris avalanche were identified from seismic reflection profiles and BPS. Faults and slumps are interpreted from seismic reflectionprofiles. Note the presence of highs within the debris flows and how the seismic reflection data (where available) shows them to be bounded by faults.**

***Fig. 2.- Mapa de distribución de fácies interpretadas del área de estudios. Los limites de los "debris flows" son cartografiados a partir de los registros de BPS, mientras que los limites de la avalancha han sidoidentificados a partir de registros de sísmica de reflexión y PBS. Fallas y slumps son interpretados a partir de perfiles de sísmica de reflexión. Cabe notar la presencia de altos morfológicos en los "debris flows" y que los perfiles de sísmica de reflexión (dónde son disponibles) muestran como estos altos son limitados por fallas.***

(Masson *et al.*, 1992a), it can not be simply explained as the result of downslope evolution of the El Golfo debris avalanche. An specific source area, with the corresponding headwall scarp, has to be identified for the Canary debris flow, and it should be most probably located on the lower slope and base-of slope of Hierro Island. In fact, there is a lack of prominent scarps between the El Golfo debris avalanche and the Canary debris flow, and the NE-SW scarp located at 3200 m depth situated behind the hummocks of the avalanche (Fig. 3) seems to be the unique prominent scarp able to explain till some extent the Canary debris flow source area. This source area is almost completely covered by up to 200 m of volcanic debris. This would imply that one of the possible failure mechanisms for the El Golfo debris avalanche is the undermining and oversteeping of the Hierro base-of-slope following the occurrence of the Canary debris flow. That, in turn, is linked to sea-level changes as a factor for slide initiation, since the Canary debris flow has been correlated to the B turbidite in the Madeira Abyssal Plain (MAP) (Simm *et al.*, 1991). Studies of megaturbidite emplacement in the MAP reveal that turbidites are deposited at periods of climatic change (Weaver and Kuijpers, 1983). However, the role of rift zones has to be taken into account as it is seen that the El Golfo slide is bounded by dykes and fractures parallel to the slide headwall (Fig. 1). Rift zones could account for the origin of the tensional cumulative stresses triggering El Golfo debris avalanche. According to Carracedo (1994), they include the wedge effect of intrusive dykes, the loading stress by new volcanic materials, progressive growth vs. instability of the volcanic edifice, associated seismicity and magma swelling .

Establishing the relation between both flows allows to determine the age of the El Golfo debris avalanche, since the age of the Canary debris flow is known from Simm *et al.*, (1991) to be 12.000 yBP. Control on the youngest limit is given by the onland scarp of El Golfo, which is covered by materials of the Tanganasoga volcano, dated to be 6.000 yBP (Fúster *et al.*, 1993). Then, the age fork for the El Golfo debris avalanche ranges from 12.000 to 6.000 yBP. According to the criteria of Moore (1994), further evidences of the youngness of the El Golfo debris avalanche would be the lack of gully incision typical of the uplift stage in the evolution of oceanic islands following shield phases.

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## References

Alonso, B., Baraza, J., Esquius, J., Farrán, M., Jornet, P., Martínez, J.C., Pérez, F., Rodríguez, P., Casamor, J.L., Prieto, M.L., Sorribas, J., Urgeles, R. (1994): *B.I.O. Hespérides, Inf. camp., Proy. CICYT.*

Carracedo, J. C. (1994): *J. of Volcanol. Geotherm.* Res., 60, 225-241.

Fuster, J.M., Hernán, F., Cendrero, A., Coello, J., Cantagrel, J.M., Ancochea, E., and Ibarrola, I.(1993): *Bol. R. Soc. Esp. Hist. Nat.*, 88, 85-97.

Holcomb, R.T. and Searle R.C. (1991): *Mar. Geotech.*, 10, 19-32.

Masson, D. G., Hugget, Q. J., Weaver, P.P.E., Brunsden, D., Kidd, R.B. (1992a): *Landslide News*, 6, 9-12.

Masson, D. G., Kidd, R. B., Gardner, J.

V., Hugget, Q. J., Weaver, P. P. E. (1992b): In *C.W. Poag and P.C.* de Graciansky (Eds.), Van Nostrand Reinhold, New York, 327-343.

Masson, D.G.(1996):*Geology*,24,3, 231-234.

Moore, J. G., Clargue, D.A., Holcomb, R. T., Lipman, P. W., Normark, W. R., Torressan, M. E. (1989):*J. Geoph. Res.*, 94, B12, 17,465-17, 484.

Moore, J. G., Normark, W. R., Holcomb, R. T. (1994): *Annu. Rev. Earth Planet.* Sci., 22, 119-144.

Simm, R.W., Weaver, P.P.E., Kidd, R.B., Jones, E.J.W. (1991): *Sedimentology*, 38, 27-40.

Pellicer, M. J.(1977):*Estud.Geol.*,33, 181-197.

Watts, A. B. and Masson, D. G. (1995): *J. Geoph. Res.*, 100, B12, 24,487-24,498.

Weaver, P.P.E., Kuijpers, A. (1983): *Nature 306*, 360-363.

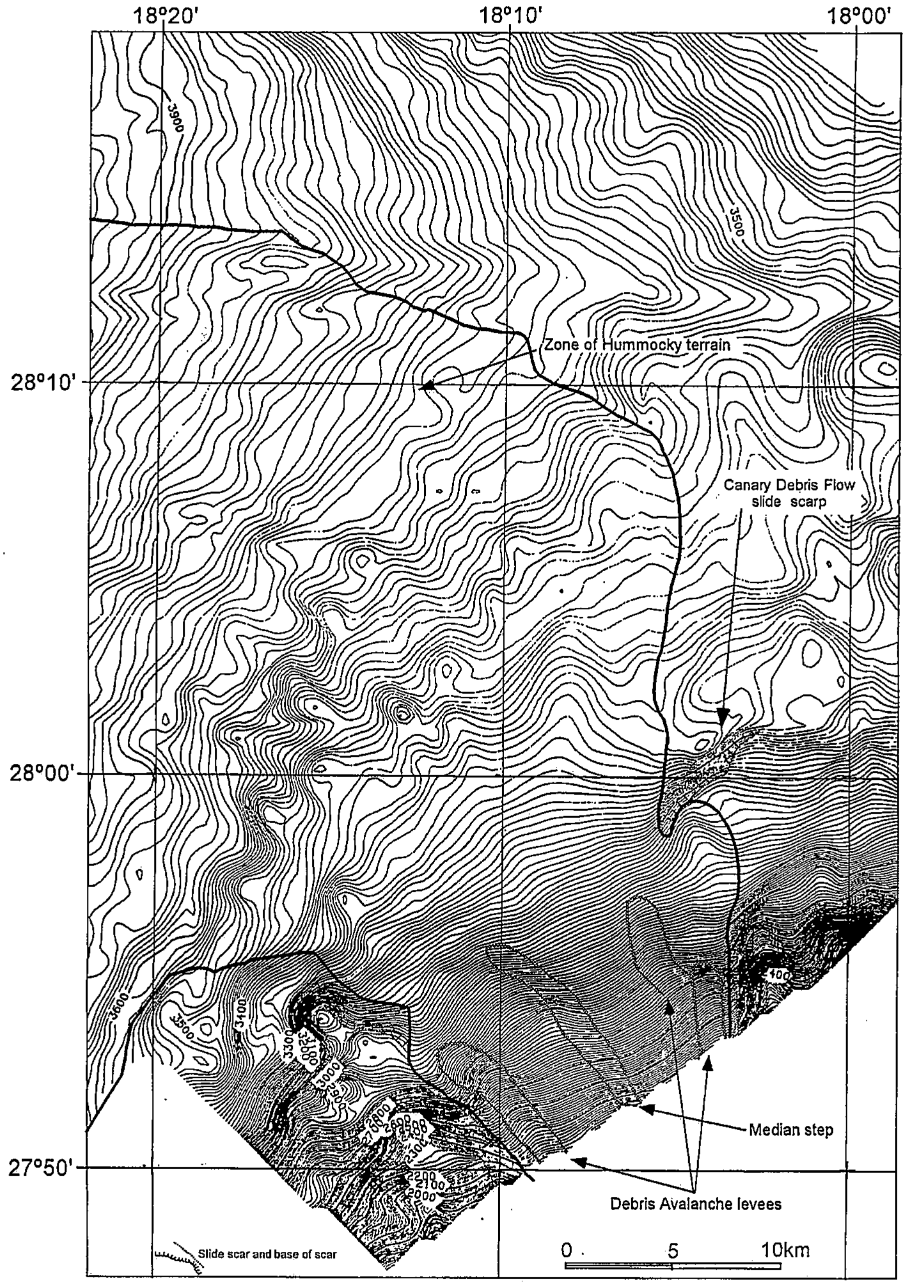


**Fig. 3.- Detailed bathymetry of the El Golfo debris avalanche headwalls. A zone of hummocky terrain appears at the foot of these scarps. This zone also truncates a scarp roughly oriented NE which could correspond to one of the source areas of the former Canary debris flow. Situation in Fig. 2.**

*Fig. 3.- Batimetría detallada de los escarpes de cabecera de la avalancha de El Golfo. Al pie de estos escarpes aparece una zona de terreno con "hummocks" que trunca otro escarpe de orientación NE. Este escarpe podría corresponder a una de las áreas fuente del "debris flow" de Canarias. Situación en la figura 2.*

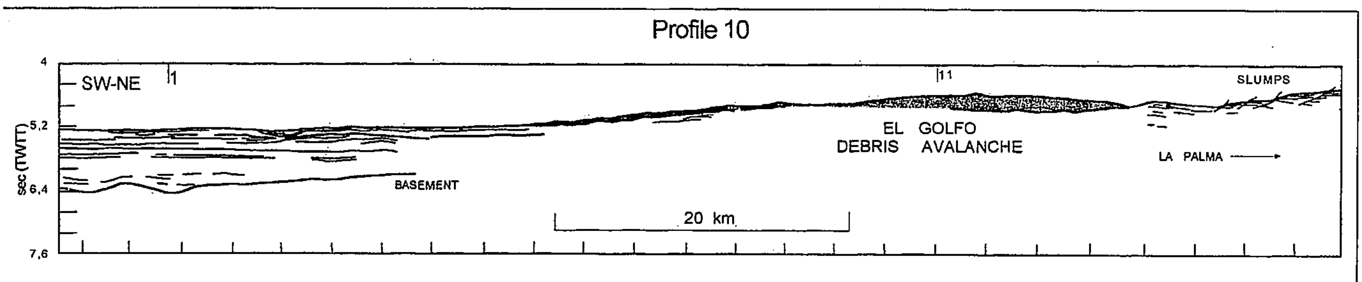


**Fig. 4.- Airgun seismic profile line drawing showing El Golfo debris avalanche. Situation in Fig. 2.**

*Fig. 4.- Esquema interpretativo de un perfil de sísmica de reflexión de cañones de aire mostrando la avalancha de El Golfo. Situación en la figura 2.*