Gravitational and oceanographic processes interaction in the upper slope gullies of the Gulf of Cadiz

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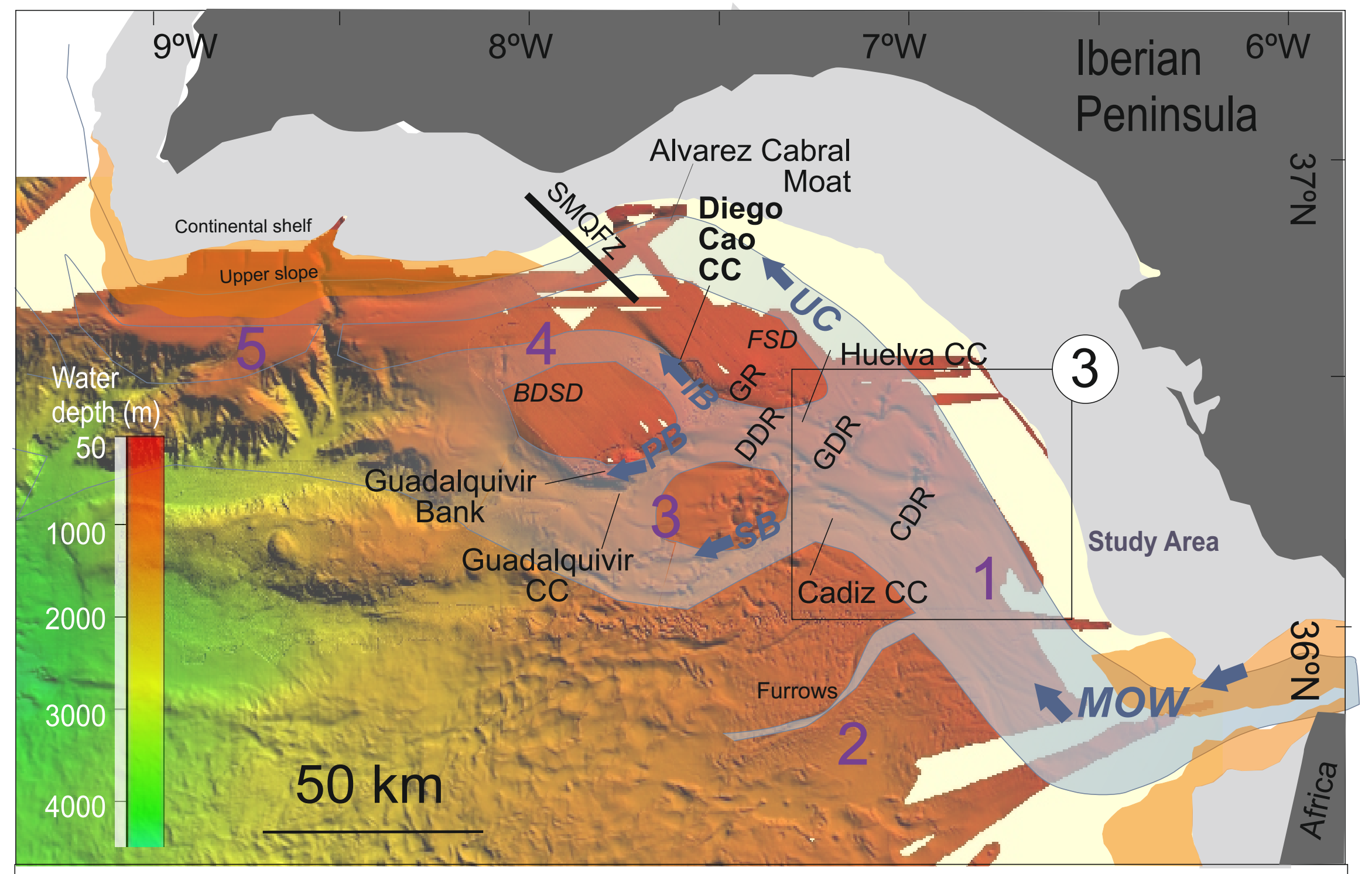
The Study Area



Gulf of Cadiz CDS
1 Proximal scour and ribbons sector
2 Overflow sedimentary lobe sector
3 Channels and ridges sector
4 Contourite depositional sector
5 Submarine canyons sector

Fig. 1. Geological and oceanographic setting and location of the study area

Oceanographic setting

The MOW exits the Mediterranean Sea through the Strait of Gibraltar as a highly energetic overflow into the Gulf of Cadiz (Figs. 1 and 2). It splits into an Upper Core (MU) and a Lower Core (ML), that is further sub-divided into smaller branches by the interaction with diapiric ridges and morphological highs on the middle slope. The Intermediate Branch flows through the Diego Cao Channel.

The present-day oceanographic regime was established in the early Pliocene, after the opening of the oceanic gate in the Strait of Gibraltar. The MOW has been affected by climatic changes during the Plio-Quaternary, undergoing successive periods of intensification.

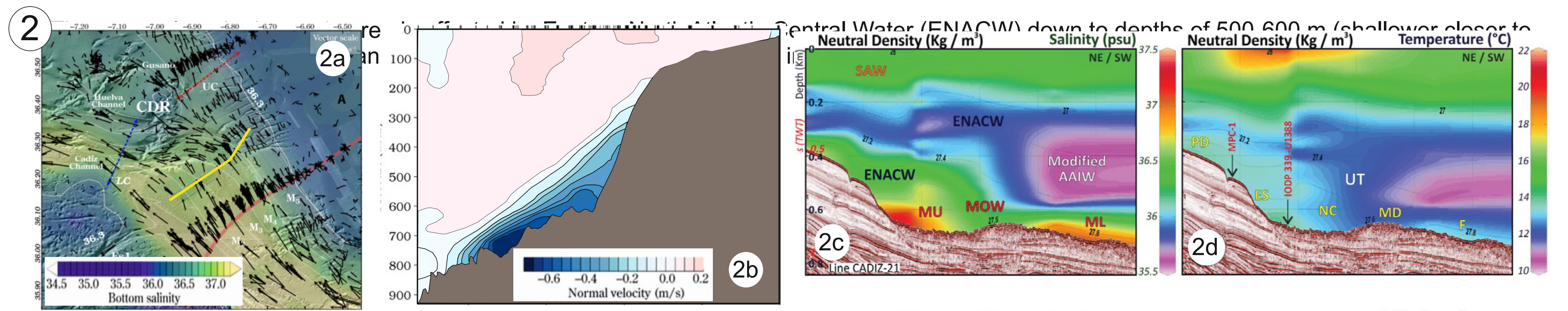


Figure 2. Oceanographic setting. a) Shaded relief map of the GoC seafloor bathymetry with near-bottom instantaneous velocity vectors (black arrows) over salinity (color shades). CDR: Cadiz Diapiric Ridge; BH: Basement High; The yellow line marks the profile in Fig. 2b; b) Mean velocities (negative for westward flow. Modified from Sánchez-Leal et al., 2017); c) and d) Hydrographic and seismic sections in the study area showing the position of the different water masses along the upper and middle slope (Hernández-Molina et al., 2014). See location of the profile in Figure 2a.

SAW = Superficial Atlantic Water
ENACW = Eastern North Atlantic Central Water
MOW = Mediterranean Outflow Water
MU = Mediterranean upper core
ML = Mediterranean lower core
Modified AAIW = Antarctic Intermediate Water
CT = Contourite Terrace
UT = Upper Terrace
LT = Upper Terrace
NC = Northern Channel
SC = Southern Channel (Main Channel)
ES = Erosional surface
F = Furrows
MD = Mounded drift
PD = Plastered drift

Geological setting

The study area is located close to the Strait of Gibraltar, adjacent to the “Proximal Scour and ribbons sector” defined in the middle slope as part of the Gulf of Cadiz Contourite Depositional System (Hernández-Molina et al., 2006). The upper slope in this region is covered by plastered contourite drifts (Brackenridge et al., 2018) dissected by valleys on the upper slope, and two main channels (upper and lower) on the middle slope (Fig. 1).

These features were developed after the opening of the Strait of Gibraltar in the Pliocene, and their present-day morphology was established in the late Pliocene-early Quaternary. The Gulf of Cadiz slope is also subjected to strong tectonic activity driven by marl and salt diapirs, both buried and outcropping in NE-SW-oriented diapiric ridges (Medialdea et al., 2009).

Datasets: the GRACO cruise

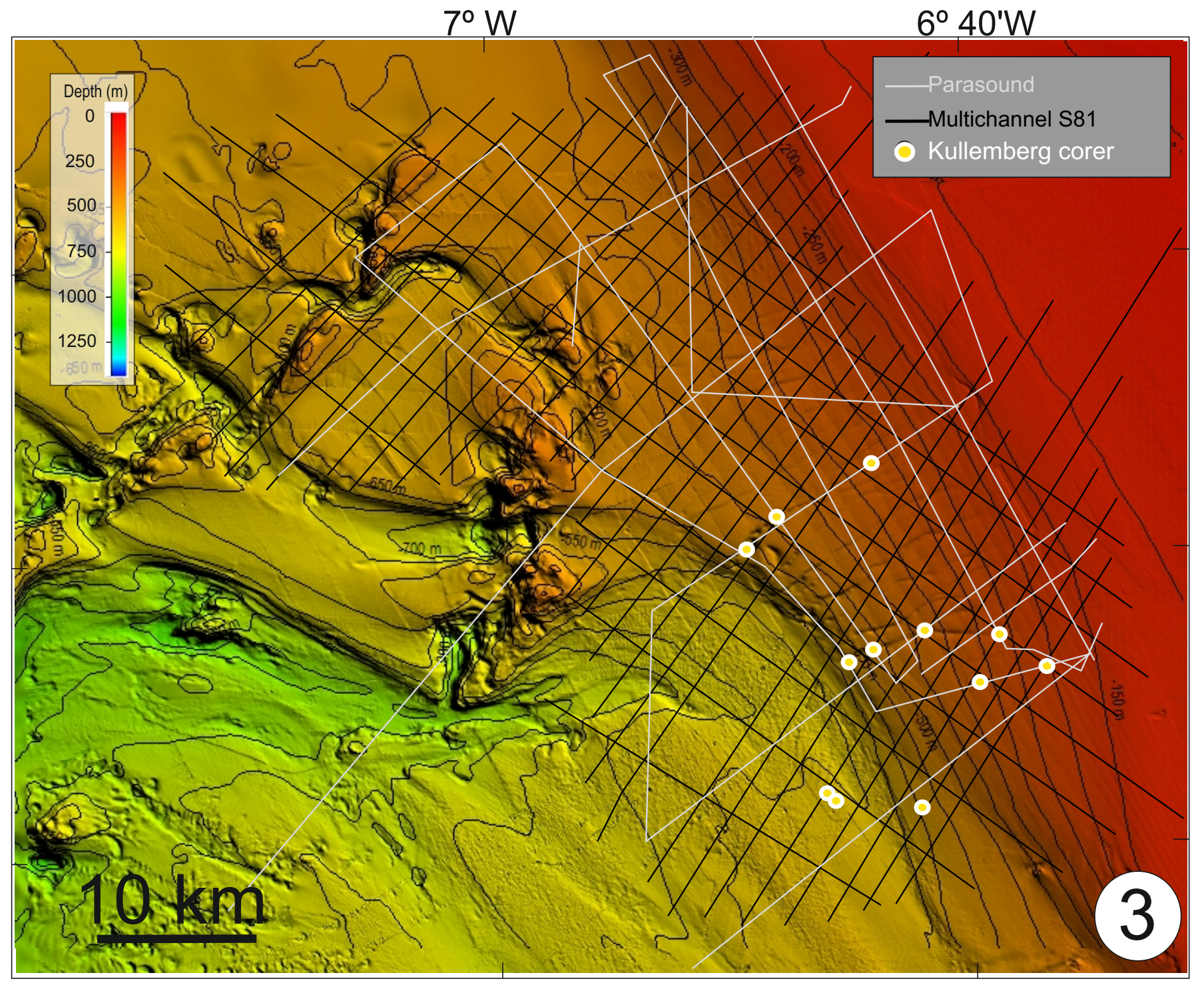


Fig. 3. Detailed bathymetric map of the study area showing the different data collected for the study

This study is based on high-resolution datasets obtained during the GRACO cruise (Eurofleets2; doi 10.17600/16001300) and Parasound profiles obtained in the CONTOURIBER and MOWER cruises. Kullenberg sediment cores were taken along the axis of two downslope-trending upper slope gullies. Physical properties (magnetic susceptibility, P-wave velocity, resistivity and gamma density) were measured with a MSCL-Geotek at GeoLab (UB). Open cores were visually described and photographed. The X-Ray Avaatech fluorescence scanner was used for the geochemical characterization of the sediment at 1 cm resolution. Selected samples have been used to perform grain size and carbonate content analysis and to obtain age datations from monospecific Globigerina bulloides and mixed planktonic foraminifera. Sediment core PC06 (Brackenridge et al., 2018) has been included in this study for reference.

Morphosedimentary characterization

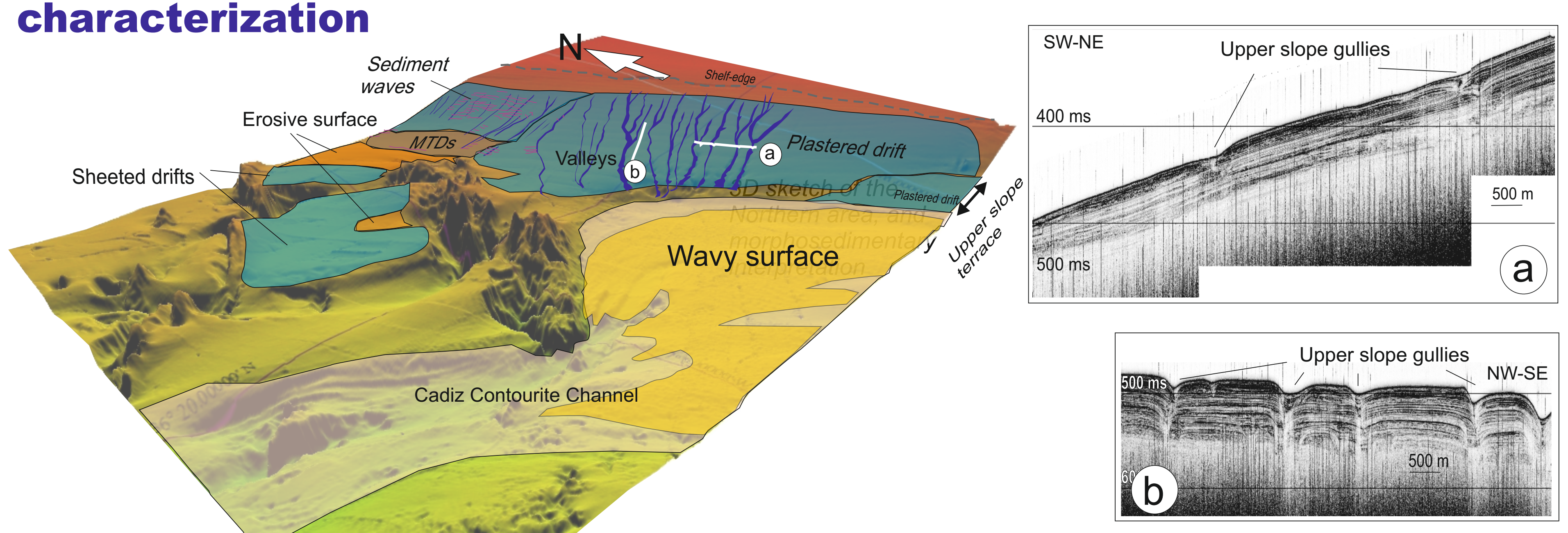
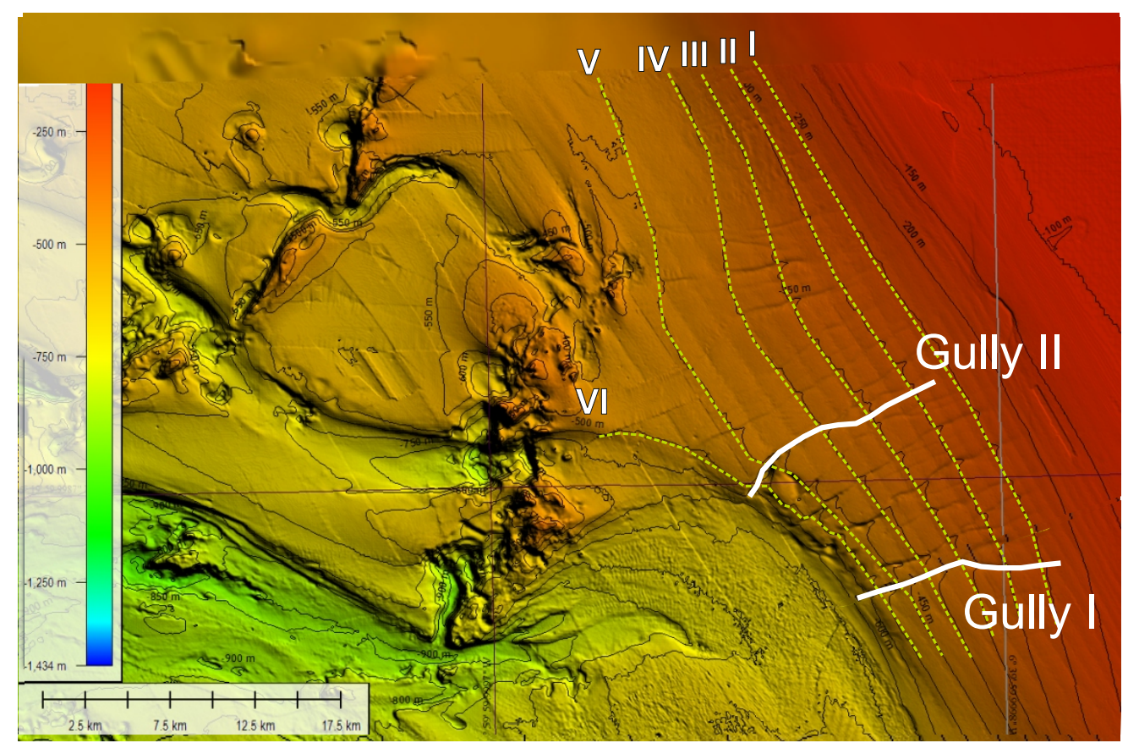


Figure 4. 3D model showing the main morphosedimentary features and Parasound profiles showing the characteristics of the Cadiz upper slope

The upper slope is characterized by a plastered drift dissected by downslope-trending valleys. The valleys asymmetry and migration suggest the influence of a NW-trending bottom current.

To the NE the slope is affected by sediment waves and by smaller-scale valleys. Downslope of the unstable slope the seafloor is covered by mass-transport deposits.

Morphology of the upper slope gullies



The upper slope gullies have their heads at depths of 205-250 m, below the continental shelf break, and they are generally asymmetric, with steeper and higher NW walls.

The valleys in the Southern area are generally longer (12-20 km), deeper (2-25 m) and wider (0.2-1 km) than the ones to the north (5.5-9.5 km long; 0.2-0.4 km wide and 1-3 m deep).

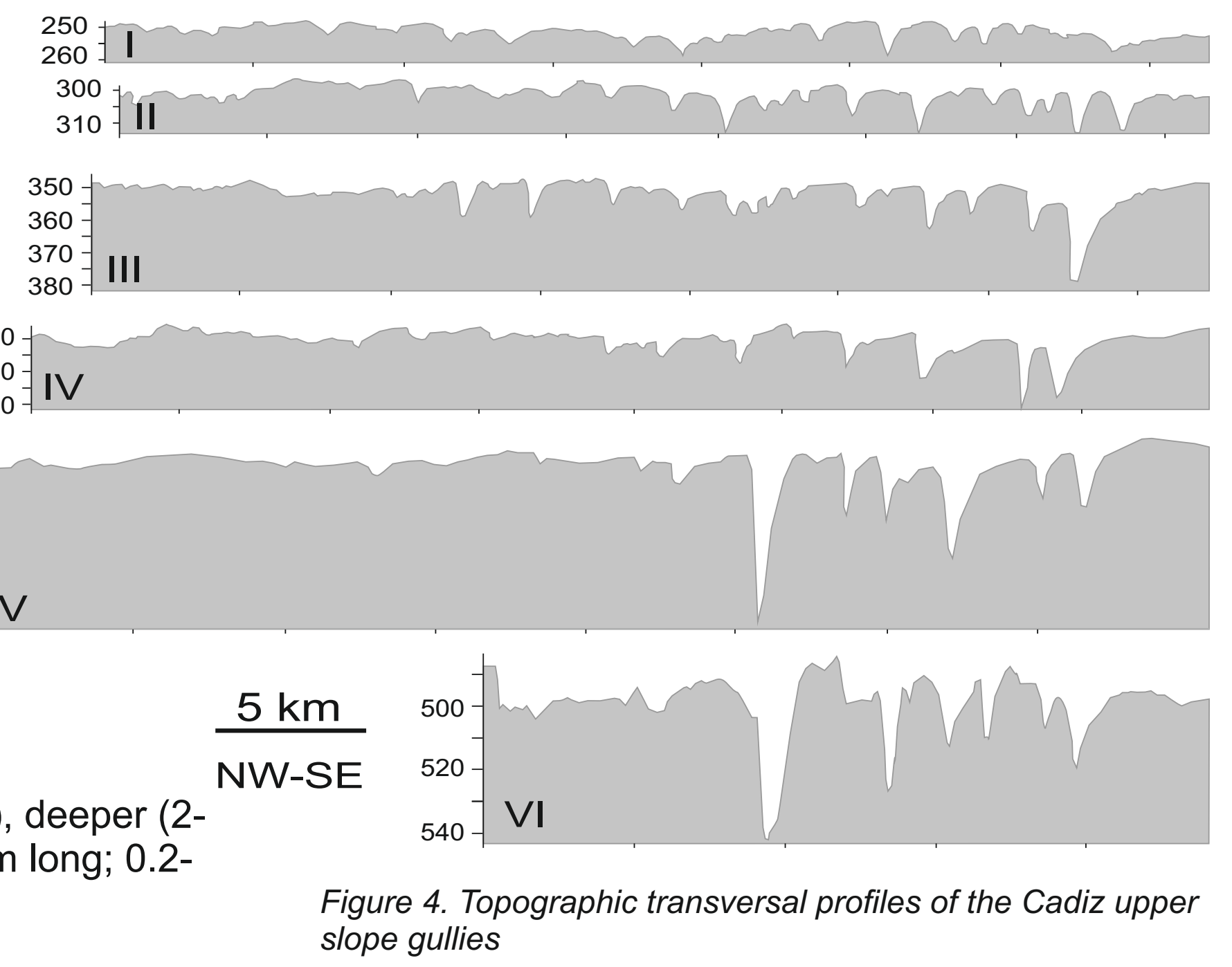
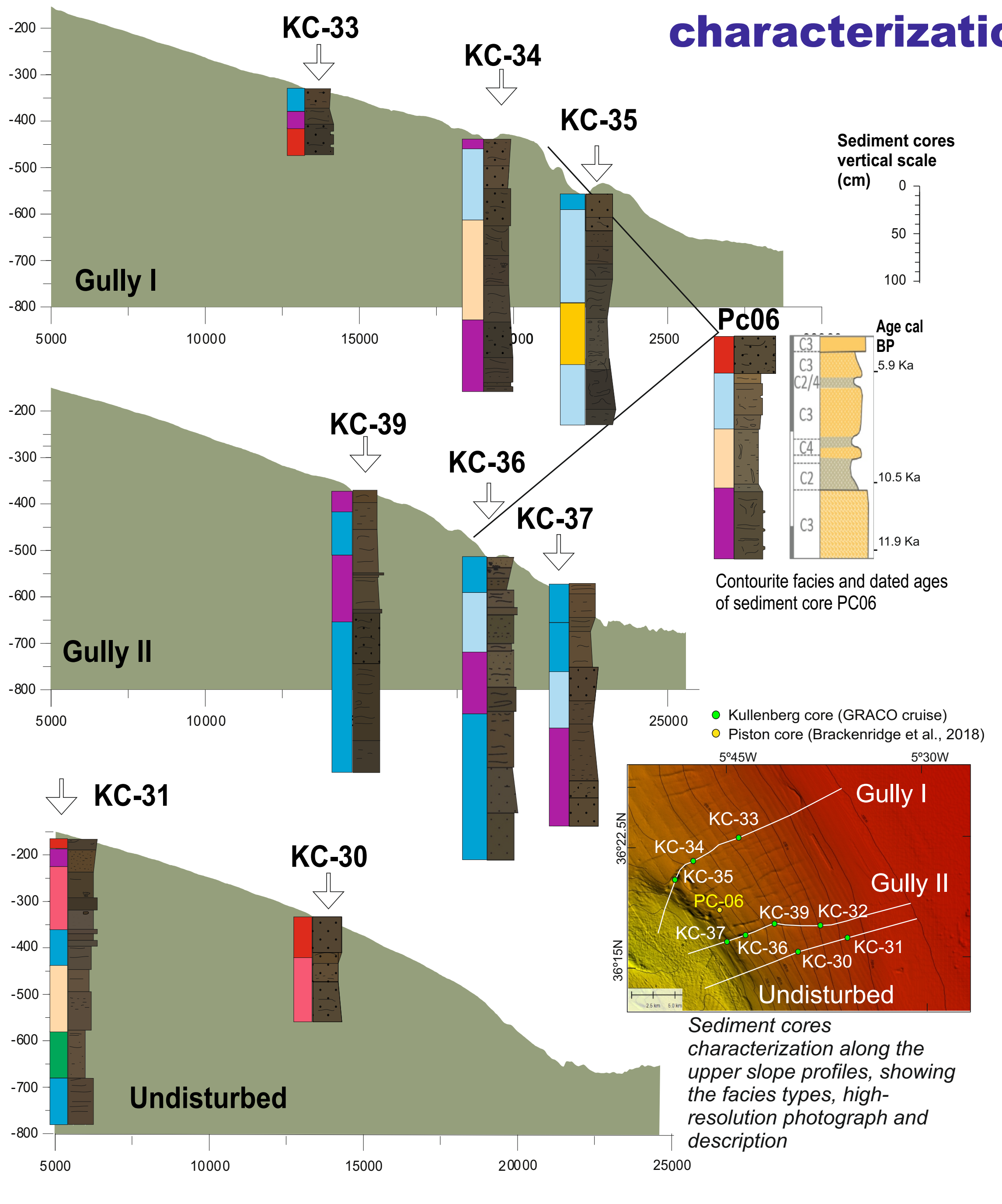


Figure 4. Topographic transversal profiles of the Cadiz upper slope gullies

Preliminary sediment facies characterization



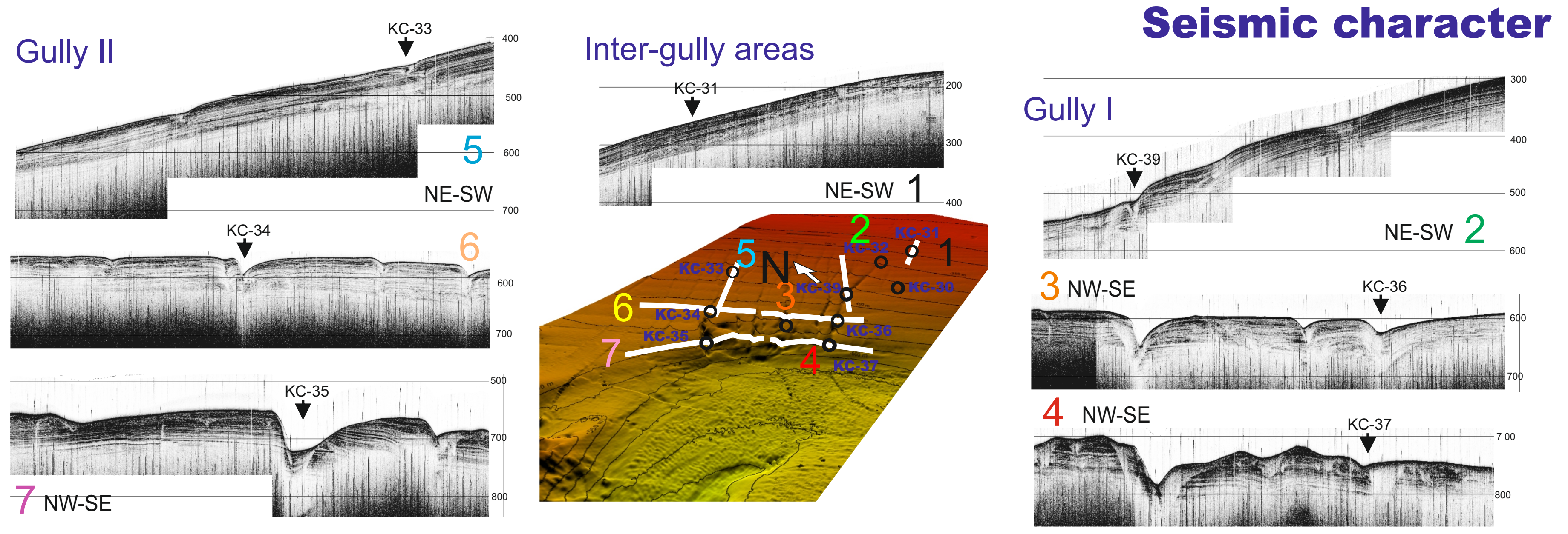
Contourite facies and dated ages of sediment core PC06

Sediment cores characterization along the upper slope profiles, showing the facies types, high-resolution photograph and description

Facies	Mean (µm)	SD	Mean Sand (%)	Mean Mud (%)	Mean VFS (%)	Mean FS (%)	Type	Sorting
A	108.92	23.32	0.86	0.14	0.44	0.39	Muddy Sand-Sand	Poorly-Moderately Sorted
B	60.33	13.22	0.72	0.28	0.36	0.34	Muddy Sand	Very Poorly-Poorly Sorted
B”	51.39	14.42	0.66	0.34	0.35	0.29	Muddy Sand	Very Poorly Sorted
C	39.33	5.36	0.57	0.43	0.32	0.23	Muddy Sand	Very Poorly Sorted
C”	49.02	14.54	0.65	0.35	0.31	0.31	Muddy Sand	Very Poorly Sorted
D	23.07	4.43	0.37	0.63	0.25	0.11	Sandy Mud	Very Poorly Sorted
D”	34.86	8.72	0.52	0.48	0.29	0.21	Muddy Sand	Very Poorly-Poorly Sorted
E	9.94	2.08	0.06	0.94	0.06	0.01	Mud	Very Poorly-Poorly Sorted

Table I. Main parameters of the grain size analysis that have allowed the differentiation of the facies types

Seismic character



	Undisturbed, inter-gully areas	Along the axis of the gullies
Seismic character	The Parasound profiles reveal layered parallel stratification with high lateral continuity and high-acoustic amplitude. Locally, the surface and sub-surface displays chaotic-transparent character. Buried gullies occur in the sub-surface that have been completely infilled by the sedimentary cover.	Along the axis of the two gullies the Parasound profiles have a higher seismic amplitude, when compared with the inter-gully areas. The axis are infilled, particularly at the shallower positions in the upper slope. The erosive character is evidenced at the deeper reaches of the gullies by the lateral truncation of seismic reflections, and is particularly clear in Gully II.
Sediment characterization	The undisturbed cores from the upper slope are characterized by very poorly to moderately sorted fine silt to very fine sand (mean between 7 and 129 µm). The percentage of mud ranges between 8 and 100%. Very fine and fine sand ranges between 0-63% and 0-52% respectively with less than 7% of medium sand.	The cores recovered from the axis of the gullies are in general less muddy (20-75%) than in the inter-gully areas. The mean varies in a narrower range between 15 and 80 µm representing very poorly and poorly sorted coarse silt to very fine sand. Very fine sand content is higher than 17%, reaching 57%whereas fine sand varies between 5 and 50%. Medium sand abundance is always lower than 8%.

Gravity flows and deep currents interaction in the Cadiz upper slope gullies

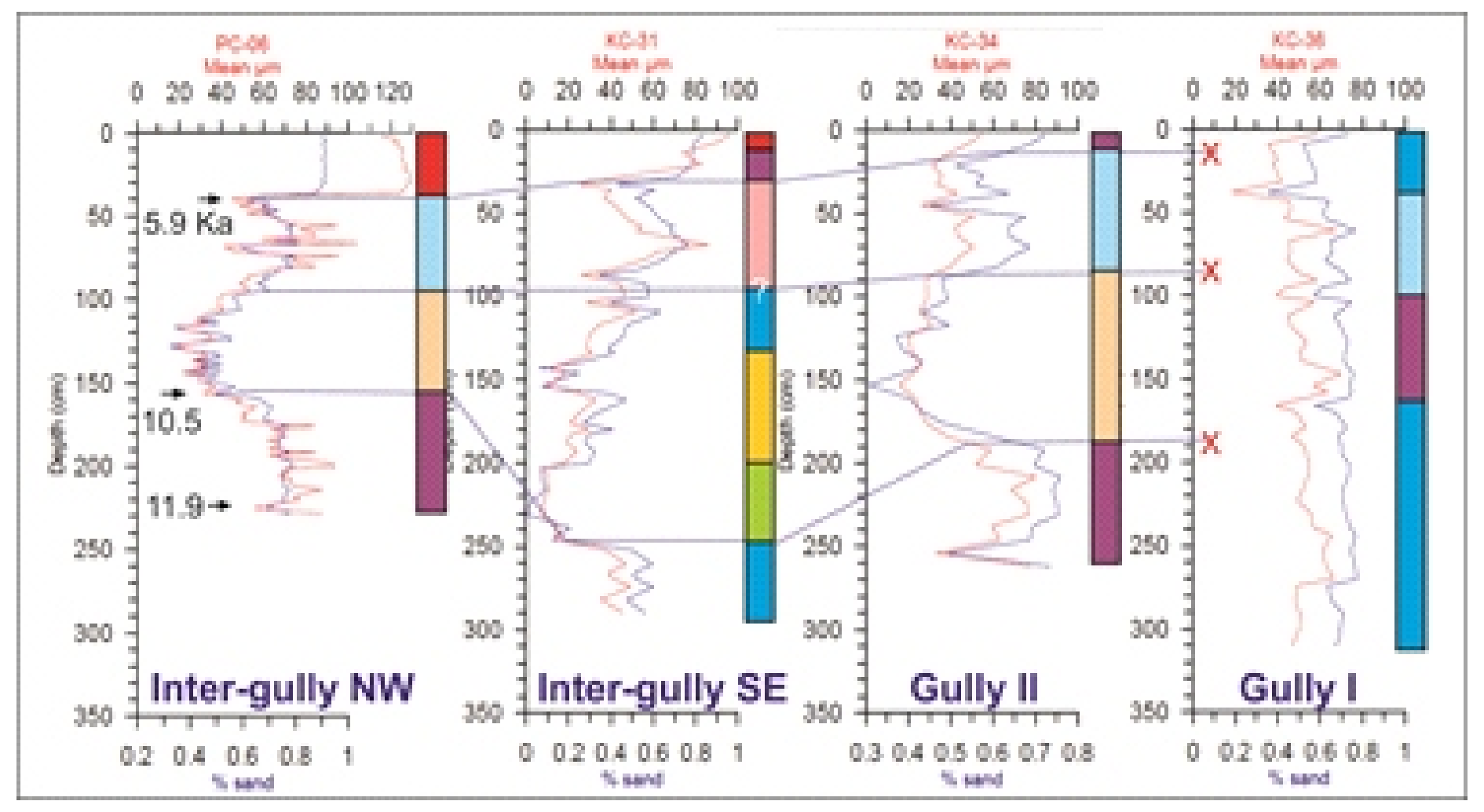


Table II. Mean grain size and sand content of four selected cores for correlation: KC-31 from inter-gullie area, KC-36 from Gully I and KC-34 from Gully II.

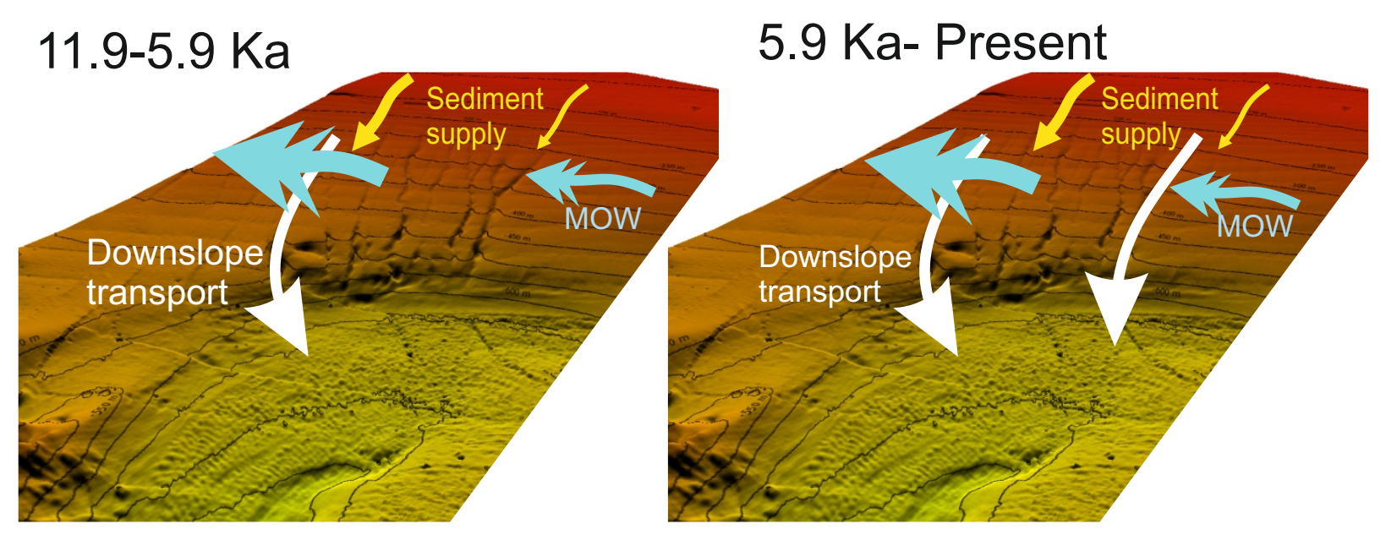
Grain-size data, supported by the XRF and Physical Properties analysis, reveal evident correlations between sediment cores from the inter-gully areas and Gully II (Table II). Only the top of Pc06 does not correlate so clearly, but the three units identified by Brackenridge et al.

In contrast, no evident correlations can be found between inter-gully areas and Gully I.

The sedimentological analysis indicates an alongslope variation, with a general increase of grain size and sand content from SE to NW (from KC-31 to PC06). This may be explained by an intensification in the MOW velocity as it sweeps the upper slope, but it can also be related to a coarser sediment supply from the continental shelf and related to gravitational processes (unconfined turbidity currents and/or mass-transport processes). PC06 shows a significant change in sedimentation, to much coarser and homogeneous grain size after 5.9 Ka cal BP (Brackenridge et al., 2018), that could be related to changes in the sediment supply due to terrestial climatic changes (Ortiz et al., 2007) combined with a sea-level stabilization (Stanley and Warne, 1994; Aleman et al., 2014).

The two gullied studied in this work present significant differences. Gully I shows similar facies distribution to the inter-gully sediment core (PC06), except for the most recent unit. This indicates that downslope transport along Gully I was mostly inactive until about 5.9 Ka, and contouritic processes dominated. It also reveals a higher variability in the dominant processes.

In contrast, sediment facies in Gully II show a higher sand content, and a smaller vertical variation in both grain size and sand fraction. This may indicate that Gully II has acted as a downslope conduit for sediment transfer from the continental slope during the entire time span of this study, even if it is affected by the MOW flow.



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