FINAL REPORT

ECORD Grant for research proposal:

New insights on submarine flank volcano evolution from geomechanical characterization of marine sediments, west of Martinique

Sara Lafuerza
Laboratoire de Systèmes Volcaniques (Institut de Physique du Globe de Paris)

Scientific objectives

Within this project, the preconditioning factors involved in the deformation and failure of marine sediments related to volcano-flank collapse events in Martinique Island have been evaluated. We used sedimentological and geotechnical data of the upper 200 meters of core at site U1400 (CARI07, Expedition 340 Scientists, 2012) drilled during the Integrated Ocean Drilling Program (IODP) Expedition 340, west of Martinique. Thanks to the ECORD grant, first analyses of sediment micro-structure and consolidation state have been obtained for five samples at Hole U1400C.

Methodology

The consolidation state of materials, which is the gradual reduction in volume and water content of low permeability material, due to the dissipation by drainage of excess pore water pressure has been investigated. Materials are considered “normally consolidated” when excess pore pressures (exceeding hydrostatic) are completely dissipated. From laboratory consolidation experiments, which measure how sediment porosity decreases with increasing stress, the maximum effective vertical stress that has acted in the past - the preconsolidation pressure (σ'_p) - can be estimated.

The ratio between σ'_p and the in situ vertical effective stress σ'_v is referred to as the overconsolidation ratio (OCR), which indicates whether a sediment is normally consolidated (OCR=1), i.e. current overburden is the largest ever supported; whether previous stresses exceeded that of current overburden, reflecting processes such as erosion, deformation or cementation (OCR>1); or if excess pore pressures maintain abnormally high porosities at depth (OCR<1). When OCR<1, excess pore pressure Δu can be expressed as $\Delta u = \sigma'_v - \sigma'_p$.

Standard consolidation experiments require minimally disturbed samples, but such sampling interferes with continuous sediment core recovery. Thus only a few undisturbed whole-round samples were obtained during IODP Expedition 340. Here we report uniaxial consolidation (oedometer) tests and hydraulic conductivity measurements performed on five samples collected from Hole C at Site U1400 (Table 1). Site U1400 penetrated mass wasting deposits D1 (~100 ka) and D2 (~25 ka) described by Le Friant et al. (2003). Deformation in these is characterized mainly by tilted bedding (Expedition 340 Scientists 2012).

Results

1. Consolidation tests

Evaluation of quality for 5 whole-round samples, based on the change in pore volume (Δe) relative to the initial pore volume (e_0), was possible for samples with OCR>1 (Lunne et al. 2006). These data suggest that samples 5H6, 7H2, 13H4 are of high quality ($\Delta e/e_0$ <0.04, Table 1). OCR obtained from oedometer tests (Table 1) are plotted together with obtained ratios of the undrained shear strength (*Su*) and the vertical effective stress (σ'_v) Su/σ'_v (Fig. 1). A linear regression results in $Su/\sigma'_v = 0.25 \pm 0.08$ for normally consolidated sediments (OCR=1). Two consolidation samples from U1400C suggest overpressures with Δu = 63% of vertical stress (63%σ'_v) in sample 10H4 (fine-grained pink tephra, Figs. 2 and 3) and 35%σ'_v in sample 19H4 (hemipelagic sediment with dark tephra) (Fig. 3).

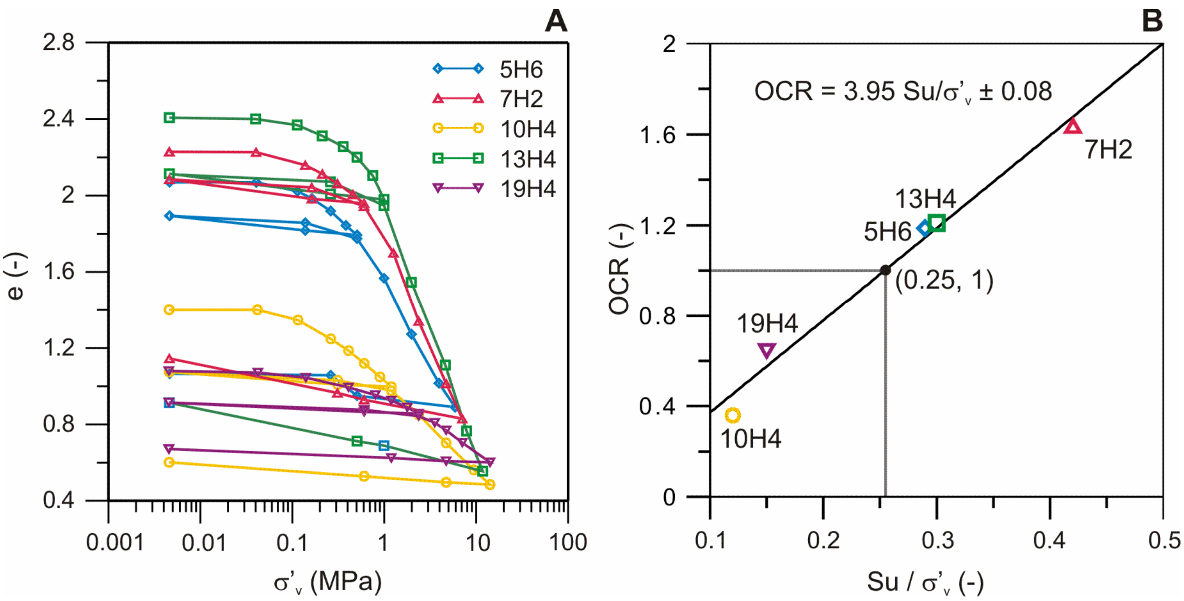

Fig. 1. A, Consolidation curves showing porosity reduction (decreasing void ratio *e*) during uniaxial loading (increasing stress σ'_v) of whole-round samples (5H6 to 19H4; Hole U1400C). B, Linear relationship between overconsolidation ratios (OCR) and Su/σ'_v.

2. Hydraulic conductivity

At effective stress conditions, the highest hydraulic conductivity (*k)* measured corresponds to the deepest sample (19H4; $2.8{\cdot}10^{-9}$ m·s^{-1}), and the shallowest (5H6; $2.0{\cdot}10^{-9}$ m·s^{-1}), with similar grain size. A slightly lower value ($1.2\text{-}2.1{\cdot}10^{-9}$ m·s^{-1}) is found for relatively coarser 13H4 (Table 1). Values of *k* an order of magnitude less ($3.4{\cdot}10^{-10}$ and $1.5{\cdot}10^{-10}$ m·s^{-1}) are found for the other two samples (7H2 and 10H4). Values of *k* at higher stresses are an order of magnitude less except for sample 7H2, which shows a smaller decrease, and sample 19H4, in which no change in *k* was noted.

Discussion and preliminary conclusions

No clear conclusions can be drawn about the link between the grain size and *k,* since calculated *k* is not proportional to sand content (Table 1), though we have measurements on a limited number of samples. This suggests that grain shape, sorting, and other micro-structural properties must control hydraulic conductivity, perhaps explaining why tephra of anomalous sample 10H4 (Fig. 2) indicates overpressure.

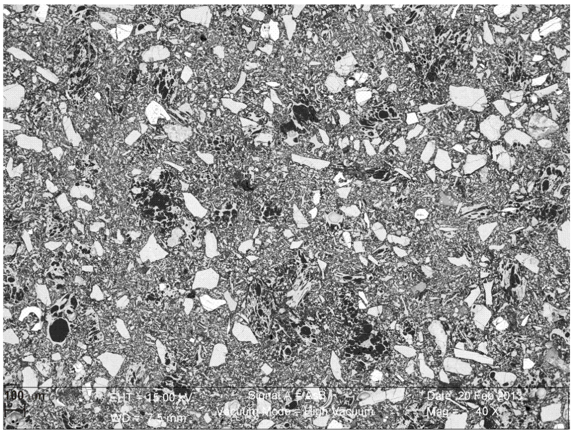

Fig.2. Micro-structure of the tephra sample 10H4 showing a relative high amount of vesiculate pumices, minerals and glass shards.

These consolidation tests provide reliable first evidence of overpressures as a potential preconditioning factor for sediment deformation and failure. Overpressure can be enhanced by undrained loading and/or seafloor acceleration triggered by debris avalanche emplacement, resulting in low shear strengths, which could account for the deformation of sediments at site U1400.

We find that the low hydraulic conductivity of hemipelagic sediment causes low rates of dewatering of turbidites and tephra layers allowing excess pore fluid pressures to persist at depth. Overpressure generation was likely enhanced during major flank collapses, leading to low shear strength and subsequent deformation of large volumes of marine sediments, as found at Site U1400.

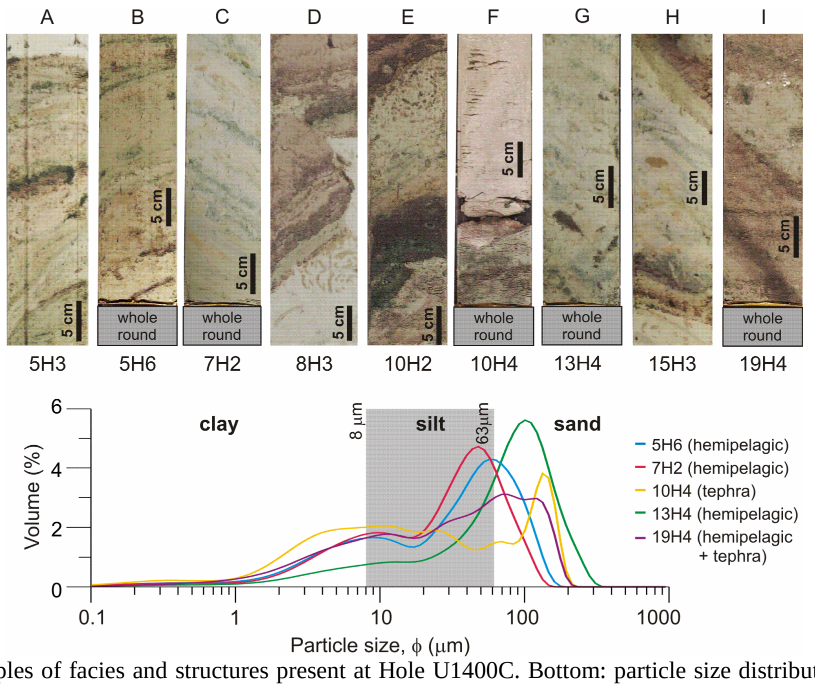

Fig. 3. A to I, examples of facies and structures present at Hole U1400C. Bottom: particle size distribution of whole-round samples.

Table 1. Physical properties measured on whole-round samples collected at Hole U1400C. *σ'ᵥ*, effective vertical stress; wc, water content; *PI*, plasticity index; e_0, initial void ratio before loading; σ'_p, preconsolidation pressure; *OCR*, Overconsolidation ratio; *Δu*, excess pore fluid pressure considering hydrostatic conditions; *k*, hydraulic conductivity.

	5H6	7H2	10H4	13H4	19H4
depth (mbsf)	47	60.7	84	109	159
description	carbonate ooze	carbonate ooze	pink tephra	carbonate ooze	carbonate ooze
σ'_v (kPa)	251	309	597	489	1240
wc (%)	74.4	80.2	52.1	82.8	37.1
PI (%)	11	12	17	28	12
Clay (%)	23.6	23	35.6	11	24.6
Silt (%)	48.9	59.1	36.7	28.6	42.9
Sand (%)	27.5	17.9	27.7	60.4	32.5
e_0 (-)	2.07	2.23	1.40	2.41	1.08
e_0 (at σ'_v)	2.02	2.18	1.31	2.34	1.03
$\Delta e/e_0$	0.02	0.02	0.07	0.03	0.04
σ'_p (kPa)	299	505	219	592	811
OCR (-)	1.19	1.63	0.37	1.21	0.65
Δu (%σ'_v)	-	-	63	-	35
k ($m\cdot s^{-1}$) at σ'_v	$2.0\cdot10^{-9}$	$3.4\cdot10^{-10}$	$1.5\cdot10^{-10}$	$1.2\cdot10^{-9}$	$2.8\cdot10^{-9}$
k ($m\cdot s^{-1}$)	$4.5\cdot10^{-10}$	$1.8\cdot10^{-10}$	$3.8\cdot10^{-11}$	$1.7\cdot10^{-10}$	$2.8\cdot10^{-9}$

References

Expedition 340 Scientists (2012) Lesser Antilles Volcanism and Landslides: implications for hazard assessment and long-term magmatic evolution of the arc. IODP Prel Rept 340

Lafuerza, S., Le Friant, A., Manga, M., Boudon, G., Villemant, B., Stroncik, N., Voight, B., Hornbach, M., Ishizuka, O., Expedition 340 Scientific Party (2013) Geomechanical characterization of submarine volcano-flank sediments, Martinique, Lesser Antilles arc. *Submitted* to Submarine mass movements and their consequences, Advances in Natural and Technological Hazards Research 32

Le Friant A, Boudon G, Deplus C, Villemant B (2003) Large-scale flank collapse events during the activity of Montagne Pelée, Martinique, Lesser Antilles. J Geophys Res 108: 1–15

Lunne T, Berre T, Andersen KH, Strandvik S, Sjursen M (2006) Effects of sample disturbance and consolidation procedures on measured shear strength of soft marine Norwegian clays. Can Geotech J 750: 726–750

Accounting of expenditures

The ECORD grant was requested for co-funding costs of laboratory analyses. Resources available at the applicant's host institution IPGP could cover the costs of the sedimentological and micro-structural analyses and partially **the costs of the consolidation tests of 2255 €** (see attached invoice).

The provided funding, of 1760 € (see invoice attached), was used to cover ~ 3/4 of the costs of the consolidation tests. Consolidation tests were performed at the laboratory of Fugro Geoconsulting (France) in July 2012.