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► **To cite this version:**

Aurélien Gay, Bernard Mercier de Lépinay, Gueorgui Ratzov, Jean-Frederic Lebrun, Serge Lallemand. Seafloor giant polygons associated with underlying polygonal faults in the Caribbean Sea, west of Grenada Basin. International Meeting of Sedimentologists 2017, Toulouse, France, Oct 2017, Toulouse, France. , 2017. ⟨hal-02384501⟩

HAL Id: hal-02384501

<https://hal.science/hal-02384501v1>

Submitted on 28 Nov 2019

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Seafloor giant polygons associated with underlying polygonal faults in the Caribbean Sea, west of Grenada Basin

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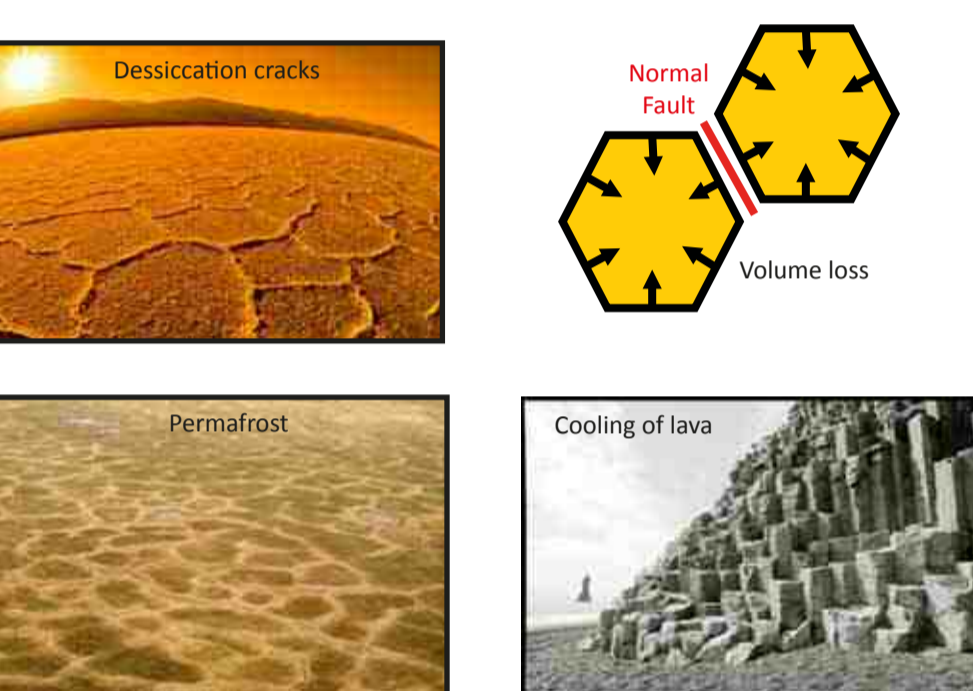
1 - INTRODUCTION

During the Garanti Cruise in May-June 2017, giant polygons have been identified on the seafloor of the Caribbean sea, in the western part of Grenada Basin. They are directly related to closely spaced polygonal faults which usually form in fine-grained clay-rich sediments (Cartwright, 1994; Lonergan et al., 1998). Such fault systems have been recognised in many basins all over the world (Clausen et al., 1993; Cartwright et al., 1997; Clausen et al., 1999; Gay et al., 2004; Hansen et al., 2004; Gay et al., 2007; He et al., 2010; Sun et al., 2010). They are usually interpreted as layer-confined because they occur within sub-horizontal intervals associated with lithological variations of the host sediments. Distinct fault tiers are defined by their own fault frequency and spacing due to different mechanical properties of the intervals (Cartwright, 1994; Lonergan et al., 1998). However, as already shown by studies in the North Sea, polygonal faults do not abruptly end at a specific stratigraphical horizon and they can locally connect to major faults structuring the basin (Gay et al., 2007). However, a polygonal fault interval (PFI) is generally buried from a few tens of meters to hundreds of meters and only a few examples have been reported outcropping at the present day seafloor such as in the Hatton Basin (Berndt et al., 2012 and references therein). In the investigated area, extending from the Saba Bank southwest of Virgin Islands in the North to the Grenada Basin west of St. Vincent in the South, the occurrence of giant polygons appears to be controlled by two major factors:

- > **The water depth:** polygons developed between 1500 and 2500 m water depths. This could be related to the nature and the grain size of particles. The area affected by seafloor and shallow buried polygons is marked in green on the main bathymetric map below.
- > **The sediment supply:** polygons developed in the vicinity of turbiditic canyons, particularly in the North where the affected area is about 60-75 km wide whereas it is 15-30 km wide in the South where it ends on the eastern flank of the Aves Ridge.

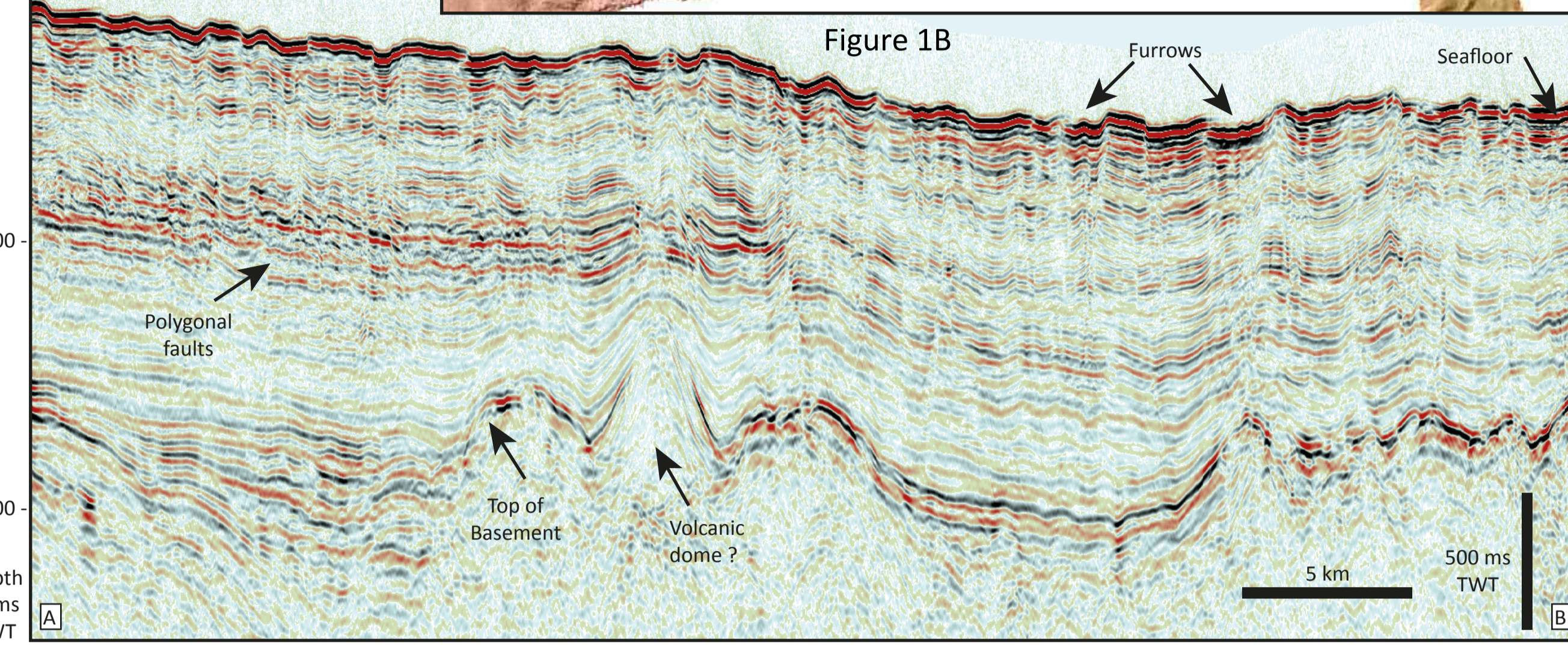
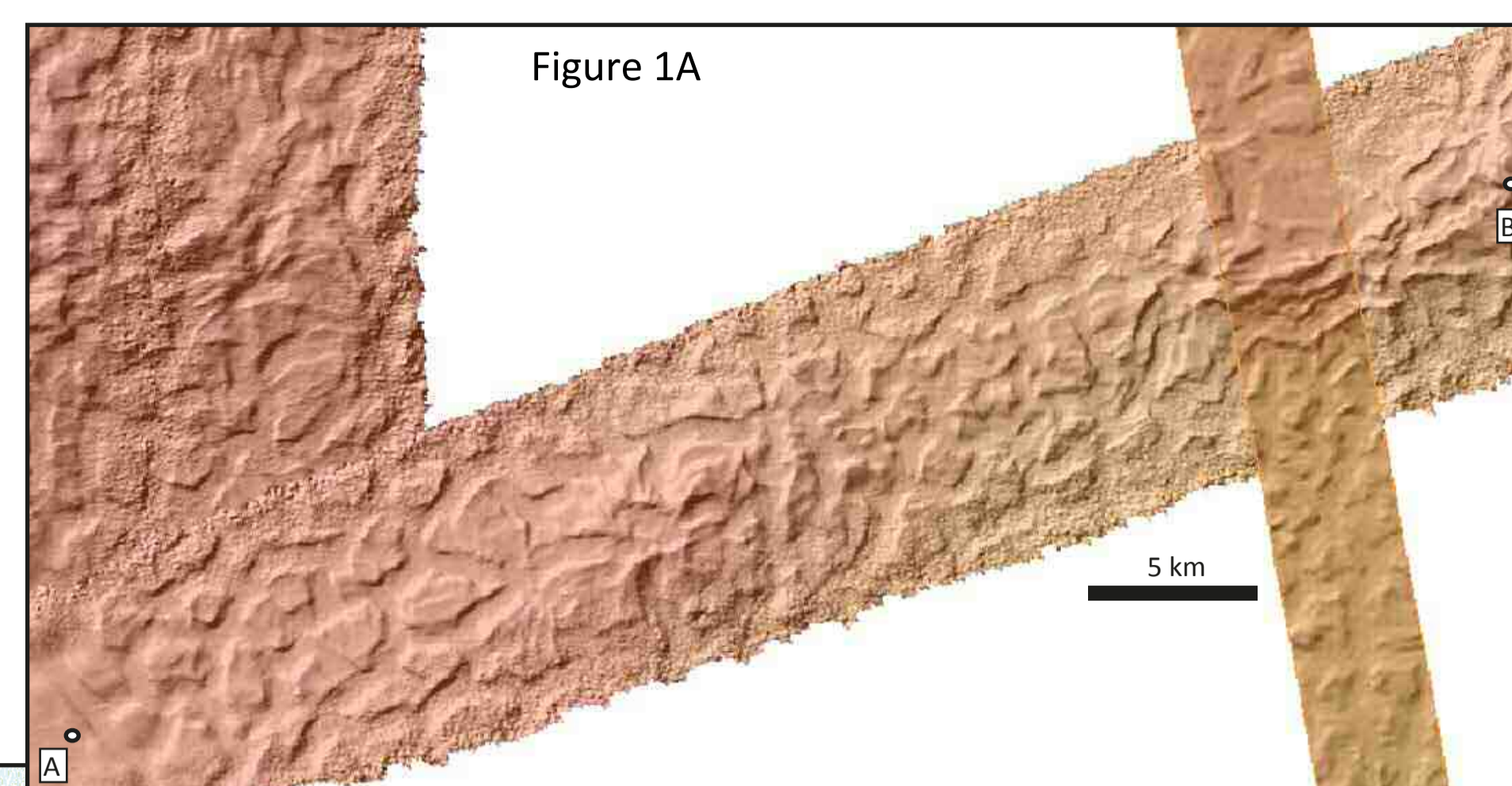
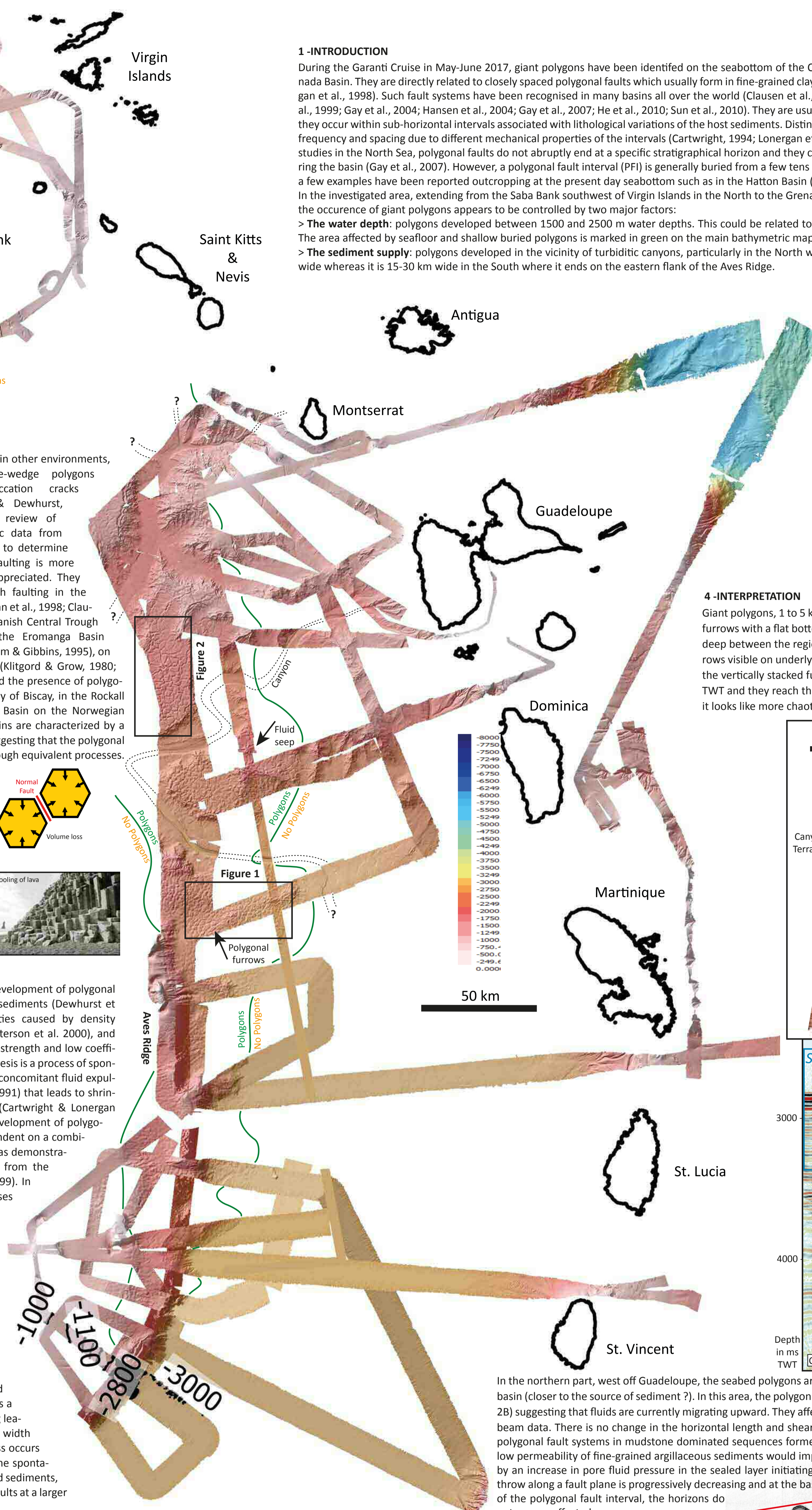
2 - SIMILARITIES

This kind of shrinkage is also known in other environments, such as cooling of lavas, ice-wedge polygons (Lachenbruch, 1962) or desiccation cracks (Weinberger, 1999). Cartwright & Dewhurst (1998) conducted a worldwide review of published and unpublished seismic data from approximately 200 basins, in order to determine whether this type of small-scale faulting is more widely developed than currently appreciated. They identified several examples of such faulting in the North Sea (Cartwright, 1994; Lonergan et al., 1998; Clausen et al., 1999), in the northern Danish Central Trough (Clausen & Korstgard, 1993) in the Eromanga Basin (Cartwright & Lonergan, 1997; Oldham & Gibbins, 1995), on the New Jersey continental margin (Klitgord & Grow, 1980; Poag et al., 1987). They also discussed the presence of polygonal fault systems in the northern Bay of Biscay, in the Rockall Trough in Ireland, or in the Vøring Basin on the Norwegian continental margin. All of these basins are characterized by a similar sedimentary environment suggesting that the polygonal fault systems could have formed through equivalent processes.



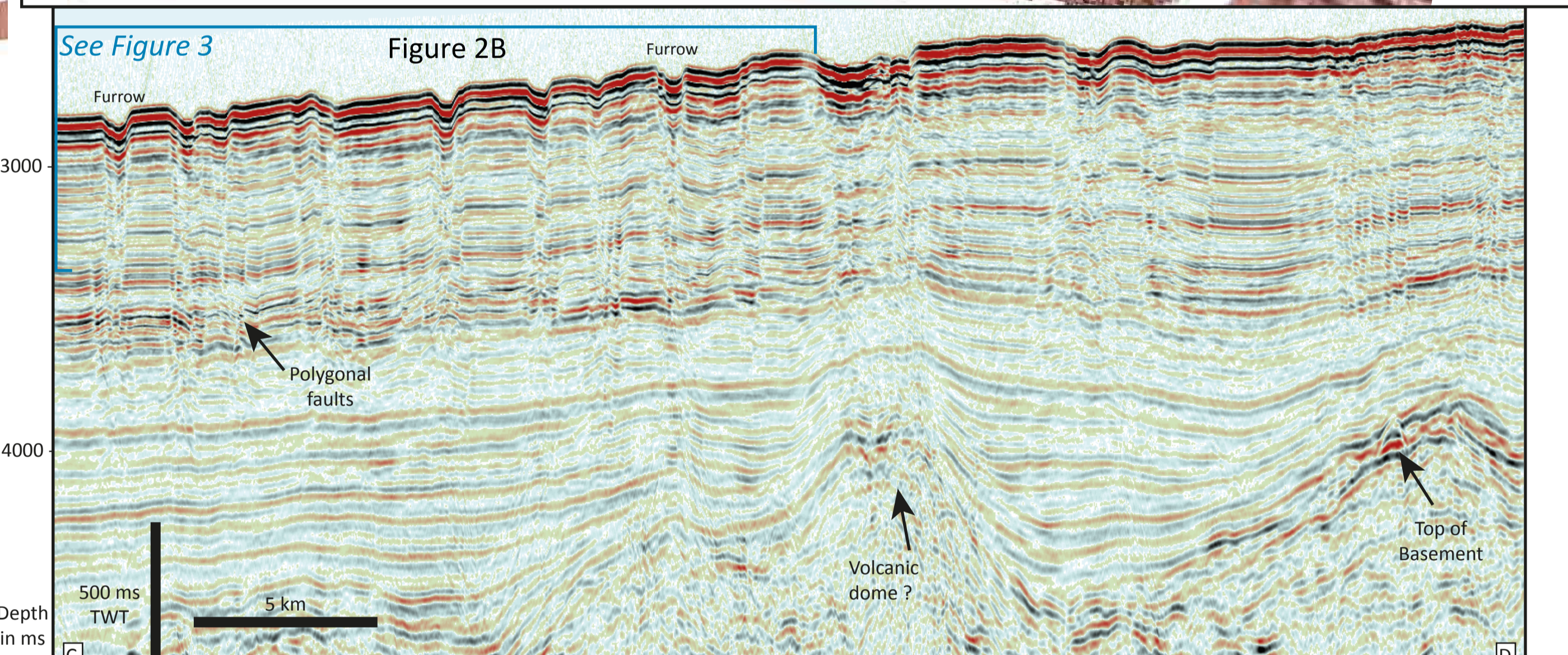
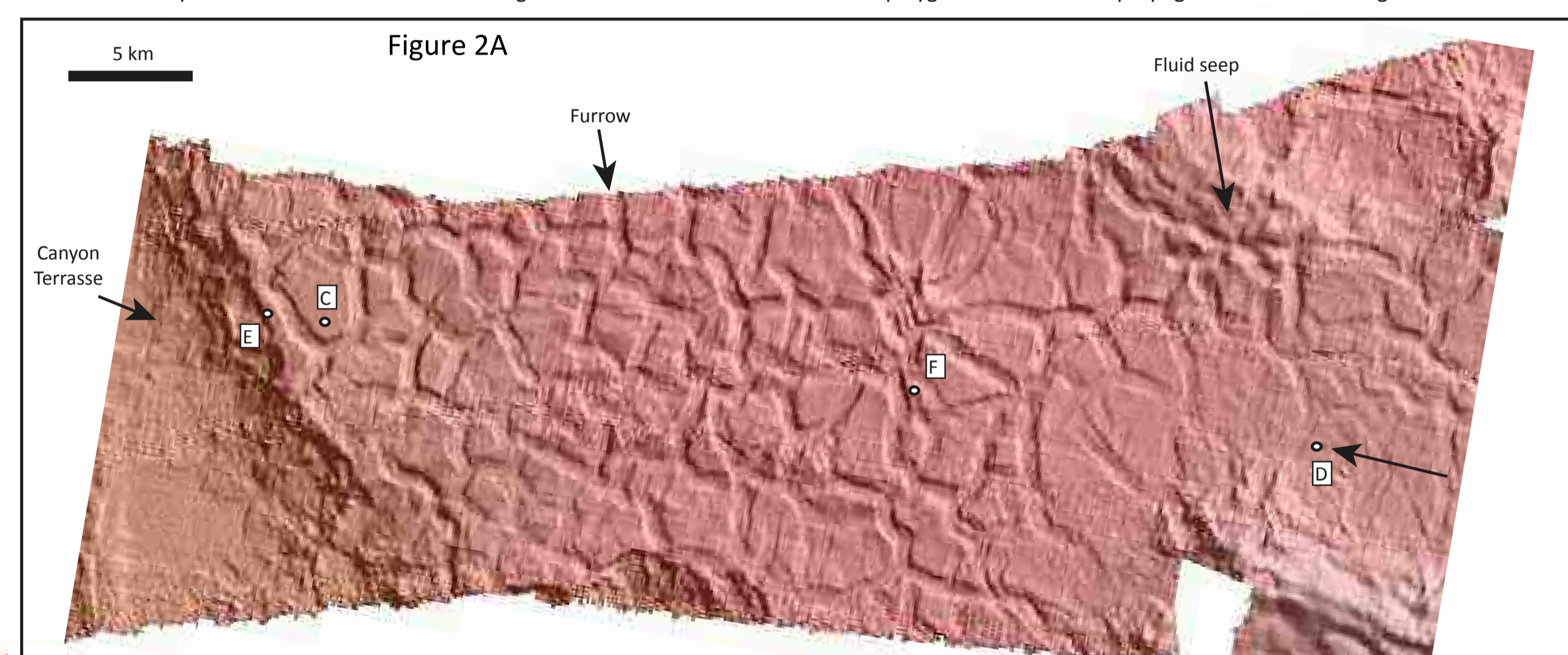
3 - PROCESSES

Possible processes involved in the development of polygonal faults include syneresis of colloidal sediments (Dewhurst et al. 1999), Rayleigh-Taylor instabilities caused by density inversions and gravity collapse (Watterson et al. 2000), and faulting controlled by residual shear strength and low coefficients of friction (Gouly 2001). Syneresis is a process of spontaneous volumetric contraction and concomitant fluid expulsion (Scherer 1986; Van Vliet et al. 1991) that leads to shrinkage in mud-dominated sequences (Cartwright & Lonergan 1996; Dewhurst et al. 1999). The development of polygonal fault systems seems highly dependent on a combination of grain size and mineralogy, as demonstrated in the Early Tertiary mudrocks from the North Sea Basin (Dewhurst et al. 1999). In the North Sea, lithological analyses conducted on wells show that the amount of shrinkage in layers appears to increase as the grain size decreases and smectite content increases (Dewhurst et al. 1999). Studies conducted in the Vøring Basin have shown that the Kai Formation is dominated by a clayey ooze (Al clay minerals > 60%) with a very high smectite content (Forsberg & Locat 2005). This composition forms a fine texture of flocculated particles, 2 µm in size. It also exhibits a typical shrinkage upon freeze-drying leaving voids that are about 5 µm in width (Forsberg & Locat 2005). This process occurs at a microscale, and could explain the spontaneous contraction of mud-dominated sediments, leading to the formation of normal faults at a larger scale.

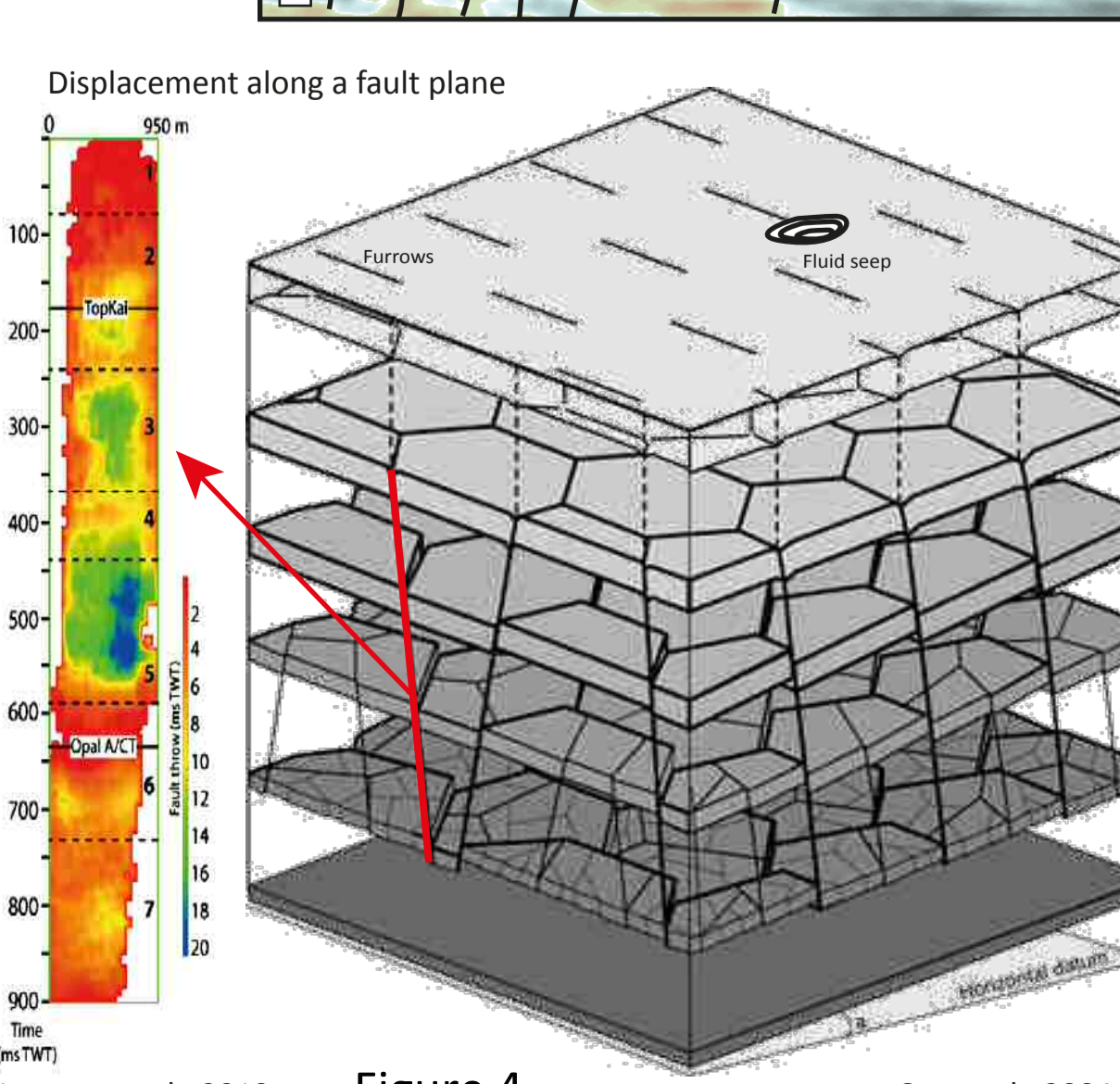
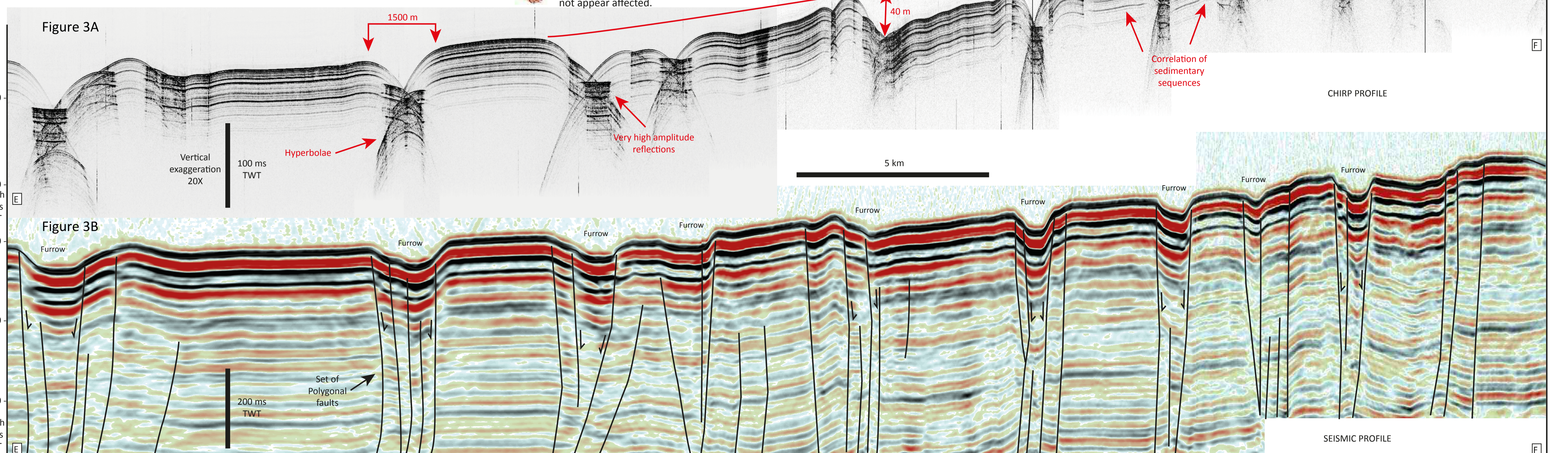


4 - INTERPRETATION

Giant polygons, 1 to 5 km wide, have been identified on the EM122 multibeam data (Figure 1A). The polygons are separated from the neighbouring polygons by 700 to 1500 m wide furrows with a flat bottom. On seismic profiles, seafloor furrows are generally seen as small depressions, a few metres deep. In the area, the depressions are about 50 to 80 ms TWT deep between the regional slope and the bottom of furrows, representing 25 to 40 m in real depths (Figure 1B). The comparison between the furrows on the seafloor and the furrows visible on underlying levels demonstrates that a large number of furrows are common to various horizons. One of the remarkable feature of the polygonal fault interval is that the vertically stacked furrows are consistently located above faults affecting the entire interval. The faults are characterized by various reflectors offsets, typically a few tens of ms TWT and they reach the seabed where they bound furrows. Towards the base of the interval the faults seem to reach an interval characterized by lower amplitude reflections and it looks like more chaotic at some points. This could be due to a change in the nature of sediments and the polygonal faults cannot propagate into such lithologies.



In the northern part, west off Guadeloupe, the seabed polygons are much wider by a factor of 10 to 20% (Figure 2A), suggesting that the size of polygons depends on the location within the basin (closer to the source of sediment?). In this area, the polygonal faults are characterized on seismic profiles by an intense dimming of reflections on both edges of the fault planes (Figure 2B) suggesting that fluids are currently migrating upward. They affect a 700 to 900 m thick interval and they reach the modern seafloor where they bound polygonal furrows visible on multibeam data. There is no change in the horizontal length and shear planes represent an apparent extension. The consequences are that the complex polygonal fault systems in mudstone dominated sequences formed during early compaction, leading to a bulk volume loss. The low permeability of fine-grained argillaceous sediments would impede the pore fluid expulsion during burial by an increase in pore fluid pressure in the sealed layer initiating failure. At depth, the throw along a fault plane is progressively decreasing and at the base of the polygonal fault interval, the horizons do not appear affected.



5 - ARCHITECTURE

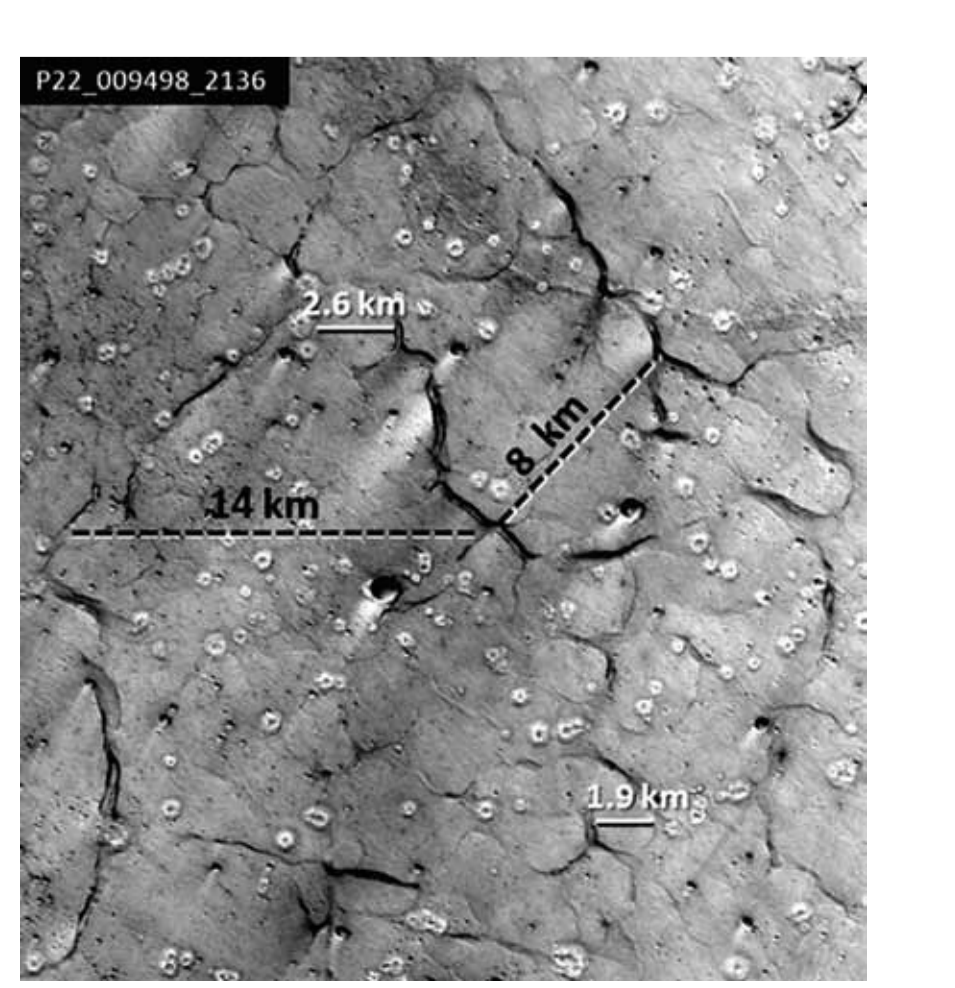
Despite a 20X vertical exaggeration of chirp profiles, the polygons have very steep flanks, defining depressions (or furrows) that are 800 to 1500 m wide and 40 m deep compared to the smooth regional slope (Figure 3A). Very high amplitude reflections occur right beneath the seabed creating large hyperbolae. This could be due to hydrocarbon-rich fluids, most probably methane, feeding benthic organisms such as bacteria responsible for in situ carbonate precipitation. A seismic profile displayed at the exact same horizontal scale shows that each depression is bounded by faults reaching the seabed (Figure 3B). In more details the faults are all normal and they are organised in set of faults. Within the set of faults, the depressed reflections are vertically stacked and the depression is increasing towards the seabed. This could be due to the upward propagation of faults that were initiated at depth and propagated simultaneously towards the base and the top of the affected interval as previously demonstrated by Gay et al. (2004) and Laurent et al. (2012) (Figure 4). This process will go on as long as the sediments deposited at the seabed have the composition required for polygonal fault development (i.e. >50% of clay among >25% of smectite). This is compatible with the volcano-clastic context in the area where clays may come from the in-situ alteration of volcanic material feeding the basin through the turbiditic canyons.

6 - CONCLUSIONS

A regional acquisition of seismic data at a basin scale provides new insights on a margin history and improves the understanding of post-depositional processes such as the very early initiation of polygonal faulting. However, at present day, polygonal faults have never been sampled nor modelled giving an uncertainty in their ability for driving fluids from deeper levels. Giant polygons have also been recognized on the Martian surface (Figure 5). They are 2 to 20 km in size. Their outlines are defined by troughs. Their large sizes distinguishes them from smaller-scale Martian polygons, typically less than 250 meters across. As they occur almost exclusively in lowlands a question arises: Are they giant clues to past oceans as suggested by Oehler et al. (2012)?

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Oehler et al., 2012 Figure 5