Surface analogue outcrops of deep fractured basement reservoirs in extensional geological settings. Examples within active rift system (Uganda) and proximal passive margin (Morocco).

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Introduction

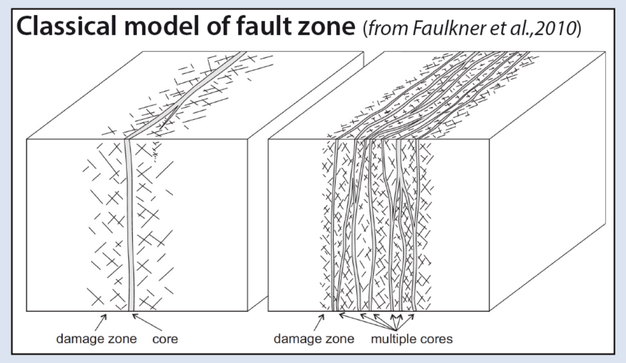
Extensive brittle faults and related fracture sets allow development of reservoir in initially low-porosity basement rocks.

Classical fault zone model (e.g. *Faulkner et al., 2010*) and multi-scale model of brittle structure networks (*Le Garzic et al., 2011*) can be used for the interpretation of the complex architecture of basement reservoirs from sub-surface data (e.g. 3D seismic data, 1D borehole electric imaging).

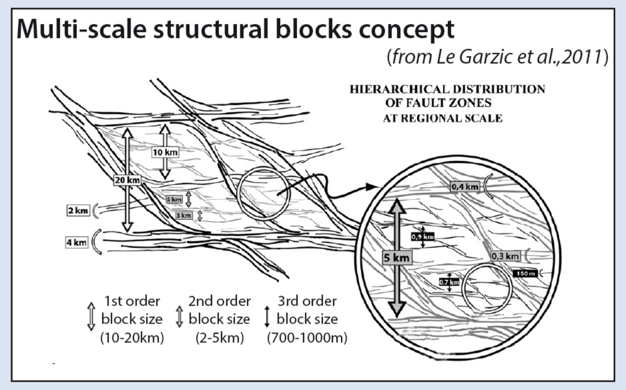
3D seismic imaging is effective to characterize the largest structural blocks and bounding structures of a basement reservoir (thickness, length, orientation, ...), but lower structural features size can not be defined. Wellbores provide discrete data at this lower scale of the reservoir, but they are usually too rare **--> Lack of sub-seismic imaging**

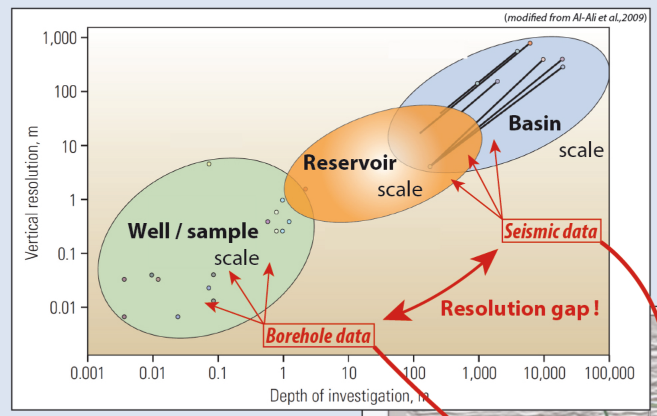
Objectives : Provide data from field analog analysis on 1st order structure size (Uganda) and on 2nd order structure size (Morocco)

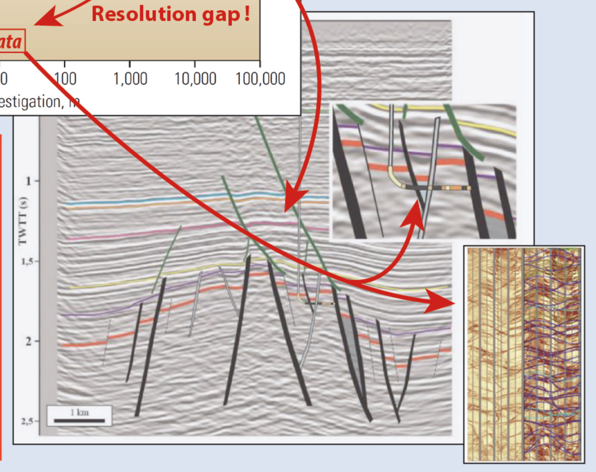
Classical model of fault zone (*from Faulkner et al.,2010*)



Multi-scale structural blocks concept (*from Le Garzic et al.,2011*)







Analog outcrop studies necessary to :

- fill up the resolution gap between seismic and bore data

- understand the multi-scale genetic and geometric relatioships between all the deformation features of the reservoir

Naturally fractured basement reservoir

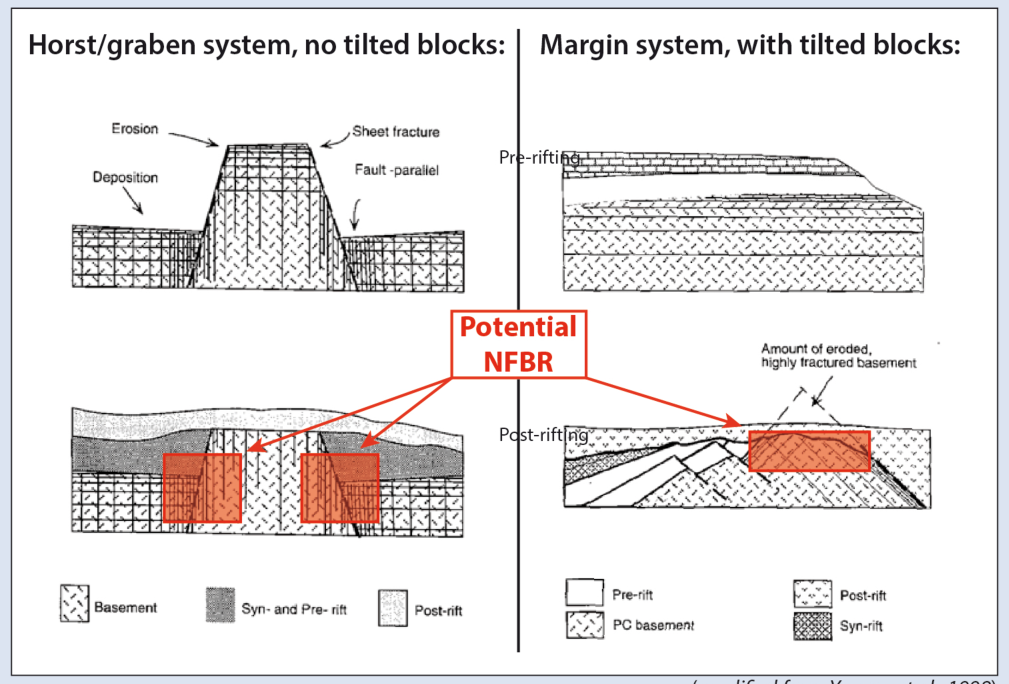
Large varieties of deep-seated resources (e.g. water, hydrocarbons, geothermal energy) are recognized in naturally fractured basement reservoirs (NFBR).

In terms of reservoir, basement rocks include those of initially none to low-porosity (igneous, metamorphic, sedimentary rocks), which have secondary good storage porosity acquired by fracturing and associated wheatering process.

NFBR are usually developed in geological extensive context:
buried hill structures , rifting systems , proximal passive margins
(e.g. Kharir, Yemen ; Soultz-sous-Forêt, Rhine graben ; Cuu-Long, Vietnam)

Basement fracture network is commonly the result of a complex structural history, with an overlay of primary fractures (for igneous rocks), several tectonic phases, dykes emplacements and various weathering processes.

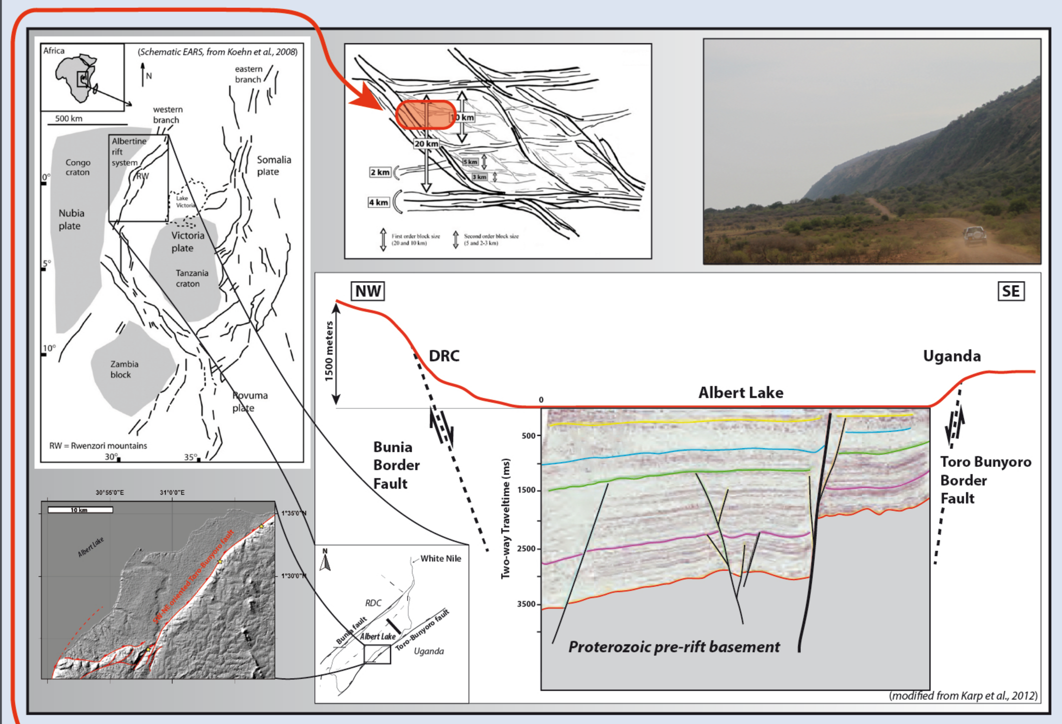
--> Understanding of a NFBR requires a good knowledge of the structural inheritance of the area



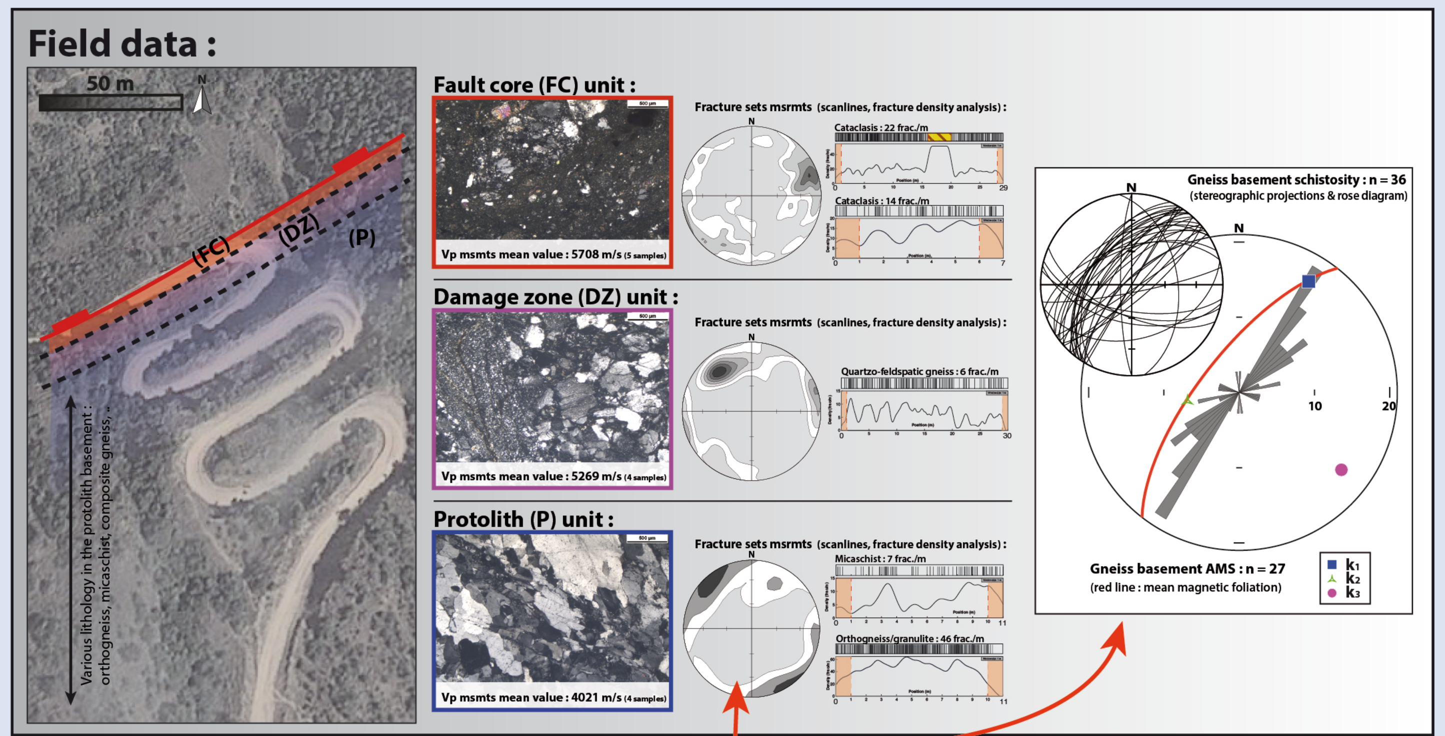
(modified from Younes et al., 1998)

The Albertine rift system (ARS) - Uganda

The ARS is an active rifting system, propagating since Upper Miocene through archaean and proterozoic various-grade metamorphic gneiss, along a former proterozoic orogenic suture.



Field data :



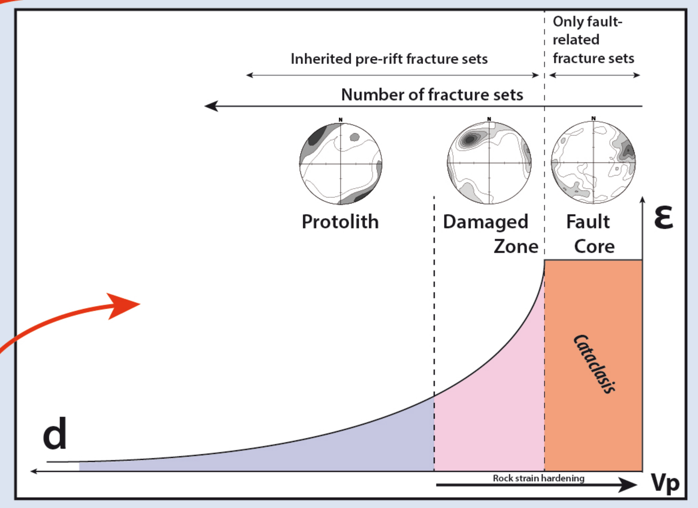
- The eastern NE-SW Toro Bunyoro border fault of the Albert Lake is a regional-scale extensive structure (~100km length)
 --> **1st order structure size**

- **Classical fault zone organisation is identified** according to the micro-structural observations. Thickness of the fault zone is estimated at **50-100 meters**.

- Various lithologies are observed along the fault. **Fracture density is mainly controlled by the lithology and the structural inheritance.** No clear relation can be identified by approaching the main rift-border fault.

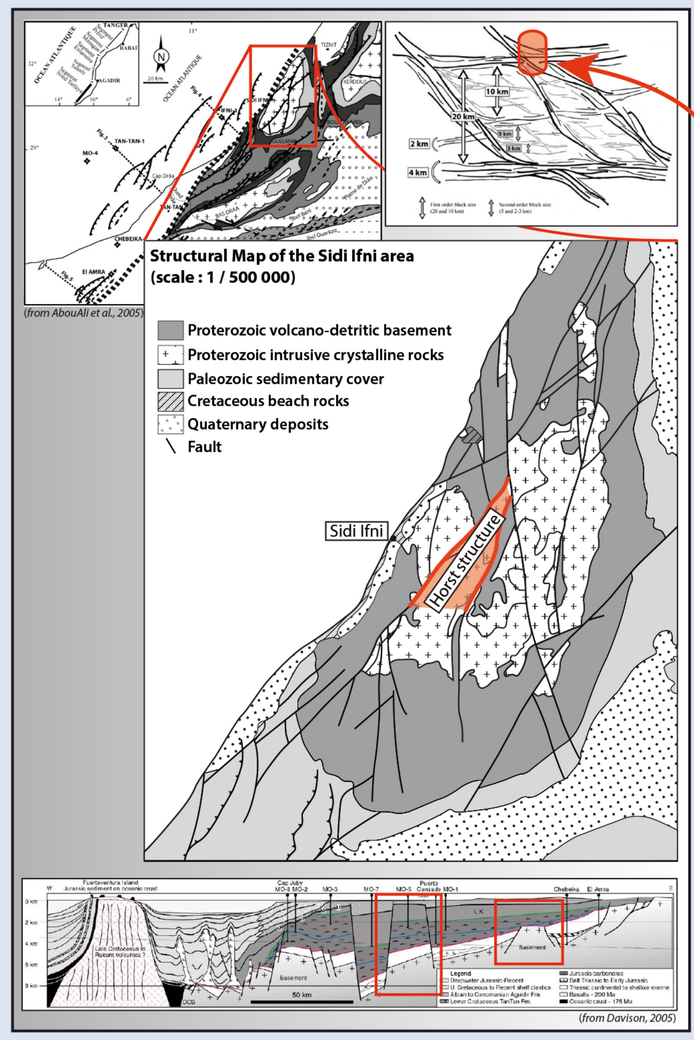
- **Protolith basement show variable oriented-fracture sets**, with a NE-SW oriented dominant one. These fracture sets are partly inherited from pre-rifting events, also consistent with the orientation of the basement fabric (from schistosity and AMS measurements).

- Brittle fracturing organization and petrophysical properties evolve toward the fault zone. Cataclasic processes induce rock strain hardening (from Vp measurements) and erase inherited structures. **Only the rifting-related fracture sets are preserved within the fault zone.**

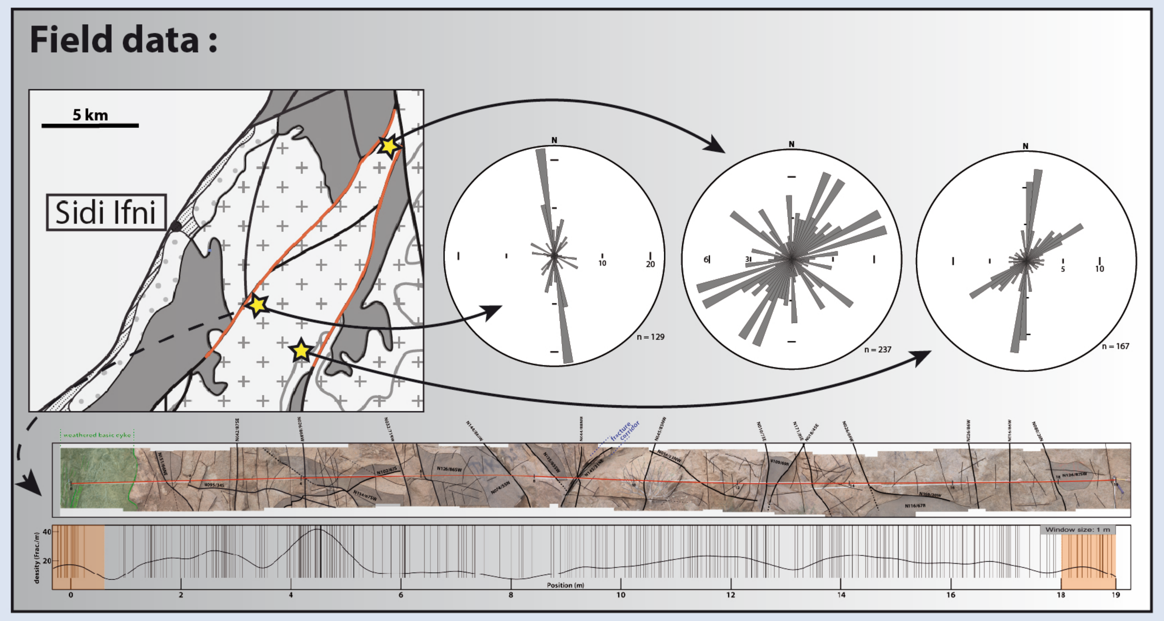


Southwestern Anti-Atlas - Morocco

The Sidi Ifni precambrian «boutonnière», located on the Atlantic proximal oceanic margin is characterized by dominant NE-SW oriented lineaments, sub-parallel to the coastline. Among these lineaments, a horst structure is identified, similar to those described offshore in the basement of the western African continental shelf.



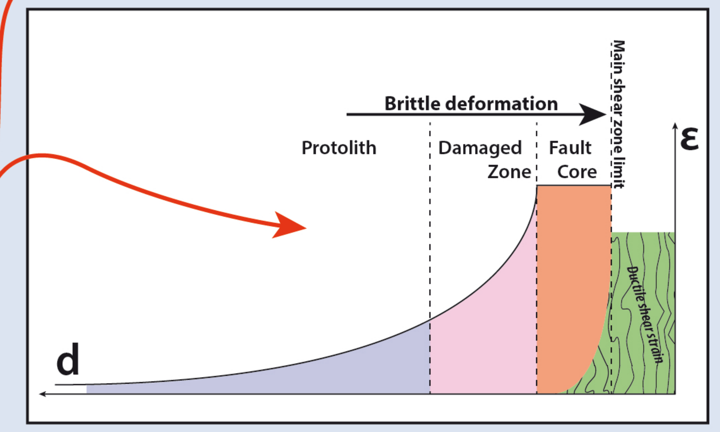
Field data :



- The horst structure identied close to Sidi Ifni is developed in **homogeneous neoproterozoic granitoid rocks**. This structure can be considered as a **2nd order structural block.**

- **Dominant fracture sets are different relative to their position** within the block and to the bounding structures.
- **Fracture density is heterogeneous** in these homogeneous crystalline rocks.
 --> Identification of lower order structural block size ?

- Inherited ductile shear zones are identified along the border fault zones of the horst structure, considered as a 2nd order structural block size. The **juxtaposition of these preserved ductile and brittle strained zones suggests a strong control of the structural inheritance** during the development of margin-related structures.



Selected references

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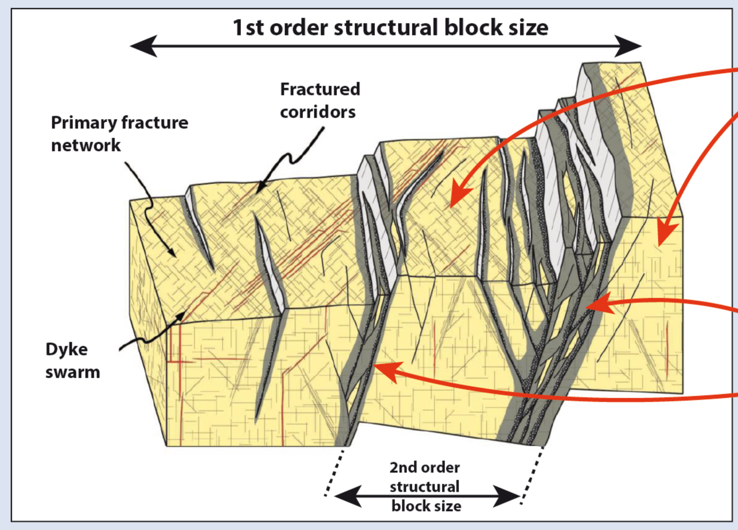
Conclusion



(from Le Garzic et al., in prep.)

--> Our field analog studies **confirm the important role of the structural inheritance** of the basement on the development of the brittle structures of a NFBR. They also confirm that **two different domains must be characterized** in the reservoir : the **structural block** and the **bounding fault zones** of this block.

1. Structural basement block (= protolith unit)

- Within the structural blocks of the reservoir, the different fracture sets are controlled both by its structural inheritance and by its lithology.
- Existence of 4th and lower structural blocks size or no scale-relationships below this scale ?

2. Bounding fault zones --> 2 different fault zones identified along different order structures size

- **1st order fault size :** strong strain localization and reset of the structural inheritance (e.g. cataclasic process). The fracture network is only related to the last main extensive tectonic phase.
- **2nd order fault size :** strain localization along preserved inherited structures (e.g. mylonitic shear zone). The fracture network of the fault zone consists of inherited and newly formed fracture sets.

Hypothesis for these 2 strain localization behaviours : depend on the length/displacement of the structures ? type of structural inheritance ? lithology ? rheology ? stress field orientation ?

Implications for fluid flow :
- **loss** of the structural inheritance --> potential drain zone through the fault-related fracture network ?
- **preservation** of the structural inheritance --> potential barrier in a passing through direction and main drain direction parallel to the fault ?