

# **Outstanding Salt Tectonics Outcrops: The Sivas Basin, Turkey\***

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## **Abstract**

The Sivas Basin, central Anatolia plateau (Turkey), shows a pronounced salt tectonics activity involving the lower Oligocene Hafik Formation. Despite the quasi-complete exposure of the structures, the tectonic evolution of the basin has been so far misunderstood because it has only been envisioned in a context of thrust tectonics. Nevertheless, the basin shows reactivation by the Miocene compression with thrust rooting along the evaporite sole. The core of the basin, a 35x25 km area near the Sivas town, displays several minibasins separated by evaporitic walls, and partially covered by remnant of Miocene gypsum canopies. The minibasins are filled by mid Oligocene to lower Miocene clastics (reds silts and fluvial sandstones), marls, and lacustrine to marine limestones, the thickness of which may reach 4 km at outcrop. The stratal architecture along evaporite walls records the progressive downbuilding of the minibasins, showing strong rotation of beds, unconformities and local interaction between evaporite extrusion and sedimentation. Within the basin, the stratal record shows thinning and spectacular angular unconformities, which are regionally observed and mark the major phases of basin development. The core of the basin displays typical Wall-and-Basin-Structure (WABS) characteristic of minibasin development above a thick salt layer. The stratigraphic pile records several major phases of allochthonous evaporite canopy development, associated with important rotation of the minibasins. The observed geometries show striking similarities with the seismic data retrieved from the exploration of salt basins, such as the Gulf of Mexico (please refer to Ringenbach et al., 2013).

## **Introduction**

Recent progress in seismic acquisition and imaging of salt-tectonic structures allows investigation of near- and sub-salt structures. Classic field examples for comparison with buried oil-bearing salt basin, deal with radial diapirs exposed in compressive settings and associated with halokinetic sequences such as in Iran, the Alps and Pyrenees forelands and La Popa in Mexico (e.g., Giles and Lawton, 2002). Welds (e.g., La Popa, Paradox Basin, USA), canopies (Axel Heiberg and Great Khavir desert in Iran) and minibasins (Flinders Range, Axel Heiberg) are less

common structures (Rowan and Vendeville, 2006; Jackson and Harrison, 2006). The finest analogues are the Axel Heiberg Island in the Canadian Arctic and La Popa in Mexico.

The Central Anatolia Sivas Basin was studied by academic teams over the last 70 years and interpreted in a thrust tectonics framework as part of the surrounding Taurides and Pontides mountain belts. The abundance of evaporites and their apparent complexity were shown to us in 2011 by the academic group working in the DARIUS consortium for paleogeography. The study of the basin as a salt tectonics analogue started in 2012, as a joint project between the University of Pau and Pays de l'Adour, the Sivas Cumhuriyet University, and Total SA.

### **Geological Setting**

The Sivas Basin ([Figure 1](#)) formed south from the Ankara-Erzincan ophiolitic suture. It is filled by highly deformed Paleocene to Quaternary sediments. The basin covers three major crustal domains: the Pontides belt to the north, the Kirşehir microblock in the middle, and the Taurides belt to the south. It developed in a context of continuing convergence related to the Tethyan closure. It is a composite flexural basin related to both southward thrusting of the ophiolitic sole from the suture zone, and northward thrusting of the Taurus block. An Eocene carbonate platform passing laterally to flysch was emplaced rapidly on top of the ophiolite. After the folding of the flysch and following the deposition of red clastics (Selimnye Formation), thick middle Oligocene evaporites were deposited during a relaxation/quiescence phase, likely involving low-angle normal faults. Compression resumed in the early Miocene, driven by the Arabian Plate collision with Eurasia, with thrusting.

The central zone of the basin exhibits salt-tectonic-related structures. It is subdivided into three domains separated by a paleohigh ([Figure 2](#)):

- A central domain which can be described as forming a wall and basin area with numerous continental Oligocene minibasins (about 15), truncated by a strong unconformity and overlain by lower Miocene shallow-marine marls. Middle Miocene lacustrine sediments were deposited above large evaporite stocks and unconformably on the tilted continental minibasins.
- A southern domain where the marine sediments are thinner and locally directly overlie the lower Oligocene Selimnye Formation. The fluvial formation that forms the bulk of the minibasin seems to be absent in the area. Folding and thrust tectonics are recorded in the upper continental Bendilkaya Formation.
- The northern domain characterized by thick, widespread evaporites is interpreted as an area of resedimentation of gypsum, partly flowing in a context of inversion of the central domain in the middle Miocene. The thick evaporite is equivalent to and is interbedded with the Bendilkaya Formation. This large evaporite layer has flowed and is the locus of present-day active minibasin.

Large volumes of gypsum are still preserved in salt walls, at the base and top of minibasins or as sheets while a certain amount of halite, responsible for the mobility, has been removed from the system. Halokinesis started during a regional tectonic quiescence, dominated by sedimentary load; initiation of minibasins was also controlled by the morphology of the basement. The main unconformity records a phase of evaporite exposure at surface, overhang and glacier formation, and rotation of minibasins; related to an increase of shortening. Most minibasins in the south and north have low-angle dips, whereas a strip of four well exposed basins has been strongly tilted and are in some cases vertical.

These four minibasins contain exposures of the finest known analogues of salt tectonic structures, the two most outstanding being Emirhan and Karayün.

### **Seismic-Scale Geometries: Direct Analogues**

The Emirhan minibasin ([Figure 3](#), see [Figure 2](#) for location) presents a ‘rocking chair’ pattern with growth strata along both sides. A strong evaporite flow toward the east of the basin resulted in a thickening of the lower fluvial reddish sequence to the west. To the east, the beds are conformable on the evaporites with important thinning and progressive unconformities. On the contrary, the western wall is diapiric with a clear cross-cutting relation between the remnant gypsum feeders and welds and the sediments. On this side and after complete rotation of Emirhan, a younger lacustrine minibasin sequence was deposited unconformably on the thick evaporite stock and the vertically dipping fluvial beds.

The Emirhan minibasin fluvial sequence terminates with a strong angular unconformity. Above it, the marine series records an eastward thickening. On this side, similarly to the western side, middle Miocene lacustrine beds overlie and truncate the evaporite stock and the fluvial series. The marked angular unconformity in Emirhan is considered a consequence of the main compression phase in the Sivas basin in the early Miocene: this accompanies the unroofing of the Taurus and shedding of ophiolite clasts incorporated in the conglomerates.

The eastern side of the Emirhan minibasin shows bedding which is conformable to the diapiric wall and which was dragged to form a 90° unconformity close to the evaporate; it wedges westwards to an angle of less than 10° to the unconformity, 200m away ([Figure 4](#)). The marine sediments onlap the marine conglomerates above the unconformity. To the south, the gypsum wall is discontinuous, alternating thick pillows and welds. Where the beds are dragged and markedly unconformable, the wall is welded. The setting is analogous to a seismic section from the contractional part of the Angola gravity tectonic system ([Figure 4b](#)). The well encountered a turbiditic channel beds below the salt canopy. Dipmeter data provide evidence of a structure comparable to the eastern structure of Emirhan minibasin. Three main dip domains are shown; the two lower ones mark the overturned limb of the mini-basin, the other one is just below the salt, marking an unconformable sequence and thus mimicking the geometries observed in Emirhan

### **Sub-Seismic Geometries: Field Observations Are Better Than Seismic.**

Minibasin growth is recorded by angular unconformities and bed rotation along the basin boundaries with the salt feeders. These halokinetic structures are rather well imaged on seismic at minibasin scale. However, local unconformities, hook or “J” structures occurring in the vicinity of diapirs boundaries, and welds (commonly located beneath salt overhangs or canopies) cannot be imaged properly even with the most recent seismic acquisition; they require dipmeter data.

Many examples of both growth and halokinetic sequences can be seen at various scales in the Sivas minibasins ([Figures 2 and 3](#)). Again, the best outcrops are located along the lateral edges of the Emirhan minibasin. The wedges and associated unconformities record the interplay between sedimentation and salt movement. When evaporite flow dominates, previously deposited sequences are folded and truncated, forming unconformities, in some cases covered by spreading salt tongues. One example of halokinetic growth sequences is shown on [Figure 5](#) (see

location in [Figure 2](#)). Here, growth strata show an apparent 90° rotation within the basal fluvial series, related to the deflation of the adjacent feeder.

It shows a sedimentary sequence prograding onto the gypsum body when the sedimentary deposition rate was higher than the diapir growth rate. Following a decrease in the deposition rate relative to the diapir growth, folding of the sequence occurred, ending with the truncation of the folded layers, and deposition of a new sequence. The angular unconformities form bounding surfaces which separate coherent packages of halokinetic sequences, defined by Giles and Lawton (2002) as “relatively conformable successions of growth strata genetically influenced by near-surface or extrusive salt movements.” The bulk of the pillow is composed of blocky crystalline translucent gypsum (arrow head) and it is often rimmed by a layer of saccharoidal gypsum (light color in [Figure 5](#)).

### **Summary**

The Sivas Basin (Turkey) is an Oligo-Miocene basin developed in an orogenic context above the Neotethys suture zone. A thick evaporitic sequence deposited during a mid-Oligocene quiet period between the Taurus and Pontides collisional belt. Erosion of the Taurus Mountains shed clastic sediments northward over the evaporitic basin, forming minibasins and associated evaporite diapirs and walls. During the main shortening phase in the early Miocene, gypsum overhangs and allochthonous sheets were emplaced in the basins. Most of the classic salt-tectonic geometries associated with the development of diapirs are strikingly well exposed; namely, halokinetic sedimentary sequences along diapir walls, welds, and evaporite glaciers and sheets, minibasins, and overturned turtle wings. These exposures rank as the finest field analogues for classical petroleum provinces controlled by salt tectonics, such as in the Gulf of Mexico and Angola.

### **Next steps**

Classical detailed mapping and logging of the series will be conducted with high resolution satellite images along with field work to address the geology of the minibasins, growth and halokinetic sequences, unconformities, etc. It is likely to enhance the tectono-sedimentary concepts developed in other salt basins, such as La Popa and the Flinders Range (e.g., Giles et al., 2004).

Ages and chronology of events are the most problematic issues. Detailed sequence logging, which has started, shows a striking similarity of sedimentary succession from one basin to another, but to date, no fossils have yet been found in the lower fluvial formations, and we hope magnetostratigraphy will help date and correlate these levels. A fine chronostratigraphy would help quantify evaporite movements. A second issue relates to the integration of this salt basin into the regional geodynamic setting, dominated by shortening of this area in a general foreland setting. In particular, the role of the basement geometry and structuration appears to be a key control exerted on basinal development, and future deformation.

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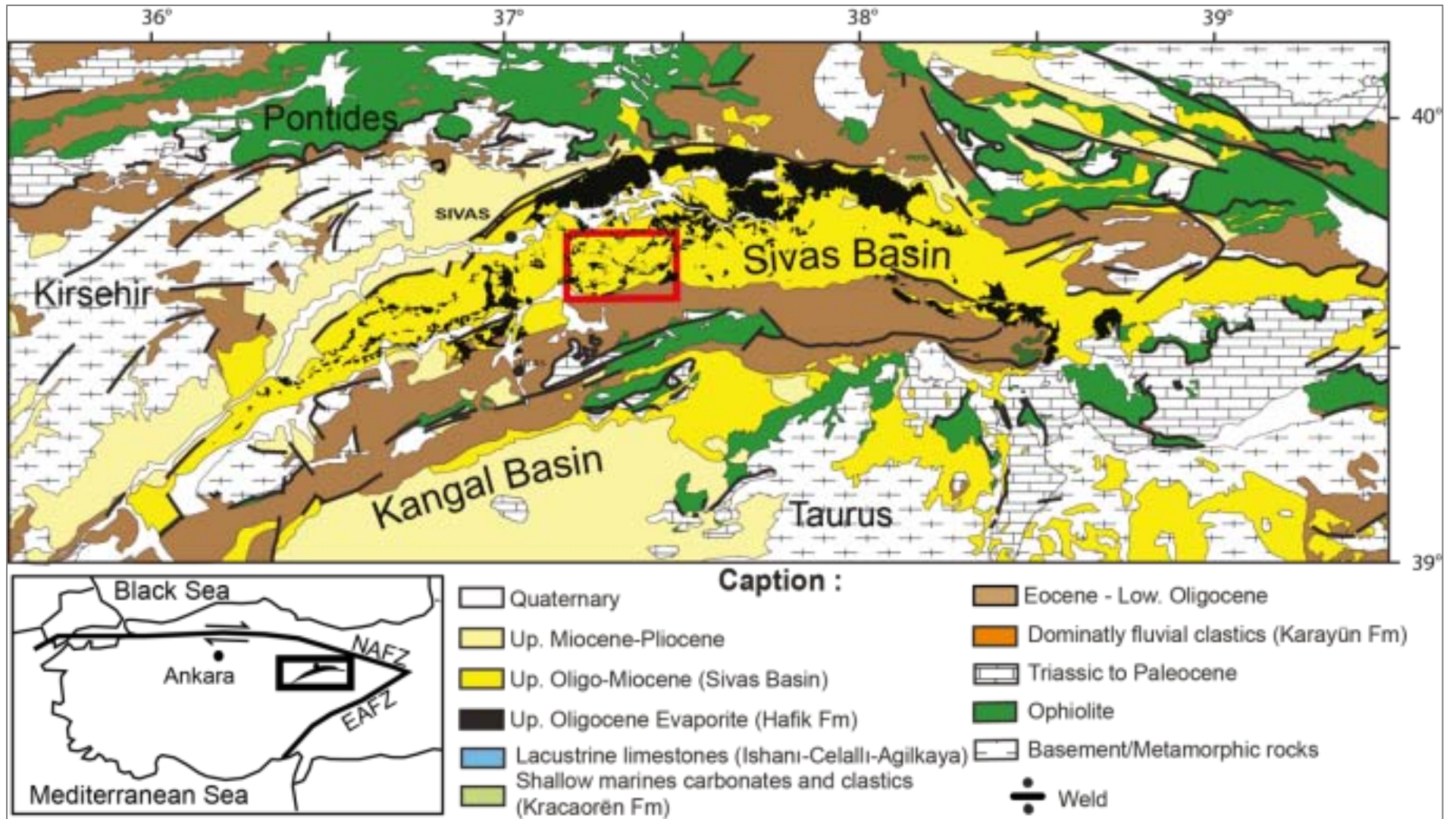


Figure 1. The Sivas Basin in its complex central Anatolia orogenic setting. NAFZ: North Anatolian Fault Zone; EAFZ: East Anatolian Fault Zone.

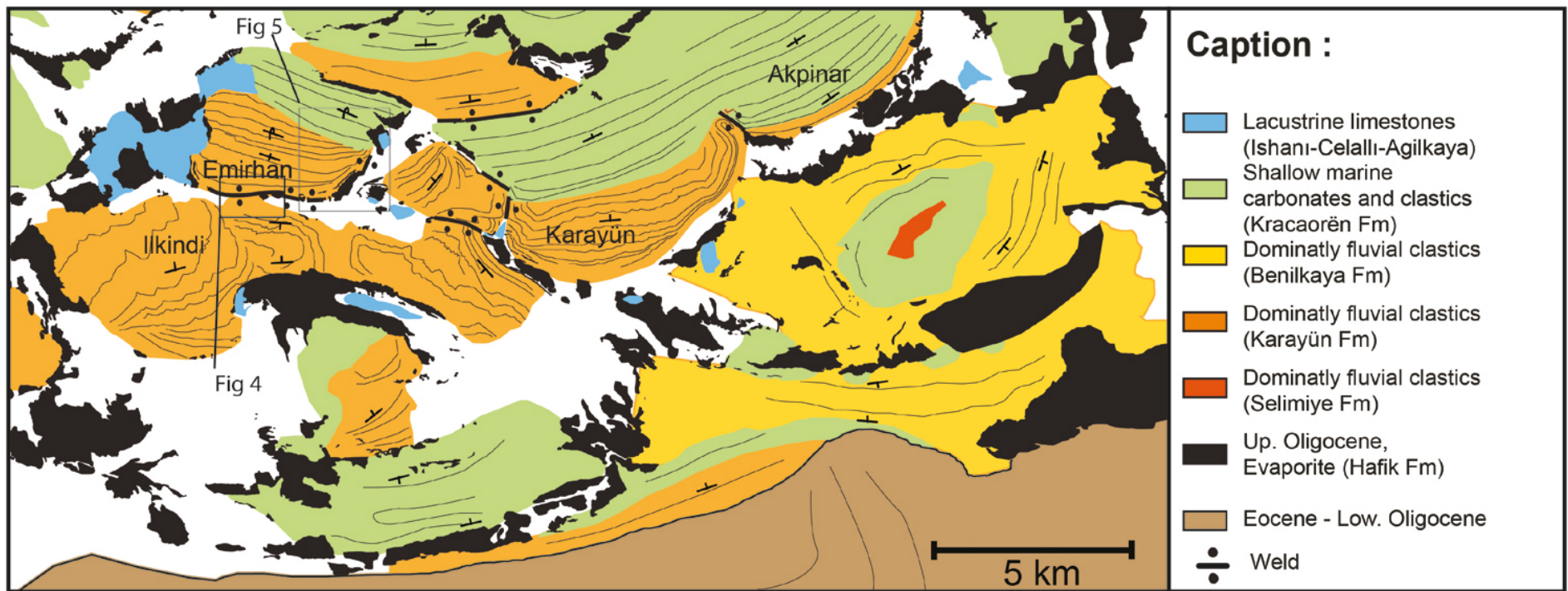


Figure 2. Detailed geologic map of the central Sivas Basin. The wall and basin central area, showing the most impressive minibasins and salt-related structures.

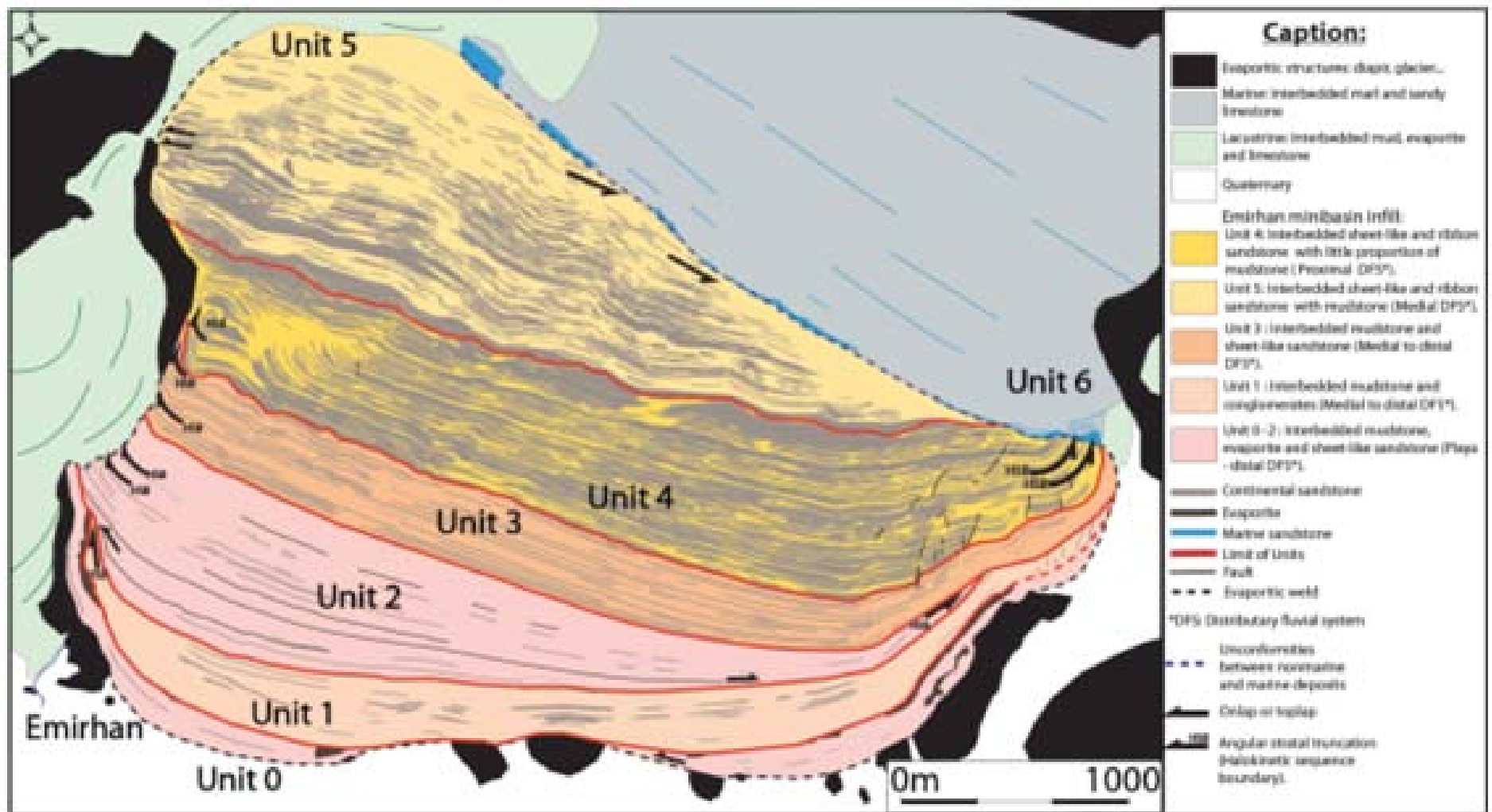


Figure 3. Aerial view and line drawing of the Emirhan minibasin deposits. A-G: Successive sedimentary succession (see text for explanation).



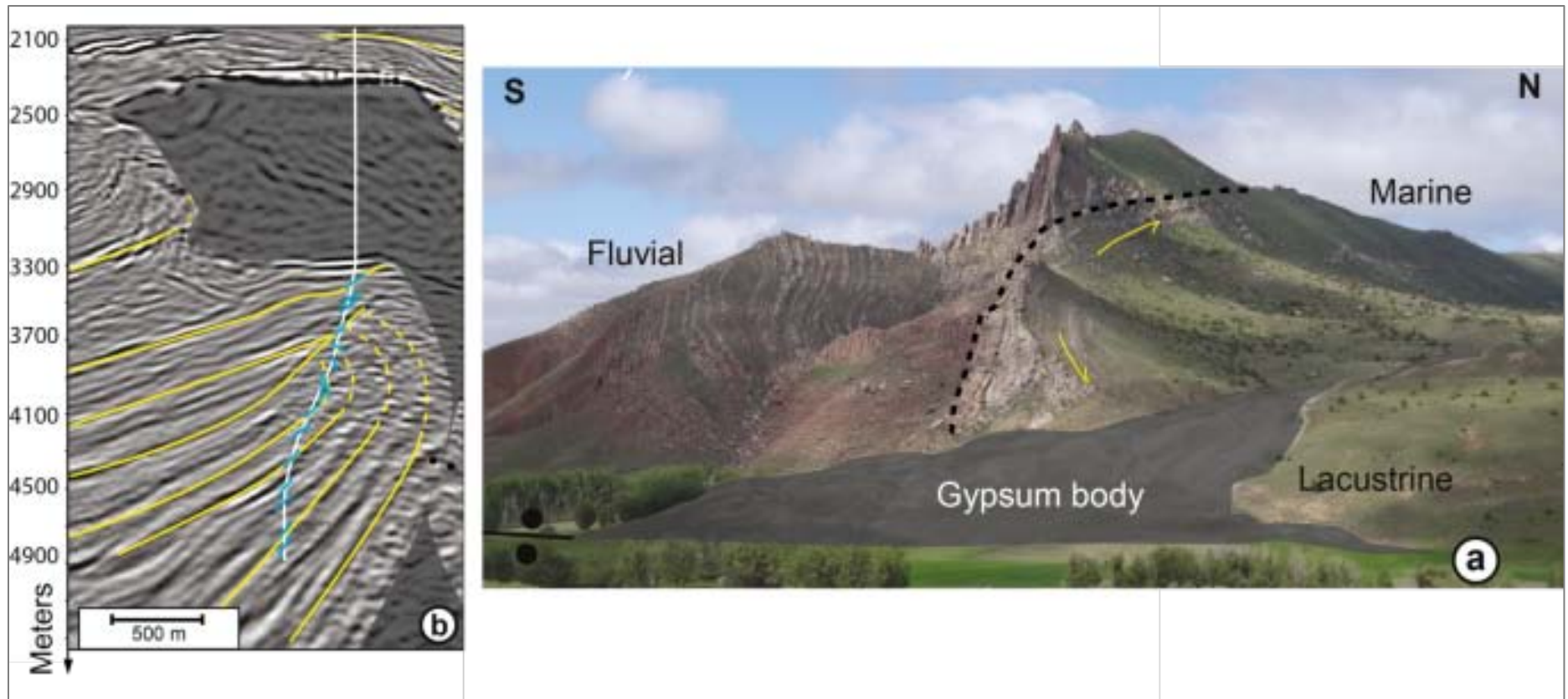


Figure 4. (a) Growth strata and unconformity in the east of the Emirhan minibasin. (b) An analogue geometry in the deep offshore Angola constrained by dipmeter data in the well (modified from Ringenbach et al., 2013).

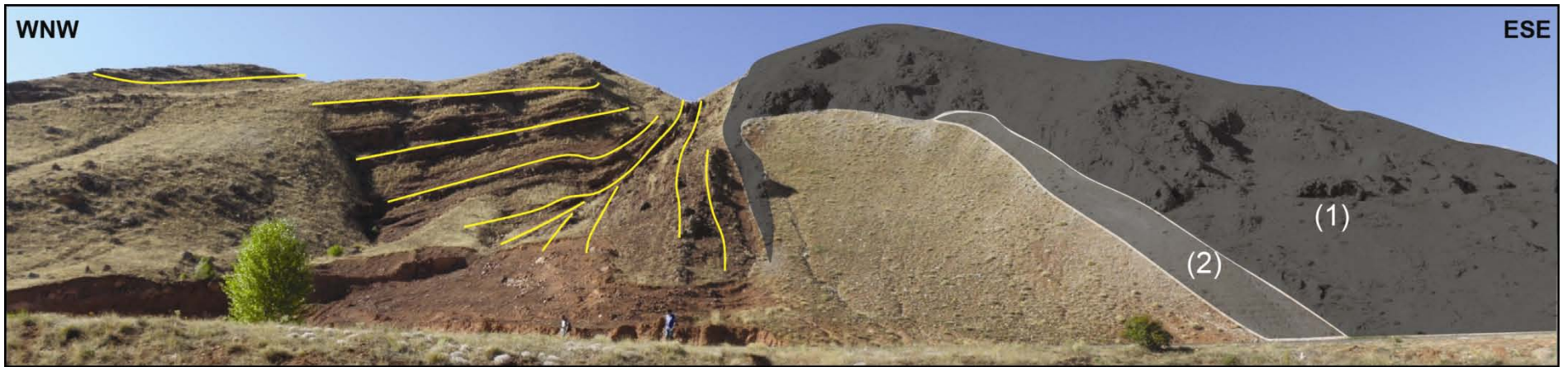


Figure 5. Feeder and halokinetic sequence at the boundary between the south Emirhan and Ilkindi minibasins. (1) Massive gypsum forming the remnant of the diapiric body; (2) Fine-grained, strained gypsum forming the body limit.