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EVIDENCES OF DUCTILE DEFORMATION IN EVAPORITES AROUND ZARA AREA (E SİVAS), SİVAS BASIN

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ABSTRACT.- A series of ductile deformation evidences and large-scale tectonic lines which remain enigmatic in the light of rigid tectonics principles were observed around Zara and Bolucan areas in the Sivas basin. One group, the evaporite walls which are closely related with the Oligocene-Lower Miocene evaporitic levels, traverses the basin for 30-40 km in an approximate E-W direction. Throughout the contacts, vertical to overturned evaporitic rocks face with the younger sediments as well as with thrusts and folds. Evaporitic diapirs of varying sizes, and basement and cover rock inclusions in the order of several 100's meters to km constitute the smaller scale second set of evidence of this kind of deformation. The available stratigraphic and tectonic data lets us suggest that the ductile deformation occurred subsequent to the N-S compression. Also speculated, that the areal extension of the Oligocene-aged Hafik gypsum is of utmost importance and the basaltic volcanism appeared in late Miocene may well be a factor decreasing the viscosity of evaporites and hence accelerating the phenomenon.

INTRODUCTION

Earth's crust, and especially sedimentary basins which could be appreciated as a memory for the processes operating on it, comprise rock-stratigraphic units of differing Theological properties. Sedimentary rocks within basins become unstable through the ongoing subsidence and some upward moving gravity structures occur mainly due to their different physico-mechanical response to stresses. The most common examples of this group of structures are salt walls and diapirs, serpentinite piercements, granite and gneiss domes and peat diapirs (Talbot, 1977).

One of the most important parameters in the course of development of upward moving gravity structures is the viscosity of source level (i.e. the sedimentary level moving, flowing upward). Low viscosity, as perceived after peat, salt and serpentinite diapirs, makes the process easier. Some other additional factors reducing the viscosity of sedimen-. tary series, for example a volcanic heat source and free water in salt tectonics, can speed up the. process (Jenyon, 1991-). A second important parameter is the density differentiation between the source level (low density) and the cover rocks (high density). In this case, a gravitational reversal comes about, and in conjunction with the viscosity parameter, the process can initiate. On the other hand, some other secondary factors (for instance, existence of regional tectonic stresses, differential loading resulted from the thickness variation of cover rocks, geometry of source layer, lateral density and viscosity changes of cover and source rocks, etc.) do play important roles in triggering the process and also determine the ultimate geometry of the structure (Talbot, 1977).

The most common and satisfactorily studied upward moving gravity structures are the salt structures. Fundamental cause of these structures is the physico-mechanical behaviour of certain salts (such as halite, silvite and carnallite) interbedded with the other evaporitic deposits. Halite, probably the lightest mineral (d=1.6 gr/cm^3) in nature keeps its low density constant while the surrounding rocks consolidate and get rid of their pore waters and hence become denser. During this early stage, when the sedimentary load over the salt horizon exceeds the values 1.8-2.7 x 10^5 kg cm$^{'2}$, it's no more *a* rigid body, but becomes ductile and flows (Richter-Bernburg, 1980).

At the early stage of ductile deformation, salt moves towards the gentle anticlines which are developed at the salt-overlying sediment boundary, by means of buoyancy or differential loading, or tectonic forces if the regional context is suitable, and builds the salt pillows. Mean wavelength of the known examples of salt pillows ranges 7 to 15 kms (Jackson and Talbot, 1986). If the main salt level is thick enough, the flowage towards the low-stress fields continues and consequently, salt stocks and walls can develop. As the process still goes on the chimneys feeding the stocks may become narrower and finally cut away resulting in the detached diapirs. Salt stocks and walls may rise as high as 5-10 km from their primary stratigraphic levels, including some rafts (i.e. rigid blocks of surrounding rocks) and they even flow on the earth's surface (Kent, 1979; Talbot, 1993).

Occurrence of extensive evaporitic deposits in Tuz gölü and Sivas basins has been known for a long time. Some geophysical and geological studies revealed the existence of 100 km long salt walls along the SW margin of the Tuz gölü basin (Uygun, 1981; Uğurlutaş, 1975). In the same basin, a borehole was drilled penetrating more than 1300 m within a diapiric salt structure (Turgut, 1978). As for the Sivas basin, ductile deformation generated within the Oligocene-aged evaporitic rocks has catched the researcher's attention since the early times (Nebert, 1956). Later, an oil exploration drill-hole (Celalli-1) performed by MTA in the central part of the basin traversed several thousand meters of evaporitic rocks. A 100 m thick rock salt level was also proved in the hole (Gedik and Özbudak, 1974). In the near past, some geological mapping studies at the south of Sivas city, clearly indicate some domal structures in evaporites (Gökçe, 1989-1990) while Yılmaz (1994) urged a direct relationship of salt tectonics with the end-Miocene regional tectonic framework. In another study, very great appearent thickness and massive appearence of the Oligocene-aged evaporitic Hafik formation was related with diapirism, and some diapiric bodies were mapped (Poisson et al., 1996). Lastly, a doctoral thesis performed by Çubuk (1994) in the İmranlı area to the east arid Karayün area at the center of the basin indicates the occurrence of very large scale salt structures and these are thought to be connected with the halokinesis driven by extensional regime in the basin.

In the present study, some structures intervening the evaporitic rocks are presented from Zara area. These structures are generally discordant with the compression-related element and are thought unlikely to be explained by means of rigid tectonics principles.

Presentation is arranged so that stratigraphy of the basin summarized at first hand with a special emphisis on the stratigraphic position and expand of evaporitic successions. Secondly, the tectonic style and resultant Jectonic elements are briefly explained. Finally, ductile deformation evidences in evaporites and their liasons with the regional tectonic framework are evaluated.

GEOLOGICAL OUTLINE OF THE SİVAS BASIN

Sivas basin is situated at the eastern part of the central Anatolia where three main tectonic units, namely Pontides, Kırşehir block and Taurid platform converge to each other (Fig. 1). The proposed geotectonic evolution schemes for the basin differ greatly. To Görür et al., 1984 the basin developed on the oceanic lithosphere and evolved as a forearc basin in relation with the closure of the Neo-Tethys. Yılmaz (1994) and Yılmaz et al., 1995 consider the basin, on the other hand, as a postcollisional one following the late Maastrichtian continental collision. Poisson et al., 1996 proposed a foreland setting for the basin, and Cater et al., 1991 supported this interpretation as supposing the occurrence of nap movements from south to north.

The oldest rocks covering unconformably the Taurid platform are of Maastrichtian-Paleocene aged shallow marine to continental deposits (Özgül and Turşucu, 1984; Yılmaz and Özer, 1984). Eocene is represented by olistostromal levels as well as lava-pyroclastics bearing turbidite

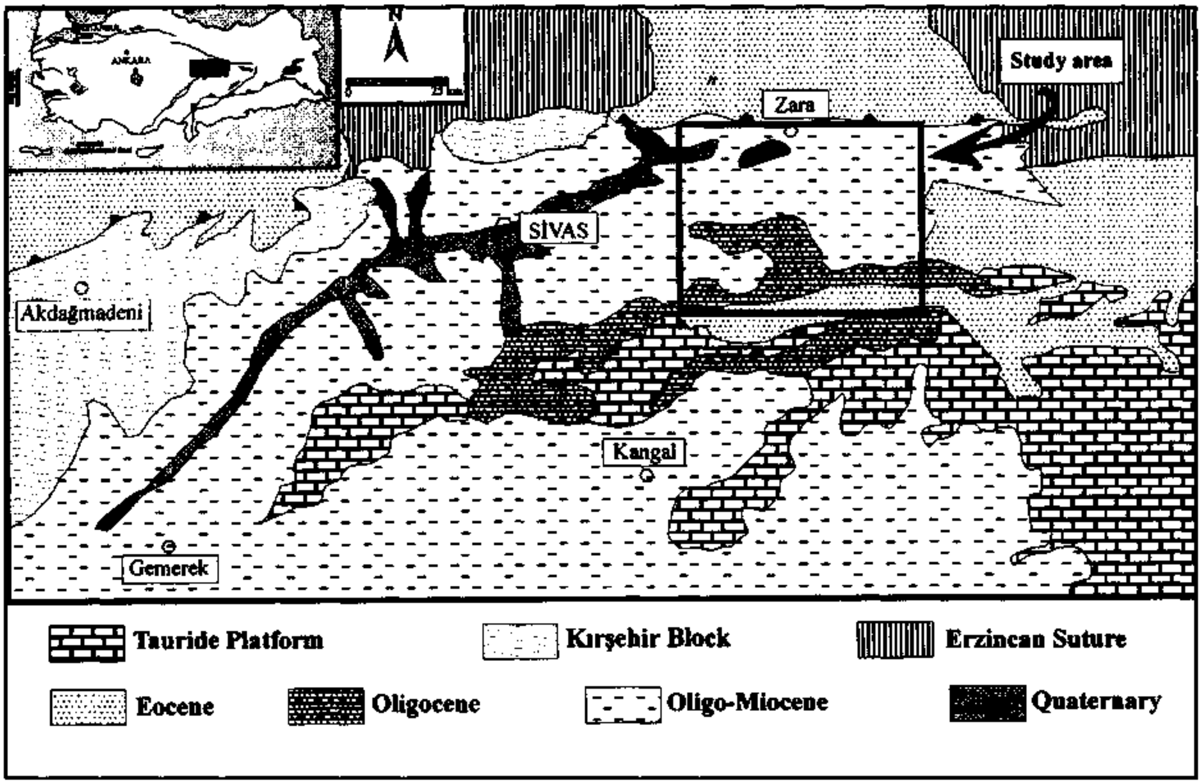

Fig. 1- Location map and main tectonic units of the study area (Simplified after the Geological Map of Turkey of scale 1/2.000.000).

sequences at the south (Kurtman, 1973), whereas the northern area was still dominated by shallow marine carbonate deposition and widespread volcanic activity at that time (Gökten and Kelling, 1991).

A regional marine regression at the end of Eocene resulted in the deposition of evaporites along the southern part of the basin. Oligocene rocks are continental *As* a whole at the west (Sümengen et al., 1987) whereas shallow marine to continental at the central areas (Gökçen and Kelling, 1985). Miocene witnessed a transgression developed from east towards west as far as Sivas city. After the early Miocene sea abondoned the region, widespread continental detritics and evaporite deposition developed and just afterwards the whole basin fill was deformed by a tectonic paroxysm (Kurtman, 1973).

STRATIGRAPHY AND POSITION OF EVAPORITIC LEVELS

The Eocene terrigenous sequence makes the oldest sedimentary rocks extending in an E-W direction along the southern part of the study area (Fig. 2). This detrital sequence becomes more and more shallower upward, gradually passing firstly to fan-delta deposits and then gypsum-bearing sediments (Çiner, 1995). Oligocene deposits (i.e. Selimiye formation) were represented by red to green colored detritals and less commonly by evaporites and carbonates at south (Fig. 3). It seems that the thickest (100 m) evaporitic body in Selimiye formation passes laterally northward to main evaporitic unit of the study area, namely Hafik formation. Around the Bolucan at the east, there are salty water sources leaking from the main evaporite level in Selimiye formation. The base of the Miocene, perhaps the uppermost part of Oligocene as sup-

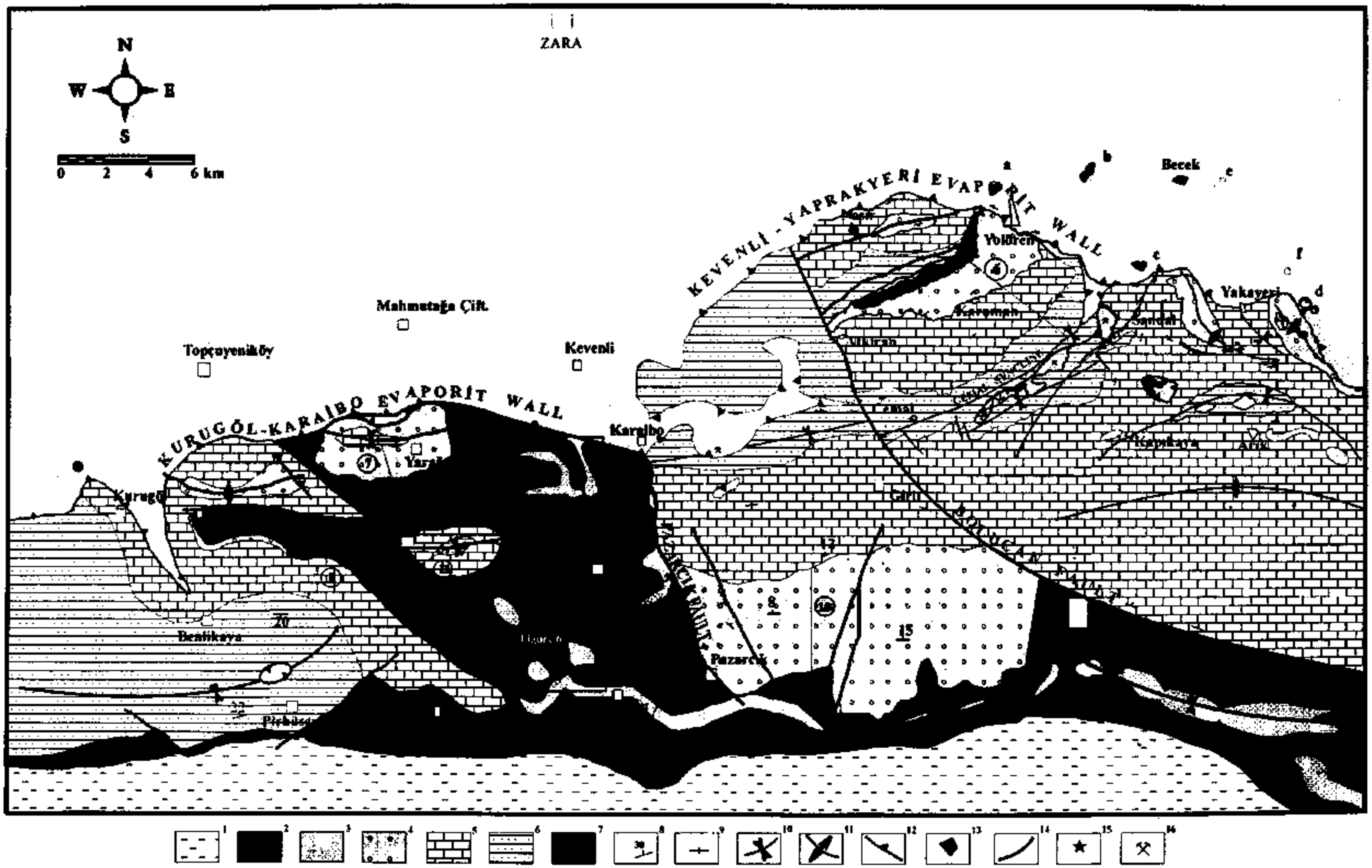

Fig. 2- Simplified geological map of the study area. 1- Eocene detrital sequence, 2- Selimiye fm. (Oligocene), 3- Hafik fm (Oligocene). 4- Karayün fm. (Mio.), 5- Karacaören fm (Mio.). 6- Benlikaya fm. 7- Volcanics. 8- Dip and strike of bed. 9- Vertical bed. 10- Syncline, 11- Anticline, 12- Thrust. 13- Village, 14- Fault. 15- Salty water source. 16- Celestite mineralization. for letter a-f refer to the text.

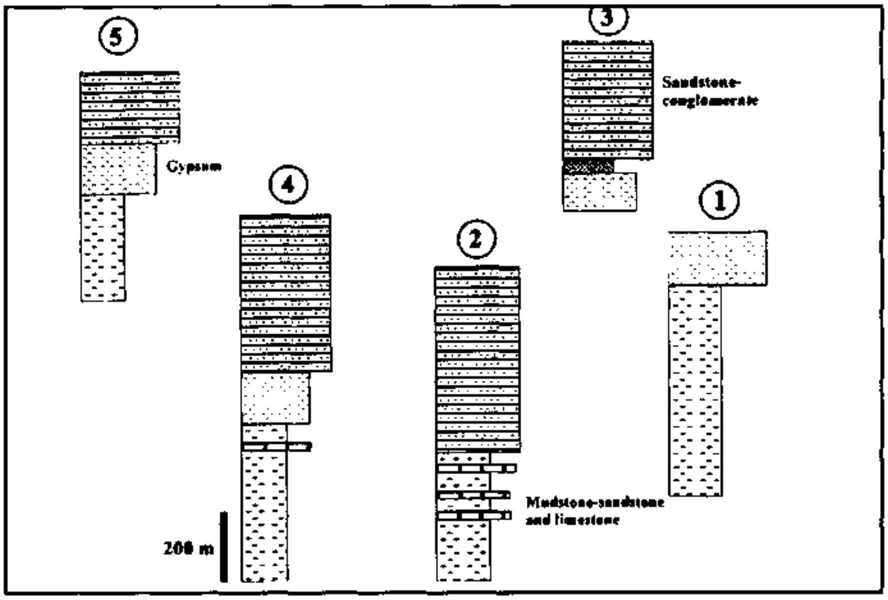

Fig. 3- Columnar stratigraphic sections of the Oligocene deposits in the study area (For section locations refer to figure 2).

posed by Poisson et al., 1996 was occupied by Karayün formation (Fig. 4). This unit is composed of mudstone and gypsum at the SW areas (around Yaragıl and Hıdıroğlu villages) and is not deposited southwards (around Selimiye and Tuzlagözü villages), perhaps due to a tectonically controlled uplift (Ocakoğlu, 1977). The uppermost part of the Karayün formation is made up of mudstone and gypsum which were probably deposited in a coastal plain setting.

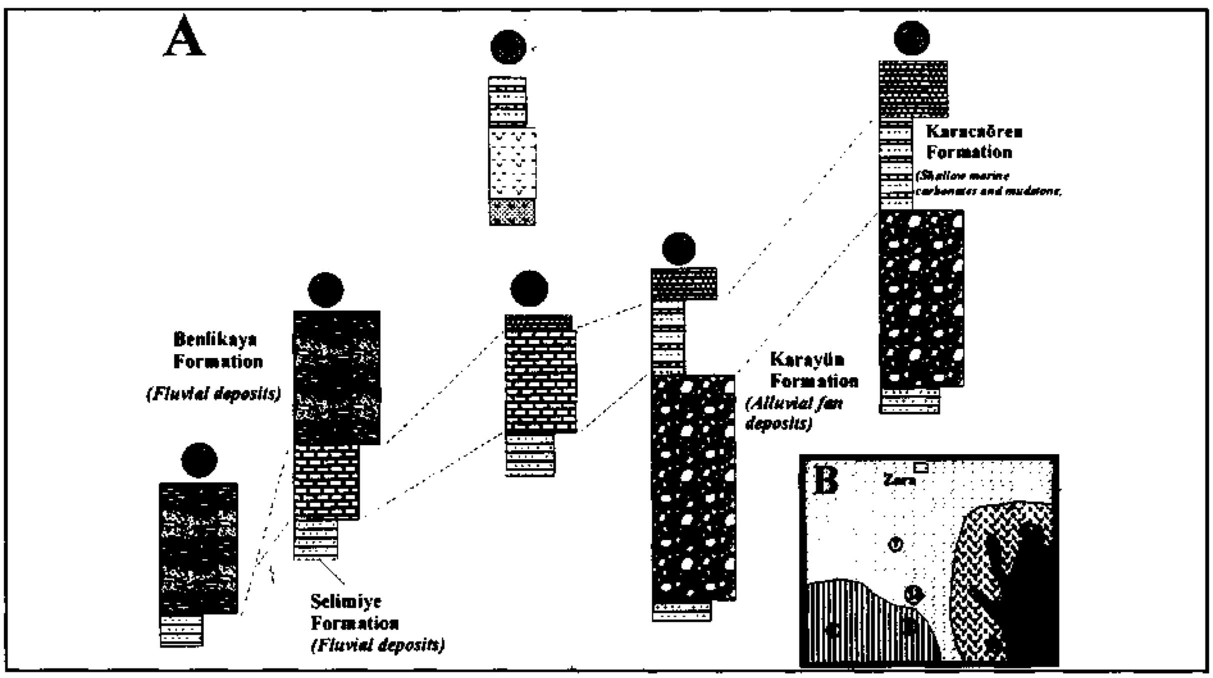

Fig. 4- A-Stratigraphic columnar sections of the Miocene deposits in the study area, B-Paleogeographic reconstruction just before the deposition of the Karacaören formation (for section locations refer to figure 2).

At the beginning of Miocene (Aquitanian), a marine transgression developed and the older continental deposits became submerged. As a result, a stratigraphic record which was deposited in a variety of environments ranging from coastal plains to open shelf has been yielded (Ocakoğlu, 1997). Within this mainly marine sequence, 10 gypsum levels with thicknesses of 1-6 m was deposited in coastal sabkhas. The uppermost part of the Miocene record in the study area is again occupied by fluvial deposits and partly by evaporitic rocks (around Pirhuseyin village). Basal relation of these rocks with the underlying marine sediments are low-angle unconformity at the south (Around Keller village), whereas conformable at the central part of the region.

In summary, it can be suggested that there are 4 well determined evaporitic levels in the investigation area. From older to younger, these are;

1. Gypsum, forming the bulk of Hafik formation. These are probably thickening from south to north due to complex depositional transitions.

2. Gypsum occupying the uppermost levels of the Karayün formation.

3. Evaporites, found at the lower section of the marine Karacaören formation, which probably formed in coastal sabkhas.

4. Gypsum, forming the uppermost part of the fluvial Benlikaya formation.

STRUCTURAL GEOLOGY OF THE SOUTHERN ZARA AREA

It would be possible to categorize the structural elements of the study area, following the aim of the study, as the elements observed in the cover rocks of evaporitic Hafik formation (which are the overlying terrigenous and carbonate rocks), and the ones observed in evaporitic rocks (mainly Hafik formation). While the first group was chiefly resulted from the N-S compression, the second group was originated due to ductile behaviour of evaporites within general tectonic framework.

Tectonic elements on the cover rocks

These are E-W trendmg fold axis and south . verging thrust faults, and NE-SW and NW-SE trending strike slip faults, all of them were possibly resulted from regional N-S compressional framework.

E-W trending folds are frequently observed in the Miocene sediments outcropped around Arık and Nasır area to the east and northeast, Tuzlagözü and Benlikaya to the west (Fig. 2). Arık syncline, which is a slightly assymetric and south verging structure has a convex-to-north geometry. These originally E-W trending structures like Arık syncline to the northeast are rotated by two major faults (Bolucan and Sandal faults) of NE-SW and NW-SE trend respectively (Fig. 2). Two thrust faults which are supposed to be E-W trending before rotation are situated to the south of Yolören village. The Yolören thrust, at the north, corresponds to a detachment surface found at the bottom of the gypsum. From thrust line to the Cemal synclinal axis to the south, Miocene sedimentary sequence shows no tectonic disturbance. Cemal thrust which is 7 km away towards the south is also dipping to the south and surrounded by drag synclines on both sides (Fig. 2).

Tectonic lines cutting the E-W trending fold axis and thrust faults in an oblique manner are especially prominent at the south of the study area. Some of those faults have no appreciable normal slip, some others (such as Bolucan faults and neigbouring NE-SW trending smaller fault) have great vertical offsets. The 600 m thick Karayün formation around Bolucan area is abruptly terminated in front of Selimiye formation due to this structure.

Ductile deformation evidences in evaporites

Kevenli-Yaprakyeri evaporite wall.-It begins around Kevenli village at the center of the study area, and extends towards the east for 30 km in a more or less E-W direction with indented pattern (Fig. 2). Gypsum beds of Hafik formation at the contact are nearly vertical. To the south of Sandal village they even thrust over Miocene sediments by an angle of 30°. Another surprising point related to this tectonic element is that a several hundred meters sized block belonging to Selimiye formation which is also clearly seen at the base of the thrust fault around Yolören village (Fig. 2 and 3) crops out within the Hafik formation as the prolongation of the mentioned thrust (Fig. 2, a). This situation may be interpreted so that horizontal offset is negligible across the evaporite wall. Another point is that, near the thrust line around Yakayeri village there are two elipsoidal gypsum blocks of several hundred meters in diameter (Fig. 2, d) "floating" in the background Hafik formation.

Kurugöl-Karaibo evaporite wall.- It enters from the western limit of the area and extends at the south of the Atkıran village for about 40 km (Fig. 2). To the east of Karaibo, both limps of the ancient evaporite ridge are well seen. To the west, around Kurugöl, Hafik gypsum makes an insertion into Miocene sediments towards the south. In this sudden diversion of the evaporite wall, effects of tectonic elements are supposed, but their continuation towards the further south (Benlikaya village) is not prominent. At the west of Karaibo which also corresponds to the southern evaporite wall (Fig. 2 and 5) an evaporite level of 100 m thick Hafik formation exhibits a complicated folding pattern. Frequent thickening at the fold axis and some isoclinal folds are thought to be several indicators of ductile deformation in these evaporitic bodies. To the east of Karaibo, on the other hand, gypsum bodies belonging to Hafik formation insert into the Miocene sequences (at least 1500 m thick) and reach at the surface and spread out slightly. Two kilometres away from the evaporite wall southward, the evaporite wall extends down there passing over the Cemal syncline (Fig. 2).

Diapiric evaporitic stocks.- Those are ellipsoidal bodies which diapirically emplaced into random levels. Some of them have no clear connection with the faults and folds related with the regional compressional regime. As an example, at the south of Bolucan, 4-5 evaporitic stocks occur 750-1500 m away in the dip direction of 100 m thick evaporitic level of Hafik formation (Fig. 6). At the centre of

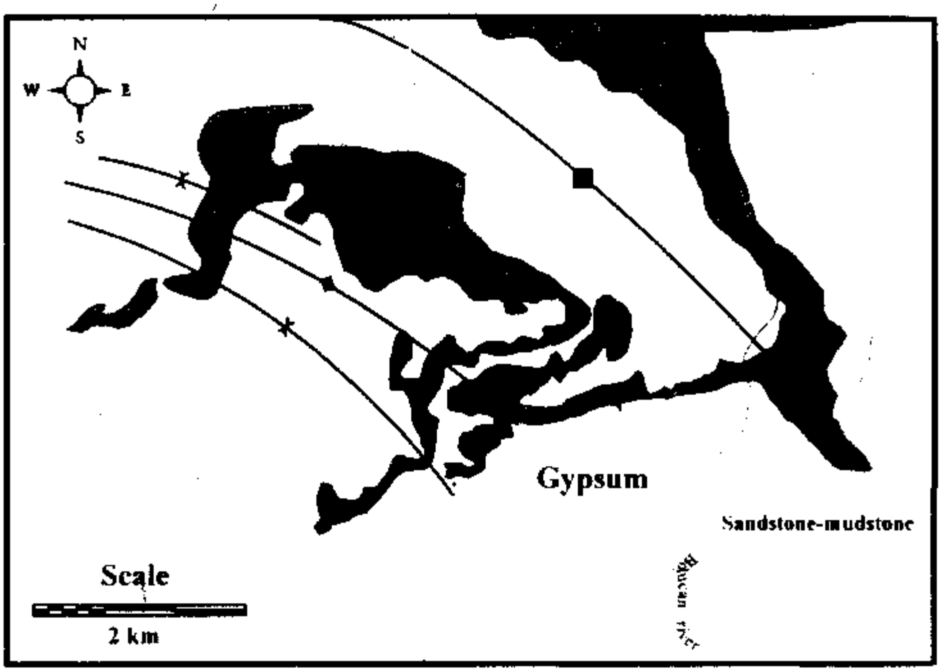

Fig. 5- Ductile deformation structures in evaporites around SW Karaibo (note the isoclinal folds and thickening at synclinal axis).

these stocks some burried salt levels may be found. Additionally, the indentation (about 400 m) on figure 6 (indicated by an arrow) seems likely an evaporite wall inhibited in its initial stage of development. Gypsum bodies outcropped in the synclinal axis at the north of Arık village are two other well-developed examples of evaporitic stocks. These bodies are likely derived from the evaporitic levels found within the marine Karacaören formation. If so, they should be diapirically elevated more than 500-600 metres from their original stratigraphic levels. Lastly, at the west of Pirhuseyin village, the white colored evaporitic body of 1 km in diameter shows clear flowage characteristics on the air photographs (Fig. 2). It is thought to be derived from the lowermost levels of Oligocene sequence.

In addition to the examples given above, 3 gypsum stocks have been observed at the NE of the study area, in relation with the Cemal thrust. Two of them lean on the south-verging thrust line while the largest one spreads over the synclinal axis southeastwards (Fig. 2).

Inclusions of basement and cover rocks disseminated within the evaporites.- Randomly distributed basement and cover rock blocks within the evaporites make another set of evidence of ductile deformation in the region. At the north of Kevenli-Yakayeri evaporite wall, basement and cover rock blocks of different sizes are found within a wide evaporitic background. Two of them (about 400-600 m in diameter) observed at just north of Yolören village (Fig. 2, a and b) belong to Selimiye and Karacaören formations respectively. These blocks show only small internal deformation. Towards further east, at the north of Sandal and at the east of Yakayeri, is seen ophiolitic blocks this time (Fig. 2, c, f and e). The block at Düden is 20 m in diameter, and includes many fractures in the central part perhaps likely occurred during the previous history (Fig. 7). Close to the periphery, gypsum becomes to fill the fractures. More outward, large ophiolitic blocks become to be separated from the main body,

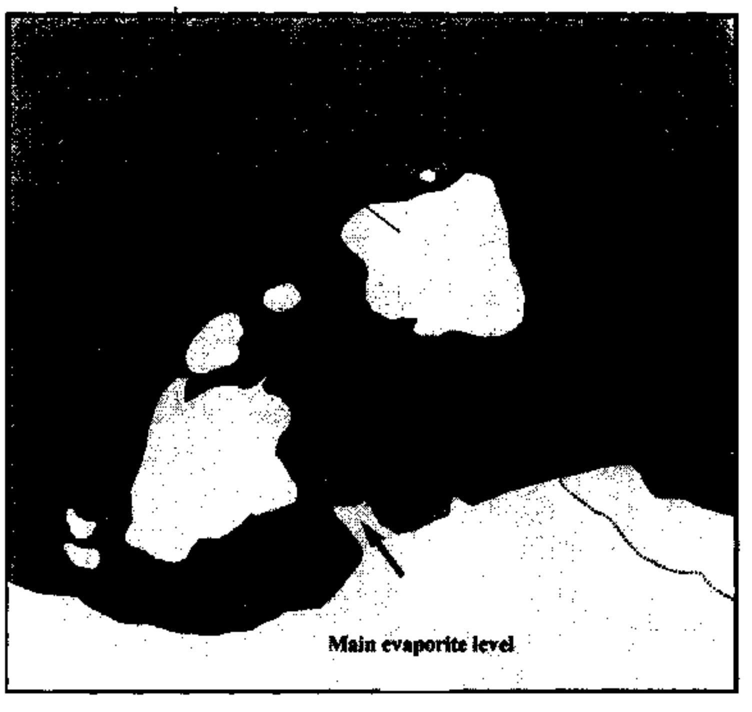

Fig. 6- Diapiric evaporite bodies in the Selimiye formation, south of Bolucan.

and emerge into the evaporitic matrix. Going more outward, rare smaller serpentinite gravels randomly float in evaporites.

All the examples observed in the study area remind us the huge (as big as 5 km) and dense inclusions appeared within the salt and evaporite complex of Hürmüz salt domes, reported by Gansser (1992). Weinberg (1993) indicated by

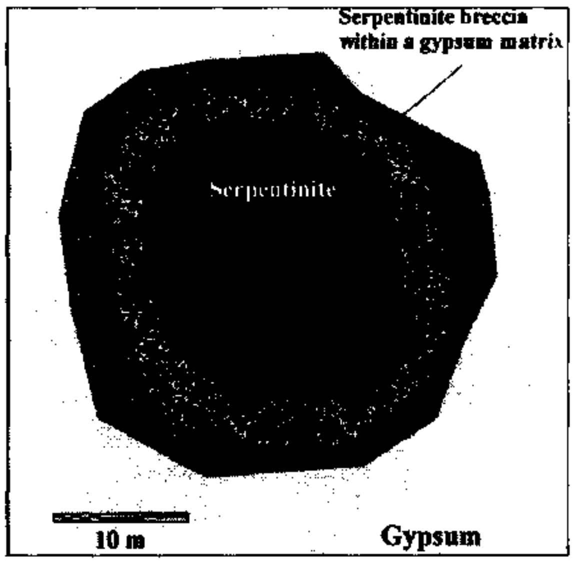

Fig. 7- Serpentinite block within the gypsum background at the east of Yakayeri.

using theoretical calculations, that those inclusions may be transported by diapiric salt movements exceeding the gravity forces of the inclusions. The observations realized in the study area indicate a similar mechanism so that the basement blocks incorporated within the dominantly evaporitic Hafik formation can be elevated upward by a ductile creep in evaporites.

DISCUSSION

Diapiric structures generated within evaporites which are observed in the study area and suggested to be widespread at the eastern part of the Sivas basin seem related with different physico-mechanical behaviour of especially evaporitic rocks and cover strata, as well as the late Miocene regional tectonic regime and distribution of evaporitic facies within the basin.

The study area which is situated at the east of Sivas basin was affected from heavy tectonic activity occurred in certain periods throughout the Oligomiocene. Both, structural elements (E-W trending fold axis and thrust fault, NE-SW and NW-S'E trending strike slip faults) and unconformities and great thickness variations observed between the sedimentary series are clues to the tectonic activity. Structural style and depositional distribution, as well as lateral facies relationships in the study area present a close similarity to that of Karayün area investigated by Cater et al., 1991. The authors urged that in Karayün area, Karayün sand bodies were transported towards the north by means of some by-pass zones determined by certain synsedimentary faults. So, they show rapid thickness variations in an E-W direction (Cater et al., 1991). According to these researchers, those N-S trending faults correspond to the lateral ramps of south verging thrust faults. In the study area, it is quite possible that the Miocene paleo-uplift which restricts the Miocene-aged Pazarcık alluvial fan from the west coincides with this kind of lateral ramp of a nappe.

In the study area, existence of a ductile deformation is evident from evaporite walls, numerous evaporite diapirs and floating alien blocks within the evaporites. In order to explain the effect of distribution of evaporitic rocks in the formational mechanism of the evaporite walls, schematic model in figure 8A is proposed for the stratigraphy of the region. The fundamental parameters in the model are thickness variations, density and viscosity of the Hafik, Selimiye and Karayün formations which have lateral transitions with each other and, that of the cover rocks. Although quantitative data obtained from the study area is lacking, it can be suggested from the previous studies that the Hafik formation which is also the source material for the diapirs in the region has lower density and viscosity with respect to neighbouring detrital rocks. It seems still difficult to asses how the model (which is likely unstable one) will behave under these conditions even if the regional tectonic stresses be ignored. Fortunately,

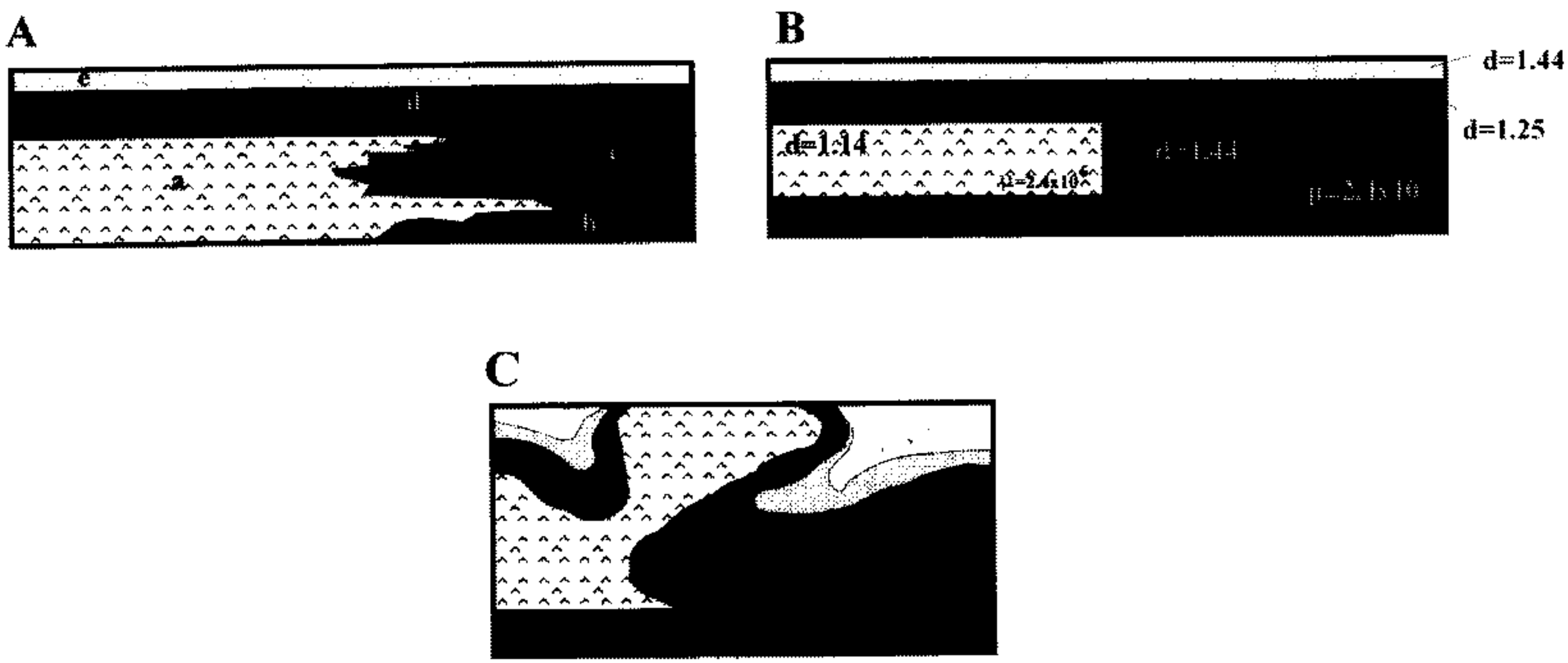

Fig. 8- A) Stratigraphic model developed for the study area. a-Hafik Fm. b-Selimiye Fm. c-Karayün Fm. d-Karacaören Fm. e-Benlikaya Fm.
B) Hypothetical model by Talbot (1977) and C) Deformation of Talbot's model under centrifuging (equal to a force of 2000 gr) for 150 seconds.

the response of a very similar model to the resultant stresses was experienced by Talbot (1977) by using artificial material (Fig. 8B). The result of Talbot's experiment is that low viscosity source rocks flow over the higher density cover elastics which are transient with the former. Meanwhile, the cover rocks are elevated and even truncated and then a dipping assymetrical upward moving gravity structure (diapir or ridge) results in. This experiment foresees conveniently the position and character of the two great evaporite walls in the study area. At the plan view, on the other hand, northerly situated and convex upward position of the Kevenli-Yaprakyeri evaporite wall, with respect to more or less E-W trending Kurugöl-Karaibo evaporite wall is drawing attention. It seems that the geometry of the Kevenli-Yaprakyeri evaporite wall is determined by the aerial distribution of PazarcIk alluvial fan system (Fig. 4B).

In this context, temperature parameter which was affected the viscosity of the Hafik formation should be seriously taken into account. In salt tectonics studies, a negative correlation has been stressed between temperature and viscosity of salt bodies. In other words, as thermal gradient increases, the flowage capacity of salt increases too (Jenyon, 1991). Jackson and Talbot (1986) indicated that anhidrite shows a similar trend. Under these given examples in the literature, it can be suggested that magmatic activity (mainly olivine sill and dykes cutting Oligo-miocene sediments) occurred at the end of Miocene does increase the flowage capacity of the evaporites. Due to the same magmatism, widespread celestite mineralization is formed within the Oligocene evaporites (Fig. 2). Majority of these mineralizations correspond to the allochthonous evaporitic zones indicated in this, study. Fluid inclusion studies on these mineralizations indicate the formational temperatures as high, as 350°C (Tekin et al., ,1994). It can be suggested that this high termal effect of magmatic origin, even be located in limited fracture zones, can reduce the viscosity of the evaporitic masses in the study area.

CONCLUSIONS

Timing of the ductile deformation observed in the evaporitic rocks can be summarized within the context of the structural history of the basin as following: Throughout the Oligo-miocene period, a depositional pattern occurs in the area so that terrigenous sediments situated mostly in the southern area while the evaporite system lies northerly (fig. 8A). At the end of the Miocene times, the whole area was subjected to a strong N-S compression, and as a result, E-W trending south vergent thrusts and assymetric folds formed. During the early phases of compressional deformation, Hafik gypsums serve as the weak (detachment) zones on which the thrusts were developed. Along these thrust faults, evaporitic rocks originally situated in very different levels in the sequence moved upward in a ductile manner. In this period, a basaltic volcanism expressing itself as sills and dikes inserted in different levels has also occurred and thermal nature of this latter possibly reduced in a certain degree the viscosity of the evaporitic rocks in the sequence. Deformation generated by regional tectonic compressional stresses likely continued by the NW-SE and NE-SW trending conjugate strike slip faults, and as a result, E-W trending previous structural lines have been partly rotated by these latter.

As an ultimate result of the N-S compression, crustal thickness in the basin increases and this thickenning likely triggered the main evaporite body (i.e. Hafik formation) to move upward in a ductile manner within the gravitationally unstable evaporite-terrigenous system. This upward movement of the evaporitic mass occurred at the plan view along an E-W line where the terrigenous-evaporite depositional transitions have been realized formerly. Some basement and cover rock blocks incorporated in the evaporitic body are also rised diapirically. Meanwhile, external erosive agents should rapidly truncate the topographically higher cover rocks above the rising diapiric mound, and after this load removal, on the other hand, diapiric uplift should be accelarated. In our opinion, the southern limit of this giant rising evaporite mass corresponds to the Kevenli-Yaprakpınar and Kurugöl-Karaibo evaporite walls in the study area. Towards the west, around SW of Sivas, where the general thrust fault pattern (i.e. south vergent, generally E-W trending faults) resembles very much to that of the study area, three anomalous north vergent thrust faults indicated by Poisson et al., 1996 between the Hafik gypsum and the southern terrigenous area can likely be related with the the rising evaporite body.

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