SEDIMENTOLOGY AND STRATIGRAPHIC SEQUENCE OF THE GAVKHONI PLAYA LAKE, SE ESFAHAN, IRAN

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ABSTRACT: The Gavkhoni playa lake is surrounded by alluvial fan deposits to the north, south and east and the Varzaneh aeolian sand field to the west. Four major sub-environments including: sand flat/saline sand flat, sand beach, mud flat/saline mud flat and salt pan and seven major facies can be recognized in this playa lake. Sand flat results from transportation of sand by wind from the adjacent sand dunes. The mud flat reflects rapid deposition on a lower flood plain during wet, shortly after sheet floods. The saline mud flat and salt pan is as a result of three stages: flooding, evaporation and desiccation. After flooding, when the shallow ephemeral lake becomes concentrated by evaporation, saline mud flat is formed and finally the formation of salt pan starts.

Regarding the sub-environments it is supposed that climatic changes played an important role in sedimentation. During periods of increased run off, sedimentation of alluvial/fluvial occurred and water table was raised at the playa lake. During periods of reduced run-off and falling water table, the saline mud flat and salt pan were formed and wind erosion of alluvial deposits resulted in formation of sand dune and sand flat.

INTRODUCTION

The Gavkhoni playa lake is located in an intramontane basin in central Iran, which is well developed parallel to the Zagros orogenic belt (Alavi 1994). This structural basin is as a supposed graben or half-graben system resulted from orogenic movements, volcanic eruptions at the end of Cretaceous and Early Eocene, and faulting which took place after the volcanism in some central parts of Iran, and also in the study area (Stoecklin 1968b in Berberian 1983).

The playa lake receives most of its water from Zayandeh river in the north. This lake is typical for many permanent lacustrines to saline lake basins within closed drainage basins in central Iran (Pakzad and Ajallocian, 2004).

Thus, stratigraphic record in this playa lake should be a good reflection of past climatic fluctuation and short-term and long-term changes of this depositional basin.

METHODS OF STUDY

Two drilled cores to the depth of up to 30 m and eleven vertical sections to the depth of up to 2 m, including trenches and pits, were utilized to study vertical and lateral activity and stratigraphy of sedimentary sub-environments. Lithostratigraphic-sedimentological sections were drawn based on vertical distribution of facies. For determination of mineralogical/lithological composition and finally provenance of sands thin sections of about 20 samples, were prepared and carbonate content of them (sand fraction) was undertaken using a chemistry method. For palaeontology studies, approximately 20 samples (sand and mud fractions) were washed through a 0.062 mm sieve. Dried residues were separated through sieves at half-phi intervals from 0.5 mm to 0.063 mm and then shells were picked by binocular microscope. Using Landsat TM images, and topographic maps (1:250 000 scale with 100 m counter interval) sub-environments and location of sampling were determined.

DEPOSITIONAL SUB-ENVIRONMENTS AND FACIES

Four major sub-environments and seven major facies can be recognized in this playa lake basin. They can be defined on the basis of texture, mineralogy, and evaporite to clastic ratio. Although sub-environments are distinct and can be mapped, their boundaries are usually gradational. They include sand flat/saline sand flat, sand beach, mud flat/saline mud flat, and a large salt pan (Fig. 1).

Sand Flat/Saline Sand Flat

The sand flat extends as a wide area in the east of the sand dunes. A few small sand dunes, covered by gypsiferous marl, occur on the sand flat. Two types of gypsum, acicular and zig-zag, occur. Acicular gypsum is usually present as interbedded with aeolian sand layers along the sand dunes in some localities. The gypsum layers are soft and friable, not more than a few centimeters thick. The zig-zag gypsum crystals are found dispersed. Based on four digged trenches (e.g location No. K in Fig. 1) up to 100 cm deep only facies medium to fine sand can be recognized.

Interpretation.– During dry periods, sand-sized clastic sediments are mostly deposited and gypsum is precipitated. The sand is transported by wind from the adjacent sand dunes and gypsum crystals are formed after saturation of water (cf. Kulke 1974). During flooding, fine-grained sediments (marl) were deposited. Interbedded sand and gypsum layers suggest periodic flooding and desiccation and deposition of wind-blown sand.

Sand/Gravel Sand Beach

Distinct and continuous sand/gravel sand beach occur in the northeast of the Zayandeh river delta and the east of the Gavkhoni playa lake as a long narrow zone. According to the study of two pits (locations No. B1 and B2 in Fig.

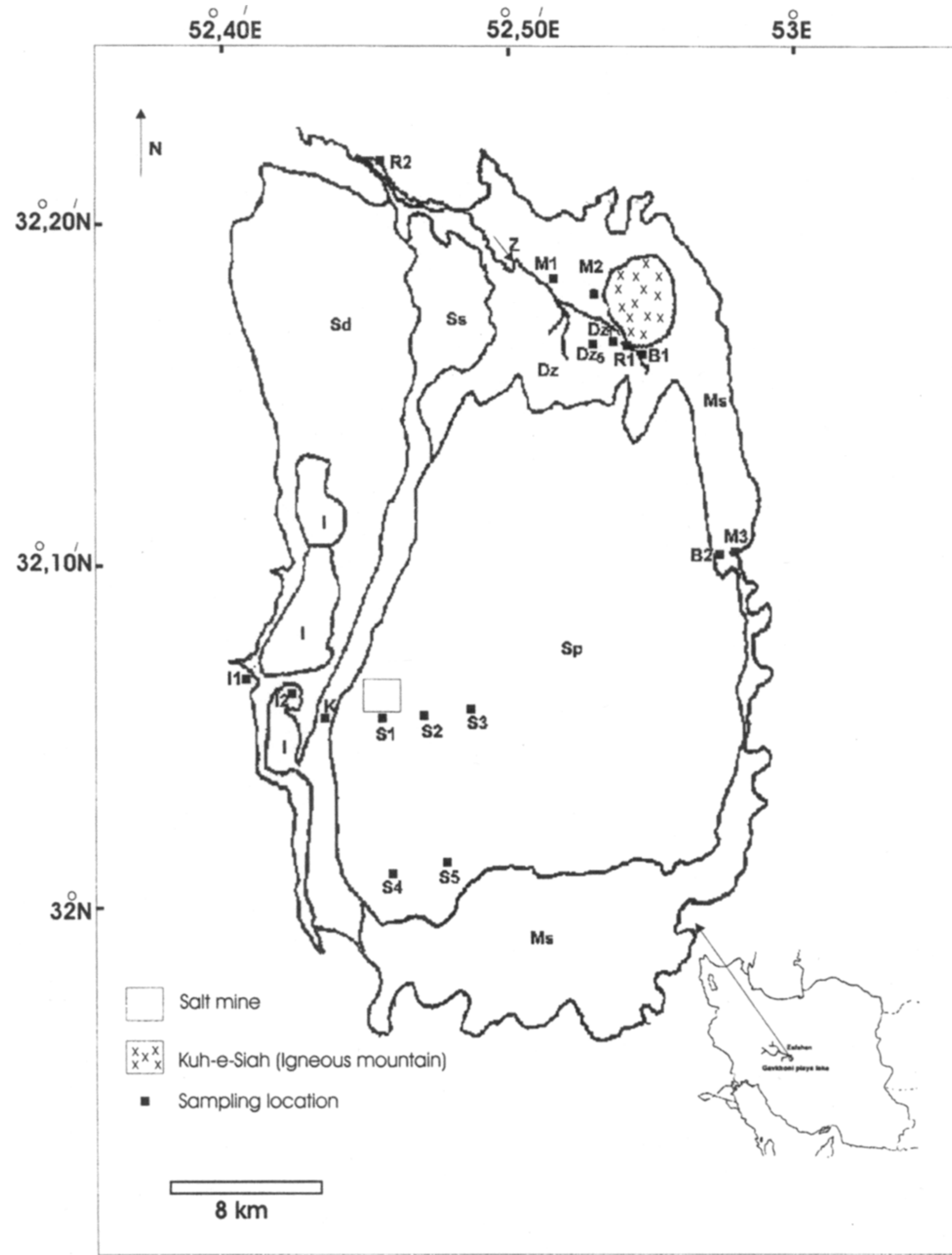

Figure 1. Simplified map showing approximate location of pits, trenches and sampling localities in the study area. Sd (sand dune), Sp (salt pan), I (interdune), Ss (sand flat/saline sand flat), Ms (mud flat/saline mud flat), Z (Zayandeh river), D(delta), B(sand/gravel sand beach).

1), two lithologies, including gravelly sand and sand, were observed. They are composed of mainly igneous and minor sedimentary, and metamorphic lithic grains, quartz, feldspar and gypsum minerals, but their frequency and composition is different in the northeastern and eastern beaches. It also contains a considerable amount of gastropod shells in the northeast of the Zayandeh river delta.

Interpretation.– The sand/gravel sand beach ridges usually form where the gradient of distal alluvial fan is relatively high and small streams transport coarse-grained sediments to the playa lake. They are formed by wave activity during playa lake level highstand. Distinct differences in mineral composition between the northeastern and the eastern sand beaches are related to the source of the sediments. The former originates from igneous, sedimentary and metamorphic rocks but the later mostly derive from igneous rocks. The gypsum crystals are most probably washed out from the mud flat.

Mud Flat /Saline Mud Flat

This sub-environment encircles the lake, except in the western part. The northern mud flat is wide, where the Zayandeh river flows into the playa lake. Mud flat is characterized by polygonal mud cracks, plant roots and root casts and is not saturated by brine. Saline mud flat is characterized by precipitation and preservation of evaporite minerals within the detrital sediments, including chiefly chaotic mixtures of mud, halite and gypsum. In contrast to the mud flat, all depositional sedimentary structures have been destroyed in the saline mud flat.

On the basis of five digged trenches (M1, M2, M3, Dz1 and Dz5, Fig. 1), five major distinctive facies can be differentiated in the mud flat and saline mud flat, i.e. salt, gypsiferous mud, muddy sand, mud and sand.

Salt.– This facies is the uppermost one in the saline mud flat. It contains a few muds and is dry, hard and roughly in dry seasons. Its thickness reaches up to 30 cm (see sections No. M1 and M2 in Fig. 2).

Gypsiferous Mud.– Massive gypsiferous mud is mainly developed in the eastern saline mud flat (see location No. M3 in Fig.1 for its position). When the groundwater table is high (a few centimeters in depth) its surface is usually moist and soft whereas in dry periods the surface is dry and hard. A large number of discoidal gypsum crystals (up to 3 cm in diameter) are scattered in the sediment.

Muddy Sand.– This facies consists of mostly fine sand-sized fraction (see section No. M1 in Fig. 2). Its lithological/ mineralogical composition comprises, decreasing in abundance, igneous, sedimentary and metamorphic lithic grains, quartz and feldspar mineral grains. Abundant gastropod and ostracod shells are present in this lithotype.

Khaki Mud.– This lithology is massive and observed in the sections No. M1 and M2 (Fig. 2). Its salinity is relatively high and contains mixtures of mud and salt especially in the upper part. There is no evidence of the presence of bedding and plant remains in this lithology.

Sand.– Massive fine to medium sand forms the lowermost lithology in the section No. M1 (Fig. 2). Its lithological/ mineralogical composition is similar to the muddy sand. It also occurs as lenticular thin layers between mud layers (see sections No. Dz1 and Dz5 in Fig. 2). There are a large number of gastropod and ostracod shells similar to muddy sand in this lithotype.

Grey/Black Mud.– Gray to black massive mud, interbedded with lenticular thin sand layers, forms the uppermost studied layers in the sections No. Dz1 and Dz5 (Fig. 2). Its thickness reaches up to a few centimeters. This facies contains abundant vegetation, root traces, plant roots and gastropod and ostracod shells. The surface layer shows extensive mud cracks and algal mats.

Yellow/Brown Mud.– Massive brown to yellow mud underlies the grey to black mud in the two studied vertical locations (see sections No. Dz1 and Dz5 in Fig. 2), with gradational boundary at the base and top. It contains a high ratio of clay to silt. The thickness of this lithology reaches up to 85 cm. There is no evidence of the presence of bedding and plant remains in this lithology

Interpretation.– Discoidal gypsum crystals occur in a seasonally vadose setting. They tend to form in the upper parts of the vadose zone of the brine pan fill where clear parallel-sided prisms are subjected to periodic dissolution and regeneration (Warren 1999). During very early diagenesis, displacive lenticular gypsum develops within the mud matrix. They form in the Howz-e-Soltan playa lake (about 260 km northeast of Esfahan) by precipitation from pore water along the bottom of ponds in which there is dissolved organic material, particularly humid acid (Fayazi 1991).

Muddy sand layers might be interpreted as contemporaneous deposition of sand and mud by a flow with insignificant change in velocities (cf. Amini 1997). The muddy sediments of the sequences reflect rapid deposition on a lower flood plain during wet, shortly after sheet floods (cf. Benison and Goldstein 2001) or probably deposited in a shallow fresh water-brackish perennial lake in a semi-arid to arid climate (cf. Talbut and Allen 1996 in Reading 1996; Benison and Goldstien 2001). The presence of the sand layers most probably represents deposition in the bottom of small and shallow distributary channels during upper flow regime periods. Change of sediments both in horizontal and vertical directions is as a result of frequent shifting and migration of the channel branches.

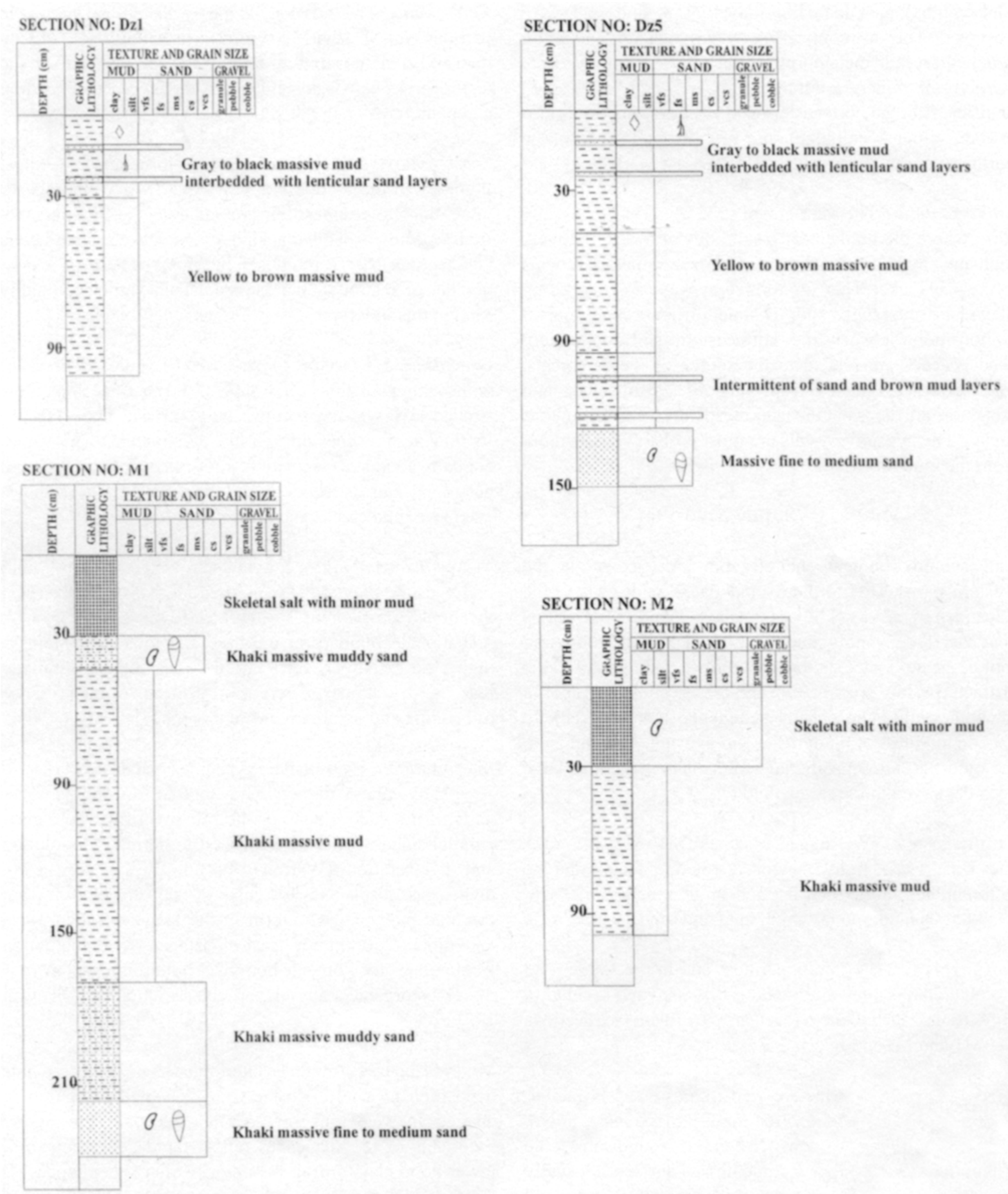

Figure 2. Graphic logs of stratigraphic sequences in mud flat and saline mud flat.

Salt Flat (Salt Pan)

Two drilled cores, up to 30 m in depth (locations No. S3 and S4, Fig. 1) provided by Nabian (1991) and three digged shallow pits and trenches (locations No. S1, S2 and S3, Fig. 1) record evaporitic and siliciclastic facies. These facies range from a few centimeters to up to 12 m thick. They include salt, black mud, sand, gypsiferous marl, and yellow/brown mud. Among these facies only the first three ones are described in detail, because there is no sufficient data about the other two facies.

Salt.– This facies covers the center of the playa lake as a crust, ranging from a few millimeters in thickness in the north to up to 150 cm in the south (e.g. see sections No. S3 and S4 in Fig. 3). Its color is usually white, but black, pink and green colors also occur in some places. The surface layer consists of a mixture of mostly halite and a few sand-sized grains. Surface halite is typically finely crystalline and has a very porous texture. Some of them also have delicate needle-like hairs of halite covering their surface.

There are thin layers of black mud interbedded with crystalline halite layers in some places especially in the southern and central parts of the salt pan.

Black Mud.- Black mud underlies the salt crust in all studied locations in the salt pan and its thickness reaches up to a few centimeters. Halite as hoppers and cubes and gypsum as acicular and discoidal crystals are scattered throughout the matrix. The size of halite and gypsum crystals is up to 2 cm. A few gastropod and ostracod shells are present in the sediments.

Sand.– Unstratified well-sorted fine to medium sands underlay the above mentioned lithology in the all studied locations (e.g. see sections S3 and S4 in Fig. 3). The sand grains are mostly composed of sedimentary, igneous lithic and feldspar and quartz grains. Halite hopper and discoidal gypsum crystals are scattered between the sand grains. It also contains a few gastropod and ostracod shells.

Greenish Gypsiferous Mud.-- This facies directly overlies brown mud in the drilled core No. S4 (see section No. S4 in Fig. 3). The thickness of this sub-facies is about 2 m.

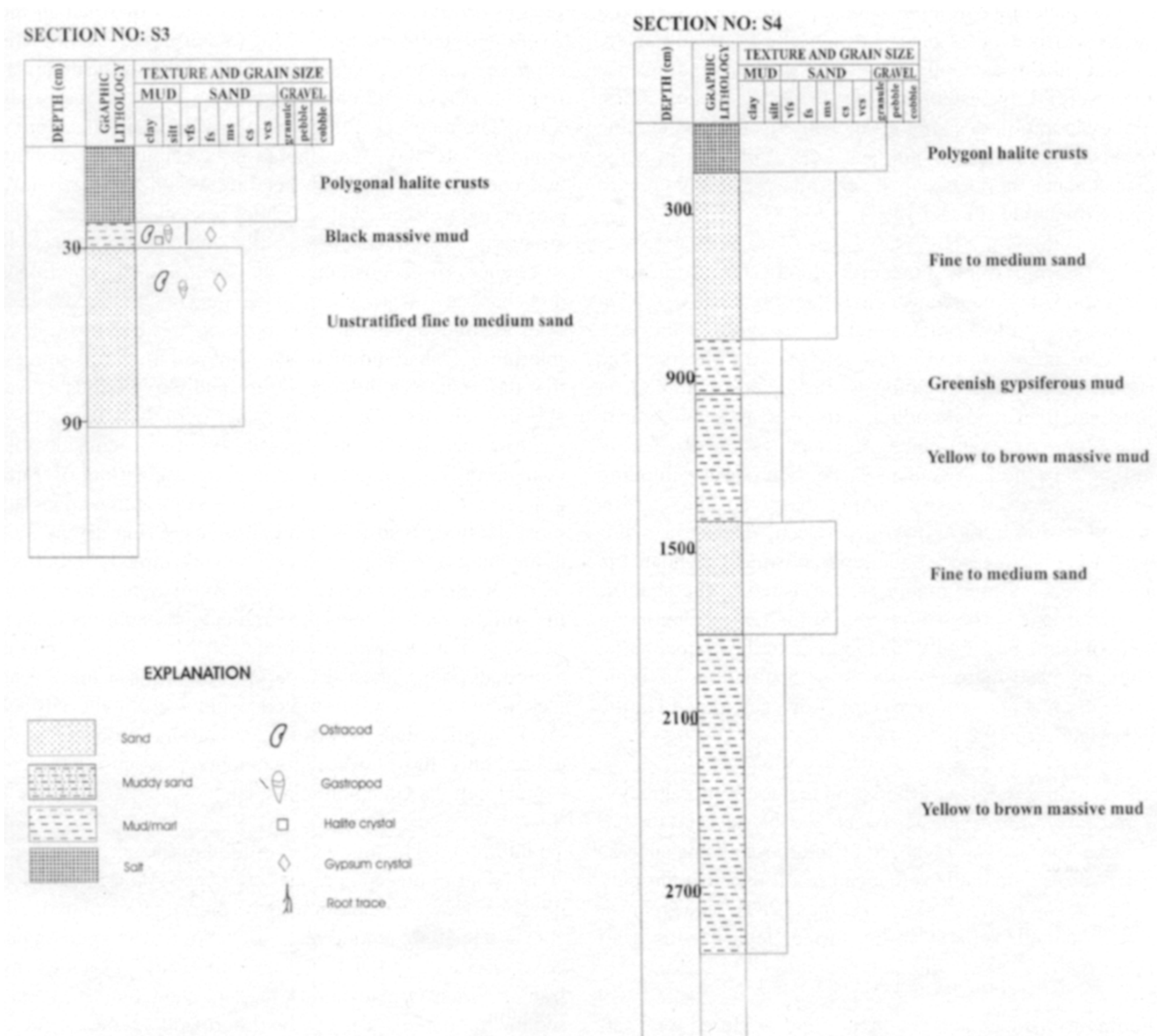

Figure 3. Graphic logs of stratigraphic sequences in salt pan.

Yellow/ Brown Mud.– This lithology is recognizable in the drilled cores No. S4 and S5 (e.g. see section No. S4 in Fig. 3) and is divided in an upper and a lower part. The upper one underlies immediately gypsiferous marl/mud and the lower one is the lowermost lithology in these cores. This facies ranges from 4 to more than 12 m in thickness.

Interpretation.– The formation of the salt pan is as a result of three stages: flooding, evaporation and desiccation. After flooding, when the shallow ephemeral lake becomes concentrated by evaporation, the formation of salt pan starts (cf. Lowenstein and Hardie 1985, Benison and Goldstein 2001). Crystallization starts at the brine surface as small plates and hopper crystals, which sink to the bottom. The individual floating crystals are cemented together where they touch to form rafts. When surface tension is disturbed, the crystals fall to the bottom, forming an accumulation of individual halite crystals and broken rafts on the brine pool floor (cf. Hovorka 1987, Handford 1982). These serve as nuclei for further growth and widespread syntaxial overgrowth that takes place on the lake floor, ultimately resulting in the development of salt crystals and surface salt crust (cf. Lowenstein and Hardie 1985). In most cases, rapid evaporation does not allow halite to form as a cubic crystal at the surface of the salt crust, although in some environments hopper-shaped crystals generally record rapid growth rate (Fayazi 1991).

During spring, minor meteoric floodwaters (rainstorm runoff and snow melt water) cover the saline pan and form a temporary shallow brackish lake. The depth of this lake is usually no more than a few tens of centimeters. The occurrence of minor flooding is much more common on saline pans than major flooding, and can create a temporarily undersaturated the saline lake without deposition of a detrital mud layer in the lake center. Repetition of such flooding can result in a sequence of partly dissolved halite crusts without detrital mud drapes in between. During a major storm flooding stage when muddy floodwaters inundate the pan, mud layers presumably are deposited in the shallow ephemeral lake. This results the formation of alternating layers of halite and mud. The presence of the hopper halite within the mud matrix results from fluctuations of brine during the wet and dry period (cf. Lowenstein and Hardie 1985; Handford 1982)

Pink to light red color of the halite is due to impregnation by traces of iron oxides between the halite crystals (cf. Hovorka 1987). The presence of microorganisms such as the flagellate Dunaliella salina can result in a striking pink coloration (cf. Watson 1989 in Thomas 1989). The greenish color of halite especially in the surface layer results from impurities of detrital sediments.

The fine to medium sand sediment intermixtured with salt crystals is derived from aeolian sands of the west of the playa lake.

The sand–sized intercalations (e.g. in section No. S4 in Fig. 3) in the salt pan sediments capped by mud most likely reflect a rapid deposition of sand during thunderstorms in a shallow temporary lake or also directly as bottom load from the Zayandeh river delta. The upward change in turn from sand, black mud into the salt unit marks the transition from a sand flat, mud-dominated playa to a salt pan.

The yellow to brown mud is probably deposited in a shallow fresh water-brackish perennial lake or flood sheets in a semi-arid to arid climate (cf. Talbut and Allen 1996 in Reading 1996; Benison and Goldstein 2001). The lack of plant roots in the mud flat reflects that the playa lake was poorly or not vegetated. This is indicative of high salinity of the pore water and frequent flooding.

CONCLUSIONS

Changing climatic conditions in the Quaternary period and melting of glaciers increased the amount of water in the rivers and activated their work (Yakushova 1986). It is supposed that this phenomenon played the most important role in relation to changing water level in the study area. The material, filling the playa basin, results from a complex interplay of evaporation, precipitation, quantity and chemistry of groundwater inflow and surface runoff, and drainage basin characteristics, e.g. clastic input. The stratigraphic sequence generally indicates considerable differences in depositional and hydrological conditions and changes in water chemistry in the Gavkhoni playa lake both in time and geographic position. The deposition of intermittent sand and mud (sand flat and mud flat) suggest that the basin was influenced repeatedly by periods of wet and dry climate. During long wet periods it has been a shallow permanent lake possibly without considerable change in water table, resulting in deposition of fine-grained sediments in the basin. The sand-grained deposits most likely derived from aeolian sands during dry periods at the margin of the sand dunes, but also directly as bottom load from the Zayandeh river delta. With increasing aridity, the middle part of the lake gradually became shallower, resulting in a saline lake and the salt pan. The salt pan is a product of the latest dry period in this playa lake. The lack of a salt crust in studied depth, except the surface layer, implies that hypersaline conditions probably have existed only in the latest sedimentation period in the recent centuries in the Gavkhoni playa lake.

To interpret the history and evolution of the lake, it may be insufficient to present a model only based on a few digged trenches. However, combined with investigation of two drill cores up to 30 m depth (e.g. section No. S4) and geological cross sections (NIOC 1975), deep wells (provided by Iranian Water Organization), the late Quaternary to recent sedimentation episodes can be described to some extent in this basin. Based on these field data, a depositional model for the Gavkhoni playa lake is suggested in Figures 4, 5.

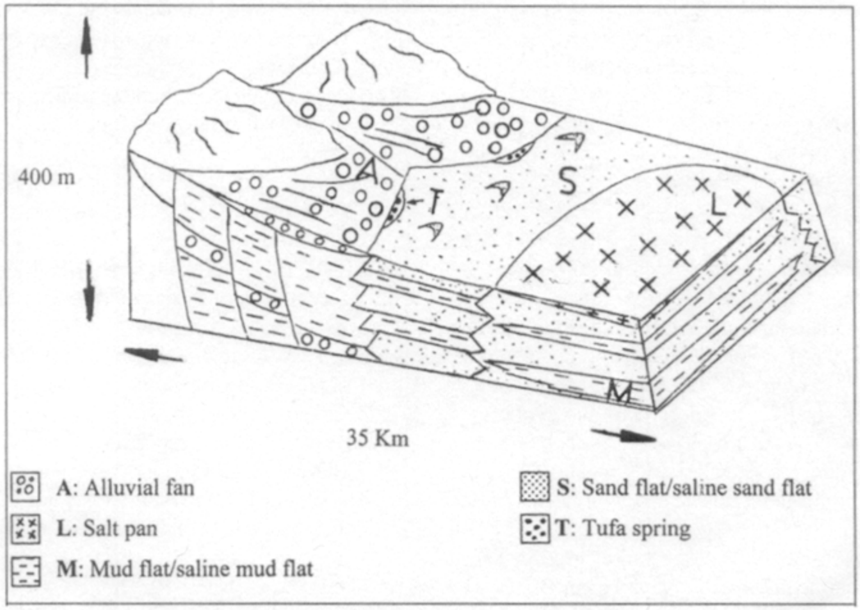

Figure 4. Hypothetic model of sedimentary infill of the Gavkhoni playa lake (see Fig 5 for position of cross section (A-A/))

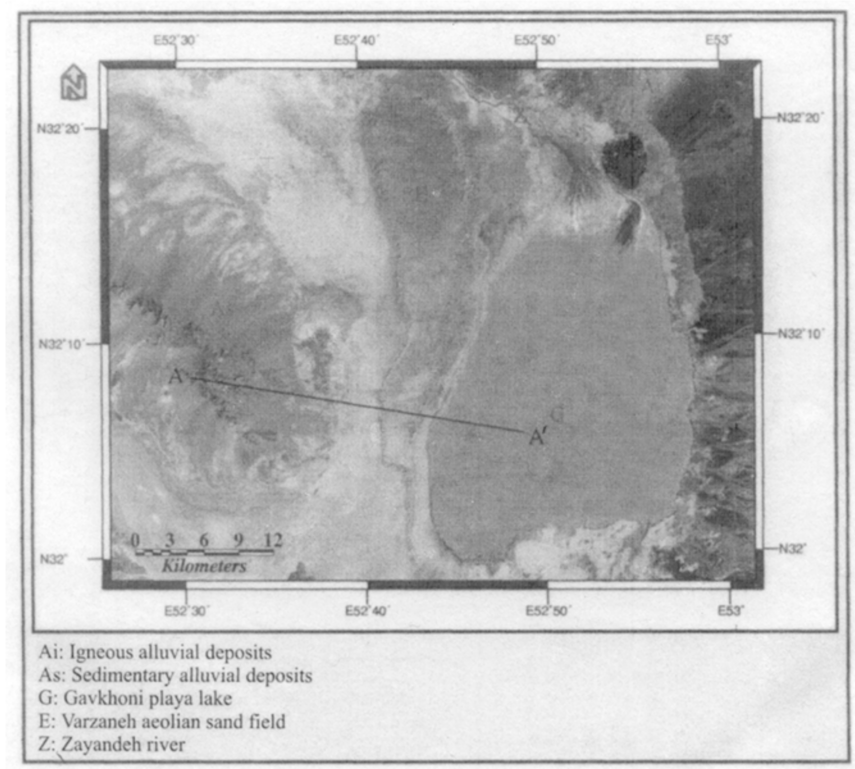

Figure 5. False color-Landsat TM image showing location of hypothetic cross-section (A-A/).

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