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The Late Cenozoic evolution of the Aksu basin (Isparta Angle; SW Turkey). New insights

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Key-words. – Eastern Mediterranean, SW Turkey, Syn-sedimentary tectonics and eustatism, Messinian salinity crisis, Pliocene, Quaternary.

Abstract. – The Mio-Pliocene basins around the Antalya gulf in SW Turkey developed above the Tauric Mesozoic platforms on which the Antalya nappes had been thrusted (in Late Cretaceous-Paleocene times). The closure of the initial Isparta Angle during these events (E-W compression) initiated the N-S orientation of the main structural lines, which persisted later and explains the orientation of the Aksu basin in contrast with the E-W orientation of the eastern Neogene Mediterranean basins. The area, and all southwestern Turkey, became emergent at the end of the Oligocene and were the site of shallow-marine carbonate deposits in the Chattian-Aquitanian, giving way to the wide Lycian basin in Burdigalian-Langhian times. The progressive emplacement of the Lycian nappes from the north over this basin provoked first its subsidence and then its emersion when the nappes attained their final position over the Bey Daglari platform in Langhian times. Coinciding, or in response to the Lycian nappes emplacement, the Aksu basin was initiated as an elongated N-S graben which was filled by thick accumulations of terrestrial and marine deposits (including coral reefs), which derived from the erosion of the Lycian allochton and its basement (Langhian?, Serravallian and Tortonian times). The syn-sedimentary tectonics : reactivation of the normal faults along the west margin of the basin, the continuous uplift of the neighbouring continental areas (beginning of the Aksu thrust), governed the geometry of the basin. As a result and due to the uplift of its northern margin, the Aksu basin migrated towards the south and in Messinian times it was reduced to a narrow gulf along the eastern margin of which the Gebiz limestones were deposited as fringing coral reefs. The age of these limestones has been debated. Our new data allow us to attribute them to the Messinian. The drastic retreat of the sea at the end of this period, provoked the erosion of large parts of the Messinian deposits and the formation of deep canyons on land and under the sea down to the Antalya abyssal plain, in which evaporites were deposited. During the Zanclean transgression, the Eskiköy-Kargi canyon was filled by coarse clastics of a Gilbert delta derived from the northern continental area following a model well known elsewhere in the Mediterranean basins. Southward, shallow-marine sands and marls unconformably cover the remnants of the Messinian deposits and the emergent areas of the southern Antalya gulf. After Zanclean times (end of Pliocene?), the Aksu basin was deformed, due to the west-directed Aksu compressional event (end of the Aksu thrust). Quaternary terraces of the Aksu river at various altitudes, as well as the terraces of the Antalya tufa can be related to sea level fluctuations.

Evolution fini-tertiaire du bassin de l'Aksu au sud-ouest de la Turquie. Nouvelles données

Mots-clés. – Méditerranée orientale, Sud-ouest de la Turquie, Golfe d'Antalya, Bassins néogènes et quaternaires, Tectonique synsédimentaire et eustatisme, Crise de salinité messinienne.

Résumé. – Les bassins néogènes du golfe d'Antalya (d'ouest en est : Aksu, Köprü, Manavgat) se forment sur un substratum composite incluant les plates-formes tauriques (Bey Daglari à l'ouest et Anatolie à l'est) surmontées par les nappes d'Antalya issues du Bassin pamphylien (Néotéthys sud) au cours du Crétacé supérieur-Paléocène, et leur couverture paléogène. La convergence E-W et la collision des plates-formes induisent des structures orientées N-S. Cette direction persistera ensuite et explique l'orientation actuelle du bassin de l'Aksu contrastant avec l'orientation E-W des bassins est-méditerranéens. Cet ensemble est recouvert au Chattien-Aquitanien par une mer peu profonde à dépôts carbonatés récifaux et péri-récifaux : la formation de Karabayir qui couvrait tout le SW de la Turquie. Sous l'effet de l'avancée des nappes lyciennes (depuis le nord), au Burdigalien et au Langhien inférieur, cette plate-forme devient subsidente au NW et le Bassin lycien se creuse et devient profond. Il est alimenté en détritiques terrigènes à partir du front des nappes lyciennes depuis le NW. La fin du Langhien est marquée par le développement de récifs de coraux dans un contexte de grands épandages deltaïques. C'est à cette époque que se forme véritablement le bassin d'Antalya, en coincidence, ou en conséquence de la mise en place des nappes lyciennes : l'ensemble du Taurus émerge, sauf le bassin d'Antalya qui s'effondre le long de failles N-S. En bordure est, la faille de Kirkavak est active. En bordure ouest, le relief abrupt à la limite des Bey Daglari est interprété comme une faille. On a donc deux mouvements en sens inverse : soulèvement des plates-formes et effondrement du bassin. Ce dernier est alors fortement réduit en surface par rapport au Bassin lycien.

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Le Serravallien est mal connu. Le Tortonien est représenté par d'énormes masses de conglomérats fluvio-marins dans lesquels s'intercalent des récifs de coraux, le long des bordures, passant à des turbidites marno-gréseuses dans les parties un peu plus profondes du bassin. Le bassin de l'Aksu est alors bien individualisé par rapport aux autres bassins du golfe d'Antalya. Le Messinien n'est connu que ponctuellement et on ne peut pas reconstituer complètement le bassin à cette période. Il devait avoir une géométrie voisine de celle du bassin Pliocène, c'est-à-dire qu'il était réduit par rapport au bassin tortonien et emboîté dans ce dernier au sud. Le faciès messinien le plus caractéristique est représenté par les calcaires de Gebiz (coraux et calcaires bioclastiques). Au nord du bassin, ils sont discordants sur le socle et plus au sud sur le Tortonien. Intercalés entre du Messinien (NN11b) et du Pliocène basal (NN12), on peut donc leur attribuer un âge Messinien. Entre les calcaires de Gebiz et le Pliocène une discontinuité résulte selon toute vraisemblance de la crise de salinité messinienne (présence également de blocs de gypse). Une érosion a accompagné la baisse du niveau marin lors de la crise de salinité comme en témoigne un canyon à parois abruptes creusé dans le Tortonien. Au Pliocène inférieur, la mer réinvestit le bassin et les canyons alors que la moitié nord du bassin émerge et le bassin pliocène s'encastre dans le bassin tortonien-messinien. Le bassin de l'Aksu se réduit, pendant que ses bordures continuent à se soulever. A la fin du Miocène et au moins jusqu'après le Zancléen, une compression d'est en ouest provoque des écaillages profonds dans le bassin et l'empilement d'écailles vers l'ouest. Cet événement (charriage de l'Aksu) affecte toute la série mio-pliocène. Au-dessus du chevauchement principal, le Tortonien peut être porté à près de 2 500 m d'altitude. Jusqu'au Pliocène la tectonique joue donc un rôle très important dans le bassin de l'Aksu. C'est au Quaternaire que les mouvements eustatiques sont les plus évidents. Les travertins d'Antalya (ou tufa) se sont déposés à l'air libre dans des bassins alimentés par des résurgences. La terrasse supérieure est à + 300 m pendant que la terrasse la plus basse est à – 40 m. Le fleuve Aksu a déposé des terrasses alluviales anciennes dont les plus hautes sont à + 70 m pendant que la base de son lit récent est à –138m. Au niveau du barrage de Kargi, l'Aksu a creusé par surimposition dans les calcaires massifs mésozoïques, une gorge très étroite de 200 m de profondeur, juste à côté du canyon messinien (rempli de Pliocène). Cette gorge permet à la rivière de franchir l'abrupt qui sépare le basin tortonien du bassin messinien-pliocène. Le creusement est post-Pliocène, sans doute en rapport avec les mouvements eustatiques du Quaternaire. En mer, il existe également un grand canyon qui ne se trouve pas dans le prolongement de l'Aksu actuel mais qui est décalé vers l'ouest, et localisé près de la bordure ouest du golfe d'Antalya. Il est probable qu'il résulte du creusement messinien de l'ancien cours du fleuve Aksu.

L'ampleur des mouvements verticaux est donc très importante (au moins 4000 m pour le Miocène inférieur). L'emboîtement des bassins plus récents dans des bassins plus anciens, se produit successivement au Miocène moyen, au Messinien-Pliocène et au Quaternaire. A chaque étape le continent se soulève pendant que les bassins s'effondrent. Le rôle de la tectonique est évident mais de quelle tectonique s'agit-il ? Le contexte du bassin d'Antalya est en effet particulièrement compliqué du fait de l'interférence : 1– d'une tectonique active en extension E-W à NE-SW avec des failles N-S et NW-SE; 2– d'une compression de l'est vers l'ouest et 3– d'une subduction de la Méditerranée du sud vers le nord sous la ride Florence et sous le bassin d'Antalya (et jusque sous le Taurus ?). Bien que pas forcément compatibles entre eux ces trois types de tectonique sont actifs ainsi que le suggère la sismicité régionale.

INTRODUCTION

In SW Turkey, since the Triassic and throughout the Mesozoic, the successive paleogeographies, and especially the creation of basins, were controlled by the geodynamical evolution of the southern Neotethys (eastern Mediterranean area), and of the adjacent continental microplates. The main paleogeographic elements in this area include two continental blocks: the Bey Daglari and the Anatolian blocks separated by a basin (the Pamphylian basin ending in the Isparta Angle), and two main systems of allochthonous ocean-derived units i.e. the Antalya nappes to the south and the Lycian and Hoyran-Beysehir-Hadim nappes to the north of the continental blocks (fig.1a). The Antalya nappes took their origin from the Pamphylian basin (southern Neotethys; the remnant of which represents the eastern Mediterranean). By contrast, the Lycian and Hoyran-Beysehir-Hadim nappes derived from the northern Neotethys. These systems of nappes converged towards the continental blocks on which they were thrusted between the Late Cretaceous-Paleocene (Antalya nappes) and the Late Eocene-mid Miocene times (northerly derived nappes). The continental blocks rifted away from the northern margin of the Gondwana plate in Late Permian-Early Triassic times [Brunn *et al.*, 1970, 1971; Gutnic *et al.*, 1979; Robertson, 1993; Dercourt *et al.*, 2000; Poisson *et al.*, 2003a]. The Pamphylian basin represented the northern part of the southern Neotethys, which resulted from this rifting (fig. 1a). This basin ended near Isparta and the area located between the continental (Bey Daglari and Anatolian) blocks was named the "Isparta Angle" (fig. 1a). In Late Cretaceous-Early Paleocene times the global geodynamics of the southern Neotethys changed and in the Antalya area, the continental blocks came to converge, then enter in collision. As a result, the Pamphylian basin was closed and its content was expelled towards the continents, giving way to the Antalya nappes. The Neogene Antalya basins developped on the top of the new paleogeography, which resulted from these events. However, the complete collision of the continental micro-plates, and the final closure of the Isparta Angle occurred only during the Late Miocene and after the Zanclean [Poisson *et al.*, 2003b]. Thus the Neogene basins were implicated in the latest compressional tectonic events. Influenced in their orientation and initiation by the first tectonic phase, in their infill by the erosion of the uplifted continental areas, they were in their turn inverted and partly destroyed. As a result, the tectonic setting of the region is highly complicated and the term "Antalya Complex" [Robertson and Woodcock, 1984] is adequate to qualify the present tectonic configuration.

The aim of this work is to summarize the Neogene history of the Aksu basin and more precisely to show; a) the role of the pre-Neogene paleogeographies and deep structures in the acquisition of the present N-S geometry; b) the

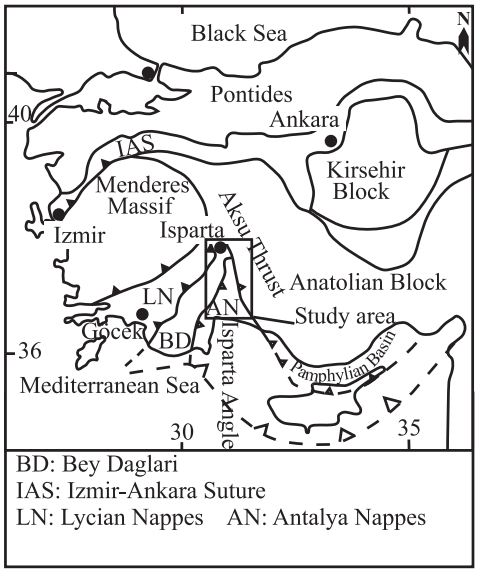

FIG. 1a. – Location of the studied area in the Eastern Mediterranean.
FIG. 1a. – *Localisation de la région étudiée en Méditerranée orientale.*

influence of the Lycian nappes emplacement on its formation and filling; c) the Messinian history of the whole Antalya area.

THE NEOGENE: PREVIOUS WORKS

The previous works concerned the entire Antalya Neogene basin, which is subdivided in three sub-basins which are from east to west: the Manavgat, Köprü çay and Aksu sub-basins. The Manavgat and Köprü çay basins are separated by the N-S Kirkavak fault, and the Köprü çay and Aksu basins by the NNW-SSE Aksu thrust (fig. 1b). These works focused on tectonic setting, bio- and litho-stratigraphy, facies analysis and paleogeography. Among the earliest workers, Altinli [1944] gave the first stratigraphic data in the Aksu basin. Thanks to the molluscs fauna, he identified the Tortonian in the Aksu conglomerates and the Pliocene. Also Tintant [1952-53], Chaput and Darkot [1953] dated the Pliocene (molluscs and foraminifera) in the south of the Aksu basin. Later, the bio-stratigraphic studies, mainly based on planktic foraminifera and nannoplankton have concerned at first the whole Antalya basins [Bizon *et al.,* 1974; Akbulut, 1977; Poisson, 1977; Monod, 1977; Gutnic *et al*., 1979; Dumont, 1976; Poisson *et al*., 1983, 1984, 2003 a, b; Akay *et al*., 1985; Akay and Uysal, 1985]. These studies provided also the lithostratigraphic subdivisions. They were completed by other works, focused on the Miocene [Flecker, 1995; Flecker *et al*., 1995, 1998], and on the Plio-Quaternary [Glover, 1995; Glover and Robertson, 1998, 2003]. Facies analysis and paleoenvironmental reconstitutions have been completed more recently [Karabiyikoglu *et al*., 1997, 2000, 2005; Tuzcu and Karabiyikoglu, 2001; Deynoux *et al*., 2005; Isler *et al*., 2005; Ciner *et al*., 2008]. A synthesis of biostratigraphic data and facies analysis, at a regional scale, led to the first paleogeographic reconstitution for the Miocene [Flecker *et al*., 2005]. Coral reefs and coral-algal boundstones are frequent at several levels in the sequences from the Late Oligocene to the Miocene. They have a great interest for paleoenvironmental reconstitutions but a rather poor value for detailed chronostratigraphical subdivisions [Karabiyikoglu *et al*., 2000, 2005; Tuzcu *et al*., 1997; Tuzcu and Karabiyikoglu, 2001]. Although it was suspected to exist in the Aksu basin, the Messinian had never been precisely dated. It has been previously described only in the Manavgat basin [Bizon *et al*., 1974; Flecker, 1995; Flecker *et al*., 2005]. In the Aksu basin, new biostratigraphic elements allows now to date more precisely the Messinian and the effects of the Messinian salinity crisis in this basin are highlighted.

THE AKSU BASIN

The Aksu basin is the western sub-basin in the Antalya Neogene gulf (fig. 1a,b). It is bordered to the west by the Bey Daglari platform. Its eastern margin is hidden below the Aksu thrust.

The main structural lines

From west to east the Aksu basin looks like a half graben tilted to the east at the footwall of a N-S fault cutting the Bey Daglari platform. From north to south the Aksu basin is composed of three superposed basins which appeared successively in three steps at the footwall of three main faults: Kapi Kaya fault (fig. 1b, 2 and 3) (Serravallian-Tortonian); Kargi fault (Messinian-Pliocene) (fig. 2 and 4) and Antalya faults (Quaternary basin) (fig. 1b and 2). The Aksu thrust (compression from east to west) [Poisson, 1977; Frizon de Lamotte *et al*., 1995; Flecker *et al*., 2005] affected the eastern margin of the basin firstly in the Latest Tortonian-Earliest Messinian and then in the Pliocene (after the Zanclean). Consequently this thrust is a synsedimentary thrust, which modified progressively the geometry of the basin by the surelevation and emersion of the hinterland separating the Aksu and Köprü basins and also probably the emergence of the northern and western margins of the Aksu basin.

The deep structure of the basin is interpretated in the W-E profile (fig. 5), on the basis of data provided by the logs of two wells: Ismail-1 and Aksu-1 located respectively west and east of Antalya (location fig. 1b). The Ismail-1 well crossed 250 m of the upper Antalya tufa terrace (Quaternary), about 100 m of Antalya nappes (Catal Tepe nappe; Yenice Bogazi unit) and then, the peridotites (Antalya nappes) [Özbey and Bagnasco, 1960]. The absence of any Tertiary deposits means that the border of the Antalya Neogene basin remained located further to the east, during the Miocene and Pliocene times. Most probably, this border was a fault. By contrast, the more recent Aksu-1 well is deeper (2856 m) and it crosses only Quaternary and Tertiary deposits. It has revealed the existence of a duplication of the Burdigalian-Langhian sequence above fragments of Antalya nappes. This duplication can be interpreted, at least, as a reverse fault or, more probably, as a westward thrust fault related to the Aksu thrust system. Just above this deep blind thrust, another one reaches the surface at the foot of the relief, which border the Quaternary alluvial plain to the east (fig. 1b). The emergence of this thrust can be observed along the Antalya-Serik road where the Early

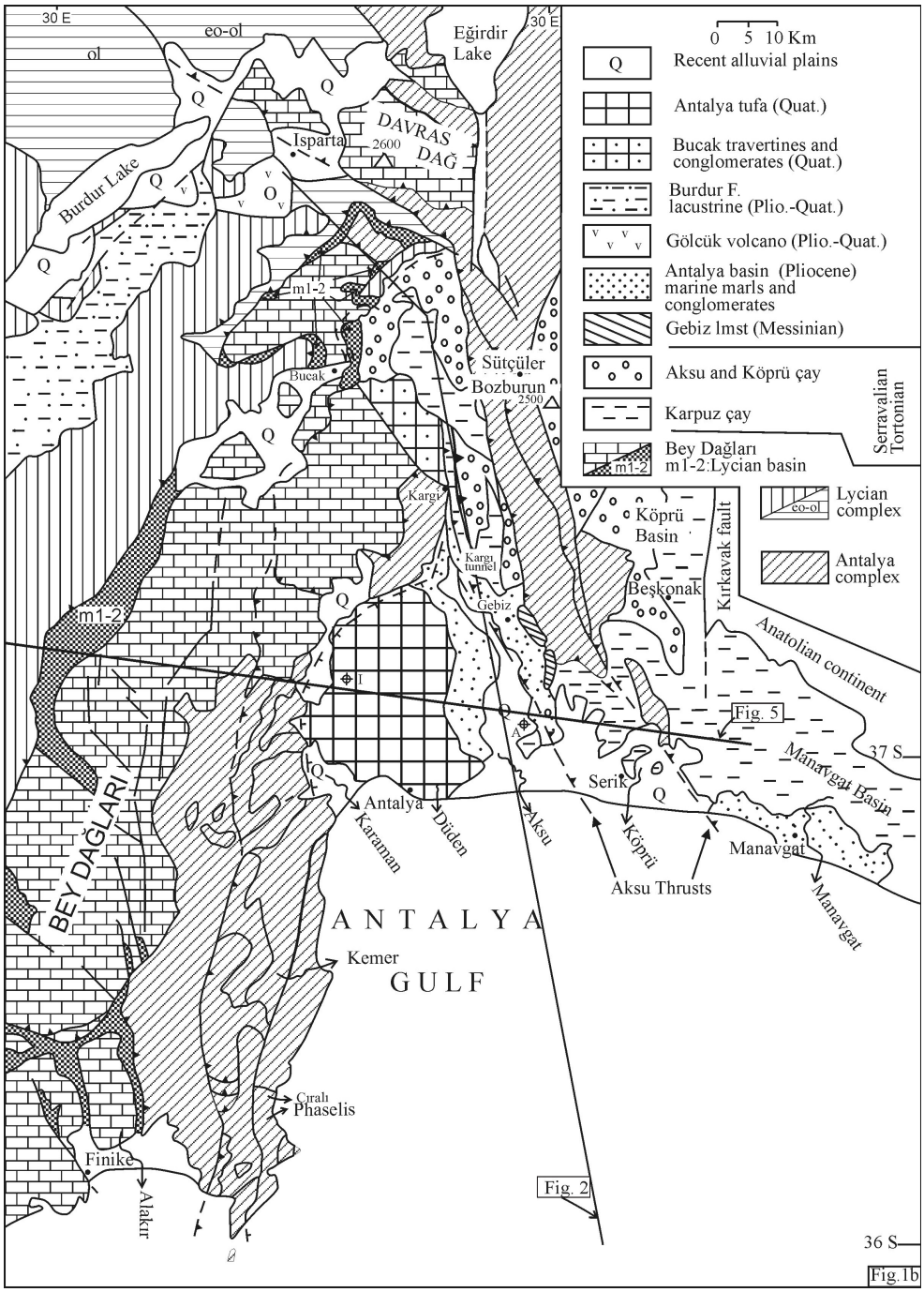

FIG. 1b. – Geological map of the Isparta angle.
FIG. 1b. – *Carte géologique de l'angle d'Isparta.*

Miocene has been uplifted [Flecker *et al*., 2005] and northwards, where ophiolites come with the Early Miocene [Özbey, 1961]. These thrusts affect the Pliocene and they could be the southern prolongation of the thrusts described in the Kargi-Eskiköy area [Poisson *et al.,* 2003b]. The existence of these thrusts to the west of the main Aksu thrust fault underlines the importance of the Pliocene tectonics (post Zanclean more precisely here), which was the last compressional tectonic event of the Aksu phase of closure of the Isparta angle.

Timing of its formation and filling

The Late Oligocene-Tortonian period

– *The pre-Miocene basement* of the Aksu basin is constituted by the Bey Daglari platform surrounded by the Antalya nappes with their Paleogene thin sedimentary cover (sandstones, marls and nummulitic limestones). Following the Late-Cretaceous-Paleogene major cycle a regional paleogeographic reorganisation ensued, which consisted of

a general emersion and concomitant erosion affecting specifically the Bey Daglari and the Antalya nappes. At that time, the Lycian nappes were located far away to the north, and they did not participate in the Late Cretaceous-Paleogene events in the Antalya area. The eroded flat surface covered large areas in SW Turkey. It was the site of a regional transgression in Late Oligocene-Aquitanian times, with the deposition of the shallow marine Karabayir limestones to the north and west [Poisson and Poignant, 1974; Poisson, 1977], and the initiation of a molassic basin to the south (the initial Antalya Neogene basin) [Poisson *et al*., 1983]. The Karabayir carbonates unconformably covered both the Bey Daglari and the Antalya nappes and the thrust faults in between [Isparta çay area: Gutnic et Poisson, 1970; Akbulut, 1977; Poisson *et al*., 2003a]. As a result, a large platform (the Karabayir platform) existed on both sides of the central and northern present Aksu valley. By contrast, a basin existed to the South and the transition from the northern platform to the southern basin is located approximately at the latitude of Antalya where the Karabayir carbonates are interbedded with coarse conglomerates [Aksu-1 well, Senel, 1997a; Antalya-Serik road, Flecker *et al*., 2005; Sohanli Dag, Poisson *et al*., 1983]. Farther east turbiditic marls, sandstones and conglomerates were concomitantly deposited in a deeper environment (the Köprü basin) at the footwall of the Kirkavak fault [Dumont et Kerey, 1975; Akay and Uysal, 1985; Flecker *et al*., 2005], which was active at that time.

– *In Langhian times*, the Lycian nappes, which were moving from the north over the Lycian basin since the Burdigalian, attained their definitive position onto the central part of the Bey Daglari. The Lycian basin was completely filled and the Bey Daglari came to emergence. These events led to a new regional paleogeography in which the emergent lands were considerably enlarged (they included the Lycian nappes and the Bey Daglari) and so, resulted in a huge continental area to the north of the primitive Antalya basin.

– *The Serravallian-Tortonian* Aksu basin was created as an approximately N-S trending graben, which cut through the

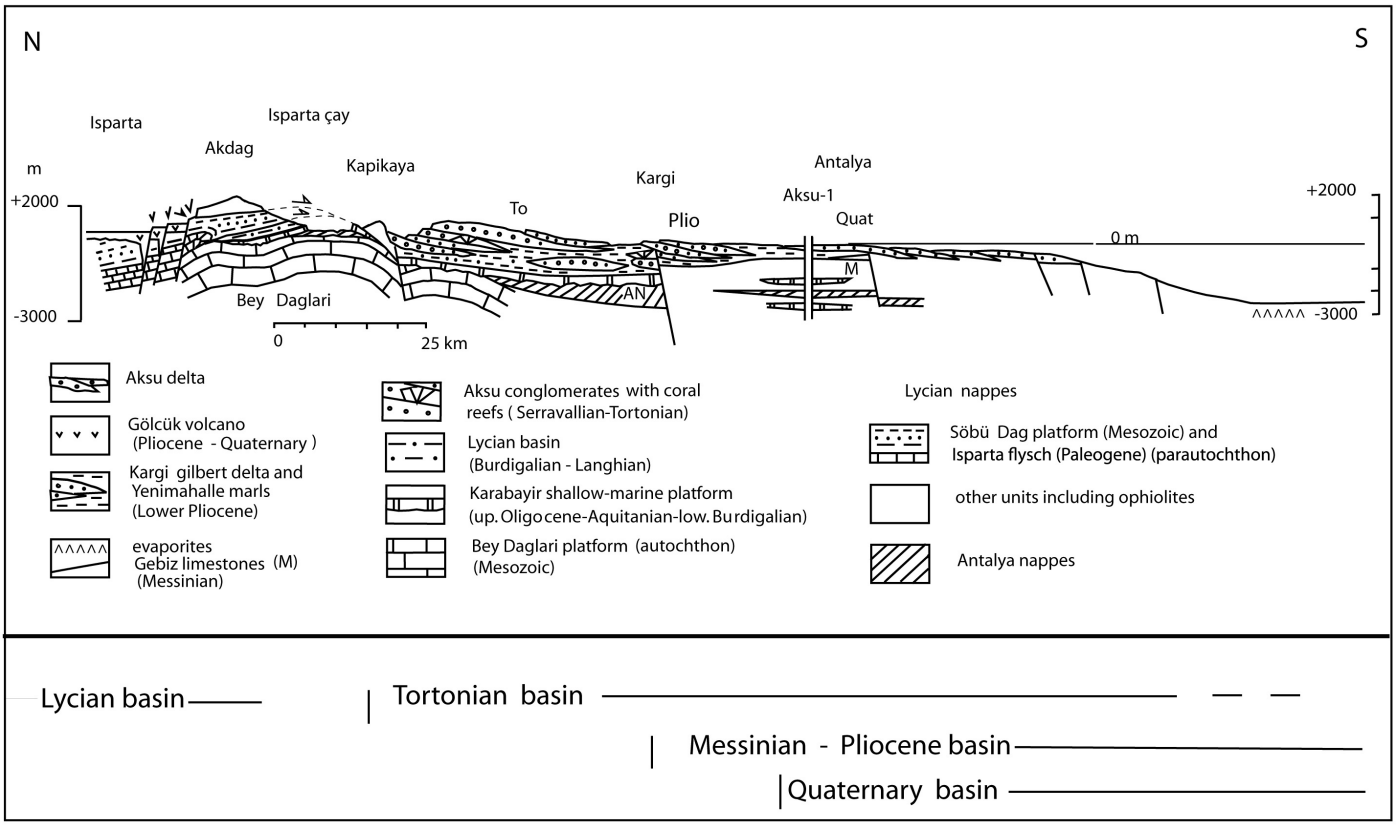

FIG. 2. – N-S longitudinal cross section through the Isparta angle, from the Lycian nappes and the Bey Daglari to the north, to the Antalya gulf to the south. This section illustrates the main steps of the formation of the Aksu basin, from N to S:
1- faulting of the Karabayir platform (Latest Oligocene-Aquitanian) and creation of the Serravallian-Tortonian basin south of the Kapikaya faults. The conglomerates covered the faults;
2- Kargi fault and creation of the Messinian and Pliocene basins;
3- Antalya faults and creation of the Quaternary-Present basin. In this basin Messinian evaporites have been tentatively detected on seismic profiles. Each step corresponds to a southwards migration of the basin and a concomitant uplift of the continent. If we take the Karabayir platform as a guide it reaches +1500 m to the north and –2800 m near Antalya to the south. This give an idea of the tilting since the Early Miocene.
FIG. 2. – *Coupe longitudinale N-S au travers de l'angle d'Isparta depuis les nappes lyciennes et les Bey Daglari au nord jusqu'au golfe d'Antalya au sud. Cette section illustre les principales étapes de la formation du bassin de l'Aksu. Du nord au sud on observera les étapes suivantes :* 1- *fracturation de la plate-forme de Karabayir (fin Oligocène-Aquitanien) avec cachetage par les conglomérats du Kapikaya (Serravallien-Tortonien) ;* 2- *effondrement du bassin plus au sud près de Kargi et formation du bassin Messinien-Pliocène ;* 3- *effondrement du bassin Quaternaire à actuel. Le fond de ce bassin correspond probablement au toit des évaporites messiniennes. Chaque étape correspond à une migration du bassin vers le sud ; en même temps les marges continentales se soulèvent. La plate-forme de Karabayir prise comme niveau repère est à +1500 m au nord et à –2800 m dans la région d'Antalya. Cela donne une idée de l'ampleur des basculements depuis le début du Miocène.*

Karabayir platform and the continental area. The major faults are trending N-S along the Bey Daglari to the west, and ENE-WSW along the Kapi Kaya (fig. 3) at the northern border of the basin. The erosion of the emergent areas produced a huge volume of terrigenous detritals, which were poured in the basin. Several kilometers thick conglomerates [Kapi Kaya, fig. 3; Kargi conglomerates, Poisson, 1977; Aksu conglomerates; Akay *et al*., 1985] were deposited along the northern and western margins of the basin in a system of fluvio-deltaic fan deltas [Flecker, 1995; Ciner *et al*., 2008]. Coral reefs inter-bedded in the conglomerates fringed the coast-line (fig. 3). The conglomerates deposited on land for a part, grade laterally in the basin with sands and marls containing planktonic foraminifera and molluscs: the Karpuz çay formation [Akay *et al*., 1985]. The sequence has been attributed to the Serravallian and Tortonian in the Kargi area [Poisson, 1977], and in the north of the basin [Akay *et al*., 1985]. Around the Kargi tunnel and in Sütçüler area the green marls intercalated in the coral reef bodies are Late Tortonian or younger (table I). The nannoplankton indicates a Late Tortonian age for the marls above the coral reefs of the Kargi tunnel. Thus the coral reefs in these two localities attributed, before, to the Tortonian are now precisely Late Tortonian in age.

TABLE I.
TABL. I.

Küçük Asar Tepe (T06-29 and T06-30)
- Planktic foraminifera = Late Tortonian-Messinian
  Orbulines and Biorbulines
  Globigerinella siphonifera
  Globigerinoides trilobus, G. extremus, G. emeisi, G. quadrilobatus, G. obliquus, G. sacculifer, G. bulloideus, G. elongatus ?, G. seigliei
  Globorotalia scitula, G. praemargaritae, G.suterae
  Globoturborotalita nepenthes, Globigerina bulloides, Neogloboquadrina humerosa
  Sphaeroidinellopsis sp.
- Nannoplankton = Messinian (NN11b)
  Amaurolithus primus, Cyclococcolithus macintyrei, Discoaster brouweri, D. pentaradiatus, D. quinqueramus, D. surculus, Triquetrorhabdus rugosus.

Gebiz (upper marls)
Early Pliocene
- Planktic foraminifera (pre-mid Zanclean) (T06-25) :
  Orbulines and Biorbulines
  Globigerinoides trilobus, G. extremus, G. sacculifer, G. conglobatus
  Globoturborotalia nepenthes
  Globorotalia margaritae margaritae, G. margaritae evoluta, G. primitiva
- Nannoplankton: (NN12) (T06-19) :
  Amaurolithus delicatus, Cyclococcolithus macintyrei, Discoaster brouweri, D. pentaradiatus, D. surculus, Triquetrorhabdus rugosus

Gebiz (intermediate marls)
- Planktic foraminifera: (Late Tortonian-Messinian-Early Pliocene ?) (samples T06-10 and T06-12)
  Orbulines and Biorbulines, *Globorotalia scitula, Neogloboquadrina aco staensis, Globoturborotalita nepenthes, Globigerinella obesa, Turborotalita quinqueloba, Globigerinoides sacculifer, G. extremus, G.* aff. *conglobatus, Globigerina foliata, Globigerinita* sp. *(glutinata* gr.*), Globigerina bulloides, Globigerina praebulloides*
- Nannoplankton: (probably Messinian**)** **(**samples 08-36 to 08-41)
  Cyclococcolithus macintyrei, Coccolithus pelagicus, Helicosphera carteri, Reticulofenestra pseudoumbilicus, Sphenolithus abies, Amaurolithus delicatus, A. primus
- Ostracods (Tortonian-Messinian) (samples: T06-07; T06-11)
  Bosquetina carinella, Paracypris polita, Aurila spp., *Olimfalunia plicatula, Bythocypris* aff. *arcuata, Loxoconcha rhomboidea, Callistocythere* sp., *Hemicytherura defiori*

Gebiz (lower marls)
- Ostracods: (sample T06-20)*:*
  Thyrrenocythere pontica, Thyrrenocythere aff. *ruggieri, Euxinocythere praebequana, Cyprideis* sp., *Cyprideis torosa, Cyprideis* aff. *tuberculata, Loxoconcha* sp., *Cytherura* aff. *pyrama, cf. Carynocythereis, Candona* sp., *Cytheretta or Pseudocytheretta, cf. Cnestocythere,* Cyprididae, Cytheridae
- Other fossils (bioclasts): otolites (*Myctophum licatae* ?), crustacean fragments, bryozoa, echinids, molluscs, benthic foraminifera

Kargi coral reefs
Planktic foraminifera (middle Tortonian or younger)(green marls associated with the coral reefs)
  Orbulina universa, O. suturalis, Biorbulina sp., *Globigerinoides extremus, G. obliquus* ss., *G. bollii* ?, *G. subquadratus, G. ruber* s.l., *Sphaeroidinellopsis disjuncta* ?, *Globorotalia scitula*.
Nannoplankton (NN11a – Late Tortonian)
  Discoaster brouweri, D. calcaris, D. pentaradiatus, D. quinqueramus (sample: T06-36)

Sütçüler (coral reef complex)
Planktic foraminifera (green marls with gastropods) (Tortonian-Messinian?)
  Globigerinoides trilobus, G. obliquus, Globoturborotalita nepenthes, G. picassiana, Globorotalia primitiva?, Orbulines

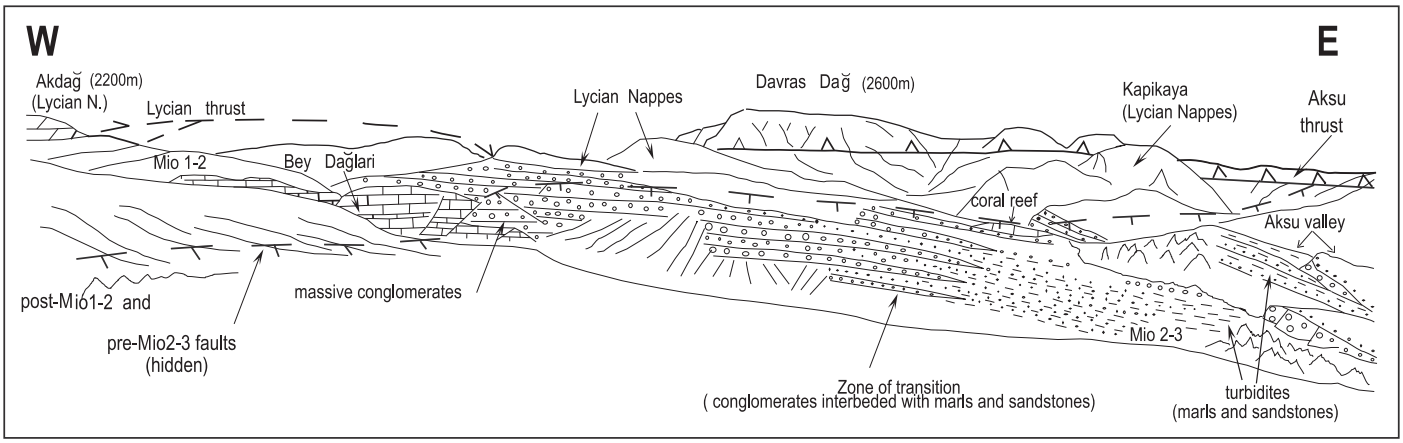

FIG. 3. – Panoramic view (and interpretative diagramme from Flecker *et al*. [2005], modified) towards the northern extremity of the Aksu basin. The faulted margin is expressed in the morphology but the faults are almost completely hidden below the Kapikaya conglomerates (Serravallian-Tortonian). In the back, below the Davras Dag, and on the right side: the Aksu thrust.
FIG. 3. – *Vue panoramique (et schéma interprétatif d' après Flecker* et al. *[2005], modifié) vers l'extrémité nord du bassin de l'Aksu. La bordure fracturée du bassin est exprimée dans la morphologie mais les failles sont presqu'entièrement masquées par les conglomérats du Kapikaya (Serravallien-Tortonien). Au fond, sous le Davras Dag, et à droite: le chevauchement de l'Aksu.*

The Messinian period

In the Antalya area, the Messinian was already evidenced in the Manavgat sub-basin along the eastern side of the Antalya gulf by Bizon *et al*. [1974], then by Flecker [1995]. In the Aksu basin our recent studies show that the Messinian is present in the Gebiz area and also southwards, along the eastern part of the basin. The Gebiz section consists of two units: a basal one, with marls, sandstones and micro-conglomerates, unconformably covered by the upper one, named the Gebiz limestones.

– *The basal unit* has been discovered in one site below the Küçük Asar Tepe. It consists of metric beds of sandy marls, alternating with fine grained sandstones and micro-conglomerates. The microfauna included in the marls indicate a moderate depth of deposition in an open marine basin, lateral equivalent of the Manavgat basin.

– *The Gebiz limestones* extend as a N-S narrow belt from Gebiz to the north, to the Asar Tepe and the Küçük Asar Tepe hills to the south (fig. 1). They are dipping westward (30° west near Gebiz) below the Pliocene marls. The facies are not uniform from north to south. In the southern outcrops, the Gebiz limestones consist of massive carbonate beds composed of large coral colonies. Below the Küçük Asar Tepe, farther south, the limestones rest on top of Messinian marls. By contrast, in the Gebiz area and farther to the north, the carbonate sequence rests on the Antalya nappes, represented by Mesozoic radiolarites and is unconformably surrounded by the transgressive Early Pliocene marls. The Gebiz section is taken as an example of the northern facies (fig.6). There, the sequence of the Gebiz limestones is composed of five members:

a) conglomerate (1-4 m), at the base, composed of pebbles with a matrix of yellow marls, gravels and sands of limestones and radiolarites clasts, grading upward in a conglomerate with calcitic cement. A layer with rodolithes (red algae) has been observed locally. The marls have delivered a rich assemblage of bioclasts and microfossils, which characterises a very shallow marine environment attributed to the Messinian (see table I and discussion below);

b) lower limestones (10 to 30 m; non dated) consisting in a well bedded succession of biocalcarenites including a level of patch-reef (two meters) composed of small colonies (10 to 30 cm);

c) intermediate marls (3-10 m) with various environments from open to restricted marine;

d) upper limestones (10 m) composed of bioclastic calcilutites and calcarenites. They are topped by a deeply buried erosional surface;

e) breccias and stromatolitic limestones have been observed in the Gebiz area and farther south along the road to Antalya. In both sites they consist, at the base, of a breccia (60 cm thick) with angular fragments of the underlying limestones, which fills the holes of the eroded surface of the upper limestones. The breccia is surrounded by a layer of undulated laminated limestones of stromatolitic type (5 to 10 cm thick), and again by breccias and stromatolitic layers. The bedding of these deposits is parallel to the surface of the upper limestones and dips gently 30° to the west. They constitute the top of the Gebiz limestones. Their age is discussed below.

The Gebiz limestones have not been crossed by the Aksu-1 well. That means that they did not exist in the central part of the basin and, thus, they can be interpreted as fringing reefs, developped exclusively along the eastern margin of the Aksu basin [Poisson *et al*., 2003b].

The age of the Gebiz limestones

Previous works

Due to their position above the Antalya nappes and above the Aksu thrust (fig. 5, 6 and 7), the Gebiz Limestones have been considered, for a long time, to post-date this thrust and the closure of the Isparta angle [Poisson, 1977; Gutnic *et al*., 1979 and map therein]. The recent discovery of thrusts in the Pliocene itself [Poisson *et al*., 2003b], have shown that the Aksu thrust and the final closure of the Isparta angle was younger than the Gebiz limestones. In the absence

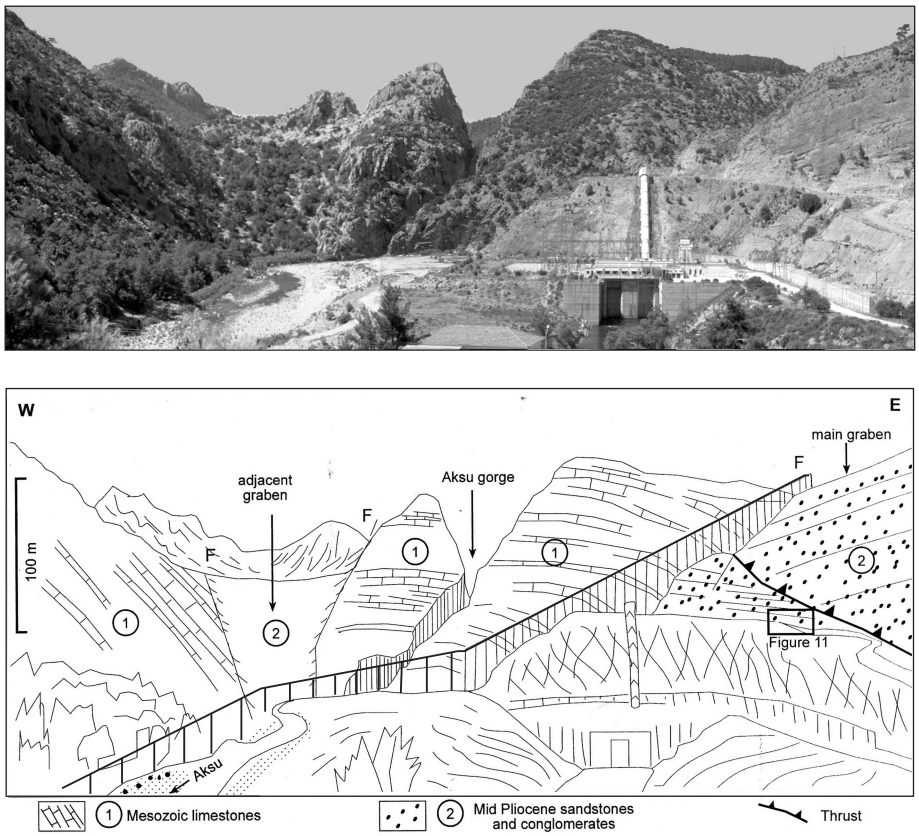

FIG. 4 a,b. – Panoramic view towards the north and interpretative diagramme of the Kargi-Eskiköy fault. The Messinian Eskiköy canyon infilled with the Pliocene conglomerates is on the right. On the left side the Kargi-Eskiköy fault is hidden below the recent alluvium of the Aksu river at the extremity of a deep recent Quaternary canyon, which incises the Mesozoic limestones [from Poisson *et al.,* 2003 b, modified].
FIG. 4 a,b. – *Vue panoramique en direction du nord (et schéma interprétatif) de la faille de Kargi-Eskiköy. Le canyon messinien d'Eskiköy avec son remplissage de conglomérats pliocènes est sur la droite. La faille de Kargi-Eskiköy est masquée sur la gauche par les alluvions récentes de l'Aksu qui sort d'un canyon du Quaternaire récent creusé par surimposition dans les calcaires mésozoïques [d'après Poisson* et al.*, 2003 b, modifié].*

of biostratigraphic markers the Gebiz limestones have been attributed successively to the Late Miocene [Bizon *et al.,* 1974]; the Early Pliocene [Poisson, 1977]; the Messinian [Akay *et al*., 1985, and Akay and Uysal, 1985]; the Tortonian [Glover, 1995; Glover and Robertson, 1998]; Late Tortonian-Messinian [Tuzcu and Karabiyikoglu, 2001; Karabiyikoglu *et al*., 2005]; Late Messinian-Early Pliocene [Poisson *et al*., 2003b].

New data

It concerns the age of the Gebiz limestones near Gebiz, and the basal term located below the Küçük Asar tepe coral reefs to the south (fig 7 and 8; table I). In this location, the assemblage of planktic foraminifera indicates a typical Late Tortonian to Messinian age and excludes the Pliocene. The nannoplankton, more discriminant, indicates a Messinian age (NN11b). In the Gebiz area, the Gebiz limestones are also pre-Early Pliocene (pre-NN12), and consequently we can consider that the entire formation is Messinian.

The age of the Gebiz limestones : discussion

The lower marls in the Gebiz section occupy a position similar to that of the Küçük Asar tepe marls (below the coral reefs limestones), which are Messinian. However, being in a very shallow-marine shelf environment, their fossil assemblages are not helping for the chronostratigraphy, with the exception of a species of ostracodes (*Euxinocythere praebequana*), which is Late Messinian in other countries [Olteanu, 1995; Bassetti *et al*., 2003, 2006; Carbonnel, 1978; Patacca *et al*., 1991].

The coral reefs just above the lower marls could represent the equivalent of the Messinian pre-evaporites formations in the Mediterranean basins and the lower marls could not be significantly younger.

The age of the *intermediate marls* above the coral reefs is debated. They were at first attributed to the Late Messinian-Early Pliocene (Fig. 3 and Table 2 in Poisson *et al*., 2003b], on the basis of a nannoplankton assemblage. As a consequence, these data suggested a marine Messinian-Pliocene continuous transition. But, due to the existence of a gap at the top of the Gebiz limestones, it is more convenient, now, to consider that a continuous Messinian-Pliocene transition does not exist in the Gebiz section and also, probably, in the entire Aksu basin. The fossil content is not clearly conclusive: the benthic foraminifera characterise a very shallow marine environment. It is also the case for the ostracods, which are nevertheless compatible with a Messinian age. The planktonic foraminifera are abundant only in some thin layers and indicate sporadic open marine

conditions, but without any good markers (table I). These intermediate marls are Messinian, and, probably, the equivalent of the pre-evaporites formations, described in the Mediterranean basins (table II).

The breccias and stromatolitic limestones cape the upper Gebiz marine limestones. They underline a gap in the marine sedimentation between the Gebiz coral reefs and the Zanclean marls. Their contact with the Zanclean marls has not been observed and they are not dated. However, this can be compared with the classic Messinian sequence described in Sicily [Decima and Wezel, 1973], Cyprus [Weisgerber, 1978; Orszag-Sperber *et al*., 1980; Rouchy, 1982], where the "Lower evaporites" (marine marls, limestones, marine gypsum, diatomites) are separated from the "Upper Evaporites" (fresh water gypsum, conglomerates, Lago-Mare) by an erosional surface.

In the Gebiz section, the succession of a very shallow marine environment, up-warding to a more restricted environment (intermediate marls) and followed by a near emersion one (stromatolites), could be the equivalent of the pre-Lower Evaporitic unit, described by Blanc-Valleron *et al.* [2002], Rouchy and Caruso [2006], Orszag-Sperber *et al.,* [2009], among others in several areas in the Mediterranean.

In the Gebiz area, we did not observe any evaporites interbedded in the sequence. However, some blocks (cubic meter in volume) of massive selenite gypsum were observed near the canal (excavation for water supply) located at the foot of the Gebiz Limestones hill, to the east of the town [Glover and Robertson, 1998]. It is not irrational to consider that they could represent a part of a more or less continuous evaporitic layer present at about 5 to 10 m below the surface and possibly interbedded between the Gebiz limestones and the Pliocene marls, after the stromatolitic layers. Then, it is not impossible that this gypsum could be considered as the so-called Lower Gypsum. However, we cannot exclude that these reefs, followed by some more restricted environment could also represent a part of the so-called "Lago-Mare" period, as it is observed in Spain [Esteban, 1979], Chelif basin, in Algeria [Rouchy, 1982].

Nevertheless, it is established now that the Gebiz limestones are Messinian in age: marine Messinian for the Gebiz section up to the upper limestones, and probably Late Messinian for the stromatolitic limestones (and the possible gypsum deposits) (table II). This allows to suggest the existence: 1) of a marine Messinian Aksu basin, the remnants of which are the Küçük Asar tepe clastics and the Gebiz limestones. At the scale of the Antalya gulf Messinian deposits are also present in the Manavgat basin to the east; 2- of a near continental Messinian Aksu basin, before the marine Pliocene.

The morphology of the Antalya gulf at the end of Messinian

The morphological evolution of the Antalya area during the Neogene is similar to that of the French Mediterranean Neogene where G. Clauzon [1996] identified "six benchmark surfaces, four of them being isochronous sequence boundaries: the Burdigalian transgressive surface, the Late Miocene (pre-evaporitic) abandonment surface, the Messinian erosional surface and the Pliocene abandonment surface". The two other surfaces are diachronous and correspond to the Late Miocene and Pliocene marine/continental transitions. In the Antalya area the "Burdigalian transgressive surface" corresponds to the Late Oligocene-Aquitanian transgressive surface (base of the Karabayir formation; fig. 2). The pre-evaporitic abandonment surface is difficult to recognize in the Aksu basin. It should correspond to the

TABLE II. – Chronostratigraphic chart for the Aksu basin (Late Miocene - Pliocene - Quaternary).
TABL. II. – *Table chronostratigraphique du bassin d'Asku.*

ANTALYA BASINS			other MEDITERRANEAN areas
0	Ma		
	Holocene	Antalya tufa (Würm : de Planhol, 1956)	
	0,12		
		Antalya tufa (>400ka : Glover and Robertson, 1998)	
1	Pleistocene		
2	1,8		
	Gelasian		
	2,59		
3			
	Piacenzian	Alakilise (Astian : Chaput, 1953; Tintant, 1954)	
	3,6		
4		Yenimahalle (NN15/16: Glover & Robertson, 1998)	
		Eskiköy (NN15: Poisson *et al*., 2003b)	
	Zanclean		
5			
		Yenimahalle; base in Gebiz area (NN12: this work)	
	5,3	(margaritae and puncticulata zones: Poisson, 1977)	
			LAGOMARE/Upper evaporites
6	Messinian	? Gebiz limestones (stromatolitic limestones and breccias)	5,57
		(discussion: this work)	Lower evaporites
			5,96
		Gebiz limestones (‹ coral reefs (Messinian: this work)	pre evaporites
7		Küçük Asar tepe marls (NN11b: this work)	
	7,25		
	Tortonian	Kargi conglomerates and coral reefs (NN11a: this work)	
8			

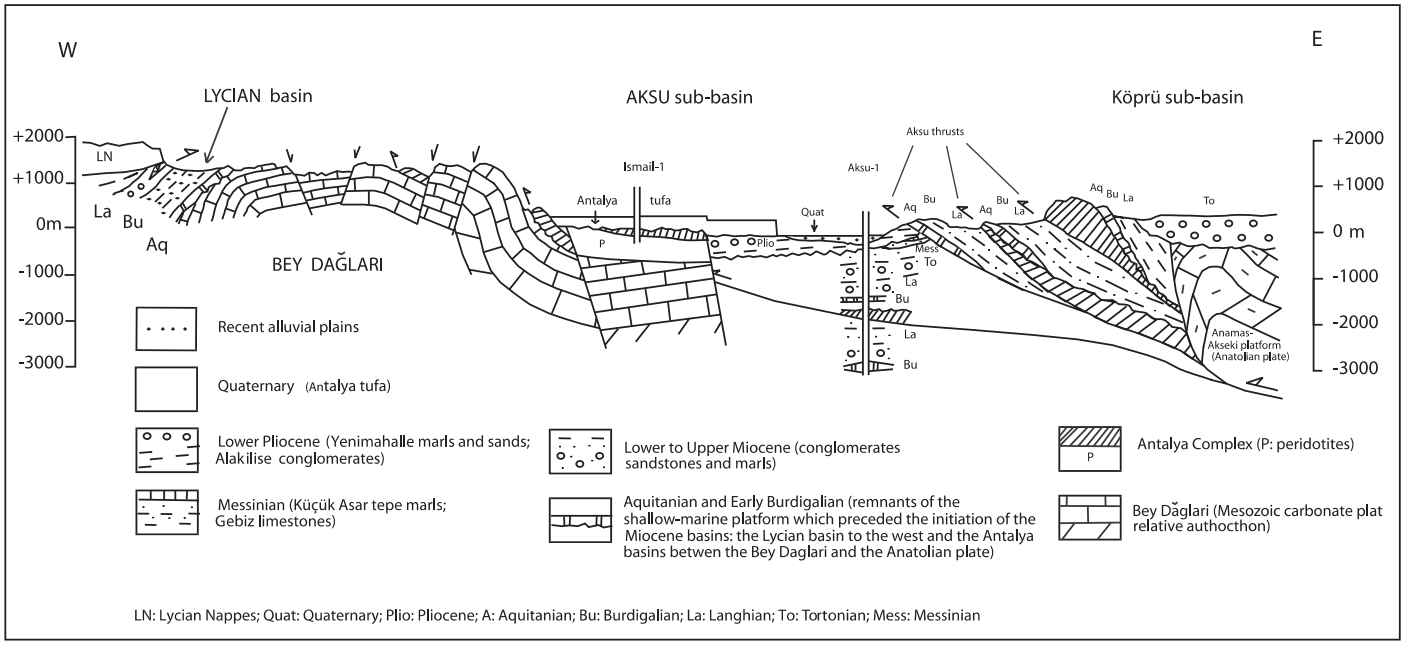

FIG. 5. – Interpretative W-E transversal cross section through the central part of the Isparta angle from the Lycian nappes to the west to the Anatolian platform to the east. To the west the Bey Daglari anticline (Mesozoic to Paleogene carbonate platform), represents the autochthon thrusted on each side by two systems of converging nappes: the Antalya nappes to the east (age of the thrust: Late Cretaceous-Paleocene, reactivated in the Late Miocene - mid Pliocene times), and the Lycian nappes (age of the thrust: Langhian). Two deep wells give data for the interpretation of the deep structure of the basin. To the west the Ismail-1 well. In the central part of the basin the Aksu-1 well [Senel, 1997] has revealed the existence of a duplication of the Miocene sequence with fragments of Antalya nappes at 2000 m below the surface interpreted as a blind thrust related to the Aksu phase.
FIG. 5. – *Coupe interprétative au travers de la partie centrale de l'Angle d'Isparta à la latitude d'Antalya, depuis les nappes lyciennes à l'ouest jusqu'à la plate-forme d'Anatolie à l'est. A l'ouest l'anticlinal des Bey Daglari représente l'autochthone chevauché sur ses deux côtés par deux systèmes de nappes convergentes, mais diachrones : les nappes d'Antalya à l'est mises en place au Crétacé supérieur-Paléocène (avec reprise au Miocène supérieur-Pliocène moyen), et les nappes lyciennes à l'ouest mises en place au Langhien. Deux sondages permettent d'interpréter la géométrie profonde du bassin. A l'ouest le sondage Ismail-1. Au centre le sondage Aksu-1 a révélé à 2000 m de profondeur l'existence d'une duplication de la série miocène et donc d'un accident impliquant aussi les nappes d'Antalya interprété comme un chevauchement lié à la phase de l'Aksu.*

surface of the Tortonian deposits located between the Kapikaya and Kargi faults, which was exhumed before the Messinian. The Messinian erosional surface is well expressed in the Kargi-Eskiköy area (Messinian canyon) and in the Gebiz area.

Messinian evaporites have been reported in the deep part of the Antalya basin [Sage and Letouzey, 1990]. There, the abyssal plain is below 2400 m (fig. 2 and 7). The northern talus of the basin has been deeply buried by a wide north-south canyon, joining the sea-side near Antalya to the abyssal plain. The formation of this canyon has resulted, certainly for a part, from the normal faults, which cut the western border of the Antalya gulf [Glover and Robertson, 1998]. However, the upper part of this canyon coincides with the mouth of the two main rivers, which cross the west of the Antalya plains: the Karaman çay to the west and the Düden çay to the east of Antalya. By contrast, no deep canyon is observed in front of the mouth of the Aksu river. In this area, a large shallow marine shelf can be observed, on which the modern sediments of the Aksu river are widely distributed. In the Aksu-1 well, the upper 138 m of conglomerates have been attributed to the Quaternary such as say to the Aksu river alluviums. The Aksu valley was thus deeper but the existence of a canyon in this area cannot be demonstrated. Most probably such a canyon existed, but it has been completely filled by the Quaternary deposits of the southern Aksu alluvial plain, which is now at a relatively high level. By contrast, at about 50 km to the north of Antalya, a pre-Pliocene canyon has been described: the Eskiköy canyon [Poisson *et al.*, 2003b]. Filled by Early Pliocene fluvio-marine deposits (see below), it could derive from the same normal faulting and erosional events, which made the Antalya canyon. The origin of this canyon is complex. Its western side coincides in the Kargi-Eskiköy area with the main system of normal faults, which gave way to the previous Tortonian Aksu basin. The Aksu river seems to have followed this faulted corridor and cut it as an elongated canyon (fig. 4). This canyon cut through the Tortonian conglomerates and the Antalya nappes.

We can thus consider that all these canyons, on land (the Eskiköy canyon), and offshore (the Antalya main canyon and the adjacent small canyons in the SW of Antalya, fig. 7), could have been buried by the rivers during the period of erosion related to the sea level drop triggering the Messinian salinity crisis. The formation of canyons during this period is evidenced by Clauzon [1982], Clauzon *et al.* [1997], in several sites in the Mediterranean but not everywhere. This fact has given rise to different attempts of scenario and are still widely debated [see Rouchy and Caruso, 2006 for references; Roveri *et al.*, 2008 for new scenario]. Messinian deposits are missing in the Eskiköy canyon and adjacent areas, and their existence is questionable, while they are found further south, in the Gebiz area. To the south of Antalya, seismic profiles show a reflector, which has been attributed to the Messinian "M" reflector [Glover and Robertson, 1998]. If so, the Messinian basin was imbricated

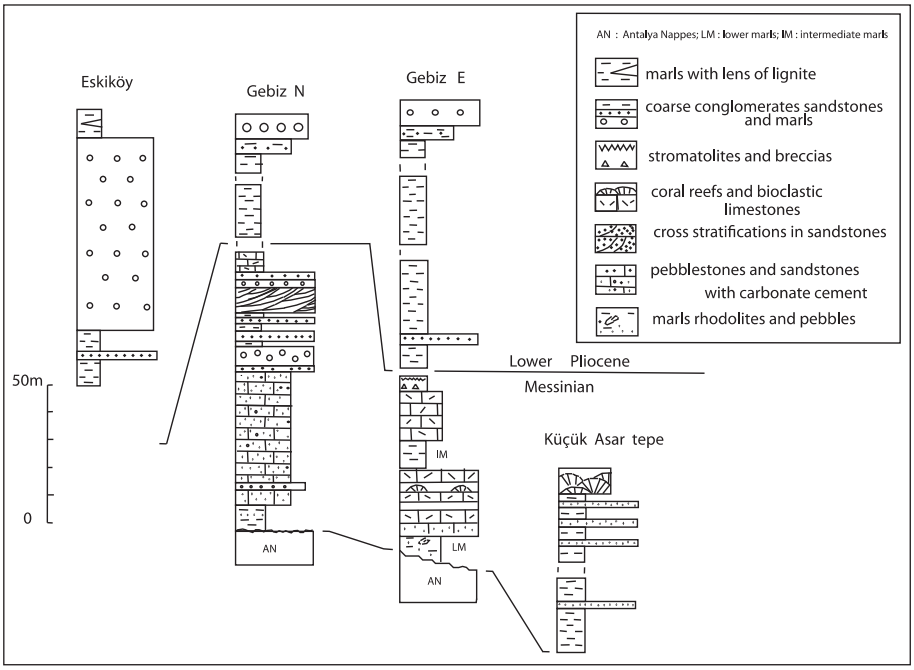

FIG. 6. – Sections of the Messinian-Pliocene sequences in the Aksu basin. During the Messinian, in the Gebiz limestones, the terrigenous clastic input decreased from north to south in the Gebiz sections and disappeared southwards where the coral reefs are thicker. During the Pliocene, from north to south also, the fluvio-marine Eskiköy Gilbert delta graded lateraly into the Yenimahalle shallow but open-marine marls
FIG. 6. – *Coupes de la série du bassin de l'Aksu au Messinien-Pliocène. Pendant le Messinien, dans les calcaires de Gebiz, les apports terrigènes diminuent rapidement du nord au sud dans les coupes de Gebiz et disparaissent complètement au sud, au Küçük Asar tepe où les récifs de coraux sont plus importants. Au Pliocène, du nord au sud également, on passe du Gilbert delta fluvio-marin d'Eskiköy aux marnes de mer ouverte peu profondes de Yenimahalle.*

in the Tortonian basin, which had been uplifted at that time. In the south of the Antalya gulf the M reflector has been also evidenced in seismic profiles through the Florence rise [Zitter *et al*., 2003], at the top of a thick layer which represents most probably the Messinian evaporites [Sage and Letouzey, 1990]. The regional morphology at the end of the Messinian was contrasted, with a canyon in the Eskiköy-Kargi area followed by the Aksu river, which crossed the Antalya alluvial plain before joining the Antalya abyssal plain, through the actively cuting Antalya canyon (fig.7).

THE PLIOCENE

The Zanclean transgression affected all the Mediterranean basins and filled the Messinian canyons. In the Eskiköy canyon, shallow-marine green marls were firstly deposited. Their rich assemblage of planktonic foraminifera and nannoplankton characterises an open-marine environment [Poisson *et al*., 2003b]. They are covered by Gilbert delta type conglomerates, caped by lacustrine lignitic marls, thus related to those described by Clauzon [1980, 1982], Clauzon and Rubino [1992]. The Eskiköy canyon was, in this way, completely filled during Zanclean times (fig. 4,5,7). By contrast, to the south of Eskiköy, in all the present coastal plain of the Antalya gulf, marine sedimentation of the Yenimahalle formation [Akay *et al*., 1985], persisted during the Late Pliocene [Chaput and Darkot, 1953; Depape and Arènes, 1953; Glover, 1995; Glover and Robertson, 1998)]. The emergence of all the Antalya basins at that time was related to a strong E-W shortening, which induced the westward Aksu thrusts [Poisson, 1977; Poisson *et al*., 2003b], (fig. 5 and 6), and the rise of all the eastern margin of the Antalya gulf, i.e. the eastern side of the Isparta angle. The Davras Dag (thick sheet of Bey Daglari carbonate platform), near Isparta, culminates at 2600 m while the Tortonian conglomerates culminate at about 2500 m in the Bozburun Dag. The kinematic studies in the Mio-Pliocene deposits of the basin near the main thrusts clearly indicate a tectonic translation from east to west (purely compressive), which turns to SW. The thrusts, which have affected the Bey Daglari massif, as far as its southern part near Finike, are of the same type and they can be attributed to the same regional compressional event [Frizon de Lamotte *et al.,* 1995)]. This event generated several superposed westwards major thrusts in the basin including the blind thrust revealed by the Aksu-1 well. This tectonic event occurred between the end of the Tortonian and the mid-Pliocene, and not only just after the Tortonian (and before the Pliocene), as it was accepted before [Poisson, 1977]. These thrusts have affected the Miocene sequences and the Pliocene as well [Poisson *et al.,* 2003b], and not only the Tortonian [Ciner *et al*., 2008]. As a consequence this compressive event cannot be considered as a local and secondary event [Glover and Robertson, 2003].

THE QUATERNARY PERIOD

This period is characterized, regionally, by a general extensional tectonic activity (fig. 1b, 2, 7) Kinematic data

indicate that the main faults are only quite normal faults, which strike NE-SW (Burdur direction), NW-SE (Dinar direction), and N-S (west Isparta Angle direction) [Temiz *et al.*, 1997]. In the Antalya Quaternary basin, the main faults are N-S, NW-SE and E-W (as it is shown by seismic profiles). The end of this period is characterised by important eustatic sea level fluctuations [Glover and Robertson, 1998]. The Karaman river cuts a canyon through the Antalya tufa (fig. 7). The Aksu river cuts a new canyon, which is not superposed to the Messinian canyon between Kargi and Eskiköy (fig. 4 and 7). Similar disposition has been described in the Var valley and was named "épigénie d'aggradation" [Clauzon, 1996]. These canyons are devoid of deposits. By contrast, in the south of the Aksu valley the Aksu-1 well cut 138 m of conglomerates below the present alluvial plain. These conglomerates have been attributed to the Quaternary [Senel, 1997, a, b], and thus to an old Aksu valley. Further south, the Aksu river joins the Antalya shelf. Most probably the Aksu canyon existed at the mouth of the river, but it has been filled during the Latest Quaternary, and can no longer be observed.

DISCUSSION AND CONCLUSION

The present study has provided new data concerning the mechanisms, which presided at the creation of the Antalya Neogene basins, more precisely the Aksu and Köprü basins, and the stratigraphy of the Neogene deposits, particularly the Messinian. The main points, which will be discussed here concern the general model of their formation and more precisely the origin of the N-S orientation contrasting with the E-W geometry of the other eastern Mediterranean Tertiary basins and the role of the tectonic events (local effects of regional geodynamics) on the formation of the basins and on the origin of their clastic infill. Also the configuration of the basin during the Mio-Pliocene transition is better known thanks to the biostratigraphic data.

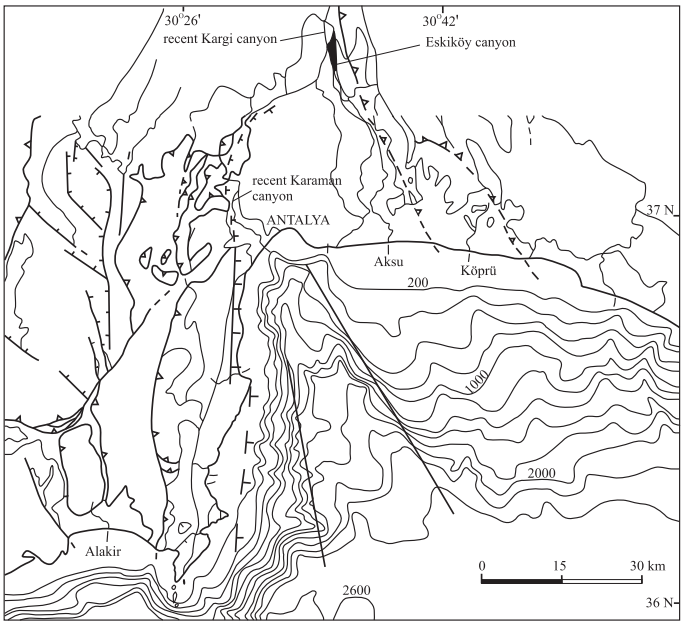

FIG. 7. – Bathymetric map of the Antalya gulf. This map shows the canyons on land (Eskiköy and Karaman) and under the sea around the Antalya gulf. The main rivers (Alakir, Aksu, Köprü and Manavgat) had certainly carved deep canyons in the slope but these are not observed on this map. Most probably the canyons could have been obliterated by the recent influx of sediments. The NW-SE main canyon had a complex origin as a Messinian canyon at first and then a Quaternary graben.
FIG. 7. – *Carte bathymétrique du golfe d'Antalya. Cette carte montre les canyons à terre (Eskiköy et Karaman) et sous la mer autour du golfe d'Antalya. Les fleuves principaux (Alakir, Aksu, Köprü, Manavgat), ont certainement creusé des canyons qui n'apparaissent pas dans la morphologie probablement parce qu'ils ont été remplis par des sédiments récents. Le canyon d'Antalya a une origine complexe : canyon au Messinien, il devient graben au Quaternaire.*

The pre-Neogene paleogeography

The N-S orientation of the Aksu and Köprü basins and their E-W assymetry were closely related to the formation of the Isparta Angle since mid Cretaceous times in two main steps: first (Cenomanian-Turonian), the Pamphylian Mesozoic basin, which separated the Bey Daglari and the Anatolian micro plates, started to close due to an E-W converging movement of the adjacent microplates. This convergence took its origin in a change of the global geodynamics in Mediterranean area (initiation of the N-S convergence of Africa and Eurasia plates). The uplift and emergence of the southern margin of the Anatolian microplate, and the subsidence to deep marine basin of the northern Bey Daglari platform resulted from this step, which initiated the formation of the Isparta angle [Poisson *et al.*, 2003a] and introduced an E-W topographic and paleogeographic asymmetry in the angle which persisted after. Secondly in Late Cretaceous-Paleocene times the accentuation of the E-W convergence of the platforms provoked their collision and the content of the Pamphylian basin was expelled with the subsequent emplacement of the Antalya nappes on the adjacent platforms, mainly on the Bey Daglari to the west [Poisson, 1977; Poisson *et al.*, 2003a]. At this stage (Late Paleocene) the Isparta angle was reduced in width and has acquired its N-S orientation with its central part strongly deformed. Just after, during the Late Paleogene the topography was smoothed and the whole of southwestern Turkey nearly emerged up to the latest Oligocene. It was followed by the sedimentation of uniform richly fossiliferous coralgal carbonates, the Karabayir limestones, which obliterated the previous relief creating a completely new paleogeography: the Karabayir platform transitional southeastwards to the Köprü basin (fig. 8). The Karabayir limestones are known at the bottom of the Lycian basin, on the Bey Daglari [Poisson and Poignant, 1974; Poisson, 1977], on the Antalya nappes in the central part of the Isparta angle [Gutnic and Poisson, 1970; Akbulut, 1977], and along the western margin of the Köprü basin [Poisson *et al.*, 1983; Akay *et al.*, 1985; Akay and Uysal, 1985]. At this time (Chattian-Aquitanian) the area was ready for initiation of the Neogene Antalya basin (fig. 8).

We can therefore conclude that the N-S orientation of the Aksu and Köprü basins, contrasting with the E-W orientation of the other East Mediterranean Neogene basins, resulted from pre-Neogene paleogeographies. The deep-seated thrust faults resulting from the closure of the initial Isparta Angle constituted a zone of weaknesses for the future Neogene faulting.

Tectonics

The extensional tectonics played an important role in the formation of the Aksu and Köprü basins (fig. 2, 8). The N-S faults which border these basins, respectively to the west and to the east, could be inherited from older periods, as old as the formation of the Pamphylian basin in the early Mesozoic [Flecker *et al*., 1995], and also due to reactivation of basement weaknesses resulting from the closure of the Pamphylian basin as depicted above. In the Aksu basin three systems of normal faults are important in particular:

– the Kapikaya fault zone (NE-SW and N-S), which constitutes the northern border of the basin. This fault cuts the Lycian nappes (mid Langhian) and of course the Karabayir platform which is thus deeply buried below the Serravallian (?)-Tortonian conglomerates (fig. 2, 3, 8);

– the Kargi fault (NE-SW and N-S) (fig. 2, 4, 8) constituted the northern border of the Messinian-Pliocene Aksu basin at about 50 km to the south of the Kapikaya fault. The origin of this fault at the southern footwall of which was the Messinian basin, is not well constrained. Most probably this fault is an older normal fault reactivated at successive periods. However, it is necessary to pay attention to the Aksu phase the first event of which deformed the Kargi (or Aksu) conglomerates (now dated Late Tortonian; NN11a), which emerged north of the Kargi fault. This event is thus younger, Latest Tortonian-Early Messinian, and a new paleogeography ensued which explains well the transgressive unconformable

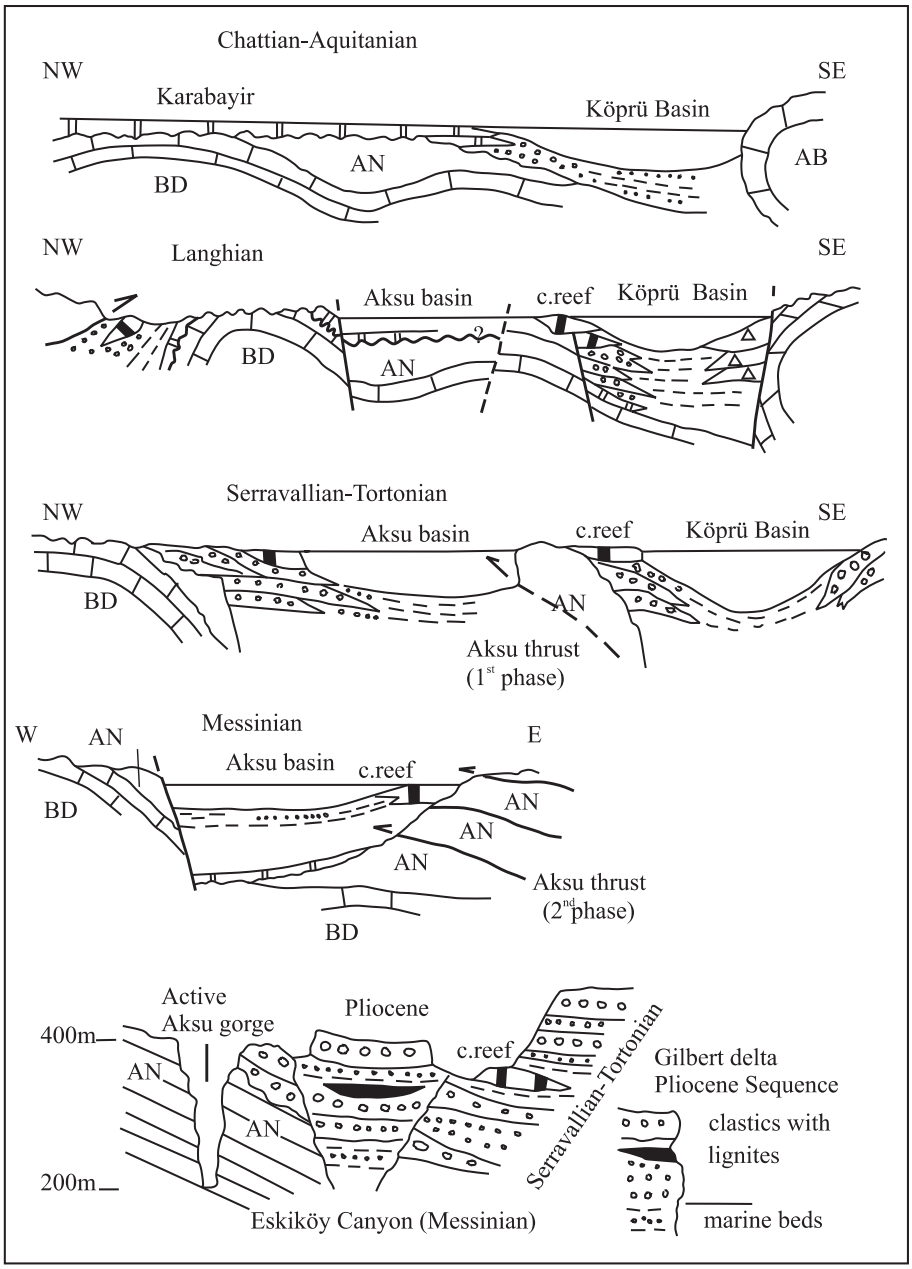

FIG. 8. – Schematic diagrammes (not to scale) illustrating the main steps of the Neogene evolution of the Aksu and Köprü basins;
FIG. 8. – *Diagrammes schématiques (sans échelle) illustrant les principales étapes de l'évolution néogène des bassins de l'Aksu et du Köprü.*

character of the Messinian deposits in the Gebiz area (fig. 5, 6, 8);

– the Antalya faults (N-S on land; NW-SE and E-W on seismic profiles) are parallel to the active normal faults around the apex of the Isparta angle, which correspond to the main directions of extension in the Extensional Province of SW Turkey [Temiz *et al*., 1997; Glover and Robertson, 1998]. This model of rapid extension in the back of a subduction zone fits well with the Quaternary Antalya gulf.

The compressional tectonics in the area are related: 1) to the Aksu phase (compression from east to west, firstly, and then to the south and SW) [Frizon de Lamotte *et al*., 1995], the last step in the westward escape of the Anatolian microplate. This escape is reputed to originate in SE Turkey due to the N-S convergence of the Arabic and Eurasiatic plates; 2) to the northward subduction of the eastern Mediterranean below the Florence rise and thus below the Antalya gulf and possibly below the Taurus belt; 3) the two above proposals being included in the model of deep deformation of the slab beneath the Bitlis-Hellenic subduction zone [Facenna *et al*., 2006].

The Aksu phase, culminating in mid Pliocene times [Fig. 2B in the model of Faccenna *et al*., 2006], was responsible for the westward tectonic imbrication of the Aksu basin with the underlying Antalya units and platform carbonates [Poisson, 1977; Poisson *et al*., 1984, 2003 b]. The asymmetry of the Isparta angle was thus reinforced during this phase: not only its eastern border culminated near 4000 m with several highs near 2500 m (including the Tortonian conglomerates of the Karaburun Dag; fig.1), but also its northern border (Davras Dag culminating near 2600 m), and it emphazised the persistance of the east to west translation of the Anatolian microplate with respect to the Bey Daglari. These data does not fit well with the model proposed by Glover and Robertson [1998], which postulate a main N-S strike-slip faulting in the Isparta angle during the same period, reducing the Aksu compression to a minor event.

The emplacement of the Lycian nappes during the Langhian provoked the complete infill of the Lycian basin to the west and the consecutive uplift and emergence of the Bey Daglari. The erosion of these new land areas provided clastic material, which accumulated in the fluvio-deltaic cones along the north and west margins of the Aksu basin during the Tortonian. As a consequence of the N-S geometry of the basin and due to the localisation of the source areas for the clastics the direction of sediment transport is from N-W and west to S-E and east.

In previous works the Messinian deposits were attributed to the Tortonian [Glover and Robertson, 1998], the Pliocene [Poisson, 1977], rarely to the Messinian and, in this case, without constraining data [Akay and Uysal, 1985; Ciner *et al*., 2008]. Two periods are characterised now by their sedimentary sequences, firstly a Messinian open marine basin followed by a period, which could correspond with the salinity crisis. Our new stratigraphic data allow now to precise a Messinian age for the Gebiz limestones sequence. This sequence is topped by an erosional surface indicating a break in the marine sedimentation between the Messinian and the Lower Pliocene, related to the sea level drop in the Mediterranean. Also, it is now demonstrated that the Eskiköy canyon (on land) and the Antalya canyons could have been cut during this period of erosion. This is in keeping with the effects of the Messinian salinity crisis described in the western Mediterranean.

To summarize, the new investigations on the Aksu basin allow to propose a model for its evolution, mainly to explain the orientation and the geometry observed, and precise its morphology during the now well dated Messinian.

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