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Late Neogene lacustrine sedimentary facies and gastropod assemblages (Granada Basin, southern Spain)

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With 30 Figures

Contents

Abstract

Sedimentary facies and fossil content of Late Neogene lacustrine and coaly sediments of the Granada Basin (southern Spain) have been analysed. Deformed layers in the Messinian to Pliocene sequence are interpreted as seismites, documenting earthquake activity during the continental sedimentation interval of the intramontane Granada Basin. The fauna contained within the beds mainly consists of fresh water gastropods with rissooidean species sometimes composing much of the sediment. The fauna is characteristic of pure fresh water throughout depositional history. Within the section there is a slight change in composition especially regarding the genera *Belgrandia*, *Melanopsis* and *Bithynia* that is probably related to a faunal shift in the area. It also reflects a biostratigraphical marker horizon, that could be of more than local importance and perhaps be traced in the entire Mediterranean region.

Zusammenfassung

Obermiozäne bis unter-pliozäne lakustrine Sedimenten des Granada Beckens (Südspanien) wurden hinsichtlich ihres Fossilgehalts und der Ablagerungsbedingungen untersucht. Deformierte Schichten werden als Seismite interpretiert, die die Erdbebenaktivität während der kontinentalen Phase des

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intramontanen Beckens dokumentieren. Die in den Seesedimenten enthaltene Fauna besteht vornehmlich aus Süßwasserschnecken, die das durchgehende Vorhandensein eines Sees mit reinem, durchlüftetem Süßwasser belegen. In der Faunenzusammensetzung erfolgt ein Wechsel, der sich besonders bei den Gattungen *Belgrandia*, *Melanopsis* und *Bithynia* dokumentiert. Der Faunenwandel ist wahrscheinlich nicht nur lokaler Natur, sondern spiegelt einen biostratigraphischen Wandel wider, der möglicherweise den Mittelmeerraum umfasst.

I. Introduction

The Betic Cordilleras and the Moroccan Rif form the westernmost part of the Alpine orogenic belt of Europe, the Gibraltar arch, containing several intramontane Neogene basins. Overviews on regional geology, paleogeography and internal structure of the different basins were published by Sanz de Galdeano & Vera (1992), Sanz de Galdeano & Rodríguez-Fernández (1995) and Fernández et al. (1995). During the Oligocene and Miocene deformation coupled compression and extension occurred in the Betics, which are situated in the northern part of the Afro-European convergence zone (Morel & Meghraoui, 1996). Neogene intramontane basins formed at major normal faults and along strike-slip faults. The central Betic Cordilleras, including their intramontane depressions, are one of the seismically most active zones in Spain with several moderate earthquakes reported during the last years. Seismic shaking is documented in the sediments of the basin due to liquefaction and slumping features in various stratigraphic levels, e.g. the Tortonian (Reicherter, 1999). Herein we concentrate on sedimentology, syn-sedimentary deformation and the fauna of the Miocene-Pliocene lacustrine interval within the Granada Basin. The gastropod fauna of the later Neogene lake is rich and shells are very well preserved. They can, therefore, be well documented and compared to those of other localities. Even though fresh water species show relatively few characters in comparison to marine species, the rather varied composition of neritimorph, caenogastropod and pulmonate species allows conclusions regarding paleoenvironment, paleobiostratigraphy and paleogeography.

Regional Geology

The Neogene-Quaternary fill of the Granada Basin displays a complex tectonic evolution and sedimentary and subsidence history since its initiation in the Early Miocene (Sanz de Galdeano & Vera, 1992; Sanz de Galdeano & Rodríguez-Fernández, 1995). Sedimentation commenced in the Early Tortonian with conglomerates and marine bioclastic sandstones, which are middle to fine-grained (depositional sequence I; Fernández et al., 1995). The planar- and cross-bedded calcarenites contain extraclasts of Subbetic limestones and cherts, micaschists and quartz grains from the Internal Zones of the Betic Cordilleras. Intraclasts contain bryozoa, algae, shell fragments, gastropods and planktic and benthic foraminifera. Thickness of this sequence is about 80 m (Lupiani Moreno et al., 1986). But there occur large variations in thickness with onlap geometries and relative highs in the basins. A very well-pronounced intra-Tortonian discontinuity of tectonic origin is developed at the top of this sequence (Estévez et al., 1980). Depositional sequence I in the center of the basin is overlain by marls , whereas delta fans exhibit typically conglomerates with a silty-sandy, mica-rich matrix, fluvial sandstones and grey laminated claystones, occasionally intercalated with gastropod-rich limestone layers of middle Tortonian age (depositional sequence II). An eustatic sea-level drop during the Late Tortonian caused evaporite deposites (gypsum and halite) of varying thickness in the basin center and a basinward shift of the marginal facies (depositional sequence III). Upper Messinian to lower Pliocene sediments (Turolian mammal stage) comprise terrigenous marls with lignitic layers which interfinger with gastropod-rich limestones and marlstones of lacustrine origin (depositional sequence IV). The following continental depositional sequences V and VI of the Early Pliocene to Holocene are made up of thick conglomerates (e.g., the Alhambra conglomerate), clay- and marlstones of Piedmont and Glacis sediments, containing several debris flow deposits, channelfills, paleosols and calcrete horizons. Occasionally, travertine plateaus developed at carbonate-

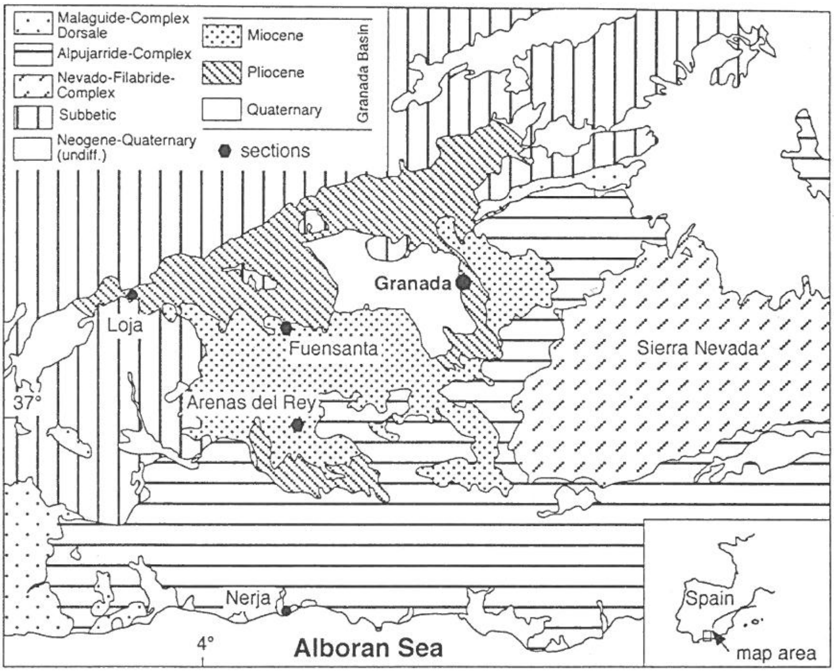


Fig. 1: Simplified geological map of the Granada Basin with studied localities in southern Spain. See inset for study area.

rich springs. The thickness of the entire basin fill partly exceeds 3000 m, especially in so-called „depocenters" (MORALES et al., 1990).

II. Sedimentary facies

The depositional sequence IV of the late Messinian to earliest Pliocene (FERNÁNDEZ et al. 1995) in the lower part of the studied section has been described by DOUVILLÉ (1906) basically after the French „Mission d' Andalousie" (BERTRAND & KILIAN, 1889), which investigated the geology of Andalusia after the 1884 Arenas del Rey earthquake. Arenas del Rey was completely destroyed during the earthquake and several major after shocks (e.g., MUÑOZ & UDÍAS, 1980; REICHERTER et al., 1999). Coaly beds of sequence IV were exploited here in small mines, especially around the old village.

The outcrop studied is located at the southwestern edge of the Embalse de los Bermejales close to the village of Arenas del Rey (Fig.1, Prov. of Granada). The outcrop stretches along the road from Arenas del Rey to Fornes, bedding dips smoothly southward, pointing to almost no post-depositional rotation (N 36° 57´ 688, W 3° 53´ 053). We concentrate on an approx. 20 m thick interval of marly lime-stones with inter-calated lignitic beds and limestones, which were sampled in detail (Fig. 2). The studied section is overlain by light grey marlstones of about 50 m in thickness occasionally inter-bedded with coaly measures and limestones. The carbonate content increases towards the top of the section. Rare fossils are here remnants of gastropds with diagenetically disolved shells. Detritic micas are abundant. The studied section is overlain by approx. 200 m of gyps-iferous marls of Late Tortonian age.

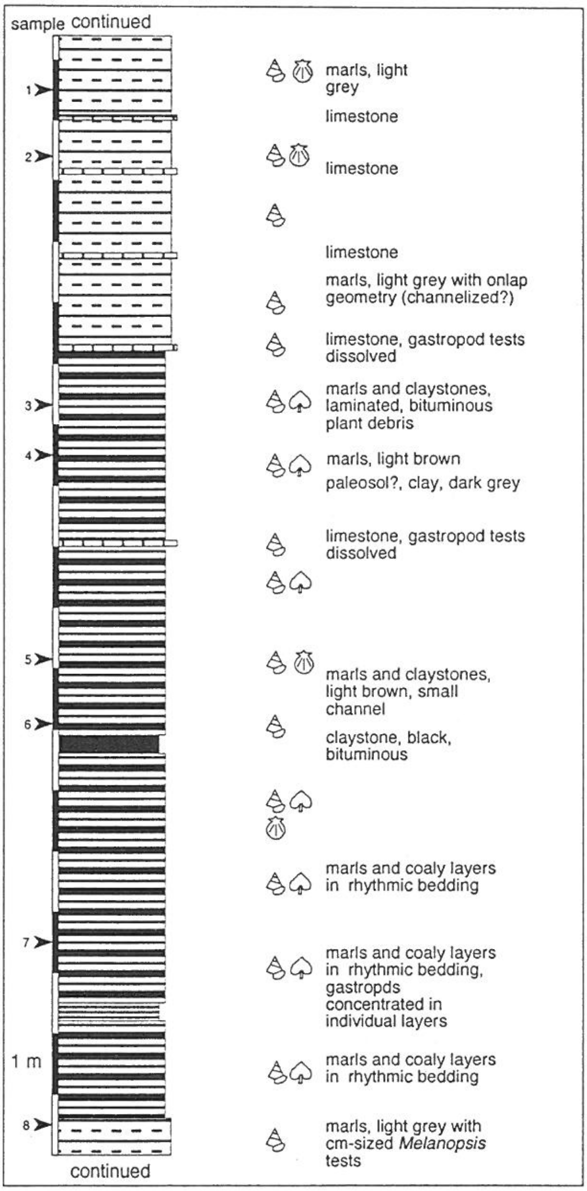
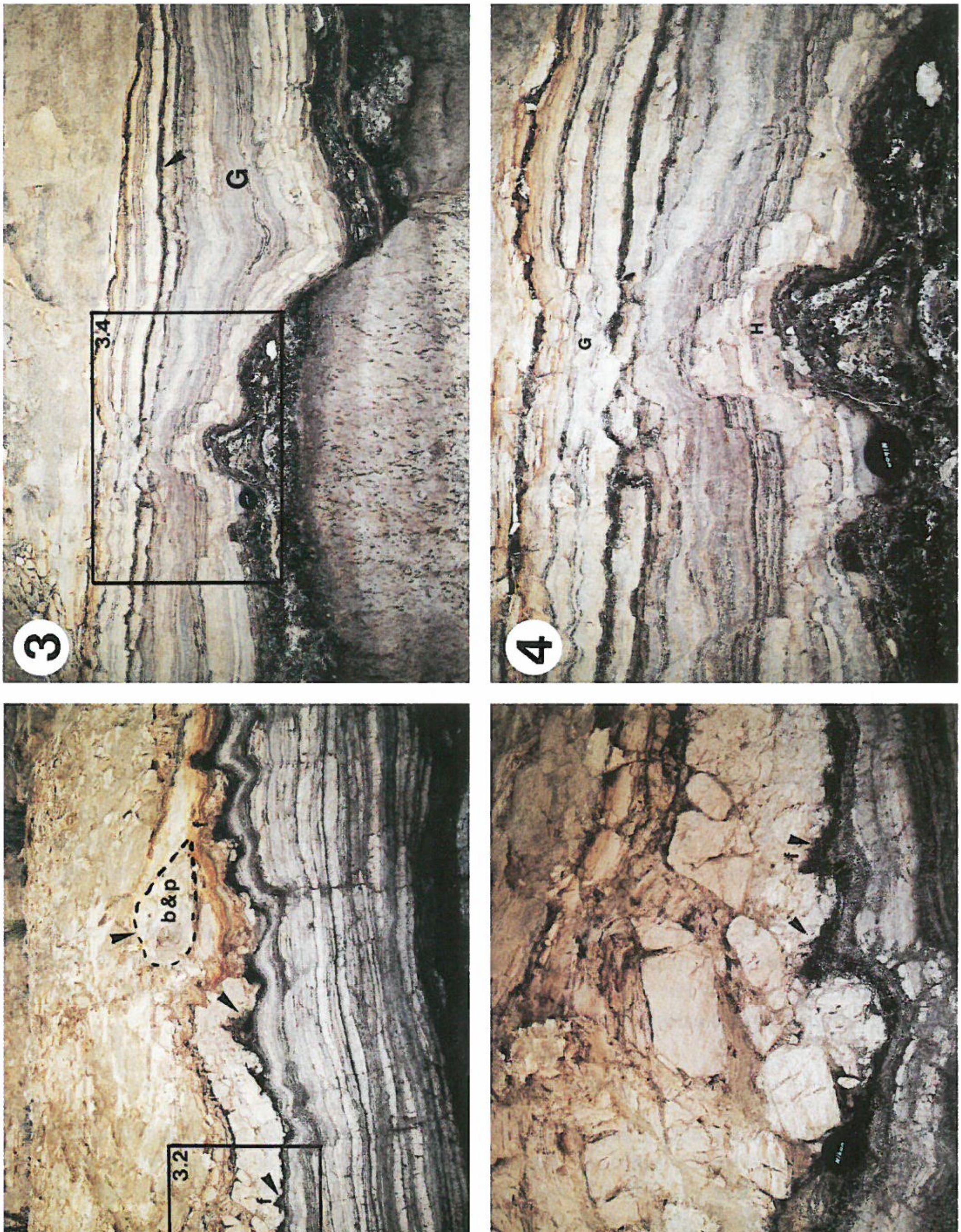


Fig. 2: Stratigraphic coloumn of the Arenas del Rey section close to the Emblase de Bermejales (Prov. of Granada). Arrows indicate sampled horizons.

The studied section of 18.50 m in thickness can be subdivided into several facies intervals. Light grey marls with cm-sized *Melanopsis* individuals form the base of the section. This is followed by a 7m thick interval of dark grey marls and coaly measures (Fig. 3-3) up to 20 cm of thickness. Occasionally, light grey to yellowish marly limestones were intercalated in the next interval (see Fig. 3-1). The structures in these two interval are discribed below. The facies is interpreted to be deltaic with paleosols and dark bitumi-nous clays (sapropels?) docu-menting varying sea-level fluctuations and swamp development in coastal shore facies. The rich gastropod fauna occurs in distinct beds, probably indicating rather low rates of sedimentation perhaps connected to gentle current winnowing and, thus, local enrichment of shells. The absence of corroded shells excludes much reworking or transport during deposition. The following part of the section is made up of grey to brownish marls with intercalated limestone beds, the coaly measure signifi-cantly get rarer and diminish to the top.

A total of eight samples of the entire interval were washed, sieved and analyzed. Additional samples for comparison have been taken from an outcrop in Fuensanta north of the studied section (Fig. 2). In Fuensanta also, light grey marls extremely enriched with small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2
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Fig. 3:

1. Lithologic change from coaly sediments towards light brown marl and marly limestones of the Late Messinian and Early Pliocene of the Arenas del Rey section. The first marly limestone bed above the dark grey marls is crushed, folded and partly eroded, and is interpreted as a seismite. The folded coaly layers inject this bed with flame-like structures. Above the seismite ball and pillows developed (arrow). Beds below and above a seismite are undisturbed. Scale see Fig. 3-2, right is W, left is E.
2. Detail of seismite (Fig. 3-1) in Messinian marls along road cut (Arenas del Rey - Fornes), Note flames (arrow) and the deformed marly limestone layer. Lens cap for scale; right is W, left is E.
3. Messinian marls along road cut (Arenas del Rey - Fornes) with coaly intercalations, E and W-dipping normal faults, which have been active syn- and post-sedimentarily (see text). Growth fault is indicated with varying sediment thickness (G), note that the two upper coaly layers (arrow) do not show faulting. Lens cap for scale; right is W, left is E.
4. Detail of the growth fault in Fig. 3-3, displaying a staircase-like normal faulting. Note inversion of the former horst into a graben during the following sedimentary history, pointing to syn-sedimentary tectonics. Lens cap for scale; right is E, left is W.

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gastropods crops out in the northern part of the basin (Mapa Geologico de España, sheet 1008 - Montefrio, 1:50.000, N 37° 10´ 900, W 3° 54´ 800). The spatial distribution of depositional sequence IV in the Granada Basin varies locally and the facies changes from marls to massive limestones with a bed thickness of 50-100 cm. In this limy facies only badly preserved remnants of gastropods due to diagenetic dissolution of the shell are present. For the description of this facies see Reicherter et al. (this volume). The bed served as a drilling point for determination of paleostresses and physical rock parameters.

In conclusion, the lacustrine facies of the depositional sequence IV within the Granada Basin differs strongly from the soft, light grey marls with deltaic intervals consisting of coaly sediments and, on the other hand, open-lake carbonate-rich facies with hard, but cavernous limestones and marly limestones. The still missing age control of the lacustrine sedimentary facies hinders a complete paleogeographical reconstruction of the Granada Basin during the studied time interval of the Late Miocene (Messinian) to Early Pliocene.

Several high-angle and low-angle normal faults cut the section. NNE-SSW striking normal faults (20°) and about E-W striking normal faults (110°) make up the majority of the observed fault planes, exhibiting vertical displacements of about 50 cm. Due to fault-slip data separation, it was possible to assign both populations of normal faults to different stress fields. NNE-SSW to NE-SW striking faults document Messinan E-W-directed extension, whereas the younger 110° striking fault point to SW-directed extension that occurred since the early Pliocene (Peters, 2000). Sanz de Galdeano (1990) described similar observations from the eastern Betic Cordilleras.

Syn-sedimentary tectonics

Deformation features in unconsolidated sediments often have a non-seismic origin and correspond to high deposition rates, e.g., in deltas. However, if various deformation features can be observed in the outcrop a seismic origin seems more likely. On the other hand, syn-sedimentary growth faults do not necessarily point at seismic shaking but may also display creep along a distinct active fault plane. Deformation of soft, cohesive sediments is induced by loading since elevated pore pressures may cause liquefaction (Obermeier, 1996). An increase of pore-water pressure leads to transformation of granular material from solid into liquefied state. It is difficult to calculate or estimate paleoearthquake intensities or magnitudes using seismites. Liquefaction starts at about M = 5, but is effective about M 5,5 to 6 (OBERMEIER, 1996). Other probable causes may represent „Sackungen" (MCCALPIN, 1996), or atectonic compaction (or dissolution) of buried sediments.

Typically, three types of these features can be distinguished and observed within silt- and marlstones of the depositional sequence IV of Arenas del Rey of the Granada Basin: loading structures as „ball-and-pillow"- and convolute structures (Fig. 3-1), crushed bedding structures, and flame structures. Internal thrusting within a marly limestone bed (Fig. 3-2) points to abrupt shortening of the individual layer associated with flame-like injections of the coaly marls and folding of the uppermost bed below the crushed layer. These structures are clearly of synsedimentary origin, the beds above and below are undisturbed. These structures are interpreted as (paleo)-seismites (Fig. 3-1). And finally, staircase-like normal faulting is associated with horst-and-graben development and growth faults (see Fig. 3-3 and 3-4). The hanging wall of the fault shows markedly greater sedimentary thicknesses, whereas the coal measures in the hanging wall display drag folding. Remarkable is that the former horst (Fig. 3-4) develops continously into a graben within 30 cm of sedimentation.

Some of the disturbance features observed within the Messinian sediments of the Granada Basin are best explained by being produced during seismic shaking, in the term of „fault-graded bedding" of SEILACHER (1969). Soft-sediment deformation in the Miocene stratigraphic units of the Gudalquivir Basin (Tortonian) was ascribed to storm activity (MOLINA et al., 1998). Seismites of sequences of similar age and lithology have also been reported from the adjacent Guadix-Baza Basin and the Alicante region (ESTÉVEZ et al., 1994). Within the depositional sequence II (marls near Otura) of the Granada Basin, slumping structures and pillar-and-dishes have been interpreted as seismites (REICHERTER, 1999), which testify seismic shaking during the Tortonian. The depositional sequence IV of Arenas del Rey contains also seismites, which are associated with growth faults, ball-and-pillow-structures and secondary structures such as flame-like injections. Horst and Graben-structures reflect the regional stress field during the Messinian obtained by paleostress analysis (PETERS, 2000). Although, some of the structures described may be related to dissolution of the gypsum-bearing strata below the studied sequence, they show the same tectonic extension direction. Later post-depositional faulting affected the sequence with the observed change of the main compressional direction (REICHERTER, 1999; PETERS, 2000).

III. Gastropod assemblages

Twenty species can be recognized, two of these may have entered the sediment subsequently. Aside from fresh water gastropods (1 neritimorph, 5 caenogastropods, 9 basommatophoran pulmonates) some land snails (4) all belonging to the stylommatophoran pulmonates and among them the two problematic species compose the fauna. Also small bivalves of the genus *Sphaerium* and several, undetermined ostracodes, the ear bones of fishes (otoliths), bone fragments and remains of green algae belonging to the Charophyta are present. All remains encountered give evidence of pure fresh water. The extreme richness in fossils of some of the washed sediment samples could indicate some kind of natural screening, this contrasts with the extremely good preservation of the most delicate juvenile shells. Probably water was rather clean, not deep and rich in dissolved calcium carbonate, otherwise delicate and thin shells would have become dissolved during deposition and within early diagenesis.. Even in fully grown specimen that have lived for at least several months, the apical portion of the shell is still well preserved. This testifies to the non-carbonate etching composition of the water (not acidic), for soft sediment forming the bottom substrate and water depth below wave base. On the other hand, the species richness indicated availability of sufficient food and limpet like species such as *Ancylus* suggest the presence of plants with large leaves. Thickets of charophytes should have been present nearby.

Systematic description

Order Neritimorpha
Superfamily Neritoidea
Family Theodoxidae
Genus *Theodoxus* Montfort, 1810

Theodoxus usually lives in fresh water on hard substrates, scraping algae and other crust forming organisms for food with its radula. The genus *Theodoxus* is among the neritoid gastropods characterized by its ontogeny which is without free larvae and by feeding on nurse eggs within the shelter of the egg capsule (Blochmann, 1882). This lecithotrophic development is reflected in the morphology of the early shell (Bandel, 1982, Pl.21, Fig.6; Riedel, 1993).

Theodoxus fluviatilis (Linneus, 1758)

(figs. 4, 5)

Description: The shell consists of 2,5 whorls measuring only 7 mm in maximum diameter with 5 mm in width and 4 mm in height when placed on the apertural plane. The only ornament is fine growth lines and a color pattern of light triangles with their pointed portion towards the outer lip. This pattern may change within the same shell along growth lines into a simple gray. The inner lip of the aperture continues in a flat callus that has longitudinal wrinkles near the columellar margin which end in tubercules, the strongest of which are near the umbilical side. The aperture is otherwise simple smooth and half-moon shaped. The protoconch consist of an about 0,3 mm wide whorl that is clearly distinguished from the teleoconch. It consists of a semiglobular cup with a narrow apertural collar added to it. It resembles the protoconch of *Theodoxus jordani* as illustrated by Riedel (1993) but is a little smaller and has a relatively larger apical cup. Only three individuals were found, a juvenile and fully grown one from Arenas del Rey (Fig.1) and a juvenile from Fuensanta.

Remarks: In the modern *Theodoxus fluviatilis* the shell is commonly dark in colour with a pattern of yellow-white streaks. But color patterns are very variable (Neumann, 1959). The operculum is D-shaped and has an internal peg. In case of the specimen from Arenas del Rey the operculum was not found.

Order Caenogastropoda
Superfamily Rissooidea
Family Bithyniidae
Genus *Bithynia* Leach, 1818
Bithynia gracilis (Sandberger, 1852)

(fig. 17)

Description: According to Royo Gomez (1922, Fig.20, Pl.12, Figs.7,8) the turbinate shell has rounded whorls and ornament of growth lines. It consists of about 5 whorls and the umbilicus is closed. The last whorl has about half shell height. The aperture is rounded and a little flattend along the inner lip but it is continuous.The calcarous operculum is concentric in construction. The shell height is about 9 mm and width about 6,5 mm.

In samples from Fuensant a lot of opercula occur, while shells are preserved only as fragmented pieces with well preserved protoconchs. The embryonic shells are larger than those of other caenogastropods studied here.

Remarks: The shell of *Bithynia gracilis* appears to be smaller than that of *B. tentaculata* (Linné, 1758) and apparently *Bithynia* is present only in this one sample. The protoconch of *B. tentaculata* is quite large measuring 0,75 X 0,90 mm with 1,5 whorls (Riedel, 1993) having developed within the egg capsule with the aid of a lot of food consisting of liquid yolk. The protoconch of the *B. gracilis* is of similar dimension and also smooth and well rounded as is the case in *B. tentaculata*.

Family Hydrobiidae

Hydrobia dubia SCHLOSSER, 1907

(figs. 6-7)

Description: According to ROYO GOMEZ (1922, Fig.21, Pl.12, Figs.13,14) the conical shell has rounded whorls and is shiny smooth, consisting of about 6 whorls. Increase in whorl width during growth changes within the last two whorls, probably due to a more rapid growth. Sutures are deep and the aperture is oval and angulated near the suture. The shell is 7,5 mm high and 4,5 mm wide with the last whorl measuring 3,5 mm. The allometric growth of the individuals from Fuensanta is quite obvious. Here individuals with four whorls appear relatively shorter than those with 5 whorls, because this change appears during growth of the fifth whorl. *Hydrobia dubia* is here extremely common. The fully grown shell is up to 6 mm high and 2,5 mm wide. Members of this species or similar species are present in Arenas del Rey usually with smooth shell in samples 5 and 6 (Fig. 2), while in samples 7 and 8 specimen have commonly one varix after four or a little more whorls. Such a varix may also be seen in the specimen from Fuensanta, and here large individuals may show an indistinct spiral ornamental pattern.

Remarks:Hydrobiids with similar shell as in the genus *Hydrobia* show very few distincitve features. It is quite possible that in the samples from Arenas del Rey, there is not only one species but several similar ones. *Hydrobia ulva* from the North Sea flats may be affected by parasitic flat worms. The infected ones grow a larger shell. Aside from variability due to slight ecological differences or possible incidents of parasite infection, also a generally similar ontogeny results in similar protoconch morphology of different species. All these factors make hydrobiid fossils, even though commonly split into many species in literature, a group that is only very little informative in paleontology (see HERSHLER & PONDER, 1998).

Belgrandia gibba (DRAPARNAUD, 1805)

(figs. 8-12)

Description: According to ROYO GOMEZ (1922, Fig.22, Pl.12, Fig.10) and MADURGO MARCO (1973, Pl.5, Figs.3,4) the small conical shell with rounded whorls is characterized by its last whorl, consisting of a thickened and detached last portion. The suture is deep and ornament consists only of growth lines. There are about 5-6 whorls. The shell reaches a size of maximally 5 mm and width of 2,5 mm, with one or two varices. The early ontogenetic shell consists of 1,2 to 1,3 whorls with a fine irregularily pitted ornamental pattern and no growth lines. The time of hatching from the egg is indicated by initiation of more or less strong growth lines and an indistinct varix. The freshly hatched animal carried a shell with about 0, 3 mm height and width, and an initial shell width of about 0,1 mm.

Remarks: *Belgrandia gibba* form one of the most common species in the analyzed samples from Arenas del Rey. It has variations within one and the same fossil population as well as among those of different layers. Before onset of a varix the spire may consist only of 3,5 or 4 whorls, but may in other individuals consist of up to 5,5 whorls. The difference in whorl number results in a quite distinct morphology. Those individuals with more whorls are larger and relatively higher and could be placed in the species *Belgrandia deydieri* (DEPERET & SAYN, 1900) as described by ROYO GOMEZ (1922), while those individuals with fewer whorls fit in the discription of *B. gibba* by MADURGO MARCO (1973). The apical angle differs considerably among individuals of *B. gibba* in one and the same population. The shell commonly ends with the varix, but may continue a bit in normal mode of coiling or, what is more common in the lower beds in Arenas del Rey continue for a more or less extended irregular whorl that detaches from normal shell coiling.

In the Arenas del Rey section (samples 1, 2 and 3) an irregular addition to the varix bearing normally coiled shell is common, with an irregular tube-like shell added that may reach a quarter whorl, rarely even more than that. In sample 4 *B. gibba* can have extremely few whorls before the varix or many whorls. Thus, this population is very variable in this regard, while usually there is no further growth addition. In samples 5, 6, 7 and 8 (Arenas del Rey) and Fuensanta samples *B. gibba* with the characteristic shell and protoconch developed only an indistict or no varix when fully grown. ESU & GIROTTI (1975) described a similar shell as that of *Belgrandia gibba* of Arenas del Rey as *Emmericia* BRUSINA, 1870 from the Pliocene of Italy. They also noted a similarity to *Nystia* TOURNOUER, 1869 and remarked that both genera differ only regarding the shape of their aperture. When the populations in the samples 1 to 4 from Arenas del Rey are compared with those of the samples 5 to 8 and those from Fuensanta, a difference in the apertural thickening can be made out, which may be as different as between *Emmericia* and *Nystia*. The former has still-living representatives in the coastal Balkan region, while *Nystia* is extinct. Perhaps *Belgrandia*, *Nystia*, and *Emmericia* represent very closely related gastropods that could be united within a single genus if early ontogeny proves to be similar. The species of this taxon could be quite informative in regard to paleobiogeographic data and reconstruction of faunal migrations.

Hauffenia schlosseri (ROYO GOMEZ, 1922)

(fig. 14)

Description: According to ROYO GOMEZ (1922, Fig.19, Pl.11, Figs.17-20) this species was described as belonging to *Valvata*. It has a small, lowly conical shell consisting of 3,5 rounded whorls and with an open umbilicus. Ornament consists of a dense pattern of collabral growth lines. The increase in whorl diameter is rapid and the last whorl is higher than the spire. The aperture is rounded and of oval shape with an angulation close to the suture and another one on the anterior columella. The apertural margin is uninterrupted. The shell measures 1,5 to 2 mm in diameter and is the same height. The protoconch is similar to that of *Belgrandia gibba*, but smaller. The specimen from Arenas del Rey and Fuensanta have a granular protoconch surface, quite unlike that of *Valvata piscinalis* O.F. MÜLLER, 1774 that has spirally lirated ornament (RIEDEL, 1993). The small shells of *H. schlosseri*, thus, appear to represent caenogastropods of the hydrobiid relation and not an allogastropod species as it would be in case if belonged to *Valvata*. Many individuals are present in Arenas del Rey (samples. 1,2,3,5,6 and 8). Many have been extracted from the sediments of Fuensanta together with opercula of *Bithynia*, *Hydrobia dubia* and *Belgrandia gibba* of the variety without varix.

Remarks: ESU (1980) suggested to place this species into the genus *Islamia*, while ESU & GIROTTI (1975) called a similarily small shell measuring only about 1 mm in height *Hauffenia minuta* (DRAPARNAUD, 1805) placing it in the Lyogyrinae of the Hydrobiidae. This genus occured in the Pliocene of Italy and is still living there. Here it is apparently quite variable in shape. In Arenas del Rey the similar *Hauffenia schlosseri* is quite distinct in its shape and a little higher than *Hauffenia simplex* (FUCHS, 1870) from the late Miocene of Hungary (SCHLICKUM, 1978). Some specimen from Fuensanta have the last whorl detached, but still retained their original shape. Similar species also lived in Greece during the late Neogene (WILLMANN, 1981, Fig.65) and were placed in the genus *Pseudamnicola* PAULUCCI, 1878. The type of *Pseudamnicola* is *P. similis* (DRAPARNAUD, 1805) which measures 4-7 mm in height and 3-5 in width, thus it is not closely related to *Hauffenia schlosseri* as is the much smaller *Hauffenia* that lives in the area from Spain to the Balkan. Similarily small hydrobiids with 1,2 mm large shells from the upper Jordan River in Israel were called *Mienisiella* by SCHÜTT (1991). *Hauffenia schlosseri* and related forms have very small and well preserved shells. They probably have a very good potential as paleobiogeographic indicators, if better studied.

Superfamily Cerithioidea

Family Melanopsidae

Melanopsis impressa KRAUS, 1852

(figs. 15-16)

Description: The shell of *M. impressa* from beds in Arenas del Rey consists of 11 to 12 whorls and is about 32 mm high and 17 mm wide (see BANDEL, 2000, this volume). Only a little more than one whorl represents the embryonic shell which measures about 0,3 mm in diameter. In the illustrated case it shows marginal fracturing which indicates that the young individual hatched from its egg case at that stage in which there was little more than one whorl of the well calcified shell. It could get damaged due to some kind of unsuccessful attack. With exception of the first three whorls which are rounded all whorls of the teleoconch are flattened on their sides. They have a very regular increase in width up to the 7th to 9th whorl, when whorl width increases more rapidly. Due to this allometric growth shell height relation changes between 10th and 11th whorl. The relation changes from last whorl composing less height than the spire to last whorl making up more height than the spire. Ornament consists only of fine growth lines on the first whorls, and from the 8th whorl onwards a spiral corner appears. It lies right above the large callus pad that features the posterior portion of the aperture. The later is drop-shaped with a narrow posterior groove formed by the callus pad and the outer lip. The callus pad on the posterior inner lip makes its appearance with the eighth whorls while it is very indistinct in earlier ones. The inner lip anterior of its callus pad curves evenly to the narrow but distinct siphonal notch.

Juvenile shells in Arenas del Rey are very common in sample 2 and here apparently most individuals died with 8 whorls and before reaching the characteristic shape. In samples 1 and 4 different growth stages are present. This difference may indicate former depth of water which in case of sample 2 would be deeper, while the others two samples were situated closer to the beach, which is the environment modern *Melanopsis* prefers when living in lakes. The juvenile shells found in sample 8 of Arenas del Rey and Fuensanta have a wider apical angle than found in the lower beds, indicating a change of *M. impressa* from an older to a newer form, perhaps by hybridization (see BANDEL, this volume).

Remarks: *M. impressa* changed very little from the lower part of the middle Miocene (Helvet) to the late Miocene of the Pannonian basin (JEKELIUS, 1944). Similar forms lived during the latest Miocene and the early Pliocene from Spain to Turkey (AZPEITIA MOROS, 1929, Fig.318, ROYO GOMEZ, 1922; SCHÜTT, 1988). Especially the *M. impressa* from lake deposits near Thessalonike in Greece is very similar (RUST, 1997). MADURGA MARCO (1973, Pl.2, Figs.5,6) described a *M. impressa* from the Pleistocene of southern Spain near Granada, which might represent the last exisiting individuals of this species.

Subclass Heterostropha

Order Pulmonata

Suborder Basommatophora

Superfamily Lymnaeoidea

Family Lymnaeidae RAFINESQUE, 1815

According to WENZ & ZILCH (1960) shells of lymnaeids are usually dextral, rarely sinistral, usually thin and with ornament of growth lines.

Genus *Lymnaea* LAMARCK, 1799

The genus represents a typical bucciniform fresh water gastropod that may carry air in its mantle cavity to use it as uplift from the bottom and for oxygen supply. The shell is usually thin and members of the genus can be recognized from their early ontogenetic shell (BANDEL, 1982; RIEDEL, 1993).

Lymnaea cucuronensis FONTANNES, 1878

(figs. 13-20)

Description: According to ROYO GOMEZ (1922, Fig.30) individuals with 5,5 whorls measure 7,5 mm in height and 4,5 mm in width. One specimen with 3,5 mm high shell consists of 4 whorls. The shell is of ovoid elongate shape with short spire. The suture is deep and ornament consists of fine growth lines. The last whorl occupies three fourth of shell height. The aperture has an inner lip with a rounded posterior portion where it consists of callus that covers the whorl. Separated from it there is a corner on the columellar part of the lip forming a fold. The protoconch has an initial cap of about 0,2 mm in width and growth lines become apparent after about one whorl is completed which measures about 0,5 mm in width and height. The transition from the protoconch (shell of animal leaving the egg) to the teleoconch is gradational. *L. cucuronensis* was recognized from Arenas del Rey (samples 5 and 8) and Fuensanta.

Remarks: The protoconch of *Lymnaea stagnalis* (LINNÉ, 1758) closely resembles that of *L. cucuronensis* (RIEDEL, 1993). The young hatches with more than 1,5 whorls and there is no change in ornament after hatching (BANDEL, 1982, Fig.100B). *L. cucuronensis* from Arenas del Rey and Fuensanta resembles *Galba (Stagnicola) palustris* (MÜLLER 1774) as in the account of ESU & GIROTTI (1975), which is common from the early Pliocene onwards and still living in Europe.

Lymnaea bouilleti MICHAUD, 1854

This *Lymnaea* is more slender and larger than *Lymnaea cucuronensis* (ROYO GOMEZ, 1922, Fig.29). Only the early whorls are preserved in sample 5 of Arenas del Rey, while at Fuensanta more or less fragmentary larger shells are present, which closely resemble *Lymnaea stagnalis* that lives in Europe.

Superfamily Planorboidea

Family Planorbidae

The planorbid strategies are to have air in the pallial cavity or a gill that is characteristic to the genus. Mostly shells are planispirally coiled. According to MEIER-BROOK (1983) all Planorbidae are morphologically sinistral since the genital openings and the anus are on the left. Consequently all *Gyraulus* snails were considered sinistral. But most planorbids carry their shell as do dextrally coiled species and the aperture is inclined accordingly.

Genus *Planorbis* GEOFFROY, 1767

Here species are united that have a planispirally coiled shell of about 10-20 mm in diameter and bluntly angular or carinate whorls.

Planorbis romani JODOT, 1958

Description: According to JODOT (1958) this species from Arenas del Rey with a little more than 5 mm in height and 12 mm in width has more rounded whorls and less deep umbilici than related species from older and younger deposits in Spain and southern France. This late Miocene species resembles modern *Planorbis planorbis* (LINNAEUS, 1758) with more rounded whorls. The initial whorl is larger than that of the externally similar *Gyraulus*, which has a lower and smaller shell and is much smaller than the protoconch of *Planorbarius* that has an even more rounded whorl flank and is much higher. In Fuensanta abundant shells are found and in Arenas del Rey, samples 5, 6, and 8 have mostly initial portions of the shell preserved.

Remarks: *Planorbis planorbis* from ponds and lakes in Europe has a shell in which the whorls are strongly convex above and may have a keel near to the lower side. According to RIEDEL (1993) the egg measures 0,12 mm and lies in a 0,6 mm wide capsule from which after nine days a miniature adult hatches with a 0,6 mm large shell that consists of 1,3 whorls. The modern species resembles our Neogene *P. romani* in this regard, but later on has a more pronounced peripheral edge or keel.

Fig.4: *Theodoxus fluviatilis* (LINNEUS, 1758) from the lower beds at Arenas del Rey with a 1,5 mm wide shell. The smooth protoconch is set off from the teleoconch with growth lines.

Fig. 5: Detail to fig. 4 with the protoconch that consists of an about 0,3 mm widw whorl that is clearly distinguished from the teleoconch.

Fig. 6: Protoconch of *Hydrobia dubia* (SCHLOSSER, 1907) from Fuensanta in apical view consists of first whorl with granulated ornament which continues in a postmetamorphic shell of 0,4 mm in diameter which shows the time of hatching quite well with a strong growth increment.

Fig. 7: A lateral view of the same shell as in fig. 6 of *Hydrobia dubia* (SCHLOSSER, 1907) with the about 1 mm high apical portion seen.

Fig. 8: The shell of *Belgrandia gibba* (DRAPARNAUD, 1805) from Fuensanta has no enlarged aperture and is about 3 mm high.

Fig. 9: The shell of *Belgrandia gibba* (DRAPARNAUD, 1805) from the lower layers in Arenas del Rey has an enlarged aperture and an irregular growth continuation added to it and measures almost 3 mm in height.

Fig. 10: Apical view of *Belgrandia gibba* (DRAPARNAUD, 1805) from the lower layers in Arenas del Rey with the enlarged aperture and an irregular growth continuation added to it. It measures 2,4 mm in width.

Fig. 11: The detail to fig. 10 shows the protoconch of *Belgrandia gibba* (DRAPARNAUD, 1805) with indication of hatching from the egg mass after 1,5 whorls of 0,48 mm in width had formed.

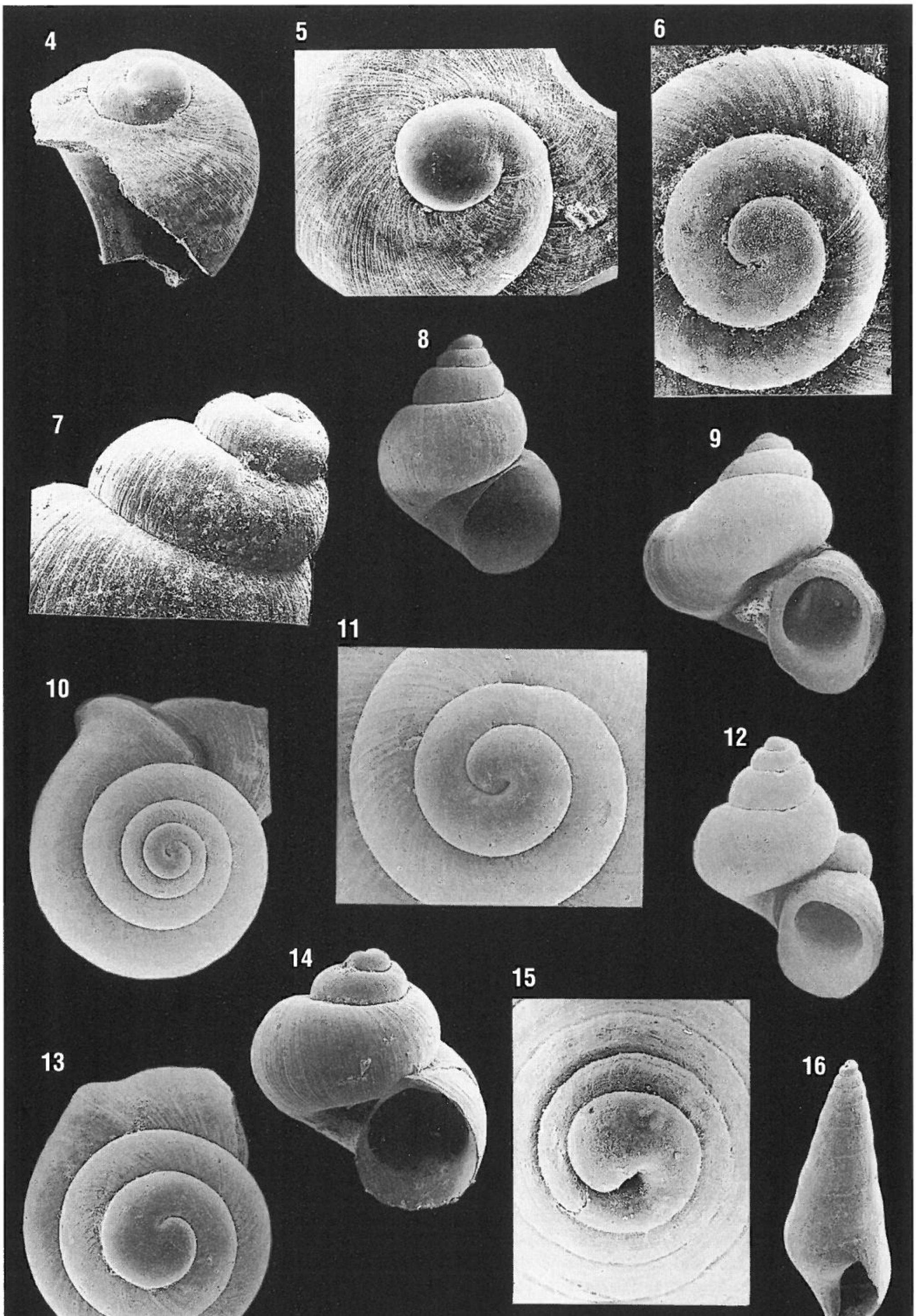
Fig. 12: The shell of *Belgrandia gibba* (DRAPARNAUD, 1805) from the lower layers in Arenas del Rey has an enlarged aperture and an irregular growth continuation added to it and measures almost 3 mm in height. The portion up to the apertural varix is more slender than in the specimen in fig. 9.

Fig. 13: Apical view of *Lymnaea cucuronensis* (FONTANNES, 1878) as illustrated in fig. 20.

Fig. 14: This fully grown *Hauffenia schlosseri* (ROYO GOMEZ, 1922) from Arenas del Rey has a 1,3 mm high shall and widely open umbilicus.

Fig. 15: Protoconch of *Melanopsis impressa* (KRAUS, 1852) from Arenas del Rey with a little more than one whorl represent the embryonic shell with 0,3 mm across. Detail to fig. 16.

Fig. 16: The juvenile shell of *Melanopsis impressa* (KRAUS, 1852) from Arenas del Rey is very slender and 4,4 mm high. Same individual as in fig. 15.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Planorbis umbilicatus MÜLLER, 1774

Description: According to ROYO GOMEZ (1922, Fig.36) the discoidal shell is flattened on the umbilical side and rounded on the apical side. The corner on the umbilical side has a ridge. The shell has a maximum size of 10 mm and height of 2 mm. Among the specimen from Fuensanta a shell with four whorls measures 6 mm in diameter. Only two specimen were found here, so this species is much less common then *Planorbis romani*. The carinate corner is distinctive to other planorbids.

Genus *Planorbarius* FRORIEP, 1806

The planorboid shell is quite large with high and evenly convex whorls. The type species is *Helix cornea* LINNAEUS, 1758 from Europe. In Africa *Planorbarius* is only present in Algeria.

Planorbarius thiollierei (MICHAUD, 1855)

(figs. 21-22)

Description: This up to 22 mm large shell of 9 mm height consists of 4 to 5 whorls (ROYO GOMEZ, 1922, Fig.37). Only the early ontogenetic whorls are present in Arenas del Rey (samples 5, 6 and 8). In Fuensanta abundant fragmentary specimen of larger size are present. This protconch consists of almost 2 whorls with the initial portion about 0, 2 mm wide, the first whorl measuring about 1 mm in width and the young hatched with a 2 mm wide shell.

The three planorbids with rounded whorls can be easily determined even if only the initial whorls are preserved. A small form with low whorls is *Gyraulus* sp, the second one with rounded and higher whorls is *Planorbis romani* and the third with rather large protoconchs and later distinct spiral ornament is *Planorbarius*.

Remarks: The embryonic shell shows rows of pits in *Planorbarius corneus* (LINNÉ,1758), and the juvenile shell shows spiral ridges with periostracal spines. When these disappear due to the disintegration of the organic periostracum, rows of pits accompanied by ridges remain on the surface of the mineral shell (BANDEL, 1991). Such a feature is not visible on the embryonic shell of *P. thiollierei* from Arenas del Rey.

Genus *Gyraulus* CHARPENTIER, 1837

This small size planorbid usually has a more rapid increase in shell width than found in *Planorbis*. Species are found worldwide and occur in any kind of fresh water environment with normal chemistry.

Fig. 17: Operculum of *Bithynia gracilis* (SANDBERGER, 1852) from Fuensanta with internaly spiral and externally concentric growth. Maximum diameter 1,6 mm.

Fig. 18: The initial whorls of *Anisus mariae* (MICHAUD, 1862) of the same shell as in fig.19 with indistinct transition from protoconch and the first whorl 0,3 mm in diameter.

Fig. 19: The shell of the multiwhorled *Anisus mariae* (MICHAUD, 1862) from the basal layers in Arenas del Rey is 2,7 mm wide.

Fig. 20: Juvenile shell of *Lymnaea cucurnensis* (FONTANNES, 1878) from Fuensanta with 2,2 mm in height.

Fig. 21: Apical view of the juvenile shell of *Planorbarius thiollierei* (MICHAUD, 1855) from Fuensanta that demonstrate the time of hatching with repaired fracture in the embryonic shell with about two whorls of about 2 mm in width.

Fig. 22: Lateral view of the same juvenile shell of *Planorbarius thiollierei* from fig.21 with transition of embryonic whorl to juvenile teleoconch. The shell is about 2 mm high.

Fig. 23: Apex of *Ancylus deperditus* (DEMAREST, 1814) from the basal layers at Arenas del Rey with the striped embryonic shell with central depression and onset of smooth teleoconch. The embryonic shell is about 0,9 mm wide.

Fig. 24: Apex of *Ancylus deperditus* (DEMAREST, 1814) from Fuensanta with the striped embryonic shell with central depression is 0,9 mm wide. Detail to fig.25.

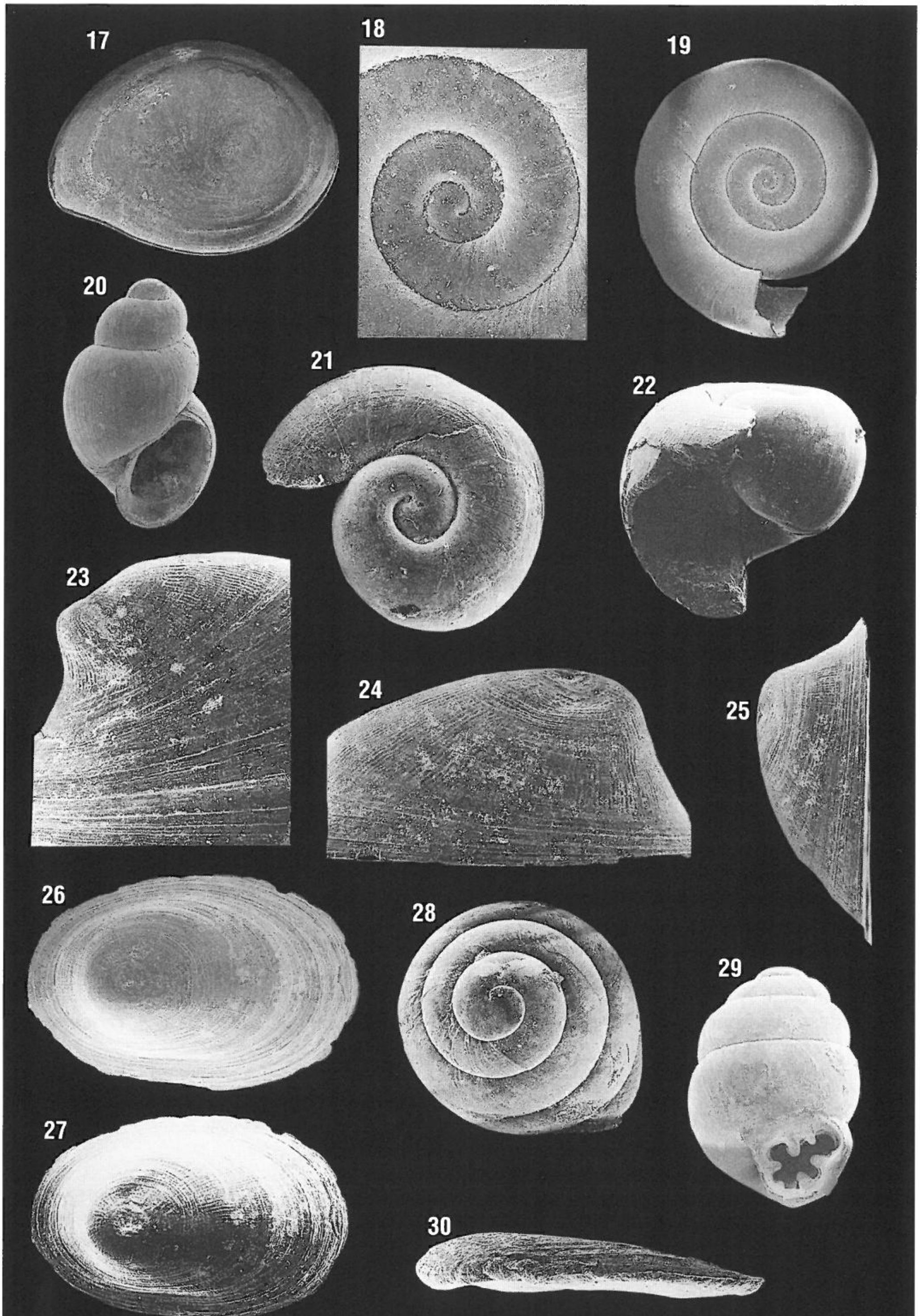
Fig. 25: *Ancylus deperditus* (DEMAREST, 1814) from Fuensanta with juvenile shell of about 1,2 mm apertural length. Fig.24 and 26 is the same specimen.

Fig. 26, 27: *Ancylus deperditus* (DEMAREST, 1814) from Fuensanta seen from above.

Fig. 28: *Vertigo antivertigo* (DRAPARNAUD, 1801) from Fuensanta in apical view with the large, smooth protoconch and teleoconch begin with growth lines. The protoconch measures about 0,7 mm across.

Fig. 29: *Vertigo antivertigo* (DRAPARNAUD, 1801) from Fuensanta of the same shell as in fig.28 in apical view. Height 2 mm.

Fig. 30: The inner shell of the slug *Milax* sp. from Fuensanta is about 4 mm long and seen from the side.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Gyraulus sp.

(figs. 18-19)

Description: A smooth small planorbid with rounded whorls and low profile has a shell that is quite variable in shape with specimen more or less well rounded at their periphery. The ornament consists of fine growth lines which do not form lamellar ribs, as is the case in the rather similar *Armiger*. In Arenas del Rey the sample 5 provided many shells, also in samples 6 and 8, and in sample 1 of Fuensanta.

Remarks: *Gyraulus*- like forms are present from Lower Jurassic onwards and are very evident already in the Purbeckian fauna and in Late Cretaceous swamps (BANDEL 1991, BANDEL & RIEDEL 1994). The species of the genus are very difficult to distinguish by shell shape.

Genus *Anisus* STUDER, 1820

The shell is very low and at its lower side almost plane with 5-8 whorls, reaching a size of 10 mm. Five species live in Europe, the Palaearctis (Sibiria) and North Africa (Algeria).

Anisus mariae (MICHAUD, 1862)

(figs. 18-19)

Description: According to ROYO GOMEZ (1922, Fig.32) the shell is flattened on both sides with a concavity on the upper side and flattened on the lower side. Ornament consists of fine growth lines. The growth of the whorls is regular with a small increase in width forming six whorls with rounded aperture. The size is about 5,5 mm in diameter and 0,7 mm in height. The species from Arenas del Rey was found only in sample 5. It is very similar to *Anisus leucostoma* MILLET, 1813 living today in European ponds and the late Neogene species illustrated by RUST (1997, Pl.10, Figs.4,5) from Greece. It can be recognized and differentiated from the other planorbids from the Neogene of Spain by its more tight coiling and relatively slower increase in shell width during growth.

Genus *Armiger* HARTMANN, 1843

Only *Armiger crista* (LINNAEUS, 1758) occurs in Europe and North Africa, other species live in North America, western Asia. The 3 mm wide shell has flattend whorls which are smooth or have strong axial ribs. It lives in small pools and among rocks in rapid streams.

Armiger lluecai (ROYO GOMEZ, 1922)

Description: According to ROYO GOMEZ (1922, Fig.38) the planispirally coiled shell is very small and delicately thin. It is almost flat on the apical side and slightly concave on the umbilical side. The shell consists of a little more than 2 whorls which are ornamented by more or less well developed fine collabral ribs. The shell measures about 2,5 mm in diameter and 0,5 mm in height. The aperture is rounded and oblique. *A. lluecai* is common in Arenas del Rey at sample 8, while *Gyraulus* occurs rarely here. It was also found in sample 5 and at Fuensanta in sample 1.

Remarks: *Armiger lluecai* resembles the living *Armiger nautilus* (= *A. crista*), that according to ROYO GOMEZ (1922) differs in regard to the position of the spire and the ornament. *A. crista* was studied in detail by GORTHNER (1992) and in its variations *A. lluecai* could easily be included. It has also been illustrated from the late Neogene of Greece by RUST (1997, Pl.10, Figs.6-8) as *A. crista* and closely resembles the species from Arenas del Rey.

Genus *Segmentina* FLEMING, 1817

This planorbid form is characterized by its tight coiling and flattened base.

Segmentina nitida (O.F. MÜLLER, 1774)

Description: The planorboid shell has a rounded apical side and a flattened umbilical side with whorls covering each other much so that the umbilicus is narrow and of the apical whorls only little is seen. Ornament consists of fine growth lines and the shell is shiny. The aperture is inclined. The shell measures about 4 mm in diameter.

Remarks: *S. nitida* occurs in Arenas del Rey (samples 5 and 8) and Fuensanta. It closely resembles those described by RUST (1997, Pl. 10, Figs.11-13) from the late Neogene of Greece. According to RUST (1997) this species has not changed in regard to shell shape since the Pannonian and occurs in Greece and Hungary. The Spanish form is exactly like these and the modern representatives of this species.

Genus *Ancylus* O.F. Müller, 1774

These small gastropods with a cap shaped shell live submerged and attached to hard substrates. Their wide open pallial cavity serves in the exchange of gases between water and blood. While Wenz & Zilch (1960) considered the Ancylidae to have developed from the Planorbidae only late in geological history their oldest records are from the Santonian of Europe (Bandel & Riedel, 1994). *Ancylus* lives in running water of streams and creeks in Europe, the Middle East and Northern Africa, including Ethiopia, with exception of the Nile province.

Ancylus deperditus Demarest, 1814

Description: According to Royo Gomez (1922, Fig.39, Pl.11, fig.10) the fragile limpet shell is up to 4 mm long, 2,5 mm wide, and 2 mm high. The conical limpet has the apex in the anterior third of the shell and only little displaced to the right. It is of elongate oval shape. The ornament consists of simple growth lines and some indistinct radial lirae. In Arenas del Rey the delicate shells were found in samples 5 and 8, and in Fuensanta specimen are up to 4 mm long. The apex has the characteristic irregular depression as present in *A. fluviatilis* living in many places in Europe.

Differences: *Ancylus deperditus* has a more central and more rounded apex than *Ancylus michaudi* Locard, 1878 and the apex lies more centrally than in *Ancylus neumayri* Fontannes, 1880, both of which may also occur in late Miocene lake deposits in the southern Iberian Penninsula (Royo Gomez, 1922).

Remarks: The modern species *Ancylus fluviatilis* Müller, 1774 was analysed by Riedel (1993) according to the shape of the protoconch, which is like that of the fossil form, but the teleoconch is less ornamented. *Ancylus* has an early ontogeny that is charcterized by the dealing with much yolk. Yolk is taken from the albuminous liquid of the egg in such quantities that the shell calcification is retarded until the limpet shape of the adult shell has been reached. A coiled shell is no longer present (Bandel, 1982, Fig.84a). Young hatch with an about 1 mm large cap-like shell.

Suborder Stylommatophora

Superfamily Achatinoidea

Family Ferrussaciidae

Cecilioides acicula (O. F. Müller, 1774)

Description: The shell is slender and shiny. Since the shell is still transparent mixing of living species in the sample may not be excluded. But since this fauna is very abundant in sample 5 of Arenas del Rey, it may also belong here. The protoconch is large and rounded, the whorls of the teleoconch are slender forming a cone with weak sutures and shiny smooth walls. The aperture is elongate with anterior notch.

Family Vertiginidae

Vertigo antivertigo (Draparnaud, 1801)

(figs. 28-29)

Description: The pupoid egg-shaped shell measures about 2 mm in height and consists of about 4,7 whorls with smooth sides. It is just like the recent species that lives all over Europe. The aperture is heart-shaped as wide as high and has a characteristic pattern of plicae on its inside (Schütt, 1993, p.31). Individuals were found in Arenas del Rey, sample 5 and Fuensanta.

Remarks: This *Vertigo* resembles in shell coloration the other fossil shells from the same sample so that land snails appear to have been washed into the lake during sedimentation.

Family Milacidae

Milax sp.

(fig. 30)

The elongate internal shell of the slug *Milax* was found in sample 8 of Arenas del Rey and in Fuensanta. Slugs may bury deeply into the ground, and thus these shells may actually not represent old ones.

Helicidae sp.

Several apical portions of a helicid shell are present in Fuensanta and they clearly belong to fossil shells which could only be determined with more complete shells.

In addition Bivalvia belonging to the genus *Sphaerium* have been extracted from samples 2 and 5 of Arenas del Rey.

IV. Results and discussion

The intramontane Granada Basin has been fractured and faulted since its initiation in the Miocene, accompanied by large and moderate earthquakes. Major extension can not only be observed in subsidence rates within the entire basin with partly over 3000 m since the Tortonian (approx. 11 m.a. before present), but also deduced from sedimentary structures. The depositional sequence IV of the Late Messinian to Early Pliocene mirrors lacustrine sedimentation close to a delta, and the shore, respectively. Marls and marly limestone intercalated with coaly measures contain several structures which may be interpreted as seismites, indicating an earthquake activity during this interval. Seismites within the Granada Basin occur also in the marine interval of the Tortonian (REICHERTER, 1999). The Pliocene-Holocene of the continental infill of the Granada Basin, consisting of conglomerates and debris (piedmont and glacis), reflects also coseismic rupturing (REICHERTER et al., 1999). It may be concluded, that since the initiation of the basin, the Granada Basin serves as a sedimentary reservoir recording seismic shaking in one of the most active zones in southern Spain.

The gastropods from the sediments of Arenas del Rey and Fuensanta are found together with charyphyte oogonia and calcified portions of stems, some fish bones and many ostracods. The gastropods are closely related to species which are still living and provide data to the paleo-environment. Above the fossil rich layers the water of the lake was not deep and sedimentation rates were low. Preservation of very delicate shells indicates quiet conditions not close to the shore and also not close to rivers or creeks issuing into the lake. The fauna has never included any species that would have had a special liking of brackish condition and it includes many species that have extraced oxygen from the water with a ctenidium. Water was, thus, of pure freshwater quality, clear and quiet. In the layers with rich fauna it was probably also not deep. The water quality allows important conclusions to the tectonic activity, since salt from the layers of the Tortonian have not been dissolved. So, seepage of salty waters may be excluded, and hence the tectonic structures may therefore be related to syndepositional movements.

Regarding changes in faunal composition there was a clear break that is evidenced by a change from a slender to a less slender form in *Melanopsis impressa* and by the evolution within the genus *Belgrandia*. Both these changes should be studied in more detail and they could possibly be utilized to get a finer stratigraphical resolution in the region and possibly the entire Mediterranean realm.

Acknowledgements

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