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LONG TIME SPAN FOR VERY SMALL SEQUENCES AND THEIR CONTROL BY Sr-ISOTOPES FOR RIGHT UNDERSTANDING OF CONDENSATION OR GAPS. THE BOYALI TEPE SECTION IN THE MESOZOIC CENTRAL TAURUS, TURKEY

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Abstract. Well defined and limited sedimentary episodes have been found in a very thin marine carbonate succession (25 metres) from Toarcian to Santonian at the Boyali Tepe. By fossils and Sr isotope ratios the ages of the depositional episodes are clearly evidenced, never condensed mixing of the fauna of different ages has been found. Therefore the Boyali Tepe section is not here considered a condensed section because many long gaps have been found and the mixing of the fauna is absent. The new data will help to reconstruct the palaeogeographical setting of the Taurus belt during Mesozoic times.

Keywords: condensation, gaps, lacunose sequences, Mesozoic, central Taurus, Turkey.

INTRODUCTION

Sedimentary successions are commonly considered "normal" or "condensed" following subjective evaluation derived from personal experience.

From subjective evaluation, the depositional environments that conditioned the "normal" or "condensed" successions were hypothetically reconstructed. In this way, being the evaluation not supported with selected and possibly discussed parameters, but mainly with the thickness of the deposits, the palaeogeographical and palaeoenvironmental reconstructions should become fantastic. Only through this type of subjective evaluations the virtual certainty is reached.

The correlation among successions of the same type enlarge the possibility of basin reconstruction and evolution, and the understanding of synsedimentary tectonism.

But, the exiting result for having utilized the supposed significance of the classification "normal" or "condensed" from "thick" and "thin" is the dramatically enormous misinterpretation.

One of the more wrong certainties is the "large and abyssal ocean of the Tethys" during the radiolarite sedimentation. Recently radiolarites inside a platform system have been described (Farinacci *et al.*, 2000; Farinacci & Barbieri, 1999).The same for the ophiolite emplacement on the ocean floor during Jurassic time! "...un lambeau de croute océanique n'a jamais prouvé l'existence d'un espace océanique et l'on a souvent inventé des "océans" pour des secteurs géographiquement limités" (Elmi, 1996).

The concept of normal or condensed succession was based only on depositional continuity of sediments having different sedimentation speed, the thickness of sediments for time-unit being for many authors the only variable parameter controlling accumulation. Ferdinàndez Lòpez & Gòmez (1991) call "stratigraphical condensation" an interval along a condensed section in which the slow sedimentation speed is annulled.

But the depositional continuity in long time span is not easy to find, whence we infer that the depositional episodes frequently are separated by hiatuses (Ager, 1993). In fact, well calibrated logs lacking sediments are normally found, giving evidence of short or long intervals of non-deposition.

The fossils in the marine sedimentary process normally are very common; by them, consequently, the steps of evolution of organisms and datation of the rocks is possible. Nevertheless, the preservation of the skeletal parts is not always easy; on the contrary some well preserved fossils do not have a stratigraphical value as well. Other causes are not favourable to their presence or to their preservation due to chemical reasons.

Following the impossibility of dating every step along thè logs, some succession have been misinterpreted and some uncorrect methods of study have been used.

But in many cases it is difficult to solve the problem related to the "short" sequences. Frequently the possibility to recognize the presence of hiatuses or the continuity of the depositional process is only represented by the application of the Sr-isotope geochemistry. It is in fact now well established that the variations in the Sr isotope composition of the sea water represent a powerful tool for dating and correlating sedimentary sequences. The improving of the method increases more and more by the control of the golden-hook fossils and Sr-isotope ratios.

USE OF Sr ISOTOPE GEOCHEMISTRY FOR DATING MARINE CARBONATE ROCKS

It is well known that marine carbonates contain variable amount of Sr entering the lattice of calcium carbonates (calcite and/or aragonite). Therefore the geochemistry of Sr in these minerals can be a suitable, though indirect, method for many different purposes, for example for studying the nature of the diagenetic processes, for stratigragraphic and chronostratigraphic reconstructions.

Speaking about the geochemistry of Sr, it is necessary to point out the meaning of the words Sr isotope geochemistry.Four naturally occurring Sr isotopes constitute the Sr isotopic complex: ^{84}Sr, ^{86}Sr, ^{87}Sr and ^{88}Sr. The abundance of 84, 86, and 88 Sr are constant in nature, in fact they are neither radioactive nor the decay product of any natural radioactive isotope.

The ^{87}Sr isotope is also stable, but its abundance shows some small variations due to the variable increments of ^{87}Sr derived from the radioactive β-decay of ^{87}Rb.

Being the radioactive decay of ^{87}Rb characterized by a half-live extremely large (50 x10E9 years) and due to the low Rb abundance in the Earh's materials, the variations of ^{87} Sr within the Sr isotopic complex are very small.

The Rb-Sr chronometer is a very useful method in determining geologic ages and the Sr isotope

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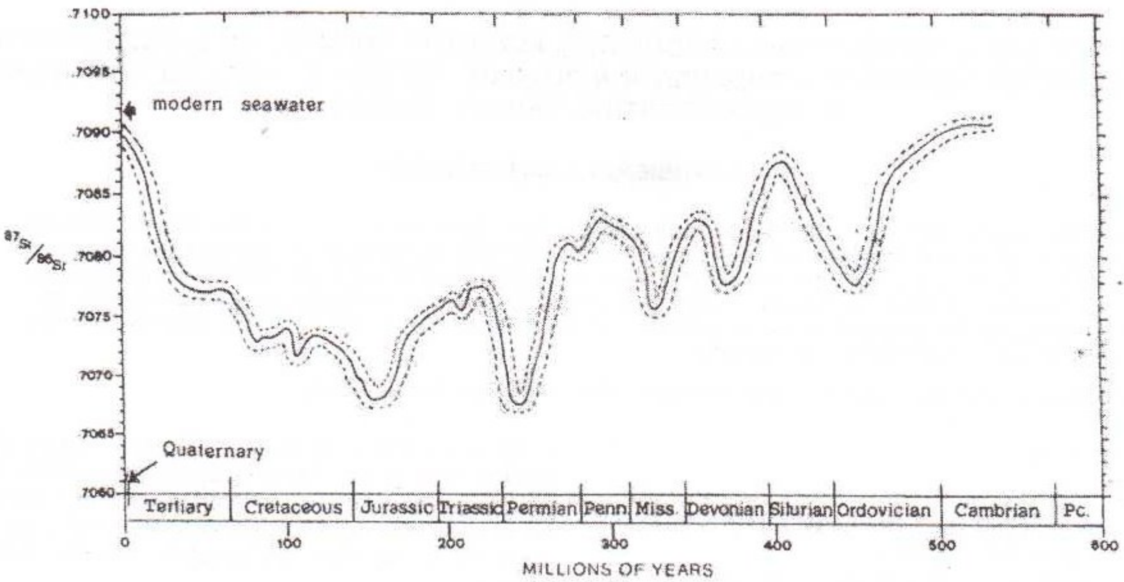

Figure 1 - $^{87}Sr/^{86}Sr$ isotope ratios in seawater from Cambrian to Present; dotted line represents the range of analytical values (data from Burke *et al.*, 1982,; De Paolo & Ingram, 1985).

composition, expressed as $^{87}Sr/^{86}Sr$, represents an important tracer of various geologic processes.

During the last years the Sr isotope geochemistry has been widely applied to the study of marine sedimentary rocks. This ratio has been applied as useful tool for chronostratigraphic purposes and for stratigraphic correlations. It is necessary to point out that the Sr isotopic ratios $^{87}Sr/^{86}Sr$, measured in the sedimentary marine carbonates formed in equilibrium with seawaters, represent the isotopic ratio of seawater at the time of the carbonate deposition. In fact, because the carbonate sedimentary materials are Rb free, their $^{87}Sr/^{86}Sr$ isotope ratio does not modify during the geologic time. In addition, it has been pointed out that, at any time, Sr is isotopically well mixed in ocean water, and this homogeneity is related to the ratio of the residence time of Sr in the oceans, t and to the homogeneization time of the oceanic waters, tm. This ratio is 4,000, so a high degree of homogeneity is expected.

Replicate analyses of modern seawater indicate a worldwide $^{87}Sr/^{86}Sr$ ratio close to 0.709175+/-0.000020. However, during the geologic evolution of the Earth, the strontium isotope ratios in the oceans modified because of the changes in the relative inputs of Sr coming to the oceans from different sources each with own strontium isotopic value.

We can consider three different fluxes :

1. submarine hydrothermal activity related to the mantle derived magmatism (like the modern oceanic ridges magmatism). As for the $^{87}Sr/^{86}Sr$ is concerned this magmatic activity is characterized by high strontium fluxes and low $^{87}Sr/^{86}Sr$ ratios (about 0.702000) in the sea water.

2. Fresh water coming from the continents. These waters show normally a salinity derived from the interaction between meteoric waters and crustal rocks which are characterized by very high strontium isotopic ratios, depending on their Rb and Sr content and from their ages. Normally these fresh waters show $^{87}Sr/^{86}Sr$ higher than 0.710.

3. Submarine dissolution of ancient sedimentary carbonates. These carbonates due to their Sr isotopic values are not able to sensibly modify the strontium composition of sea waters.

A reliable record of the Sr isotope composition can be used for understanding the role of the various sources in controlling present and past seawater chemistry.

There is increasing evidence that a close relationship exists between the Sr isotopic composition of seawater and the geologic time.

Wickman (1948) proposed that the decay of ^{87}Rb in the Earth's crust would lead to an increase of about 30% in the $^{87}Sr/^{86}Sr$ of the seawater in the last 3350 Ma. Gast (1955) and Hedge & Walthall (1963) found much smaller increases than those predicted by Wickman. Accornding to Hedge and Walthall, this discrepancy is due to an overestimation of the Rb/Sr ratio of the Earth's crust. Koepnick *et al.* (1985) suggest that the $^{87}Sr/^{86}Sr$ of seawater has increased only about 1.4 percent throughout the geologic time. Peterman *et al.* (1970) determined ratios of aragonitic shells from paleontologically dated time intervals within the Phanerozoic. They documented both an increased and decreased strontium isotope ratio with geologic time (see Fig. 1). These early findings have generally been supported by Dash & Biscaye (1971) and Veizer & Compston (1974). The latter authors also argued about the reasons why the marine carbonates must have the $^{87}Sr/^{86}Sr$ ratio of the seawater at the time of their formation and the role of the diagenetic processes that generally produce an increase of the ratio or leave it unaltered.

Since 1974, additional papers on the $^{87}Sr/^{86}Sr$ ratios determined in marine carbonates, evaporites and phosphate samples of known ages have been published (see Tremba *et al.*,1975; Brass, 1976; Burke *et al.*, 1982; De Paolo & Ingram,1985; Koepnick *et al.*, 1985; Jones *et al.*, 1994).

All these data permit the definition of the curve of seawater $^{87}Sr/^{86}Sr$ ratios versus geologic time starting from Late Cambrian to Holocene, as shown in Fig. 1. This figure confirms the general shape as previously defined by Peterman *et al.* (1970) and Veizer & Compston (1974). Strontium isotope ratios, close to that

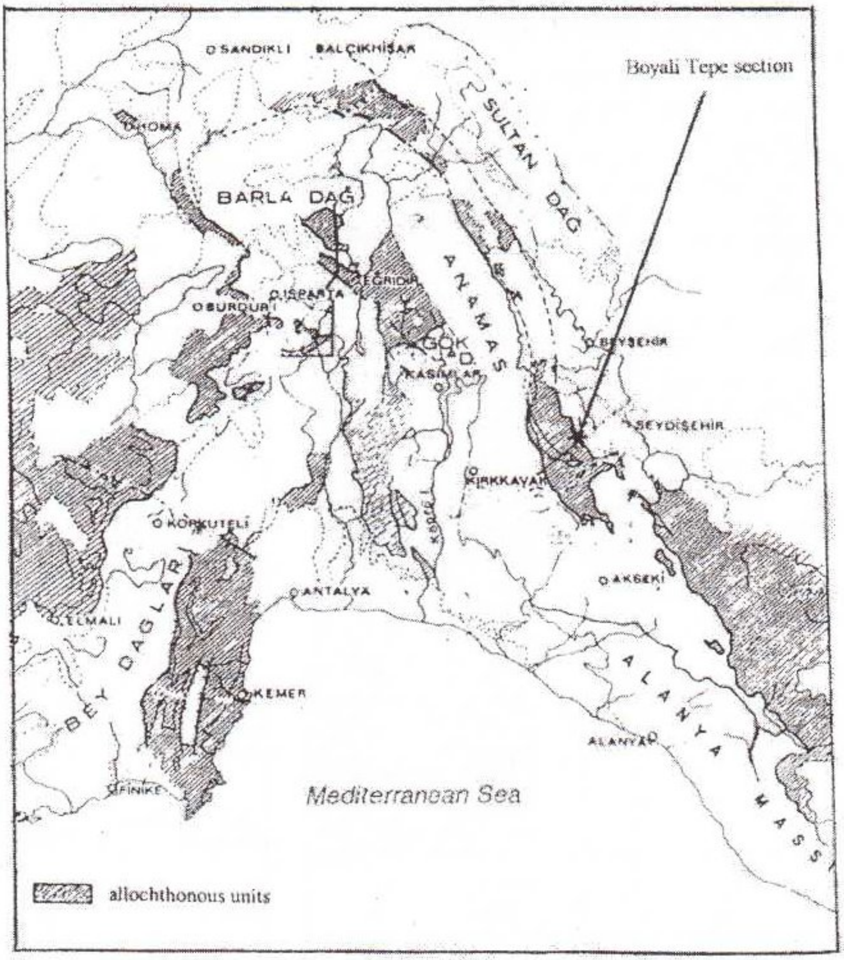

Figure 2 - Location map of the study area.

of modern seawater (0.709175+/- 0.000020), during the Late Cambrian to Early Ordovician time, started to fluctuate from Ordovician time, with the lowest ratios , close to 0.7068 in Late Permian and Jurassic time.

These temporal variations of the Sr isotope ratio of seawater are related to the changing fluxes of Sr from isotopically distinct sources within the crust. High ratios would indicate prevailing old sialic rocks as the ^{87}Sr radiogenic source ($^{87}Sr/^{86}Sr$ higher than 0.7100). On the contrary, low strontium isotopic ratios would suggest a major role of mafic volcanic and intrusive rocks from active margin and ocean basin ($^{87}Sr/^{86}Sr$ close to 0.7020). The shape of the $^{87}Sr/^{86}Sr$ curve seems to be controlled significantly by geologic evolution of the Earth through the Phanerozoic time.

According to Burke et al. (1982), the actual circumstances leading to these fluctuations likely involve a great number of factors, such as variations in the lithologic composition of the crust involved in the weathering processes, landscape of the continents, changes in climate, extent of magmatic activity and nature of the volcanic materials. Many of these factors may be related to global tectonic processes, thus the temporal variations in seawater may be evaluated in terms of tectonic implications.

The curve of seawater $^{87}Sr/^{86}Sr$ ratios versus geologic time provides a useful basis for dating marine carbonates, evaporites and phosphate rocks but only when these materials show high strontium content , a very low insoluble residue and low diagenitic grade. A measure of the diagenetic influence can be evaluated on the basis of the Sr, Fe and Mn amount in the marine sedimentary rocks.

In conclusion the strontium isotope geochemistry can be usefully applied for stratigraphic and chrono-stratigraphic recostructions but this geochemical parameter cannot be used without the paleontological and geological information. In fact, as it is possible to observe from the curve of Sr isotope variation throughout Phanerozoic time, for the same isotopic values it is possible to obtain very different chronostratigraphic data.

THE BOYALI TEPE SECTION

Nearby the main road, between Beysehir and Akseki, about 5 km from Huglu village, Boyali Tepe section crops out (Fig.2), showing a reversed succession of layered marly limestones, cherty limestones and radiolarites for 25 m in thickness from Toarcian Rosso Ammonitico to Cretaceous Scaglia.

All sequence is characterized by red-pink color. The beds are crossed by thin calcite veins mainly of three generations reliable to the different tectonic events. The last one is responsible also for stylolites. The fractures are bordered or sometimes filled by iron oxides.

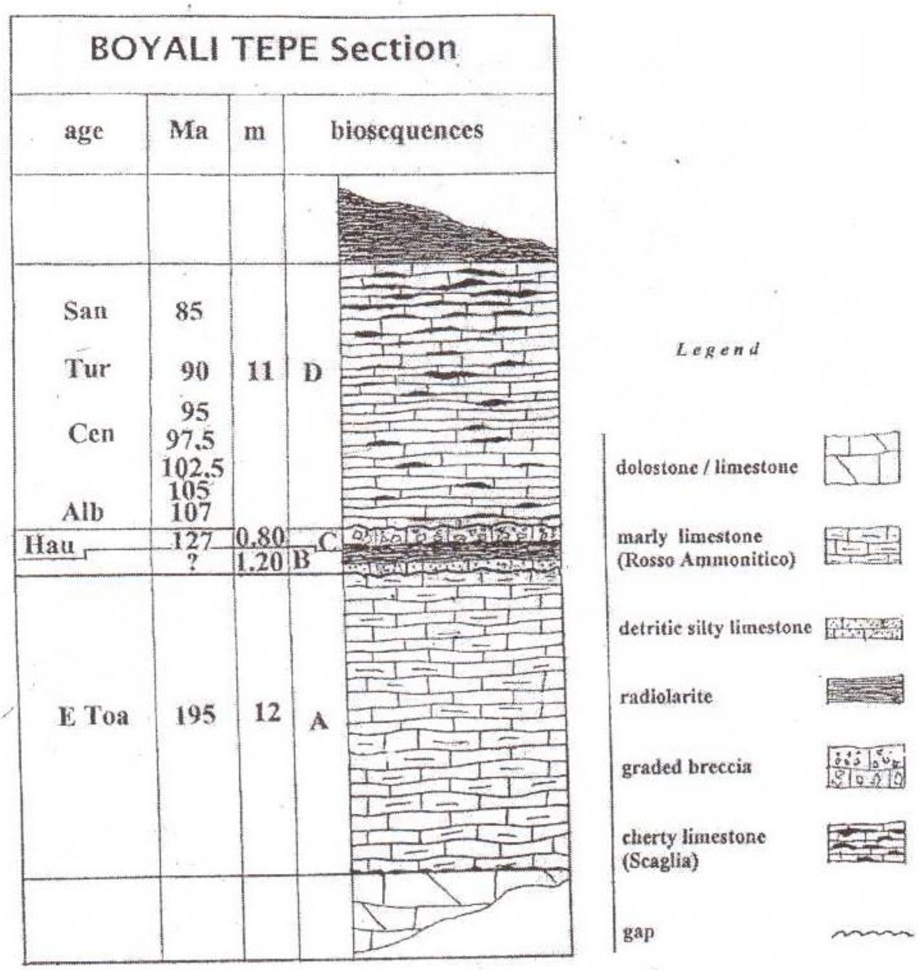

Figure 3 - Log of the Boyali Tepe outcrop, with ages obtained by Sr isotopes and fossils. The major gaps are evidenced.

The Biosequences

From Early Toarcian to Santonian some depositional episodes have been recognizzed, divided in 4 biosequences. Inside and between them, many gaps are responsible for the shortness of the section (Fig. 3). The Boyali Tepe outcrop has been previously studied for the first time by Gutnic & Monod (1970) and recently by Varol & Tunay (1996). The above authors consider the Boyali Tepe section as condensed sequence sedimented in deep sea environment.

Boyali Tepe Biosequence A

At the base on the Triassic dolostones and limestones, transgressively overlie about 12 metres of nodular marly Rosso Ammonitico. From lower beds some ammonites, studied by R. Mouterde were found: their age is early Toarcian (*fide* Gutnic & Monod, 1970).

The ammonite fauna has been found only at the basal layers of the biosequence, along the whole biosequence there are few radiolarians, small thin shelled gastropods, some ammonite embrios, aptychi and many ostracods. Some small filaments are identified as broken ammonite shells, the presence of *Bositra* is escluded. The age controlled by ammonites is confirmed by the datation of Sr isotope ratio, with the result of 195 Ma, that is early Toarcian (acording W.B. Harland *et al.* scale). The radiometric analyses along the biosequence gave always the same value. Therefore early Toarcian is the age of the 12 metres of Rosso Ammonitico. This thickness is usual for early Toarcian Rosso Ammonitico also in other regions of Western Tethys (in Italy, France, Hungary, Greece). The Rosso Ammonitico of the Boyali Tepe section corresponds to the typology of this widespread Tethyan formation (Nicosia *et al.*, 1991).

Boyali Tepe Biosequence B

On a discontinuity surface the following biosequence (1.20 m) has not given an age by Sr isotope because the sediment is not carbonate.

The thin basal level is clastic without fossils, followed by chert deposit with radiolarians badly preserved for palaeontological analysis. Therefore this first chert deposit, presumably belongs to radiolarian chert of Late Jurassic in western-central Taurus.

Clastic deposits and radiolarite are strongly red-colored by Fe oxides.

Silt and radiolarite of the biosequence are the only m 1.20 undated sedimentary accumulation between Early Toarcian Rosso Ammonitico and Hauterivian calpionellid episode. The undated Biosequence B is suspended within a time span of about 68 Ma.

Boyali Tepe Biosequence C

It is represented by 0.80 m of graded brecciated limestone in which the brecciated elements, originated from reexhumed small pieces of the underlying radiolarian mud, were still soft at the moment of the deposition. In the micrite matrix calpionellids are present, confirmed by the radiometric age. There are also large thick specimens of *Lenticulina* sp.;.*Tintinnopsella carpathica* Murg. & Fil. and *Calpionellites darderi* Colom are the calpionellids of the breccia.

Sr isotope analysis gave a value of 127 Ma corresponding to Hauterivian. Rarely calpionellids have been found in Hauterivian. Without ammonites the last calpionellids were considered Valanginian. Granier *et al.* (1995) in a short discussion on the calpionellid survival after Valanginian, pointed out the frequence of this founding. Remane *et al.*,1996, observed that it is impossible to establish a precise age to the disappearance of the calpionellids within Hauterivian, having just found them in Early Hauterivian times. The finding of Granier *et al.* (1996) in Alicante, Spain, associated with ammonites. *Pseudothurmannia* gr. *grandis* Busn. allow dating to the Latest Hauterivian (*fide* Granier *et al.*, 1995)..

Boyali Tepe Biosequence D

After a major gap of 20 Ma between Hauterivian and Albian, Biosequence B is represented by 11 m of pink-red cherty limestone. Within the nodules radiolarians are present.

From the base to the top of the biosequence planktonic foraminifers are developed, just well studied by M. Elkholi, the list being published in Gutnic & Monod (1970). The ages obteined by planktonic foraminifers are now controlled by Sr-isotope analysis. The assemblages of each age result independent from each other and no mixing is present in the assemblages.

22 Ma is the time span in which only Albian, Cenomanian, Turonian and Santonian have been represented by assemblages in a discontinuous trend, gaps between them being extensively developed. Therefore it is not easy to know how long the accumulation spent to form the layers representative of well defined intervals of each age given by fossils assemblages.

But, being the evolution of the Cretaceous planktonic foraminifers very fast, the time of the discontinuous accumulation of 11 m during 22 Ma was less than the time involved in the gaps among record of the assemblages.

In fact during Albian we have obtained three well defined ages: 107 Ma, 105 Ma and 102.5 Ma. Between the first two there was lacking deposition for 2 Ma, 2.5 Ma between the last two. But the refinement of the radiometric method is not sufficient enough for this time interval to know how long each of the three intervals in the Albian age, in which assemblages have unchanged composition.

A gap of 5 Ma is documented between Albian and Cenomanian. At the base of Cenomanian 97.5 Ma and then 95 Ma the different assemblages are the characteristics of Early Cenomanian, also if separated by a gap of 2.5 Ma.

After Early Cenomanian a gap of 5 Ma is extended to reach the development of the Turonian assemblage where 90 Ma is the value of Sr-isotope analysis.

Moreover 5 Ma is a gap developed between Turonian and Santonian, where at 85 Ma the assemblage is typical of this age.

The Boyali Tepe Biosequence D represents a well documented example of non-condensed, but strongly lacunose unit of 11 m, being from the base to the top 22 Ma past, the majority of which without sedimentation.

GAPS AND RECORD

At the base Early Toarcian marly limestone transgressively overlies the Upper Triassic massive or bad stratified limestone and dolostone sedimented on a subsiding evaporitic shallow plain (sabkha facies). Between them, probably caused by a subaerial exposure, sediments of Late Triassic up to Toarcian are lacking. In western and central Taurus subaerial exposures are well documented, during this time span, for the presence of lower and middle Liassic paleosol (Imrassan paleosol) and estuarine deposits (Cayir formation).

The Liassic drowning in western Taurus, widespread during Pliensbachian, here became in Toarcian with the Rosso Ammonitico deposition, as the typical sedimentary episode of tectonic instability (Nicosia *et al.*, 1991).

In the Boyali Tepe Biosequence A, the Rosso Ammonitico is developed without chert, also if few radiolarians are present together with some benthonic calcareous foraminifers, thin shelled gastropods and ammonites well developed or embryonic.

This Early Toarcian carbonate episode happened in a very short time, Sr-isotope ratio is not changed during the whole biosequence of 12 m.

Moreover the absence of hard-grounds, of karst erosion, sink-holes and neptunian dikes, frequently present inside the so widely studied formation in other Tethyan regions (see: Rosso Ammonitico Symposium Proceedings, Farinacci & Elmi *Eds*, 1981), and the presence of gastropods, aragonitic shells of ammonites, frequently broken to form small pieces in "filament" shape, hyaline benthonic foraminifers, radiolarians with calcite epygenesis, are the characteristics of the shallow open sea Rosso Ammonitico, sedimented continuously, without hiatuses, during a short time span.

At the top an evident discontinuity marks a very important event: after a long lacking of deposition, the "main gap", the beginning of the silica sedimentary episode occurred. The so-called "main gap" is developed at the discontinuity of the top boundary of the biosequence. This long hiatus was just found in Western Taurus in Barla Dag and Anamas Dag, previously found in Apennines, Dinarids, Albanids (Farinacci *et al.*, 1997 and references therein).

The next Biosequence B is a detrital deposit of residual reworked material without fossils, probably the product of transgressive sweeping, followed by a layer of typical radiolarite. No radiometric age was possible to establish. Both levels are contained within the time span of 68 Ma, between the value of 195 Ma at the top of Early Toarcian marly limestone and the value of 127 Ma at the Hauterivian calpionellid breccia. They are short episodes that probably happened after the "main gap", this hypotesis is suggested by the analogy with the Zindan section (Farinacci & Barbieri, 1999) where the restarting of the sedimentation after the "main gap" happened with shelf carbonate layers followed by silt and radiolarian chert episode, similar but shorter to Biosequence B of Boyali Tepe.

The graded breccia of the Boyali Tepe Biosequence C has a radiolarian fauna within the mud fragments, and calpionellids inside the muddy matrix. Of course the age of the breccia is the age of the matrix, probably also the brecciated radiolarian fragments, almost soft at the moment of reworking (pebbly breccia) are penecontemporaneous. As explained in the description of the biosequence, the age of the matrix is Hauterivian.

The erosional surface between biosequences C and D marks a gap of 20 Ma because the upper restarting sedimentation became in Albian, dated by fossils and Sr-isotopes.

The following 11 m of the Biosequence D is made entirely by tipical "scaglia", cherty well bedded limestones. Inside there are many long gaps without discontinuities or changes of the lithology. Neveretheless very poor thicknesses of each episode (only Albian and Santonian carbonates develop more than two metres each) represent the presence of some zonal assemblages of Albian, Cenomanian, Toarcian and Santonian (Elkholi *in* Gutnic & Monod, 1970). In Fig. 3 is clearly evidenced the gaps and the sedimentary episodes in which the "scaglia" limestone is divided, being the record well dated and limited in time

Understanding the gaps - conclusion

The large amount of hiatuses distributed in the Boyali Tepe section, along the always marine sedimentary succession, evidences the episodic nature of the sedimentation.

The difficulty to understand why these interruptions occurred is linked mainly to insufficient number of the parameters considered. It is a problem not easily solved by classic sedimentology.

The centimetric Sr-isotope analyses made in the log and the palaeontological study of the assemblages clearly evidence some immense non-depositional breaks. On the other hand in the depositional episodes the density of the fauna is normal, being considered "normal" the density of the fauna of other more developed occurrences of Rosso Ammonitico and Scaglia in other localities distributed in the peri-Mediterranean regions.

From Toarcian to Santonian the first gap is contained between Rosso Ammonitico and m 1.20 of silty level followed by radiolarite, presumably of Late Jurassic, that is a gap of 45 Ma about.

Positioning Biosequence B more under or more above, the problem is the same: larger hiatus under, or large hiatus above.

The mechanism of the "main gap" that in Boyali Tepe is contained between biosequences A and B has been studied in many localities of the Western Tethys. Sometimes an easy interpretation is possible because the presence of paleokarst. Therefore we assume the interpretation for mid-late Jurassic "main gap" explained in the Albanian Ionian zone (Dodona *et al.*, 1994) and in the Barla Dag (Taurus) (Farinacci *et al.*, 2000), for subaerial exposure. The tectonic mechanism explained in the above papers can be applied to the "main gap" so largely widewspread in the peri-Mediterranean regions and to be interpreted as due to a thermal up-doming, preceeding the ophiolite upper Jurassic eruption, that brought large portions of Western Tethys sea floor near the surface or in subaerial exposure.

Then, a general collapse of the area is ascribed from Oxfordian up to later Jurassic, and sedimentation restarts again. The marine volcanics liberated abundant silica that created the chemical conditions for the life of an enormous emount of radiolarians, and consequently the deposition of the Upper Jurassic radiolarites.

The Early Cretaceous long gap and all the gaps distributed inside the Upper Cretaceous "Scaglia" are more unusual in the peri-Mediterranean regions, but well represented in Taurus belt. They are always linked to the geodynamc evolution of the area and to the chemical conditions of the sea water. "Scaglia" is developed on a very large area from Italy to Crimea, being gaps inside the formation, increased from Italy toward East. In the Taurus mountains "Scaglia" with many hiatuses is also cupping the carbonate platform system (e.g. Bey Daglari rimmed platform and Barla Dag ramp).

The wrong interpretation of the Boyali Tepe section as a condensed sequence could not allow a correct palaeogeographical reconstruction because a continuous sedimentation must be presumed inside a quiet basin. That is in contrast with the geodynamic history of this region.

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