Geological Society, London, Special Publications

Dating of the Black Sea Basin: new nannoplankton ages from its inverted margin in the Central Pontides (Turkey)

J.-C. Hippolyte, C. Müller, N. Kaymakci and E. Sangu

Geological Society, London, Special Publications 2010; v. 340; p. 113-136
doi:10.1144/SP340.7

Dating of the Black Sea Basin: new nannoplankton ages from its inverted margin in the Central Pontides (Turkey)

J.-C. HIPPOLYTE[1]*, C. MÜLLER[2], N. KAYMAKCI[3] & E. SANGU[4]

[1]*LGCA, University of Savoy, CNRS UMR 5025, 73376 Le Bourget-du-Lac, France*
Present address: CEREGE, Aix-Marseille III University, CNRS UMR 6635, Europôle Méditerranéen de L'Arbois, BP 80, 13545 Aix en Provence, France

[2]*IFP, 6 bis rue Haute 92500 Rueil-Malmaison, France*

[3]*Middle East Technical University, Department of Geological Engineering, 06531-Ankara Turkey; Utrecht University, Forth Hoofddik Paleomag Lab. Budapestlaan 17, 3584 CD Utrecht, the Netherlands*

[4]*Kocaeli University, Department of Geological Engineering, 41100 Kocaeli, Turkey*

**Corresponding author (e-mail: hippolyte@cerege.fr)*

Abstract: The Eocene uplift and inversion of a part of the Black Sea margin in the Central Pontides, allows us to study the stratigraphic sequence of the Western Black Sea Basin (WBS). The revision of this sequence, with 164 nannoplankton ages, indicates that subsidence and rifting started in the Upper Barremian and accelerated during the Aptian. The rifting of the western Black Sea Basin lasted about 40 Ma (from late Barremian to Coniacian). In the inner, inverted, Black Sea margin, the syn-rift sequence ends up with shallow marine sands. The uppermost Albian to Turonian was a period of erosion or non deposition. This regional mid-Cretaceous stratigraphical gap might result from rift flank uplift, as expected in the case of a thick and cold pre-rift lithosphere. However, coeval collision of the Kargi Block, along the North Tethyan subduction zone at the southern margin of the Pontides, might also have contributed to this uplift. A rapid thermal post-rift subsidence of the margin occurred during the Coniacian–Santonian. Collision of the Kirşehir continental block commenced in Early Eocene time (zone NP12) giving rise to compressional deformation and sedimentation in piggyback basins in the Central Pontides, whereas the eastern Black Sea was still opening.

It is commonly accepted that the Black Sea Basin opened as a back-arc basin during the Mesozoic, as a consequence of the northward subduction of the Neotethys ocean (Hsü *et al.* 1977; Letouzey *et al.* 1977; Zonenshain & Le Pichon 1986). Alternatively, it may have opened under an extensional regime following the Palaeo-Tethyan collision and overthickening of the crust (Yiğitbaş *et al.* 1999, 2004). However, its precise timing of opening is still under debate (e.g. Nikishin *et al.* 2003). The eastern Black Sea Basin (EBS) (Fig. 1) is supposed to have rifted in the Upper Paleocene (Robinson *et al.* 1995; Robinson 1997). This Paleocene (post-Danian) age of rifting is supported by the presence of an almost complete Mesozoic to Lower Paleocene series in exploration wells drilled on the Shatsky Ridge (Fig. 1) (e.g. Robinson *et al.* 1996). The western Black Sea Basin (WBS) (Fig. 1) is generally considered to have rifted during the middle Cretaceous (Late Barremian or Aptian–Albian–Cenomanian; e.g. Finetti *et al.* 1988; Görür 1988; Manetti *et al.* 1988; Görür *et al.* 1993; Robinson *et al.* 1996). This age is based on facies and thickness variations in the Cretaceous stratigraphic sequence of the Central Pontides (Görür 1988, 1997; Görür *et al.* 1993). However, pointing out that arc magmatism started in the Western Pontides only in the Turonian, Tüysüz (1999) then Sunal & Tüysüz (2002) suggested that the main opening phase had occurred during the Turonian–Maastrichtian. Moreover, based on heat-flow data, Verzhbitsky *et al.* (2002) obtained a 70–60 Ma age (Maastrichtian–Danian) for the lithosphere of the western and eastern basins.

Surface data concerning the rifting and evolution of the Black Sea can be obtained from the thrust belt of the Pontides, which extends all along its southern margin. The Eocene compression and thrusting have uplifted sediments of the of the Black Sea margin. Therefore, the Cretaceous 'syn-rift' sequence can be precisely dated by onshore studies (Fig. 2). We focused our work in the Central Pontides Belt (Fig. 1) where good outcrops of the Mesozoic-Palaeogene sedimentary sequence are present

From: Sosson, M., Kaymakci, N., Stephenson, R. A., Bergerat, F. & Starostenko, V. (eds) *Sedimentary Basin Tectonics from the Black Sea and Caucasus to the Arabian Platform.* Geological Society, London, Special Publications, **340**, 113–136. DOI: 10.1144/SP340.7 0305-8719/10/$15.00

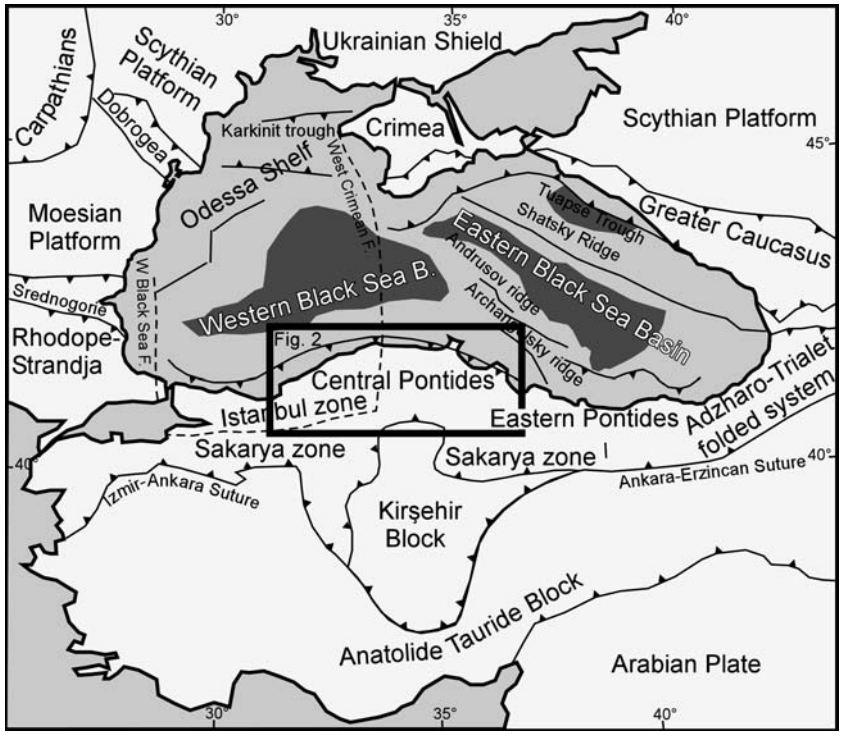

Fig. 1. Location of the arc of Central Pontides between the Western Black Sea Basin and the Kirşehir Block (modified after Robinson *et al.* 1996; Robinson 1997; Okay & Tüysüz 1999).

(Görür 1988; Tüysüz 1999), while the Eastern Pontides are mainly constituted by an Upper Cretaceous-Oligocene magmatic arc (e.g. Yılmaz *et al.* 1997). The Central Pontides Belt results from the inversion of part of the southern margin of the WBS. Thus it may comprise sequences related to the opening of the WBS, and therefore the oldest syn-rift deposits of the Black Sea.

In order to constrain the timing of the western Black Sea opening, we have collected 164 samples from the Cretaceous to Palaeogene sedimentary sequences, in 143 localities of the Central Pontides (Table 1). The samples are dated by nannofossils, which provided precise ages for the stratigraphic sequence of the Black Sea margin. The observed main nannofossil assemblages used for each age determination are summarized in Table 2.

Overview of the stratigraphic sequence of the Pontides

Owing to facies and thickness variations, the Cretaceous sequences of northern Turkey have been divided into a number of formations with local names that cause a great deal of confusion. Görür (1997) has proposed a simplified stratigraphic scheme by distinguishing a 'syn-rift' sequence of Early Cretaceous age, from a 'postrift' sequence (Fig. 3).

Lower Cretaceous sediments are generally rare around the Black Sea Basin. They crop out extensively in the Central Pontides (Fig. 2), in particular in the Ulus and the Zonguldak Basins (Fig. 2). It was from stratigraphic studies of these two basins that Görür (1997) proposed that the Çağlayan Group (Fig. 3) represents the syn-rift deposits of the western Black Sea. This group is a 200–1300 m thick sequence of grey to black shales, marls and sandstone. Its clastic nature contrasts with the underlying grey to white limestone of the İnaltı Formation (Derman & Sayılı 1995) (Fig. 3). According to Görür *et al.* (1993) and Görür (1997) these sediments, that are rich in organic matter, are witness for anoxic conditions resulting from restricted water circulations. They proposed that such anoxic conditions resulted from the disintegration of the carbonate platform by normal fault scarps that isolated the western Black Sea rift from the main Tethys Ocean located to the south. The carbonates of the İnaltı Formation are not reliably dated. Locally foraminifers of Late

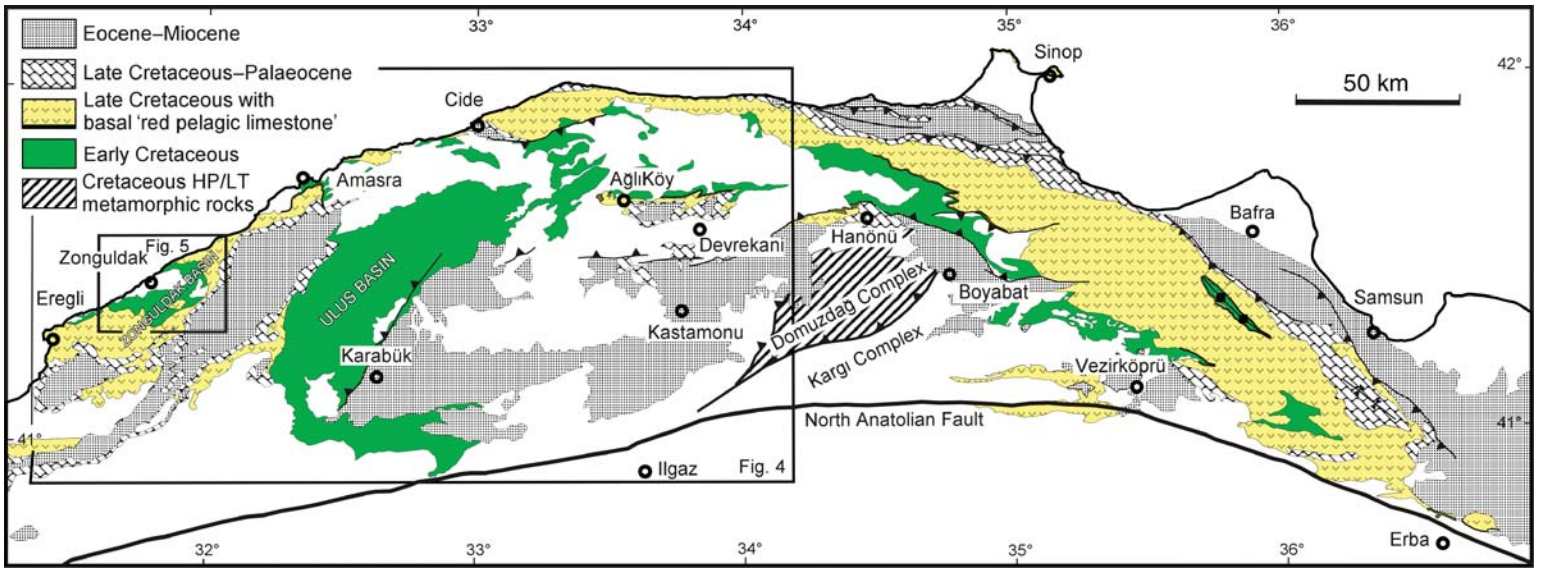

Fig. 2. Structural sketch of the Central Pontides arc with location of the studied area (Fig. 4) and the Lower Cretaceous basins. The north Anatolian fault runs through the subduction complexes.

Table 1. *Coordinates and ages of the 164 samples dated with nannoplankton*

Longitude UTM36	Latitude UTM36	Sample name	Formation names	Nannoplankton age
458996	4596877	03-1	Caglayan, Ulus	Early Cretaceous
456035	4598317	03-2	Caglayan, Ulus	Early Cretaceous
435771	4562960	03-5	Akveren–Atbasi	Lower Campanian
373397	4570272	03-7	Yemisliçay, Kale	Coniacian–Santonian
392428	4586435	03-8	Caglayan, Kilimli	Early Cretaceous
412724	4581106	03-9	Akveren	Upper Maastrichtian–Eocene
411056	4582529	03-10	Caglayan, Sapça–Himmetoglu	Early Cretaceous
452433	4621005	03-11	Caglayan, Kilimli	Lower Aptian
452433	4621005	03-12	Cemaller	Coniacian
452433	4621005	03-13	Kapanbogazi, Basköy	Santonian
452433	4621005	03-14	Yemisliçay, Dilence	Santonian
452433	4621005	03-15	Kapanbogazi, Basköy	Coniacian–Santonian
547642	4613153	03-16	Akveren–Atbasi	Campanian
554238	4617551	03-17	Caglayan	Early Cretaceous
544191	4649177	03-21	Yemisliçay	Santonian
495198	4635760	03-23	Akveren–Atbasi	Upper Paleocene
452595	4620704	03-24	Kilimli	Aptian
565862	4583615	04-2	Kusuri	Lower Eocene NP13
559198	4614685	04-4	Akveren–Atbasi	Lower Campanian–Maastrichtian
505499	4633850	04-5	Akveren–Atbasi	Upper Paleocene NP5
505499	4633850	04-6	Akveren–Atbasi	Upper Paleocene NP5
501158	4638416	04-7	Kusuri	Lower Eocene NP13
493185	4634755	04-8		Upper Valanginian–Lower Barremian
542097	4617526	04-11	Kapanbogazi	Santonian
542097	4617526	04-12	Caglayan	Hauterivian
542097	4617526	04-13	Caglayan	Hauterivian
542097	4617526	04-15	Kapanbogazi	Santonian
542097	4617526	04-16	Kapanbogazi	Santonian
542158	4617960	04-19	Caglayan	Barremian
593438	4647043	04-20	Akveren–Atbasi	Upper Maastrichtian
595432	4646305	04-21	Akveren–Atbasi–Kusuri	Lower Eocene NP13
669099	4630111	04-22	Akveren–Atbasi	Upper Paleocene NP9
653700	4609944	04-23	Caglayan	Berriasian–Valanginian
675286	4587100	04-24	Kusuri	Lower Eocene NP13
658851	4594733	04-25	Kusuri	Middle Eocene NP14
646635	4597624	04-26	Kusuri	Lower Eocene NP13
373427	4570281	04-29AB	Yemisliçay, Kale	Santonian
374757	4569983	04-30	Yemislisçay, Sarikorkmaz	Santonian
378272	4574985	04-31	Yemisliçay, Red Pellagic L.	Late Cretaceous
389917	4584302	04-32	Inalti	Lower Cretaceous
390201	4585136	04-33	Caglayan, Kilimli–Inpiri	Lower Cretaceous
443577	4607278	04-36	Kusuri	Middle Eocene
452624	4621116	04-41	Caglayan	Lower Aptian
452624	4621116	04-42AB	Cemaller	Santonian
453044	4620737	04-45	Caglayan	Barremian
443147	4609861	04-46	Akveren, Alapli	Upper Campanian
435284	4563157	04-47	Akveren–Atbasi	Upper Paleocene NP9
445964	4561524	04-51	Caglayan, Ulus	Barremian
450541	4561488	04-53	Inalti	Early Cretaceous
460527	4555717	04-55	Caglayan, Ulus	Early Cretaceous

(*Continued*)

Table 1. *Continued*

Longitude UTM36	Latitude UTM36	Sample name	Formation names	Nannoplankton age
462152	4556461	04-56	Kusuri	Middle Eocene
471258	4563317	04-58	Kusuri	Lower Eocene NP13
480964	4563642	04-59	Kusuri	Lower Eocene NP13
523991	4564113	04-60	Kusuri	Lower Eocene NP13
563169	4579102	04-61	Kusuri	Lower Eocene NP12
564605	4574754	04-62	Kusuri	Middle Eocene
559672	4609981	04-65	Kusuri	Lower Eocene NP12
555747	4610851	04-66	Kusuri	Middle Eocene NP14
542097	4617526	04-69	Kapanbogazi	Santonian
551523	4611032	04-70	Kusuri	Lower Eocene NP12
551523	4611032	04-70A	Kusuri	Lower Eocene NP13
551523	4611032	04-70C	Kusuri	Lower Eocene NP13
378854	4575113	06-2	Yemisliçay, Red Pellagic L.	Late Cretaceous
391811	4585492	06-4-8	Caglayan, Kilimli-Inpiri	Barremian
392563	4582373	06-11	Caglayan, Tasmaca	Upper Aptian
392734	4582133	06-12	Caglayan, Tasmaca	Upper Aptian
390750	4580399	06-13	Caglayan, Cemaller	Upper Albian
390327	4580791	06-14	Caglayan, Cemaller	Early Cretaceous
389590	4581575	06-15	Caglayan, Velibey	Azoic
410187	4558194	06-17	Atbasi	Uppermost Paleocene NP9
409612	4557625	06-19	Atbasi	Lower Paleocene NP3
409553	4557439	06-18,20	Atbasi	Upper Paleocene NP5
409519	4557956	06-21	Atbasi	Uppermost Paleocene NP9
409666	4559005	06-22	Atbasi	Lowermost Eocene NP10
424088	4571398	06-23	Atbasi	Lower Eocene NP11
419895	4576332	06-24	Kusuri	Lower Eocene NP12
417958	4578064	06-25	Kusuri	Lower Eocene NP13
411483	4582015	06-27	Caglayan, Tasmaca	Lower Albian
411483	4582015	06-28	Yemisliçay, Dereköy, Cambu	Late Cretaceous
411056	4583307	06-30	Caglayan, Sapça	Upper Aptian
411056	4583307	06-31	Caglayan, Sapça	Upper Aptian
410172	4584966	06-32	Caglayan, Sapça	Lower Albian
392539	4585066	06-33	Caglayan, Velibey	Azoic
392523	4582627	06-34	Caglayan, Velibey	Azoic
393694	4581731	06-35	Caglayan, Tasmaca	Lower Albian
394184	4581736	06-36	Caglayan, Tasmaca	Lower Albian
392268	4581087	06-38	Caglayan, Cemaller	Upper Albian
391715	4581112	06-39	Caglayan, Cemaller	Upper Albian
452010	4620905	06-40	Caglayan	Upper Aptian
452010	4620905	06-41	Cemaller	Coniacian–Santonian
452427	4620910	06-42	Kapanbogazi	Santonian
452613	4621066	06-43,44	Caglayan	Barremian
452568	4621172	06-45	Caglayan	Barremian
453579	4620743	06-49-51	Caglayan	Barremian
453500	4618943	06-52	Caglayan	Upper Aptian
454874	4621982	06-57	Caglayan	Upper Aptian
454731	4621724	06-58	Caglayan	Upper Aptian
446318	4614856	06-59	Akveren, Alapli	Lower Campanian
446544	4614643	06-60	Akveren, Alapli	Lower Campanian
443132	4609951	06-61	Akveren, Alapli	Upper Campanian
430130	4595224	06-62	Kusuri	Middle Eocene NP14b
419134	4602847	06-63	Yemisliçay, Unaz	Santonian
404250	4594100	06-64	Caglayan, Kilimli–Inpiri	Upper Aptian

(*Continued*)

Table 1. *Continued*

Longitude UTM36	Latitude UTM36	Sample name	Formation names	Nannoplankton age
404075	4594084	06-66	Caglayan, Kilimli–Inpiri	Upper Aptian
403348	4594134	06-67	Caglayan, Kilimli	Aptian
400957	4592334	06-68	Caglayan, Kilimli	Lower Aptian
401409	4592715	06-72	Caglayan, Kilimli–Inpiri	Lower Aptian
402512	4593636	06-73	Caglayan, Kilimli–Inpiri	Lower Aptian
405098	4587045	06-74	Caglayan, Velibey	Azoic
408407	4586323	06-75	Caglayan, Sapça	Upper Aptian
408014	4584886	06-76	Caglayan, Sapça	Upper Aptian
410755	4585914	06-77	Caglayan, Sapça	Upper Aptian
412041	4586200	06-78	Caglayan, Sapça	Lower Aptian
412210	4586567	06-79-81	Caglayan, Sapça	Lower Aptian
447811	4606314	06-82	Kusuri	Middle Eocene NP15
447937	4605242	06-83	Kusuri	Upper Eocene NP19-20
454929	4598996	06-84	Akveren–Atbasi	Upper Santonian–Lower Campanian
459896	4596892	06-86	Caglayan, Ulus	Aptian
466436	4598877	06-87	Caglayan, Ulus	Aptian
468909	4602930	06-88	Caglayan, Ulus	Aptian
471798	4607246	06-89	Caglayan, Ulus	Aptian
471947	4608846	06-90	Caglayan, Ulus	Upper Aptian
472331	4609988	06-91	Caglayan, Ulus	Upper Aptian
469483	4608745	06-92-95	Caglayan, Ulus	Upper Aptian
473794	4604309	06-96-97	Caglayan, Ulus	Aptian
478087	4608282	06-98	Caglayan, Ulus	Barremian
483322	4608514	06-99	Caglayan, Ulus	Barremian
487851	4611048	06-100	Caglayan, Ulus	Barremian
495665	4612761	06-101-105	Caglayan, Ulus	Barremian
478790	4586589	06-106	Caglayan, Ulus	Upper Aptian
476576	4584049	06-107	Caglayan, Ulus	Upper Aptian
474867	4578606	06-108	Caglayan, Ulus	Upper Aptian
468740	4569277	06-109	Caglayan, Ulus	Lower Cretaceous
467866	4564677	06-114	Caglayan, Ulus	Upper Aptian
483687	4544118	06-121	Kusuri	Lower Eocene NP12
488495	4544328	06-122	Kusuri	Middle Eocene NP16-17
490515	4544543	06-124	Kusuri	Eocene
490515	4544543	06-125	Kusuri	Middle Eocene NP17
613771	4608680	06-126	Atbasi	Uppermost Maastrichtian
614080	4608670	06-127	Atbasi	Upper Paleocene NP9
613865	4607737	06-129	Paleocene–Eocene	Middle Eocene NP14b
628232	4609604	06-133	Atbasi	Uppermost Maastrichtian
628232	4609604	06-134	Atbasi	Lower Eocene NP13

Oxfordian–Berriasian age were found (Derman & Sayılı 1995). In its stratigraphic log, Görür (1997) considers an Oxfordian–Barremian age for the İnaltı Formation and an Aptian–Cenomanian age for the uperlying clastic Çağlayan Formation.

The Çağlayan Formation is overlain, with a slight angular unconformity, by red to pinkish, thinly bedded pelagic limestones, with volcaniclastic intercalations in its upper part. The basal red pelagic limestone form the Kapanboğazı Formation (e.g. Görür *et al.* 1993) for which an upper Cenomanian to Campanian age was proposed based on foraminifers (Ketin & Gümus 1963). According to Görür (1997) the drastic change in the style of sedimentation from the dark coloured siliciclastic sediments of the Çağlayan Formations, which accumulated in anoxic conditions, to the overlying red pelagic limestones, resulted from a rapid widening of the rift, end of anoxia, and a regional subsidence. This author interprets the Kapanboğazı Formation as a synbreakup succession.

Table 2. *Nannofossil assemblages recognized for each age determination of Table 1*

Stage	Nannoplankton zone	Nannofossil assemblages
Upper Eocene	NP 19-NP 20	*Chiasmolithus oamaruensis*, *Cycloccolithus formosus*, *Dictyococcites dictyodus*, *Discoaster barbadiensis*, *Ericsqonia subdisticha*, *Isthmolithus recurvus*, *Reticulofenestra umbilica*
	NP17	*Cribrocentrum reticulatum*, *Cyclococcolithus formosus*, *Dictyococcites dictyodus*, *Discoaster barbadiensis*, *D. saipanensis*, *D. tani nodifer*, *Reticulofenestra umbilica*, *Sphenolithus radians*, *Zygrhablithus bijugatus*
Middle Eocene	NP 15	*Chiasmolithus gigas*, *C. grandis*, *C. solithus*, *Discoaster barbasiesis*, *Reticulofenestra cf. umbilica (small)*, *Rhabdosphaera gladius*, *Sphenolithus furcatolithoides*, *S. pseudoradians*, *Zygrhablithus bijugatus*
	NP 14b	*Chiasmolithus grandis*, *C. solitus*, *Cyclococcolithus formosus*, *Discoaster barbadiensis*, *D. sublodoensis*, *Reticulofenestra cf. umbilica (small)*, *Rhabdosphaera inflata*, *Sphenolithus radians*, *Zyghrablithus bijugatus*
	NP 13	*Same assemblage as in zone NP 12 but without Mathasterites tribraciatus*
Lower Eocene	NP 12	*Campylosphaera dela*, *Chiasmolithus solitus*, *Cyclococclithus gammation*, *C. formosus*, *Discoaster barbadiensis*, *D. binodosus*, *D. lodoensis*, *Discoasteriodes kuepperi*, *Marthasterites tribrachiatus*, *Sphenolithus radians*
	NP 10	*Discoaster binodusus*, *D. multiradiatus*, *Marthasterites contortus*
Upper Paleocene	NP 9	*Coccolithus pelagicus*, *Discoaster gemmeus*, *D. multiradiatus*, *Ellipsolithus macellus*, *Ericsonia subpertusa*, *Fasciculithus tympaniformis*, *Sphenolithus anarophus*, *Toweius eminens*
	NP 5	*Ellipsolithus macellus*, *Ericsonia subpertusa*, *Fasciculithus tympaniformis*
Lower Paleocene	NP 3	*Chiasmolithus danicus*, *Coccolithus pelagicus*, *Cruciplacolithus tenuis*, *Ericsonia subpertusa*, *Zygodiscus sigmoides*
Upper Maastrichtian		*Arkhangelskiella cymbiformis*, *Ceratolithoides aculeus*, *Cribrosphaera ehrenbergii*, *Eiffellithus turriseiffeli*, *Lithraphidites quadratus*, *Microrhabdulus decoratus*, *Micula murus*, *M. staurophora*, *Prediscosphaera cretacea*, *within the latest Maastrichtian occurrence of Micula prinsii*
Upper Campanian		*Broinsonia parca*, *Ceratolithoides aculeus*, *Cribrosphaera ehrenbergii*, *Eiffellithus eximius*, *E. turriseiffeli*, *Lucianorhabdus cayeuxii*, *Prediscosphaera cretacea*, *Reinhardtites anthphorus*, *Quadrum gothicum*, *Q. trifidum*
Lower Campanian		*Same assemblage as within the Upper Campanian but without Quadrum gothicum and Q. tifidum*
Santonian		*Eiffellithus eximius*, *E. turriseiffeli*, *Lucianorhabdus cayeuxii*, *Marthasterites furcatus*, *Micula staurophora*, *Prediscosphara cretacea*, *Reinhardtites anthophorus*, *within the uppermost part occurrence of Broinsonia parca expansa*
Coniacian		*Same assemblage as in the Santonia but without Reinhardtites anthophorus*
Upper Albian		*Eiffellithus turriseiffeli*, *Eprolithus floralis*, *Hayesites albiensis*, *Parhabdolithus angustus*, *P. embergeri*, *Prediscosphaera cretacea*, *Tranolithus orionatus*, *Zygodiscus diplogrammus*, *Watznaueria barnesae*
Lower Albian		*Ellipsagelosphaera communis*, *Eprolithus floridanus*, *Parhabdolithus angustus*, *P. infinitus*, *P. embergeri*, *Prediscosphaera cretacea*, *Vagalapilla matalosa*
Upper Aptian		*Chiastozygus litterarius*, *Coronolithoin achylosus*, *Ellipsagelosphaera communis*, *Eprolithus floralis*, *Nannoconus bucheri*, *N. circularis*, *N. elongatus*, *N. quadriangulus apertus*, *N. quadriangulus quadriangulus*, *Parhabdolithus angustus*, *Rucinolithus irregularis*

(*Continued*)

Table 2. *Continued*

Stage	Nannoplankton zone	Nannofossil assemblages
Barremian		*Calcicalathina oblongata*, *Cruciellipsis chiastia*, *Cyclagelosphaera margerelii*, *Micrantolithus obtusus*, *Nannoconus colomii*, *N. globulus*, *N. kamptneri*, *N. steinmannii*, *N. wassalii*, *Parhabdolithus asper*, *Watznaueria barnesae*
Hauterivian		*Bipodorhabdus colligatus*, *Bipodorhabdus colligatus*, *Calcicalathina oblogata*, *Cruciellipsis cuvillieri*, *Cyclagelosphaera margerellii*, *Ellipsagelosphaera communis*, *Lithraphidites bollii*, *Watznaueria barnesae*
Berriasian–Valanginian		*Cyclagelosphaera deflandrei*, *C. margerelii*, *Ellipsagelosphaera communis*, *Nannoconus colomii*, *Parhbdolithus embergeri*, *Runcinolithus wisei*, *Watznaueria barnesae*

Tüysüz (1999), however, points out that according to a back-arc basin model, the syn-rift formation should include evidence of arc magmatism. He proposes that the older unit showing evidence for arc magmatism, the Dereköy Formation (Fig. 3), is the real syn-rift sequence. This formation, is exposed in the Zonguldak Basin, and consists of thick lavas and carbonates of probable Turonian age. It is

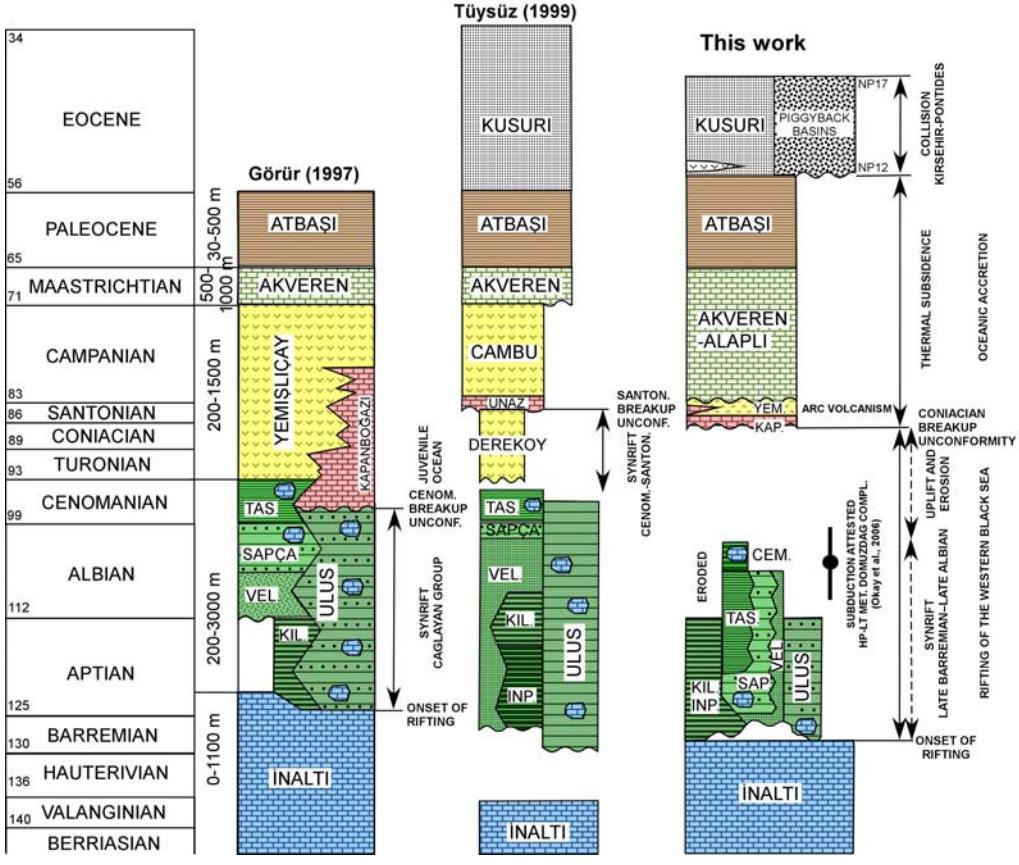

Fig. 3. Comparison of dating of the stratigraphic formations of the Central Pontides (Black Sea coast, Zonguldak Basin and Ulus Basin). CEM, Cemaller Formation; INP, İnpiri Formation; KAP, Kapanboğazı Formation; KIL, Kilimli Formation; SAP, Sapça; TAS, Tasmaca Formation; YEM, Yemişliçay Formation; VEL, Velibey Formation.

noteworthy that, if this interpretation is correct, it would mean that the rifting of the Western Black Sea started in Turonian time and not, as commonly accepted, in Aptian time.

Effectively, it is now accepted that no arc magmatism developed in the western Pontides during the Lower Cretaceous (Okay *et al.* 2006). However, volcanic and volcaniclastic rocks are the main elements of the Upper Cretaceous Black Sea margin sequence. The Kapanboğazı Formation conformably passes upwards to the Yemişliçay Formation (Görür 1997), which is a thick succession (up to 1500 m) of volcanic rocks and volcaniclastic sediments with intercalations of red pelagic limestones similar to those of the Kapanboğazı Formation (Fig. 3). Based on foraminifers, a Turonian to Campanian age was assigned to this formation (Aydın *et al.* 1986; Tüysüz 1999). The Yemişliçay Formation is overlain by the Akveren Formation of Maastrichtian age (Ketin & Gümüs 1963). This calciturbidite marks the end of magmatic activity in the Maastrichtian (Tüysüz 1999; Sunal & Tüysüz 2002). It is overlain by the Atbaşı Formation of Palaeogene age.

Nannoplankton dating of the Pontide stratigraphic sequence

In the following we present the sedimentary units of the three main areas used in previous studies to establish the general stratigraphic sequence of the Central Pontides (Görür *et al.* 1993; Görür 1997; Tüysüz 1999): the Black Sea coast, the Zonguldak Basin and the Ulus Basin. Nannoplankton age determinations were made to better constrain the age of these units and their correlations. For reasons of simplicity, we follow the tectono-stratigraphic schema of Görür (1997) that distinguishes the syn-rift Çağlayan Group from the post-rift Upper Cretaceous sequences.

The syn-rift Çağlayan Group

Black Sea coast

Along the Black Sea coast, a 0–200 m thick sequence of dark coloured Cretaceous rocks (sandy or clayey limestones) of the Çağlayan Group (Fig. 3), overlays the Upper Jurassic–Lower Cretaceous İnaltı limestones and older rocks. The İnaltı limestone was interpreted as representing the south facing carbonate platform of the Neotethys Ocean (Koçyiğit & Altıner 2002). The onset of terrigenous sedimentation on the carbonate platform corresponds to a major change that could be related to the opening of the Black Sea rift (Görür 1988). It is therefore crucial to date the oldest deposits of this group.

Near Zonguldak, Kilimli and Amasra (Fig. 4) the Çağlayan Group is represented by the Kilimli Formation (Tokay 1952; Görür 1997) (Fig. 3). It is an alternation of limestone, marls and shales that contains ammonites and nannoplanktons indicating an Aptian age (Tokay 1952; Akman 1992). In the

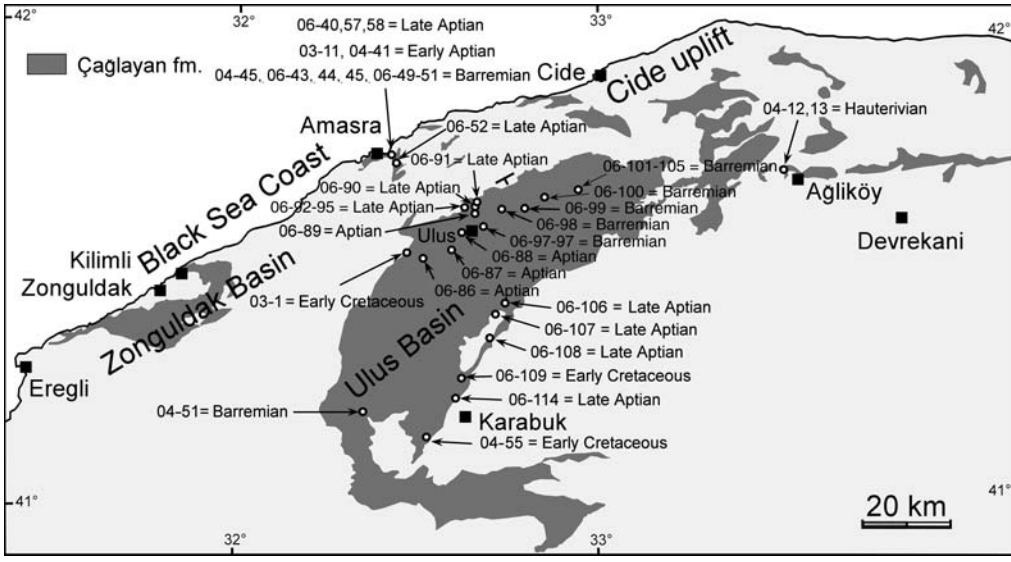

Fig. 4. The Early Cretaceous Çağlayan Group and its sites of nannoplankton dating (cf. Table 1).

Zonguldak area, Tüysüz (1999) also distinguished the lower part of the sequence which includes sandstones, sandy limestone and marls of the Late Barremian-Early Aptian, as the İnpiri Formation. However, as the Kilimli and İnpiri Formations have similar facies and are in the same stratigraphic position, we combine them informally as the Kilimli-İnpiri Formation (Fig. 5).

Nannofossils confirm a Barremian age for the base of the clastic sequence west of Zonguldak (sample 06-4, Fig. 5). Near Amasra, a Barremian age was also determined at the base of the clastic sequence (samples 04-45, 06-43, 44, 45, 06-49, 50, 51, Fig. 6). At Amasra, an Early Aptian age was found in the lower part of the sequence (sample 04-41, Fig. 4) but here most of the Çağlayan sequence have a Late Aptian age (samples 06-40, 06-52, 06-57, 06-58) (Figs 4 & 6). Similarly, at Kilimli, the samples collected along a 3 km long new road cut (06-68, 06-72 and 06-73) (Fig. 5) indicate an Early Aptian age, and the samples collected in the upper part of the sequence East of Kilimli (06-64 and 06-66) indicate a Late Aptian age (Fig. 5). It is concluded that along the Black Sea Coast, the Kilimli-İnpiri sequence locally started in the Barremian, but most of the sediments were accumulated during the Late Aptian (Fig. 6). This dating of the first clastic sequence on the platform, together with numerous normal faults observed in the Lower Cretaceous sequence along the Black Sea coast from Zonguldak to Ereğli (Fig. 7), suggest that the rifting and breakup of the carbonate platform (Görür 1993) started in the Barremian whereas tectonic activity and subsidence reached its climax during the Aptian.

Zonguldak Basin

In the Pontides, the best exposures of the Lower Cretaceous sequence are found in the Zonguldak Basin, immediately SE of the city of Zonguldak (Fig. 5). In this area, the Çağlayan Group was previously studied in detail and subdivided into four formations, the Velibey (Fig. 8), Sapça (Fig. 9), Tasmaca and Cemaller Formation (Fig. 10) (Yergök *et al.* 1989; Görür 1997; Tüysüz 1999; Figs 3 & 5).

In contrast with the Black Sea coast sections, in most of the northern margin of the Zonguldak Basin, the shelf carbonates of the İnaltı Formation have been eroded before deposition of the Lower Cretaceous detrital sequence. Yellow-orange sands and

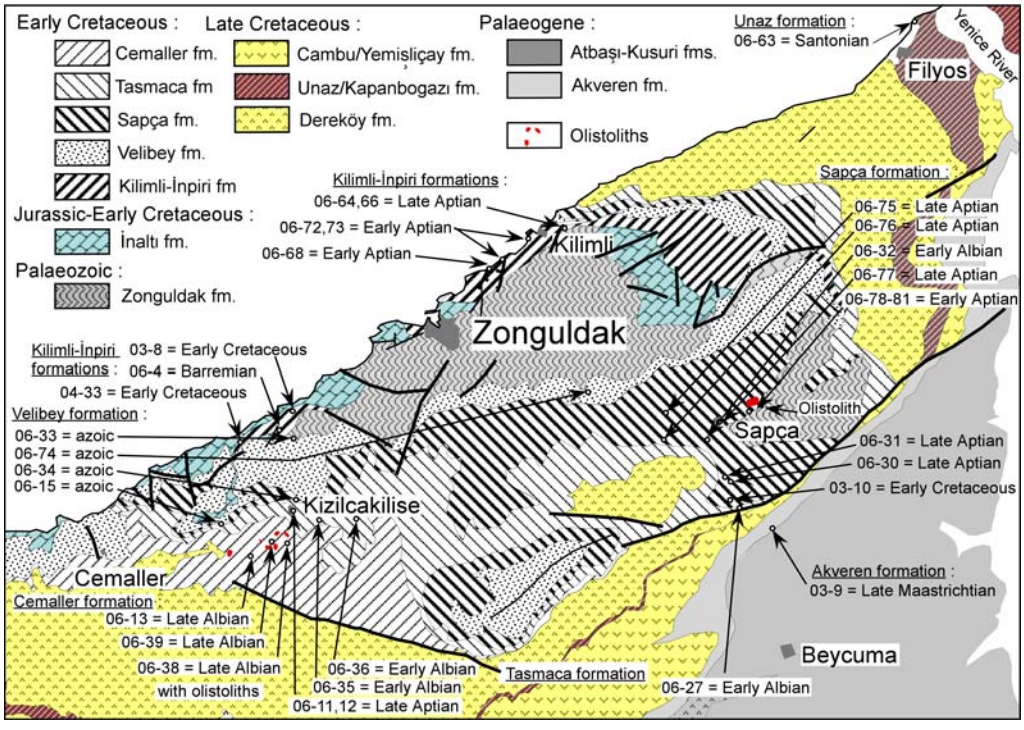

Fig. 5. The formations of the Early Cretaceous Çağlayan Group around Zonguldak (Yergök *et al.* 1989; location on Fig. 2) with sites of nannoplankton dating.

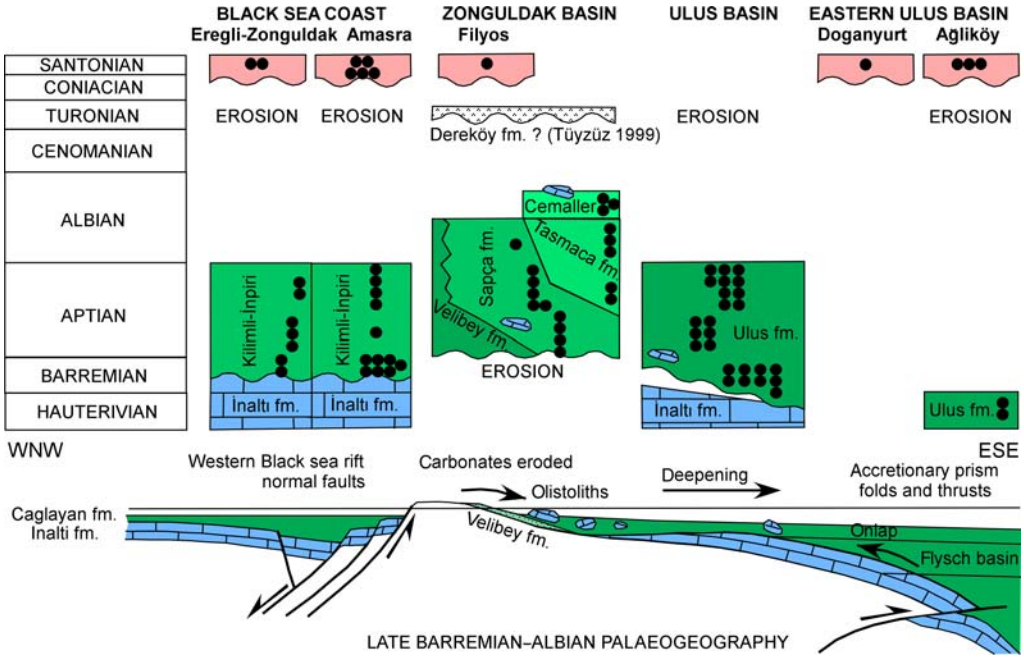

Fig. 6. Stratigraphic position of the samples (each dot represents a sample with precise nannoplankton dating) and tentative palaeogeographic interpretation of the facies and age of the Çağlayan Group on a NW–SE section.

well bedded sandstones of the Velibey Formation (Fig. 8) rest directly on the Palaeozoic sequences (Fig. 5). No nannofossils were encountered in the samples collected from the Velibey Formation to constrain its age of deposition. Likewise no palaeontological data have been reported in the previous studies from the sandstones and gravels of this formation (Fig. 8). The sand of the Velibey Formation consists of 95% quartz. Such an amount of quartz and intense fracturing observed in some outcrops could suggest that some rocks mapped as the Velibey Formation belong to the Pre-Jurassic basement. But its stratigraphic position seems to support an Aptian age. For example, to the NE of Zonguldak, the Velibey formation is underlain by the Kilimli Formation and is overlain by the Sapça

Fig. 7. Stratigraphic contact of the Barremian-Aptian Kilimli-İnpiri Formation (Çağlayan Group) on the İnaltı Jurassic-Neocomian limestone west of Zonguldak (near site 06-4 of Barremian age, Fig. 5). Along the Black Sea coast, the Çağlayan Formation was cut by numerous normal faults like this one.

Fig. 8. Velibey Formation (Çağlayan Group) near Kızılcakilise (Fig. 5). Barren (continental) sandstones and gravels.

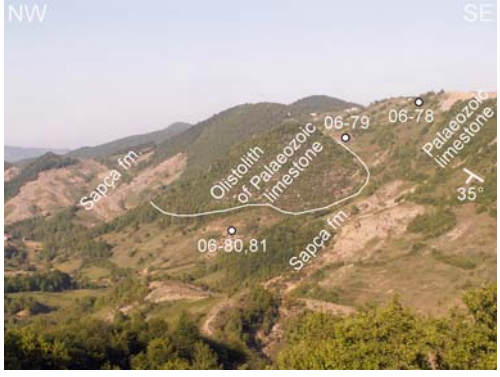

Fig. 9. Sapça Formation (Çağlayan Group) at Sapça (Fig. 5), with an olistolith of Palaeozoic limestone (Zonguldak Formation). Samples 06-78 to 06-81 are Lower Aptian.

Formation. To the west of Zonguldak, it overlies the İnaltı limestone and is overlain by the Cemaller Formation (Fig. 5). In addition, Tokay (1952) and Derman (1990) reported the presence of rudists, possibly of Late Albian age, in limestones interbedded in its upper part. This allowed Görür (1997) to propose an Early Albian age for these yellow sands. West of Kizilcakilise (site 06-15, Fig. 5), a new road cut allows observation of what is probably a progressive transition between the shelf carbonates (İnaltı limestone) and the Velibey Formation (Yergök *et al.* 1989). In this section, white quartz gravels and sandstone layers alternate with dark coal-bearing carbonaceous sandstones. The sample 06-15 collected from this section was barren. However, Late Aptian nannofossils in the samples collected from marls above it (06-11, 06-12, Fig. 5) suggest a pre–Late Aptian age for this outcrop of the Velibey Formation (Fig. 6).

The Velibey Formation is overlain by the marine Sapça Formation (Fig. 9), which is similar in aspect with the Kilimli-İnpiri Formation, but more sandy (Fig. 7). It is an alternation of dark coloured sandstones with marls or shales rich in organic matter. Its thickness varies from 50 to 450 m and its macrofauna indicates an Albian age (Fig. 3) (Tokay 1952; Aydın *et al.* 1987; Görür *et al.* 1993). The Tasmaca Formation, another formation of the Çağlayan Group (Fig. 3), is mainly developed near Kızılcakilise (Figs 5 & 11). This formation is a 100–400 m thick succession of poorly bedded organic matter, rich black shales and argillaceous limestones similar to those of the Sapça Formation (Figs 9 & 11). Tokay (1952) proposed that the Tasmaca Formation is of Cenomanian age, based on ammonite fauna.

However, nannofossil determinations performed in this study allow precise dating of various levels of the Sapça and Tasmaca Formations. The samples collected from the Sapça formation are dated as Early Aptian (samples 06-78, -81), Late Aptian (samples 06-30, 06-31, 06-75, 06-76, 06-77), and Early Albian (sample 06-32) (Figs 5 & 6). In contrast with the Cenomanian age of Tokay (1952), the nannofossil samples collected from the Tasmaca Formation indicate Late Aptian (samples 06-11, 06-12), and Early Albian ages (sample 06-27, 06-35, 06-36) (Figs 5 & 6). Therefore the Sapça and Tasmaca Formations were contemporaneous during Late Aptian–Early Albian (Fig. 6). We conclude that these formations correspond to local variations in facies and bedding of contemporaneous deposits.

Fig. 10. Cemaller Formation (Çağlayan Group) at site 06-13 between Kizilcakilise and Cemaller (Fig. 5). Marls and sands with thin coal intercalations (in dark). At neighbouring sites 6-38 and 6-39 with olistoliths, nannoplanktons also indicate a Upper Albian (first part) age.

Fig. 11. Tasmaca Formation (Çağlayan Group) at Kizilcakilise (Fig. 5). Samples 06-12 and 06-11 (in the village) are Upper Aptian. The top of the formation is Lower Albian (samples 06-35, 36, Fig. 5).

In the south of the Zonguldak Basin, the Tasmaca Formation is overlain by the Cemaller Formation (Fig. 5). This formation is reported on the MTA 1:100 000 geological map (Yergök *et al.* 1989) but included in the Senonian units on the MTA 1:500 000 geological map (Aksay *et al.* 2002), and also considered as part of the Upper Cretaceous series by Tüysüz (1999) who describes a 'shallow marine Cenomanian clastic sequence'. Effectively, the Cemaller Formation does not fit with the deepening character of the basin as indicated by the Sapça and Tasmaca Formations and consists of sands with intercalations of clay and coal (Fig. 10). However, it contains limestone olistoliths similarly to the underlying formations of the Çağlayan Group (Figs 5 & 9). Moreover, our three samples (06-13, 06-38, 06-39, Fig. 5) yielded nannoplankton allowing a precise age determination of the first part of the Upper Albian. On one hand, this age is compatible with the Late–Early Albian age of the underlying Tasmaca Formation (Figs 5 & 6). On the other hand, it contrasts with the previously proposed Cenomanian age (Tüysüz 1999), and therefore, invalidates the discontinuity in sedimentation between the Cemaller Formation and the underlying formations of the Çağlayan Group. The middle Cretaceous unconformity noted by Tüysüz (1999) is in fact stratigraphically above the Cemaller Formation.

In the Zonguldak Basin, the Çağlayan Group is overlain by the Dereköy Formation of probable middle Turonian age (Tüysüz 1999). Therefore, the Albian and Cenomanian deposits are missing in this basin (Fig. 6). Note that in the NE of the Zonguldak Basin, the Cemaller Formation was not deposited or was eroded before the middle Turonian.

We conclude from these nannoplankton ages that the Velibey, Sapça, Tasmaca and Cemaller Formations of the Zonguldak Basin form a continuous sequence from Late Barremian to the first part of the Late Albian, characterized by non-volcanogenic dark clastic material with limestone olistoliths (Fig. 6). Considering that the Çağlayan sequence was interpreted as syn-rift by Görür (1993) our nannoplankton dating would confirm the Aptian–Albian age of rifting (Fig. 3). However, in contrast with Görür's (1993) rifting model, the syn-rift sequence does not end up with deep deposits, but with shallow marine sands of the Late Albian Cemaller Formation. Furthermore, in the Zonguldak area, the Middle Cretaceous unconformity corresponds to a major gap in sedimentation (Fig. 3).

Ulus Basin

The NE–SW trending Ulus Basin is the largest Lower Cretaceous basin of the Pontides (Fig. 2). In contrast to the Zonguldak Basin, the Çağlayan Group is described as a single unit: the Ulus Formation (Fig. 3). It starts at the bottom with coarse clastic rocks and grades rapidly into turbiditic sandstones and shales. In the eastern part of the Ulus Basin the flysch deposits are poor in fossils, indicating an Early Cretaceous age (Tüysüz 1999).

In this study we precisely dated 27 samples from 18 localities in the flysch sequence of the Ulus Basin (Fig. 4). The ages ranged from Hauterivian near Ağlıköy, (Fig. 4, samples 04-12, 13, Table 1) and Barremian in the centre of the basin (samples 04-51 and 06-98 to 06-105) to Late Aptian (06-90 to 06-95 and 06-106 to 06-108, Fig. 4). These ages are similar to those found along the Black Sea Coast and in the Zonguldak Basin (Fig. 6). Surprisingly the youngest deposits of the Ulus Formation (Late Aptian) were found at the base of the sequence on the northwestern edge of the Ulus Basin (Fig. 4; close to the platform carbonates of the İnaltı Formation). Moreover, samples 06-106 to 06-108 contain reworked species from the Barremian. This reworking and the onlap of the Çağlayan Formation on the surrounding outcrops of the carbonate basement suggest tectonic activity and tilting during sedimentation, since the Barremian.

In the Ulus basin, the age of the clastic sequence, is older than along the Black Sea coast (Hauterivian at Ağlıköy, Fig. 4). However, the geodynamic significance of the age of onset of detritic sedimentation in this basin is not as clear as along the Black Sea coast. Effectively, in this basin, we could not observe large normal faults as along the Black Sea coast (Fig. 7). Moreover, there are conspicuous compressional structures with intensity of deformation increasing toward the south and the east (Ağlıköy area), that is toward the accreted high-pressure–low-temperature complexes of the Early Cretaceous subduction zone (Okay *et al.* 2006). It is thus possible, that in contrast to the Kilimli-İnpiri Formation, the Ulus flysch was deposited on the accretionary wedge (Fig. 6). Therefore we will not consider the age of the Ulus Formation as critical for indicating the age of onset of the Black Sea rifting.

Near Ağlıkoy, in the East of the Ulus Basin (Fig. 4), black shales of Hauterivian age (samples 04-12, 13) are unconformably overlain by the Kapanboğazı Formation of Santonian age (samples 04-11, 15, 16, Table 1), and the Barremian, Aptian, Albian, Cenomanian, Turonian and Coniacian are missing (Fig. 12). In the Ulus Basin, the youngest sediments of the Ulus Formation are Late Aptian. Similar to Black Sea coast and the Zonguldak Basin, the Albian, Cenomanian and Turonian deposits are missing in all of the Ulus Basin, which reveals a major gap in sedimentation in the Central Pontides (Fig. 6). This gap indicates erosion or non-deposition in the mid-Cretaceous. In any case this

Fig. 12. Unconformity of the Kapanbogazy red pelagic limestone (Santonian, samples 04-11, 15, 16) on the Çağlayan sandstone (Hauterivian-Barremian, samples 04-12, 13, 19) near Ağlıköy (Fig. 4).

regional gap was unexpected because according to most of the models (Görür 1988; Okay *et al.* 1994; Robinson *et al.* 1996; Banks & Robinson 1997), the WBS was opening at that time (Fig. 3).

Upper Cretaceous–Eocene post-rift sequence

The Upper Cretaceous volcanic-sedimentary sequence

In contrast to the Lower Cretaceous Çağlayan sequence, characterized by rapid facies variations, a thick sequence of Upper Cretaceous micritic limestone, volcanogenic and volcanic rocks, overlies the Lower Cretaceous and older rocks in most of the Central Pontides (Fig. 2). The limestone layers are mainly present within the lower part of the sequence and are named as the Kapanboğazı Formation (Figs 3 & 13) (Görür *et al.* 1993). They are white to pink (hematite rich) micritic and laminated limestones, in decimetric beds with thin clay intercalations (Fig. 14). They contain foraminifers indicative of a pelagic environment (Görür *et al.* 1993). Volcaniclastic and volcanic rocks intercalations become dominant upwards and the mainly volcanogenic sequence was called the Yemişliçay Formation (Görür 1997) (Figs 3 & 14).

The 10–50 m thick basal 'red pelagic limestone' of the Kapanboğazı Formation is present over most of the Central Pontides (Fig. 2). It overlies various older rocks including the Lower Cretaceous and Carboniferous. A few kilometres NE of Amasra, a new roadcut allows observation of the unconformity of the Upper Cretaceous rocks with the underlying Lower Cretaceous black shales of the Kilimli-İnpiri Formation (Yergök *et al.* 1987) (Fig. 15). It is an angular unconformity of locally up to 50° (Fig. 15). Above the angular unconformity the sequence starts with 5–10 m of yellowish sands (Cemaller Formation, Yergök *et al.* 1987), with some pebbles at the base locally. It is characterized by abundant burrows, lamellibranches, gastropods, indicating a shallow marine environment, and pieces of coal probably reworked from the Carboniferous basement cropping out nearby (Fig. 15).

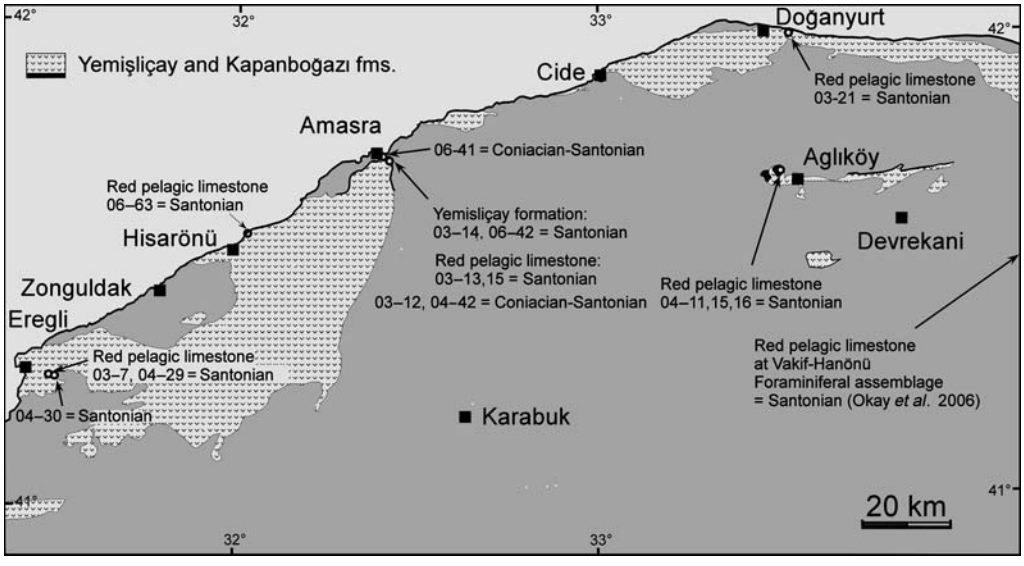

Fig. 13. Late Cretaceous Kapanboğazı and Yemişliçay Formations with their sites of nannoplankton dating (cf. Table 1).

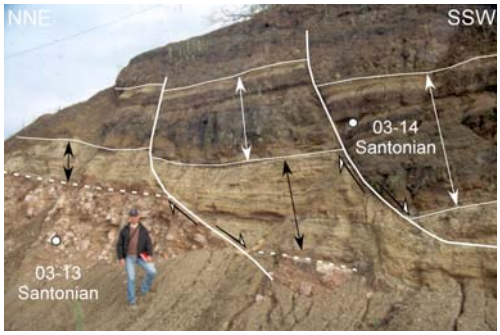

Fig. 14. Kapanboğazı (red pelagic limestone) and Yemişliçay (volcaniclastic sediments) Formations at Amasra (Fig. 13). These formations are cut by syndepositional listric normal faults. The layers of the Yemişliçay Formation are thicker in the downthrown blocks. A syntectonic wedge of clays of the Yemişliçay Formation is dated from the Santonian (03-14). The red limestones are also Santonian (samples 03-13 and 06-42).

Thin sections in the shallow marine sandstones show abundant benthic foraminifers that contrast with the dominantly pelagic foraminifers of the Kapanboğazı red limestone immediately above (Fig. 15). The sharp contact between the sandstones and the pelagic limestones implies a sudden deepening of the Black Sea margin (Tüysüz 1999).

Samples collected from the Kilimli-İnpiri Formation around Amasra contain nannofossils from Barremian to Late Aptian in age (Fig. 6). Above the angular unconformity, the sands are of Coniacian–Santonian age (samples 03-12, 04-42, 06-41). They were mapped as the Cemaller Formation (Yergök *et al.* 1987), however, our new dating indicates that they are much younger than the Late Albian Cemaller Formation exposed near Zonguldak. We therefore consider that there is no correlation between these sands near Amasra, and the Cemaller Formation exposed near Zonguldak. The Amasra sands belong to the Upper Cretaceous trangressive sequence. In agreement with their Coniacian–Santonian dating, the overlying red pelagic limestone of the Kapanboğazı Formation (named Basköy Formation on the geological map, Yergök *et al.* 1987) contains nannofossils of Santonian age (samples 03-13, 15) (Fig. 12).

Our nannoplankton ages show that sediments of the Albian, Cenomanian and Turonian are missing in the Amasra stratigraphic sequence (Fig. 6) confirming the Middle Cretaceous gap mentioned above (Figs 6 & 12). Moreover, the observation of an angular unconformity at Amasra demonstrates that the gap in the Cretaceous sequence is at least partly due to erosion (Fig. 15). Note that another angular unconformity, with another dip direction in the Kilimli-İnpiri Formation, can be observed between this location and the city of Amasra. The

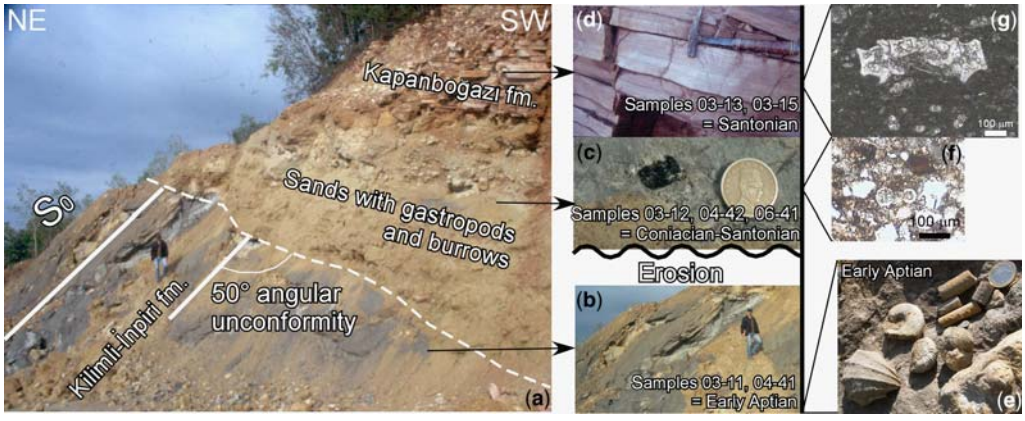

Fig. 15. Angular unconformity of the Late Cretaceous on the Early Cretaceous at Amasra (Fig. 13). (**a**) The black shales of the Kilimli-İnpiri Formation (Çağlayan Group) are tilted to the West and are overlain by yellowish sands and red limestone of the Kapanboğazı Formation. (**b**) The Kilimli-İnpiri Formation is dated with nannoplankton from Barremian (06-43, 06-44) to Lower Aptian (under the unconformity, samples 03-11, 04-41). (**c, d**) The yellow sands are Coniacian–Santonian, and the red limestones are Santonian. Even if the very first layers above the İnaltı shelf carbonates of the Kilimli-İnpiri Formation are Barremian, the base of the sequence already contains echinoids, gastropods, belemnites and ammonites (**e**) of Lower Aptian age. The yellow sands contain clasts of coal from erosion of the nearby Carboniferous sequence (c). Shallow marine environment is indicated by gastropods, burrows and abundant little planktonic foraminifers (**f**). In contrast, the Kapanboğazı limestone is characterized by large planktonic foraminifers (Globotruncanidae) indicative of a much deeper environment (**g**).

middle Cretaceous angular unconformity also shows that tectonic deformation occurred before the Coniacian–Santonian transgression. Variations in thickness (hectometres) of the Kilimli-İnpiri Formation around Amasra, and a local hard ground at the base of this clastic sequence indicate that vertical movements occurred during the deposition of these Barremian–Aptian sediments suggesting extensional block faulting at this time.

The Upper Cretaceous section continues with the Kapanboğazı red pelagic limestone. Based on planktonic foraminifers, Görür (1997) dated the Kapanboğazı Formation as Cenomanian to Campanian (Fig. 3). Such a large time span places this formation as a possible lateral equivalent of the Tasmaca and the Yemişliçay Formations. Based on nannofossil study we could precisely date the red pelagic limestone and the Yemişliçay Formation at several localities. Around Zonguldak, a red pelagic limestone is named the İkse Formation of Turonian–Campanian age (Yergök *et al.* 1987). It corresponds to the formation named Unaz in Tüysüz (1999). NE of Zonguldak, near Hisarönü (Fig. 13), nannofossils found in this formation indicate a Santonian age (sample 06-63). Near Ereğli (Fig. 13) we also found red pelagic limestones in the İkse Formation, but we could not find characteristic nannoplankton species for a precise age determination (Upper Cretaceous, sample 06-2, Table 1). However in this area, we found similar pinkish limestones in the Kale Turonian–Campanian Formation (Yergök *et al.* 1987) lying above the Ikse Formation. The nannofossils also indicate here a Santonian age (samples 03-7, 04-29, Fig. 13).

These ages are in agreement with the foraminifer dating of Tüysüz (1999) who bracketed the age of the Unaz Formation to the Late Santonian–Campanian (Fig. 3). Considering that our nine ages of the red pelagic limestone in five different localities throughout the Central Pontides (Ereğli, Hisarönü, Amasra, Doganyurt and Ağlıköy, Fig. 13) are the same, we conclude that this limestone is Santonian and therefore does not interfinger with the syn-rift Aptian–Albian Tasmaca Formation (Fig. 3, Görür 1997). Furthermore, taking into account the angular unconformity described above, it is clear that a Lower Cretaceous sedimentary cycle has to be distinguished from an Upper Cretaceous cycle and that there is a tectonic event occurring in between.

Around Zonguldak, a local formation, comprising clastic, volcanogenic clastic and pyroclastic rocks, is well developed between the Unaz (Kapanboğazı) limestone and the formations of the Çağlayan Group. Tüysüz (1999) named these rocks as the Dereköy Formation (Fig. 3). Yergök *et al.* (1989) had distinguished four formations in this series: the Cemaller sandstone of Albian–Cenomanian age; the Gökçetepe Formation (lahar and volcaniclastic sands); the Başköy Formation (volcanogenic clastic and marls); and the Dilence Formation (pyroclastic rocks and tuff) of Turonian–Campanian age. Tüysüz (1999) pointed out that the volcanic rocks of the Dereköy Formation represent the onset of arc magmatism in the region, which became more active during the Campanian (Cambu Formation) (Fig. 3). Intercalated in this sequence of pyroclastic and andesitic-basaltic lavas, he found pelagic limestone with foraminifers of middle Turonian age. According to Tüysüz (1999) the upper part of the Cemaller Formation, that he considers as Cenomanian, interfingers with the Middle Turonian pyroclastic rocks and lavas. Therefore he proposes that the Dereköy Formation is Cenomanian–Turonian in age.

However, taking into account our Late Albian nannoplankton dating of the Cemaller Formation near Zonguldak (Fig. 5), and the general gap between the Lower and Upper Cretaceous formations, we cannot follow this interpretation that includes the Cemaller Formation of Zonguldak in the Dereköy Formation and we will not retain this global dating of the Dereköy Formation. Unfortunately, we do not have any new age determination for the Gökçetepe, Basköy and Dilence Formations around Zongudak because they are mainly volcanogenic rocks, and we could not check the middle Turonian age based on foraminifers for the Dereköy Formation (Tüysüz 1999). Note, however, that while near Cide, the Cemaller, Basköy and Dinlence Formations, included in the Dereköy Formation by Tüysüz (1999), contain foraminifers suggesting a middle Turonian–Coniacian age for the Dereköy Formation (Tüysüz 1999), our nannoplankton ages in the same area (Amasra) are more recent, Coniacian–Santonian. Note also that near Amasra, the Basköy and Dilence Formations (Yergök *et al.* 1987), that form the Dereköy Formation of Tüysüz (1999), correspond on the geological maps to the Kapanboğazı and Yemişliçay Formations of Görür *et al.* (1993). The age of the Dereköy Formation seems not well constrained. Considering that it corresponds to the lower part of the Yemişliçay Formation of Görür (1997) (Fig. 3), it is possible that it is Santonian, like the rest of the volcanic sequence that we dated.

Finally we can precisely date the extent of the regional mid Cretaceous stratigraphic gap. Taking into account our lack of ages for the volcanogenic part of the Dereköy Formation near Zonguldak, we conclude that in the Western Pontides, deposits from the uppermost Albian to the lower Turonian are missing. Our sections in the Amasra area (samples 03-12, 04-42, 06-41) and in the Ağlıköy area (samples 04-11, 15, 16) suggest, however, that this stratigraphic gap may extend from the uppermost Albian to the Coniacian.

The Kapanboğazı red pelagic limestone passes upwards into the Yemişliçay Formation (Görür *et al.* 1993) equivalent to the Cambu and Dereköy Formations of Tüysüz (1999) (Fig. 3). This formation is an up to 1500 m thick widespread series of volcaniclastic sediments and volcanic rocks (andesites and basalts) with local intercalations of red pelagic limestones similar to the Kapanboğazı limestones (Ketin & Gümüs 1963; Görür 1997) (Fig. 14). It includes the Kazpınar, Liman, Kale and Sarıkorkmaz Formations of Yergök *et al.* (1989).

Based on foraminifers, a Turonian to Campanian age was proposed for this formation (Aydın *et al.* 1986; Tüysüz 1990; Görür *et al.* 1993) (Fig. 3). However, similar to the Kapanboğazı Formation, we have always obtained a Santonian age consistently from several localities in the Central Pontides. For example, at Amasra we dated green and yellow marls intercalated in the lower part of the Yemişliçay volcaniclastic rocks (samples 03-14, 06-42) (Figs 13 & 14). Near Ereğli, nannofossils found in the calciturbidites of the upper part of the volcanogenic sequence (Kale Formation), confirm this Santonian age (sample 04-30) (Fig. 13). Note that within the volcanogenic sequence, the intercalations of red pelagic limestone also gave a Santonian age at Doğanyurt (sample 03-21), at Ereğli (samples 03-7, 04-29) and at Hisarönü (sample 06-63, Fig. 13). This age is in agreement with our Santonian dating of the underlying Kapanboğazı Formation. Seven kilometres south of Amasra we could date the oldest sediments above the volcanic and volcanogenic sequence of the Yemişliçay Formation. These grey marls named the Alaplı Formation and equivalent to the Akveren Formation of Görür *et al.* (1993), contain nannofossils of lower Campanian age (samples 06-59, 60) (Fig. 16). Finally, our nannoplankton dating allows for bracketing the age of the Yemişliçay Formation from the Turonian–Coniacian–Santonian–Campanian (e.g. Görür 1997) to the Santonian (Fig. 3). This result is in agreement with the recent age determination by Okay *et al.* (2006) of a section east of our studied area, near Hanönü, where the basal and upper part of the Yemişliçay Formation contain foraminifers characteristic of the Coniacian–Santonian.

The Upper Cretaceous–Cenozoic sedimentary formations

The extensive magmatism ceased after deposition of the Yemişliçay Formation (e.g. Tüysüz 1999). Whereas Paleocene to Eocene volcanic rocks are well developed in the Eastern Pontides, they are present only locally in the studied area. Sedimentation continues above an unconformity with a 500–3000 m thick mainly turbiditic sequence. While in the southern part of the Pontides, the siliciclastic turbidites of the Gürsökü Formation (Ketin & Gümüs 1963) are generally interpreted as a Maastrichtian forearc flysch sequences (Görür *et al.* 1984; Koçyiğit 1991; Okay *et al.* 2006) in the studied area the Akveren, Atbaşı and Kusuri Formations are distinguished in the Maastrichtian to Eocene sequence (Aydın *et al.* 1986; Görür 1997; Tüsüz 1999, Fig. 3).

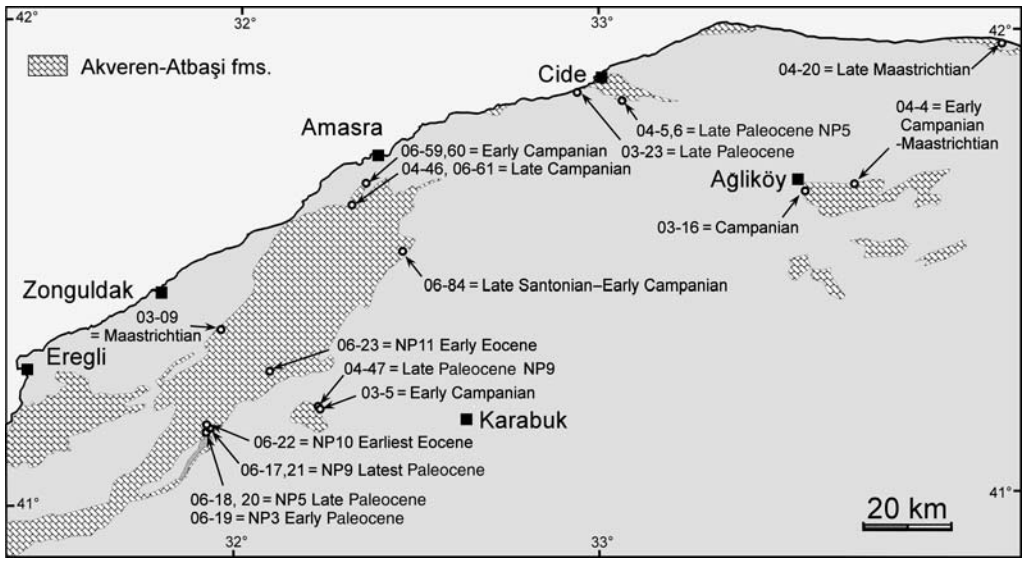

Fig. 16. Campanian-Paleocene Akvenren and Atbaşı Formations with their sites of nannoplankton dating (cf. Table 1).

The Akveren Formation consists of carbonates and calciturbidites. In the western Pontides, this formation unconformably overlies the older rocks including the Early Cretaceous Ulus Formation. According to Tüysüz (1999) fossils at the base of the Akveren Formation confirm that sedimentation started in a shallow marine environment; then the 10–40 m thick carbonate mudstone of the Atbaşı Formation denotes a pelagic environment. The Akveren and Atbaşı Formations are followed by the 1000–1500 m thick siliciclactic turbidites of the Kusuri Formation.

According to Görür (1997) and Tüysüz (1999), the Akveren calciturbidites are Maastrichtian in age and the Atbaşı Formation is Paleocene in age based on foraminifers (Fig. 3). Our nannoplankton dating confirms that the calciturbiditic flysch extends into the upper Maastrichtian (samples 03-9 and 04-20) (Fig. 16). But as mentioned above, nannofossils indicate that the oldest sediments resting on the Yemişliçay volcanogenic formation, the Alaplı marls, equivalent to the Akveren Formation, are older: Early Campanian (samples 06-59, 60) (Fig. 16). In the upper part of the Akveren-Alaplı Formation we dated thinly bedded limestone of the upper Campanian (samples 04-46, 06-61), thus confirming an age older than estimated before (Görür 1997; Tüysüz 1999). We conclude that the Akveren-Alaplı Formation extends from the Lower Campanian to the Upper Maastichtian, which is in agreement with the nannoplankton dating of the underlying Santonian Yemişliçay Formation (Fig. 3).

Near Ağlıköy, in the eastern part of the studied area (Fig. 16), we could date as the same age the dark sandstones of the Caylak Formation, (Campanian, sample 03-16 and Early Campanian–Maastichtian, sample 04-4). We infer that this sandstone, that contains echinids and that onlaps the older formations (Akat *et al.* 1990), represents a shallow marine facies of the Akveren Formation on the southern margin of the Campanian Black Sea.

To the east of our mapped area, near Hanönü (Fig. 2), a thick sequence of grey marls with 10–20 m white limestone at its base is transgressional on the Yemişliçay-Gürsöku Formations. Okay *et al.* (2006) recently found nannofossils of the Late Paleocene–Lower Eocene. Our samples gave ages ranging from the uppermost Maastrichtian to Middle Eocene (uppermost Maastrichtian for samples 06-126 and 06-133 base of the limestone at the entrance of the village of Sirke and East of Hanönü; Late Paleocene NP9, Early Eocene NP13 and Middle Eocene NP14b for samples 06-127, 06-134, and 06-129 respectively, taken from the marls above the basal limestone, Table 1). The local presence of uppermost Cretaceous at the base of the transgressional limestone is further confirmed by the finding of an ammonite near Sirke. Considering the timing of the opening of the Black Sea (Robinson *et al.* 1995), we propose that this transgression on the accretionary wedge is related to the opening of the EBS.

In the Zonguldak-Amasra area, the turbidites reach the upper Eocene in age. The following nannoplankton zones were identified in the Akveren, Atbaşı and Kusuri Formations: Paleocene NP3 (sample 06-19) NP5 (samples 06-18, 20), NP9 (samples 04-22, 06-17,21), Earliest Eocene NP10 (samples 06-22) and NP11 (sample 06-23) (Fig. 16), Early Eocene NP13 (sample 06-25), Middle Eocene NP14b (sample 06-62) and NP15 (samples 06-82), Late Eocene NP19-20 (samples 06-83, Fig. 17). In contrast, in the inner part of the Pontide Belt, the Palaeogene sequence fills intramountaineous basins: Karabük Basin, Eflani Basin, Kastamonu Basin, Devrekani Basin (Fig. 17), Boyabat Basin, and Vezirköpru Basin (Fig. 2). Intraformational unconformities at the edge of the basins (Fig. 18) show that they are syncompressional piggyback basins formed and filled during the construction of the Pontide Belt, similar to those described in Central Anatolia (Kaymakci 2000). The filling of these intra-mountainous synthrusting basins starts in the lower Eocene (zone NP12, e.g. sample 06-121) and ends in the middle Eocene (zone NP17, e.g. sample 06-125) (Fig. 17). Therefore, even if sedimentation seems continuous in the Zonguldak-Amasra area, on our maps we have distinguished the Paleocene sequence (Akveren and Atbaşı Formations, Figs 3 & 16) from the Early-Eocene and Middle-Eocene sediments (Çaycuma and Kusuri Formations, Figs 3 & 17), deposited in a compressional setting. Note that they have a very different geographic distribution, being present in particular inside the Pontide thrust belt (compare Figs 16 & 17).

Geodynamical implications

Dating of the stratigraphic sequence of the Black Sea margin in the Central Pontides allows distinguishing two main periods of deposition: Barremian–Albian, and Coniacian–Eocene. It reveals a long mid-Cretaceous period of erosion that contrasts with the classical models of this margin where an Aptian–Albian rifting was immediately followed by rapid Upper Cretaceous thermal subsidence (e.g. Görür *et al.* 1993).

Barremian to Albian

The Barremian–Albian sedimentary cycle starts with shallow marine clastic sediments. The Lower Cretaceous black shales and sandstones were

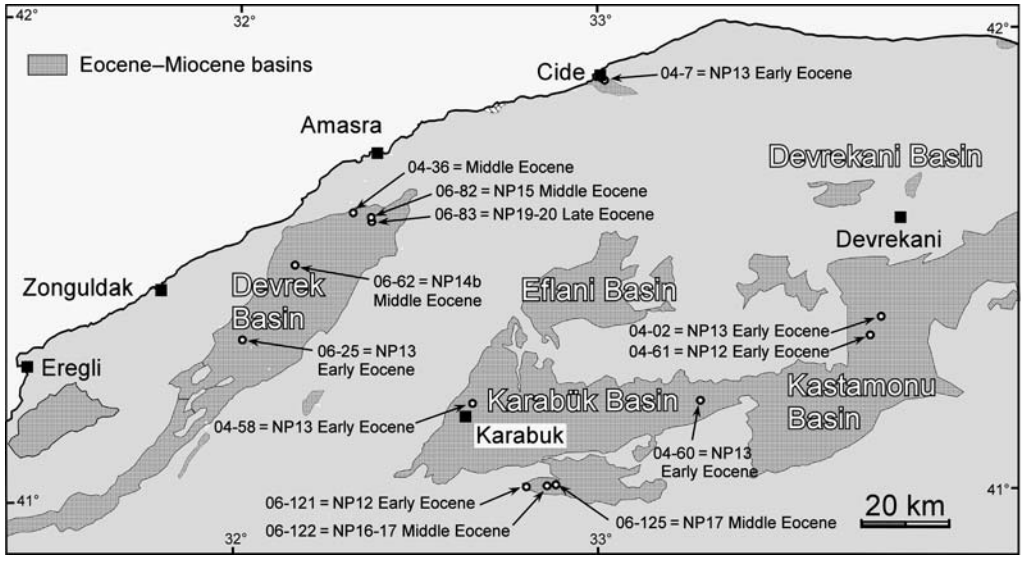

Fig. 17. Eocene–Miocene basins with their sites of nannoplankton dating (cf. Table 1). During Eocene piggyback basins are created within the Pontide trust belt. Eocene marine sediments range from NP12 to NP17 in the Eflani, karabük and Kastamonu piggyback basins. Marine sediments up to NP19-20 (Upper Eocene) were found in the Devrek Basin.

interpreted as indicating anoxia during the Black Sea rifting and were related to the opening of the Black Sea as a back-arc basin (Görür *et al.* 1993). This argument is not conclusive because anoxic events are frequent worldwide during this period. Besides, as noticed by Tüysüz (1997) the general absence of subduction-related magmatism during the Early Cretaceous does not support this interpretation. However, there is strong evidence that supports the syn-rift interpretation of the Lower Cretaceous sequence. The arrival of detrital material on the carbonate platform denotes a major environmental change. At Amasra, Aptian sediments contain abundant clasts of Carboniferous coal attesting for local uplift and erosion during Lower Cretaceous subsidence and sedimentation. We could observe numerous normal faults that control thickness variations in the Lower Cretaceous deposits along the Black Sea coast (Fig. 7). This syntectonic sedimentation is also attested by the presence of olistoliths. Blocks of up to several tens of metres, mostly derived from the Upper Jurassic–Lower Cretaceous İnaltı limestone, have been found in the Kilimli (Görür 1997), Sapça (Derman 1990) and Tasmaca Formations (Siyako *et al.* 1981). We have also identified a 300 m long olistolith of Palaeozoic limestone within the early Aptian Sapça Formation (Fig. 9). The presence of normal faults, thickness variations, olistoliths and hard grounds in the Lower Cretaceous sequence allows dating the rifting from the Barremian to the Albian.

Fig. 18. Stratigraphic wedging at the front of a reverse fault along the northern margin of the Kastamonu Eocene basin. Such intra-formational angular unconformities at the border of the Eocene basins demonstrate that they are syncompressional piggyback basins.

After deposition of hundreds to thousands of metres of sediments, this sedimentary cycle ended up in the upper Albian with sedimentation of shallow marine sands. Nannofossil dating gives evidence for a regional gap ranging from the uppermost Albian to the Turonian/Coniacian. An angular unconformity at Amasra demonstrates that this stratigraphic gap is partly erosional (Figs 12 & 15). Considering that this erosion follows syn-rift sedimentation and subsidence, we propose that it results from a thermally induced uplift of the rift

shoulders. Such rift flank uplift can be expected during rifting of a thick (cold) lithosphere with high mechanical strength and high depth of necking (level of no vertical motions in the absence of isostatic forces; Fig. 19), which was inferred for the WBS (Robinson *et al.* 1995; Spadini *et al.* 1996; Cloetingh *et al.* 2003).

The onset of rifting was characterized by the break of the carbonate platform and the arrival of clastic deposits (Görür 1988). This normal faulting of the carbonate platform is evident all along the Black Sea coast between Zonguldak and Amasra (Figs 2, 6 & 7). This SW–NE ridge was probably a horst during the Cretaceous. To the SE, Okay *et al.* (2006) have evidenced SW–NE trending units of Cretaceous high-pressure–low-pressure metamorphic rocks. The Ulus Basin, elongated in the same SW–NE orientation is located between the Zonguldak-Amasra horsts and this Cretaceous accretionary complex. Our dating reveals a diachronous age for the base of this clastic sequence. Clastic sedimentation already existed during the Hauterivian in the eastern areas (near Ağlıköy, Figs 2 & 12) while carbonate deposition continued in the Zonguldak-Amasra horsts to the West. Likewise, compressional deformation of the Ulus Formation grades rapidly toward the SE and the accretionary complexes (Fig. 2). Taking into account this SW–NE structural trend and this WNW–ESE evolution of the deformation and sedimentation, we propose that the deep depositional environment of the Ulus flysch and its intense deformation are related to its proximity to the Lower Cretaceous accretionary prism (Fig. 6). In this frame, the Hauterivian age of Ağlıköy might not mean that extension occurred earlier in this area, but that deep marine conditions existed along the active margin (Fig. 6).

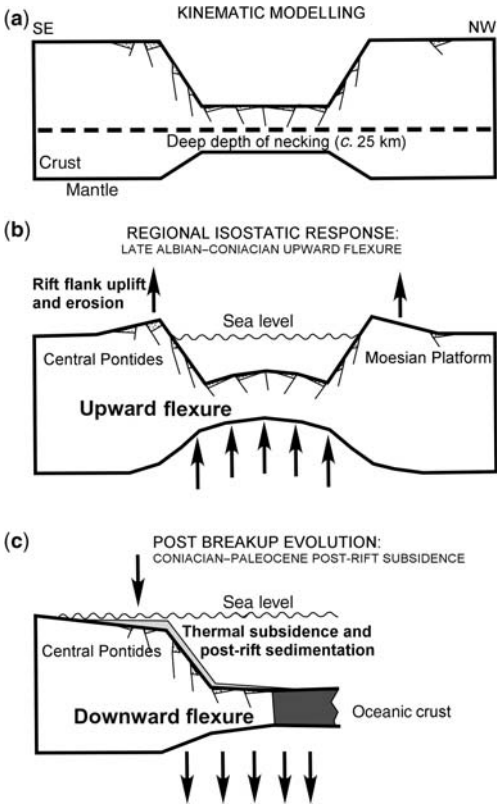

Fig. 19. The rifting of the western Black Sea Basin in relation with the concept of lithospheric necking. Stratigraphic data show that the rifting started in Late Barremian and was very long at 40 Ma. In the Central Pontides, during the rifting, the change from sedimentation to erosion denotes rift flank uplift starting in Late Albian. These results support the models of rifting of a thick (cold) lithosphere with a large depth of necking (level of no vertical motions in the absence of isostatic forces) [(**a**) and (**b**), modified from Spadini *et al.* 1996]. Note that in the case of the Black sea the uplift of the southern rift shoulders might have been enhanced by the collision of the Kargi continental block. Following the continental breakup the margin subsided and the post-rift deposits onlapped the Central Pontides in Coniacian–Santonian (**c**).

Coniacian to Eocene

Following the Turonian erosion, a new sedimentary cycle starts with Coniacian–Santonian shallow marine sands and a thick Santonian volcanic and volcaniclastic sequence with pelagic limestones intercalated. It continues with the deposition of the Akveren-Atbaşı flysch sequence which onlaps older rocks (Fig. 3). The distribution of the Senonian deposits along the Black Sea and their north–south variations in facies clearly indicate that they are deposits of the Black Sea margin (Figs 13 & 16). The sharp transition from shallow marine sands to pelagic limestone (Fig. 15) indicates a rapid deepening of the margin that is probably related to a post-rift thermally induced subsidence (Görür 1988). The large thickness of the Senonian-Paleocene sequence (up to 3000 m, Fig. 3) and its widespread distribution, support this post-rift interpretation. Consequently the stratigraphic sequence of the Central Pontides allows precise determination of the age of rifting of the WBS: from Late Barremian to Coniacian–Santonian time (Fig. 3). We conclude that the rifting of the western Black Sea was very long: 40 Ma.

Compression and uplift occurred from Eocene to present times. In the Pontides, the Eocene sequence was generally deposited within intra-mountainous basins (Fig. 17). Intra-formational angular unconformities (Fig. 18) demonstrate that compression

was syndepositional. Therefore, the age of the onset of compression could be accurately determined by dating the older syncompressional deposits. In the Central Pontides they are of Early Eocene age (nannoplankton zone NP12). We explain the marine sedimentation in the intra-mountainous piggyback basins by the combined effects of post-rift subsidence of the Black Sea margin and loads of the Pontide thrust piles, in compensating the compressional uplift at its beginning. After the subsidence and filling of the piggyback basins by the end of Middle Eocene (NP 17), compressional deformation continued as shown by the folding of the uppermost Eocene marine sediments. We relate the Eocene onset of compression, to the collision of the Kirşehir continental block, a promontory of the Tauride–Anatolide Block (Fig. 1). This local collision explains the diachronous onset of compression between the Central Pontides (Early Eocene, NP12) and the Greater Caucasus (Late Eocene, e.g. Robinson *et al.* 1995). The indentation of the Kirşehir Block into the Pontides resulted in the northward convex arc geometry of the Central Pontides (Kaymakci 2000; Kaymakci *et al.* 2003*a*, *b*) and the inversion and uplift of part of the southern Black Sea margin whose sequence is now exposed onshore.

Discussion

The Mesozoic–Cenozoic stratigraphy of the Central Pontides shows that the region experienced two main subsidence phases separated by an uplift and erosion during the Cretaceous. The significance of these movements needs to be discussed in the frame of the geodynamic evolution of the Black Sea. It is clear that the Lower Cretaceous represents a period of rifting. However, this rifting was not associated with arc volcanism (e.g. Okay *et al.* 2006) and according to Tüysüz (1999) could predate an Upper Cretaceous rifting and oceanic spreading contemporaneous of arc volcanism.

Zonenshain & Le Pichon (1986) proposed that the Black Sea results from back-arc extension during three successive episodes: 1) Early–middle Jurassic (opening of the Great Caucasus Basin); 2) Late Jurassic–beginning of the Cretaceous (opening of the Pre-Black Sea); and 3) end of the Cretaceous–Early Palaeogene. While the second event didn't lead to complete breakup of the basement, the third episode of extension led to the formation of deep oceanic basins partially closed during the Cenozoic. This model was controversial because during the Neocomian the circum Black Sea region was a shallow shelf (Görür 1988). However, it considers the possibility of pre-Black Sea rifting episodes.

Accordingly, the Barremian–Albian extensional tectonics (Fig. 7) could be interpreted as a pre-Black Sea rifting that may not have resulted in a complete break-off of the basement. The Ligurian back-arc basin showed such an evolution. Its Provençal margin was cut by NNE–SSW grabens belonging to the Eocene–Oligocene west European intracontinental rift, and then it was broken-off obliquely along the ENE–WSW Late Oligocene Liguro–Provençal back arc rift, that evolved to an oceanic basin (Hippolyte *et al.* 1993). A supporting evidence for a similar pre-Black Sea rifting unrelated to subduction, could be that along the Black Sea coast subsidence started in Barremian, before the beginning of convergence of Africa with respect to Europe (before 120–83 Ma, Rosenbaum *et al.* 2002). Such an idea of extensional tectonics unrelated to subduction was already proposed by Yiğitbaş *et al.* (1999).

However, the age of eclogites in the South of the Pontides, shows that, even though there was no arc magmatism in the Pontides during the Late Jurassic–Early Cretaceous (e.g. Okay *et al.* 2006), subduction and accretion were acting on the northern margin of the Neotethys Ocean during the Albian. Therefore, the Early Cretaceous subsidence and extensional faulting evidenced along the Black Sea coast (Fig. 7) might be related to this subduction. Moreover, in South Dobrogea and in the Moesian platform (Burchfiel 1976; Sandulescu 1978) carbonate deposition was marked by the arrival of abundant terrigenous material during the Aptian–Albian, suggesting that the Barremian–Albian rifting affected the conjugate margins of the western Black Sea. Furthermore, seismic data show that the Karkinit through West of Crimea, opened probably during the mid-Cretaceous and has an Upper Cretaceous–Eocene post-rift sequence (Robinson *et al.* 1996). Finally, palaeomagnetic analyses of the Kapanboğazı Formation in the Central Pontides indicates a palaeolatitude of 21.5°N, (Channell *et al.* 1996) with the implication that the WBS was opened by the Coniacian–Santonian (Okay *et al.* 2006).

In the frame of the Lower Cretaceous rifting, the middle Cretaceous erosion of the Pontides region most probably results from a thermal uplift of the rift shoulders. Seismic data from offshore Romania and Bulgaria show a regional unconformity in agreement with this thermal doming interpretation (Robinson *et al.* 1996). However, we cannot exclude that a part of the stratigraphic gap identified was related to the evolution of the subduction zone to the south. Effectively, the recent study of Albian eclogites in the accretionary complex south of the studied area (Okay *et al.* 2006) shows that an up to 11 km thick crustal slice (the Domuzdag complex, Ustaömer & Robertson 1997) of the Tethyan oceanic crust was metamorphosed

at HP-LT at 105 ± 5 Ma and exhumated in Turonian–Coniacian times in a fore-arc setting. This exhumation might be the consequence of the collision of the Kargı continental block that occurred just before, along the south facing Tethyan margin of the Pontides (Okay *et al.* 2006). It is thus possible that this collision participated in uplifting the Central Pontides during the Cenomanian–Turonian. This accretion was followed by the initiation of a new subduction zone to the south (Okay *et al.* 2006). We infer that this new subduction zone was wider than the Barremian–Albian one that was only related to the opening of the WBS. Effectively this later might have extended all along the Santonian volcanic arc, which is present in all of the Pontides, and was related to the opening of the EBS and the possible reactivation the WBS.

Conclusion

Nannofossil investigations provided accurate ages for the sedimentary units of the Central Pontides. That superposed formations dated independently provide compatible ages supports the validity of our age determinations.

The rifting of the WBS, that broke up the Upper Jurassic to Lower Cretaceous carbonate platform, started within the Barremian, but the main tectonic activity and subsidence took place during Aptian to Albian times. The syn-rift sequence (Çağlayan Formation) is a detritic sequence containing olistoliths. It is characterized by rapid variations in facies and thickness, especially across normal faults.

In the inner Black Sea margin, now inverted in the Pontides Belt, sediments of uppermost Albian to Turonian age are missing. This large regional stratigraphic gap, although not clearly identified by means of foraminifers, corresponds to the breakup unconformity of Görür (1997). Although tectonic analysis is necessary to better constrain the origin of the Cretaceous vertical movements, the observation of numerous normal faults in the Early Cretaceous series, and the angular unconformity observed at Amasra, support the idea that erosion occurred during rifting. It is interpreted here as resulting mainly from the thermal uplift of the western Black Sea rift shoulders.

Age determinations based on nannofossils show that the post-rift subsidence, which was thought to start in Cenomanian time (Görür 1997), only began in the Coniacian–Santonian. The Cretaceous arc-volcanism that was considered to occur during the Turonian to Campanian, is bracketed to the Santonian in the Central Pontides.

Our study confirms that the opening of the Black Sea was diachronous. The rifting of the WBS predates the Paleocene–Eocene rifting of the Eastern basin. We show that, different to the EBS, the rifting of the WBS was very long (40 Ma) and produced a major uplift of the rift shoulders. These two different characteristics indicate that the WBS, in contrast to the EBS, opened on a thick lithosphere and involved a large depth of necking (about 25 km) as proposed by Spadini *et al.* (1996) and Cloetingh *et al.* (2003) based on modelling (Fig. 19).

The stratigraphic dating of the Cenozoic sequence also constrains the timing of the Pontides compression. We show that along the southern margin of the Black Sea the orogenic movements are also diachronous. They started in the Central Pontides in the Lower Eocene, with the collision of the Kırşehir block.

This work was supported in 2003 and 2004 by the MEBE Programme and in 2006 by TUBITAK (Turkey) (Project No. ÇAYDAG-105Y146) and the University of Savoy (France). We are grateful to A. Arnaud and J. P. Thieuloy for foraminifer and ammonite determinations. Our thanks go also to Professor A. Okay and Professor E. Yiğitbaş for their constructive reviews.

References

Akat, U., Akçören, F. *et al.* 1990. *Geologic Map of the Kastamonu B-17 Quadrangle, 1:100 000.* Maden Tetkik ve Arama Genel Müdürlüğü, Ankara.

Akman, A. Ü. 1992. *Amasra-Arit arasının jeolojisi*. PhD thesis, Ankara University.

Aksay, A., Pehlivan, S., Gedik, I., Bilginer, E., Duru, M., Akbas, B. & Altun, I. 2002. *Geological Map Of Turkey, 1:500 000, Zonguldak Paftası*. Maden Tetkik ve Arama Genel Müdürlüğü, Ankara.

Aydin, M, Serdar, H. S., Şahintürk, Ö, Yazman, M., Çokuğraş, R., Demir, O. & Özçelik, Y. 1987. Çamdağ (Sakarya)-Sünnicedağ (Bolu) yöresinin jeolojisi. *Geological Society of Turkey Bulletin*, **30**, 1–14 (in Turkish with English abstract).

Aydin, M, Şahintürk, Ö *et al.* 1986. Ballıdağ-Çangaldağı (Kastamonu) arasindaki bölgenin jeolojisi. *Geological Society of Turkey Bulletin*, **29**, 1–16 (in Turkish with English abstract).

Banks, C. J. & Robinson, A. G. 1997. Mesozoic strike-slip back-arc basins of the Western Black Sea region. *In*: Robinson, A. G. (ed.) *Regional and Petroleum Geology of the Black Sea and Surrounding Region*. American Association of Petroleum Geologists, Memoir, **68**, 53–62.

Burchfiel, B. C. 1976. Geology of Romania. *Geological Society of America Special Paper*, **158**, 82.

Channell, J. E. T., Tüysüz, O., Bektas, O. & Sengör, A. M. C. 1996. Jurassic-Cretaceous paleomagnetism and paleogeography of the Pontides (Turkey). *Tectonics*, **15**, 201–212.

Cloetingh, S., Spadini, G., Van Wees, J. D. & Beekman, F. 2003. Thermo-mechanical modelling of the Black Sea Basin (de)formation. *Sedimentary Geology*, **156**, 169–184.

Derman, S. 1990. Faylı basen kenarindaki sedimentasyon. Bati Karadeniz' de Kretase' den bir örnek.

Proceedings of the 8th International Petroleum Congress and Exhibition of Turkey, 314–321 (in Turkish).

Derman, S. & Sayili, A. 1995. İnaltı Formation: a key unit for regional geology. *In*: Erler, A., Ercan, T., Bingöl, E. & Örçen, S. (eds) *Geology of the Black Sea Region*. Proceedings of the International Symposium on the Geology of the Black Sea Region. Mineral Research and Exploration Institute of Turkey (MTA), 104–108.

Finetti, I, Bricchi, G., Del Ben, A., Pipan, M. & Xuan, Z. 1988. Geophysical study of the Black Sea. *Bolletino di Geofisica ed Applicata*, **30**, 197–324.

Görür, N. 1988. Timing of opening of the Black Sea Basin. *Tectonophysics*, **147**, 247–262.

Görür, N. 1997. Cretaceous syn- to post-rift sedimentation on the southern continental margin of the Western Black Sea Basin. *In*: Robinson, A. G. (ed.) *Regional and Petroleum Geology of the Black Sea and Surrounding Region*. AAPG Memoir, **68**, 227–240.

Görür, N., Oktay, F. Y., Seymen, I. & Şengör, A. M. C. 1984. Paleotectonic evolution of the Tuzgölü basin complex, Central Anatolia: sedimentary record of a Neo-Tethyan closure. *In*: Dixon, J. E. & Robertson, A. H. F. (eds) *The Geological Evolution of the Eastern Mediterranean*. Geological Society, London, Special Publications, **17**, 455–466.

Görür, N., Tüysüz, O., Aykol, A., Sakinc, M., Yığıtbaş, E. & Akkök, R. 1993. Cretaceous red pelagic carbonates of northern Turkey: their place in the opening history of the Black Sea. *Eclogae Geology Helvetica*, **86**, 819–838.

Hippolyte, J. C., Angelier, J., Nury, D., Bergerat, F. & Guieu, G. 1993. Tectonic-stratigraphic record of paleostress time changes in the Oligocene basins of the Provence, southern France. *Tectonophysics*, **226**, 15–35.

Hsü, K. J., Nacev, I. K. & Vuchev, V. T. 1977. Geologic evolution of Bulgaria in the light of plate tectonics. *Tectonophysics*, **40**, 245–256.

Kaymakci, N. 2000. *Tectono-stratigraphical evolution of the Çankırı Basin (Central Anatolia, Turkey)*. PhD thesis, Geologica Ultraiectina. No. 190, Utrecht University Faculty of Earth Sciences, The Netherlands.

Kaymakci, N., White, S. H. & van Dijk, P. M. 2003*a*. Kinematic and structural development of the Çankırı Basin (Central Anatolia, Turkey) a paleostress inversion study. *Tectonophysics*, **364**, 85–113.

Kaymakci, N., Duermeijer, C. E., Langereis, C., White, S. H. & van Dijk, P. M. 2003*b*. Oroclinal-bending due to indentation: a paleomagnetic study for the early Tertiary evolution of the Çankiri Basin (central Anatolia, Turkey). *Geological Magazine*, **140**, 343–355.

Ketin, I. & Gümüs, Ö. 1963. *Sinop-Ayancik arasindaki III. bölgeye dahil sahalarin jeolojisi hakkinda rapor, 2*. Kisim, Jura ve Kretase Formasyonlarinin etüdü. Türkiye Petrolleri Arama Grubu Arsivi (unpublished report), No. 213–288.

Koçyiğit, A. 1991. First remarks on the geology of the Karakaya Basin: Karakaya orogen and pre-Jurassic nappes in eastern Pontides, Turkey. *Geologica Romana*, **27**, 3–11.

Koçyiğit, A. & Altiner, D. 2002. Tectonostratigraphic evolution of the North Anatolian Palaeorift (NAPR): Hettangian-Aptian passive continental margin of the Northern Neo-Tethys, Turkey. *Turkish Journal of Earth Sciences*, **11**, 169–191.

Letouzey, J., Biju-Duval, B., Dorkel, A., Gonnard, R., Kritchev, K., Montadert, L. & Sungurlu, O. 1977. The Black Sea: a marginal basin; geophysical and geological data. *In*: Biju-Duval, B. & Montadert, L. (eds) *International Symposium on the Structural History of the Mediterranean Basins*. Technip, Paris, 363–376.

Manetti, P., Boccaletti, M. & Peccerillo, A. 1988. The Black Sea: remnant of a marginal basin behind the Srednegorie-Pontides island arc system during the Upper Cretaceous-Eocene times. *Bolletino di Geofisica Teorica ed Applicata*, **30**, 39–51.

Nikishin, A. M., Korotaev, M. V., Ershov, A. V. & Brunet, M. F. 2003. The Black Sea basin: tectonic history and Neogene-Quaternary rapid subsidence modelling. *Sedimentary Geology*, **156**, 149–168.

Okay, A. I., Şengör, A. M. C. & Görür, N. 1994. Kinematic history of the opening of the Black Sea and its effect on the surrounding regions. *Geology*, **22**, 267–270.

Okay, A. I. & Tüysüz, O. 1999. Tethyan sutures of northern Turkey. *In*: Durand, B., Jolivet, L., Horvath, F. & Séranne, M. (eds) *The Mediterranean Basins: Tertiary Extension within the Alpine Orogen*. Geological Society London, Special Publications, **156**, 475–515.

Okay, A. I., Tüysüz, O., Satir, M., Özkan-Altiner, S., Altiner, D., Sherlock, S. & Eren, R. H. 2006. Cretaceous and Triassic subduction-accretion, high-pressure–low-temperature metamorphism, and continental growth in the Central Pontides, Turkey. *Geological Society of America Bulletin*, **118**, 1247–1269.

Robinson, A. 1997. Introduction: tectonic elements of the Black Sea region. *In*: Robinson, A. (ed.) *Regional and Petroleum Geology of the Black Sea and Surrounding Region*. AAPG Memoir, **68**, 1–6.

Robinson, A., Rudat, J. H., Banks, C. J. & Wiles, R. L. F. 1996. Petroleum geology of the Black Sea. *Marine and Petroleum Geology*, **13**, 195–223.

Robinson, A., Spadini, G., Cloetingh, S. & Rudat, J. 1995. Stratigraphic evolution of the Black Sea inferences from basin modelling. *Marine and Petroleum Geology*, **12**, 821–835.

Rosenbaum, G., Lister, G. S. & Duboz, C. 2002. Relative motions of Africa, Iberia and Europe during Alpine orogeny. *Tectonophysics*, **359**, 117–129.

Sandulescu, M. 1978. The Moesic Platform and the North Dobrogean orogen. *In*: Lemoine, M. (ed.) *Geological Atlas of Alpine Europe and Adjoining Areas*. Elsevier, Amsterdam, 427–460.

Siyako, M., Aksoy, Z., Bürkan, K. A. & Demir, O. 1981. *Zonguldak dolayinin jeolojisi ve hidrokarbon olanakları: Türkiye Petrolleri A. O. Arama Grubu Arsivi* (unpublished report), No. 1536.

Spadini, G., Robinson, A. & Cloetingh, S. 1996. Western v. Eastern Black Sea tectonic evolution: pre-rift lithosphere controls on basin formation. *Tectonophysics*, **266**, 139–154.

SUNAL, G. & TÜYSÜZ, O. 2002. Palaeostress analysis of Tertiary post-collosional structures in the Western Pontides, northern Turkey. *Geological Magazine*, **139**, 343–359.

TOKAY, M. 1952. Contribution à l'étude géologique de la region comprise entre Eregli, Alaplı, Kızıltepe et Alacaağzı. *Maden Tetkik ve Arama Enstitüsü Mecmuası*, **42–43**, 37–78.

TÜYSÜZ, O. 1990. Tectonic evolution of a part of the Tethyside orogenic collage: the Kargı Massif, northern Turkey, *Tectonics*, **9**, 141–160.

TÜYSÜZ, O. 1999. Geology of the Cretaceous sedimentary basins of the Western Pontides. *Geological Journal*, **34**, 75–93.

USTAÖMER, T. & ROBERTSON, A. H. F. 1997. Tectonic-sedimentary evolution of the North-Tethyan margin in the Central Pontides of northern Turkey. *In*: ROBINSON, A. G. (ed.) *Regional and Petroleum Geology of the Black Sea and Surrounding Region*. American Association of Petroleum Geologists Memoir **68**, 255–290.

VERZHBITSKY, E., KUZIN, I. & LOBKOVSKY, L. 2002. Age and thickness of the lithosphere within the Western and Eastern Basins of the Black Sea according to geophysical data. *Turkish Journal of Earth Sciences*, **11**, 231–242.

YERGÖK, A. F., AKMAN, Ü *ET AL.* 1987. *Batı Karadeniz Bölgesinin Jeolojisi (I), 1:100 000*. Maden Tetkik ve Arama Genel Müdürlüğü, Ankara.

YERGÖK, A. F., AKMAN, Ü *ET AL.* 1989. *Batı Karadeniz Bölgesinin Jeolojisi (II), 1:100 000*. Maden Tetkik ve Arama Genel Müdürlüğü, Ankara.

YIĞITBAŞ, E., ELMAS, A. & YILMAZ, Y. 1999. Pre-Cenozoic tectono-stratigraphic components of the Western Pontides and their geological evolution. *Geological Journal*, **34**, 55–74.

YIĞITBAŞ, E., KERRICH, R., YILMAZ, Y., ELMAS, A. & XIE, Q. 2004. Characteristics and geochemistry of Precambrian ophiolites and related volcanics from the Istanbul-Zonguldak Unit, Northwestern Anatolia, Turkey: following the missing chain of the Precambrian South European sutre zone to the east. *Precambrian Research*, **132**, 179–206.

YILMAZ, Y., TÜYSÜZ, O., YIĞITBAŞ, E., CAN GENÇ, S. & SENGÖR, A. M. C. 1997. Geology and tectonic evolution of the Pontides. *In*: ROBINSON, A. G. (ed.) *Regional and Petroleum Geology of the Black Sea and Surrounding Region*. American Association of Petroleum Geologists Memoir, **68**, 255–290.

ZONENSHAIN, L. P. & LE PICHON, X. 1986. Deep basins of the Black Sea and Caspian Sea as remnants of Mesozoic back-arc basins. *Tectonophysics*, **123**, 181–211.