Late Barremian Heteroceratidae Hyatt 1900 (ammonoidea), from the Sarcheshmeh Formation (Koppeh Dagh Basin, Northeast Iran): biostrartigraphy and paleobiogeoraphy

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Abstract
Some representative taxa of the Family Heteroceratidae from the Sarcheshmeh Formation are studied. These are: *Heteroceras* cf. *colchicus* Djanelidze, *Heteroceras* spp., *Martelites* cf. *tenuicostatus* (Kakabadze), *Martelites securiformis* (Simonovich, Bastevich and Sorokin), *Martelites* cf. *tinae* (Eristavi), *Martelites* sp.1, *Martelites* sp. 2, *Argvethites* sp., *Imerites sparcicostatus* Rouchadze and *Paraimerites* sp. These indicate a Late Barremian age. The *Imerites giraudi* and *Martelites securiformis* Biozones are proposed for the Upper Barremian Sub-Stage in the Koppeh Dagh Basin. The paleobiogeographic distribution of the Heteroceratidae during Late Barremian is discussed.

Keywords*: Early Cretaceous; Late Barremian; Ammonite; Heteroceratidae; Koppeh Dagh (Kopet Dagh) Basin; Iran.*

Introduction

The Koppeh Dagh (Kopet Dagh) sedimentary basin is situated in the northeastern Iran and the south of Turkmenistan. The Iranian part of the Koppeh Dagh Basin is geographically located between 54º 00′ to 61º 14′ E and 36º 00′ to 38º 16′ N (Figure 1). It formed as an intracontinental basin after the closure of the Hercynian Ocean following the Early Cimmerian orogeny (Berberian and King 1981). From the Jurassic up to the Eocene, relatively continuous sedimentation is recorded, with five major transgressive-regressive sequences in the eastern Koppeh Dagh (Afshar-Harb, 1979, 1983). Subsidence began in the basin in the early Middle Jurassic (Afshar-Harb, 1979; Seyed-Emami & Alavi-Naini, 1990; Seyed-Emami *et al*., 1994, 1996). Fault-controlled subsidence from Jurassic to Oligocene times led to the deposition of up to 10 km of sediments (Berberian & King, 1981).

The Cretaceous strata of the Koppeh Dagh Basin are divided by Afshar Harb (1979) into nine formations (Figure 2). A single megasequence embraces the bulk of the Lower Cretaceous sedimentary rocks. It begins with the conglomerates and sandstones of the Shurijeh Formation, and ends with dark grey shales and siltstones of the Sanganeh Formation.

Detailed geological studies are performed by geologists of the National Iranian Oil Company (NIOC) during the 1960s and 1970s. The most important publications are by Afshar-Harb (1969, 1979, 1994) on the general geology and petroleum geology, Kalantari (1969) on Jurassic and Cretaceous foraminifera, and Hubber (1976) and Afshar-Harb (1982, 1983) on geological maps. Cretaceous ammonites are reported by Immel *et al*. (1997), Raisossadat (2004, 2006, 2010), and Mosavinia *et al*. (2007, 2014). Raisossadat & Moussavi-Harami (1993, 2000) studied the Sarcheshmeh and Sanganeh foraminifera and sea-level changes in the eastern part the Koppeh Dagh.

Material and Method

The studied ammonites come from the lower part of the Sarcheshmeh Formation at Takal Kuh (TAK 1 and TAK 2) and Amand (AM) sections (Figure 3). About 228 specimens of ammonites have been collected. Only some selected specimens are photographed; the figures are drawn in Corel draw software.

Ammonite classification is based on phylogeny as far as possible. Elements such as suture line, ornamentation and coiling are important in interpreting ammonite phylogeny. However, study of ontogeny and dimorphism provide an additional key for better understanding of ammonite classification and evolution.

Numerous papers have been used for the identification and for determining the distribution. Identified ammonites are classified according to Wright *et al.* (1996) in generic level. In parallel other works have been mentioned in case. All collected samples are kept in Geology Department of University of Birjand.

Geological setting

The Koppeh Dagh Basin is the second most important hydrocarbon province of Iran after Zagros. The Koppeh Dagh basin formed as an intracontinental basin in north-east Iran, after the closure of the Hercynian Ocean following the Early Kimmerian orogeny (Berberian & King, 1981; Brunet *et al.*, 2009). From the Jurassic through to the Eocene, relatively continuous sedimentation is recorded by five major transgressive- regressive sequences in the eastern Koppeh Dagh (Afshar-Harb, 1979, 1983).

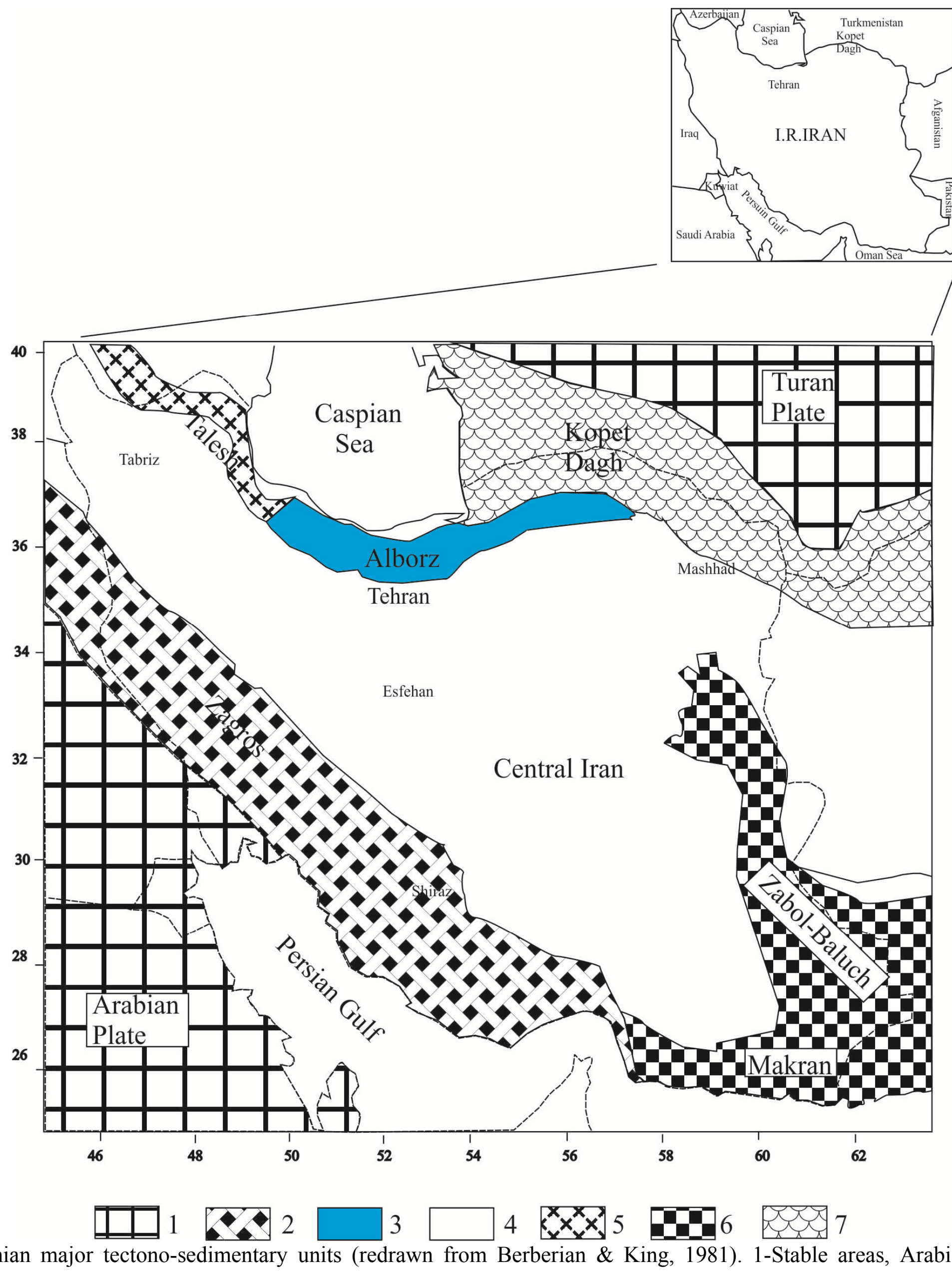


Figure 1. Iranian major tectono-sedimentary units (redrawn from Berberian & King, 1981). 1-Stable areas, Arabian Precambrian platform in south west and Turanian Hercynian Plate in north east, 2- Zagros, including Zagros foredeep, main sector of the marginal active fold belt peripheral to stable areas and High Zagros, 3- Alborz Mountains, 4- Central Iran lying between the two marginal active fold belt, 5- Talesh, Armenian late Hercynian belt with a possible continuation to Iranian Talesh Mountain, 6- Zabol-Baluch and Makran post-ophiolite flysch troughs, 7- Koppeh Dagh folded belt and foredeep.

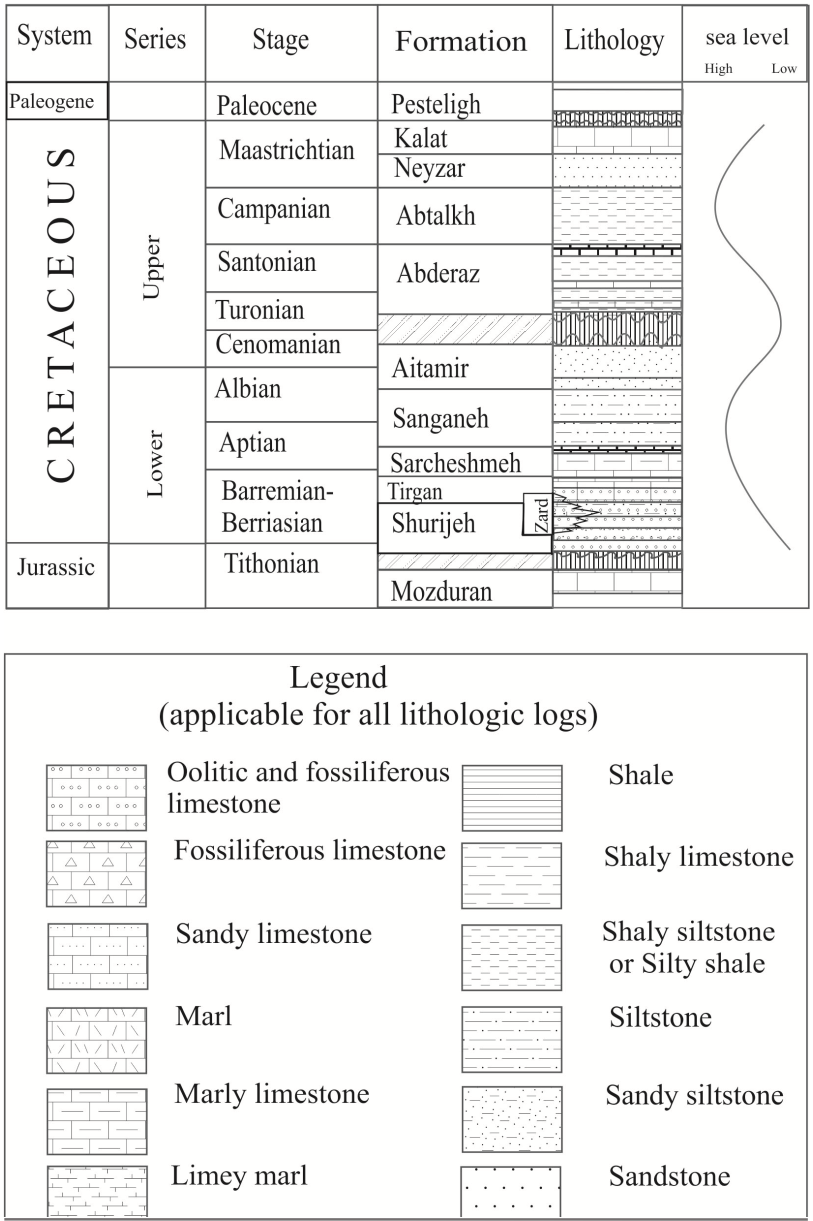


Figure 2. General stratigraphical column for the Cretaceous of the Koppeh Dagh Basin (modified from Kalantari, 1987 and Immel *et al.*, 1997).

Subsidence started in the Koppeh Dagh basin in the late Early Jurassic (Afshar-Harb, 1979; Seyed-Emami & Alavi-Naini, 1990; Seyed-Emami *et al.*, 1994, 1996). Fault-controlled subsidence of the basin from Jurassic to Oligocene times has resulted in up to 10 kilometres of sediment being deposited (Berberian & King, 1981).

From near the end of the Jurassic through to the Early Cretaceous (Neocomian), the sea withdrew from the eastern Koppeh Dagh basin towards the west, and a sequence of fluvial siliciclastic sediments was deposited across the eastern part of the basin (Mosavinia & Wilmsen, 2017). The marine limestones west of the study area recorded the establishment of marine environments sometime during the Early Cretaceous in the central and western parts of the Koppeh Dagh basin (Afshar-Harb, 1979, 1994). During the Barremian, southeastward transgressions across the Sarakhs area re-established marine environments that persisted through the Late Cretaceous, except for a short period during the Late Cenomanian or Early

Turonian (Afshar-Harb, 1979). Red beds of the Pesteligh Formation were deposited during the early Paleocene regression and were followed by deposition of marine Eocene-Oligocene sediments and Mio-Pliocene-Pleistocene nonmarine sediments.

Repeated transgressions and regressions continued through the Miocene, when the basin was folded during the late Alpine compression, creating the anticlinal traps of the Khangiran and Gonbadli gas fields (Afshar-Harb, 1979; Moussavi-Harami & Brenner, 1993).

Stratigraphy

Sarcheshmeh Formation

The Sarcheshmeh Formation (Afshar Harb, 1994) consists of two informal members, a lower marl and an upper shale member. At the type section, the lower member consists of 178 m of uniform light green grey to bluish grey marl, which is weathered to pencil type fragments. A 20-cm-thick oyster coquina occurs at the top of this member in the type locality. The upper member consists of 98 m of dark bluish grey calcareous shale overlain by 34 m of alternating bluish-grey shale and thin limestones (Afshar-Harb, 1979; Raisossadat & Moussavi-Harami, 1993). The formation is moderately weathered and forms a distinct greyish rock unit between the ridge-forming, Tirgan Formation and the low weathering dark grey to black shales of the Sanganeh Formation.

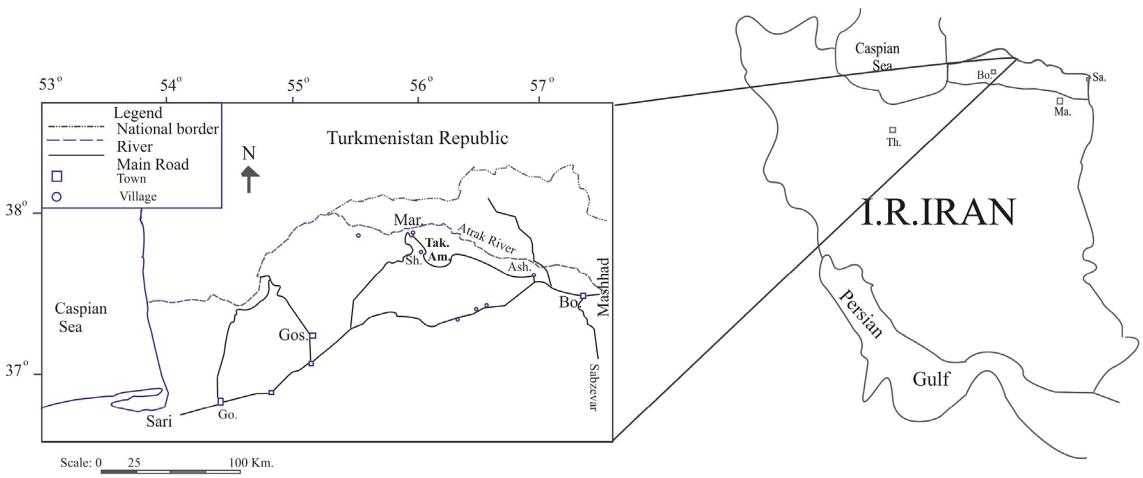
Kalantari (1969) suggested an Aptian age for the Sarcheshmeh Formation, based on foraminifera. But Immel *et al.* (1997) suggest a Late Barremian to Early Aptian age, based on the following taxa: *Colchidites securiformis*, *C. ratshensis*, *C. tenuicostatus*, *C. tinae*, *C.* sp. ex. gr. *colchicus*, *Imerites favrei*, *Anahamulina nicortsmindensis*, *Hemihoplites* sp., *Prodeshayesites tenuicostatus* and *Deshayesites latilobatus*.

Raisossadat (2002, 2003, 2004) reported the following genera and species: *Aconeceras* (*Aconeceras*) *haugi, Ancyloceras* cf. *mantelli*, *Argvethites* sp., *Paraimerites* sp., *Australiceras* sp., *Barremites* cf. *difficilis, Cheloniceras* (*Cheloniceras*) spp., *Deshayesites* cf. *consobrinoides*, *D.* cf. *dechyi*, *D. Deshayesi*, *D.* cf. *euglyphus*, *D.* cf. *involutus*, *D. Luppovi*, *D.* cf. *multicostatus*, *D. Oglanlensis*, *D.* cf. *planus*, *D.* cf. *tuarkyricus*, *D. Weissi*, *D.* cf. *weissiformis, D.* Sp. 1, *D.* Sp. 2, *D.* Spp., *Dufrenoyia* sp., *Turkmeniceras multicostatum, Eogaudryceras* (*Eogaudryceras*) sp., *Eogaudryceras* (*Eotetragonites*) sp., *Heteroceras* cf. *colchicus*, *H.* spp., *Imerites sparcicostatus*, *Martelites* cf. *tenuicostatus*, *M.* Cf. *tinae*, *M. Securiformis*, *M.* Sp. 1, *M.* Sp. 2, *Parahoplites* cf. *maximus, Pedioceras* cf. *anthulai*, *Pedioceras* sp., *Phylloceras* sp., *Phyllopachyceras* sp., *Toxoceratoides* sp. and *Turkmeniceras* cf. *tumidum*. Based on the above assemblage a Late Barremian- Early Aptian age is suggested.

Measured sections

Takal Kuh sections

Takal Kuh is situated 55 km northwest of Ashkhaneh (Figure 3).



Am.= Amand Ash.= Ashkhaneh	Bo.= Bojnord Go.= Gorgan	Gos.= Gonbad Kavus Sh.= Shahrabad	Mar.= Maraveh tappeh Tak.= Takal Kuh

Figure 3. Geographical names and their positions, location of measured section is shown bold.

Takal Kuh section 1 is located at 37° 43′ N and 56° 10′ E; Takal Kuh section 2 is located 37° 43′ N and 56° 7′ E about 5 km west of section 1. The lithology in both sections is very similar; with exception of some minor lateral changes.

At Takal Kuh section 1, the Sarcheshmeh Formation has a thickness of 1150 m. and rests conformably on the Tirgan Formation. The lowermost part of the Sarcheshmeh Formation consists mostly of grey marly limestone and a few shaly limestones. The presence of *Barremites* cf. *difficilis*, *Heteroceras* cf. *colchicus*, *H.* sp. 1, *Imerites sparsicostatus*, *Martelites securiformis*, *M.* cf. *tenuicostatus*, *M.* cf. *tinae*, *M.* sp. 1, *M.* sp. 2, *Paraimerites* sp., *Argvethites* sp., *Toxoceratoides* sp., *Turkmeniceras* cf. *tumidum* and *T. multicostatum* in these beds indicates a Late Barremian age.

The first appearance of *Deshayesites* is regarded as the base of the Aptian stage (Hoedemaeker & Rawson 2000); it occurs here in sample 24 of section 1 (Figure 4).

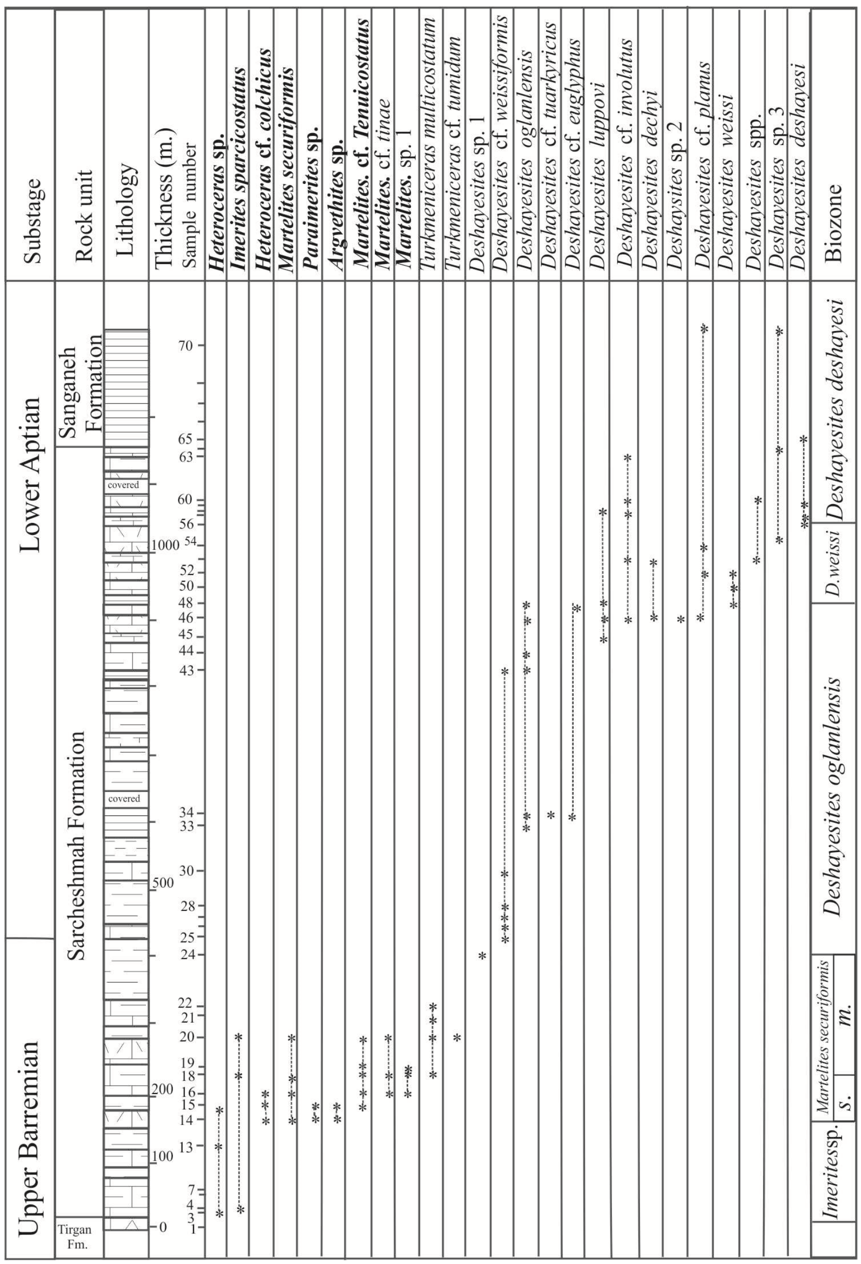


Figure 4. Ammonite range chart of the Sarcheshmeh and Sanganeh Formations in the Takal Kuh section (1), s.= *securiformis* Subzone, m.= *multicostatum* Subzone (Deshayesitidae Family discussed in Raisossadat, 2004).

Thin to medium-bedded shaly limestone, marl and marly limestone are predominant in the middle and upper part of the section. A few sandy limestone beds are also intercalated. The uppermost 100 m of the formation consist of grey laminated shales with light grey to yellowish grey, medium-bedded, sandy fossiliferous limestone intercalations. Following ammonitesare present:
Deshayesites cf. *tuarkyricus*, *D. oglanlensis*, *Pedioceras* sp., *Ancyloceras* cf. *manteli*, *Deshayesites weissiformis*, *D.* cf. *euglyphus*, *D. luppovi*, *D.* cf. *involutus*, *D.* cf. *dechyi*, *D.* cf. *planus*, *Phylloceras* sp., *Phyllopachyceras* sp., *Deshayesites deshayesi*, *D. weissi*, *D.* sp. 2, *D.* sp. 3, *Melchiorites* aff. *melchioris*, *Aconeceras haugi*, *Cheloniceras* (*C.*) sp., *Deshayesites* cf. *consobrinoides*, *D.* cf. *multicostatus, Eogaudryceras* (*Eogaudryceras*) sp. and *Australiceras* sp., Cymatoceratidae (Nautiloidea) also ocur. These indicate an Early Aptian age.

Other macrofaunas, such as echinoderms, brachiopods and pelecypods, are present in some layers. Bioturbation, which may reflect echinoderm and pelecypod activity, is seen in the marls and marly limestones.

Takal Kuh section 2 is about 4 kilometres west of section (1). The lithology is very similar to that of section (1), with minor lateral changes in some beds (Figure 5).

Sarcheshmeh Formation (1220 m.): In the first 700 metres of the section the following ammonites are found: *Argvethites* sp., *Martelites securiformi*s, *M.* cf. *tinae*, *M.* cf. *tenuicostatus*, *M.* sp. 1, *M.* sp. 2, *Deshayesites luppovi, D. oglanlensis*, *D.* cf. *tuarkyricus*, *D.* cf. *weissiformis*, *Heteroceras* cf. *colchicus*, *Turkmeniceras multicostatum* and *T.* cf. *tumidum*, which indicate a Late Barremian-Early Aptian age. The base of the Aptian is set at the first appearance of *Deshayesites* in sample number 17.

The upper part of the section consists of 300 metres of grey and dark grey marl and marly limestone alternations with fossiliferous limestone intercalations. These layers contain the following ammonites; *Deshayesites* cf. *euglyphus*, *D. luppovi*, *D. oglanlensis*, *D.* cf. *planus*, *D. weissi*, *D.* cf. *weissiformis* and *Pedioceras* sp.

Australiceras sp., *Deshayesites* cf. *consobrinoides*, *D.* cf. *dechyi*, *D. deshayesi*, *D.* cf. *multicostatus*, *D. weissi*, *E.* (*Eogaudryceras*) sp., *Cheloniceras* sp. and Cymatoceratidae (Nautiloidea) occur in the last 200 metres. The ammonites indicate a Late Barremian-Early Aptian age.

Amand section
This section is located about 18 km east of the Takal Kuh section 1 (Figure 3). It is near to the Amand road and extends to Amand village. The base of the section is at 37º 47′ N and 56º 20′ E. Lithologically this section is similar to the Takal Kuh sections.

The Sarcheshmeh Formation has a thickness of 1110 m. The lower contact of the formation with the underlying Tirgan Formation is faulted. The lowermost part of the section consists of an alternation of marly limestones and shaly limestones, and is devoid of ammonites. The thickness of this part is about 200 m. The next 150 m are similar but contain a few thin-bedded limestones. Ammonites are mostly found in the marly limestones and include *Martelites* cf. *tenuicostatus*, *M.* cf. *tinae*, *M.* sp. 1, *M.* sp. 2 and *Heteroceras* cf. *colchicus* indicating a Late Barremian age. This is followed by an alternation of shales and shaly limestones with a few marly beds. These layers contain *Barremites* cf. *difficilis*, *Martelites securiformis*, *M.* cf. *tenuicostatus*, *M.* cf. *tinae*, *Turkmeniceras multicostatum*, *T.* cf. *tumidum*, *Deshayesites* cf. *euglyphus* and *D. oglanlensis*. The first appearance of *Deshayesites* in sample 13 (Figure 6) indicates the base of the Aptian, as noted above.The upper part of the section consists of an alternation of shaly limestone, marly limestone, shale and marl, occasional with thin-bedded limestones. The number of shale beds decreases and that of marly beds increase in the uppermost part of the formation in which there are also sandy and fossiliferous limestone intercalations. The highest fossiliferous limestone marks the top of the formation. *Deshayesites* cf. *weissiformis*, *D. luppovi*, *D. dechyi*, *D.* cf. *involutus*, *D. weissi*, *D.* cf. *planus*, *D. deshayesi*, *D.* cf. *consobrinoides* and Cymatoceratidae are recorded from this level.

Based on the recorded ammonites a Late Barremian to Early Aptian age is suggested.

Systematic Description

Order Ammonoidea Zittel, 1884
Suborder Ancyloceratina Wiedmann, 1966
Superfamily Ancylocerataceae Gill 1871
Family Heterocetidae Hyatt 1900

Delanoy (1997) has studied the Heteroceratidae of south-east France in detail. His division into genera shows some differences with Wrights's (1996) classification. Here I follow Delanoy's classification, in which differentiation at generic and sub-generic level is based on the presence or absence of tubercles (a major character in classification of some other heteromorph groups, too) and the nature of the coiling.

Delanoy (1997) put the type species of *Colchidites* (*C. colchicus*) in *Heteroceras*. Therefore he treated *Colchidites* as an invalid genus and distributed its species between *Heteroceras* and *Martelites*. He noted that the transition from *Heteroceras* to *Martelites* is marked by the development of a planispiral stage between helix and shaft/ hook.

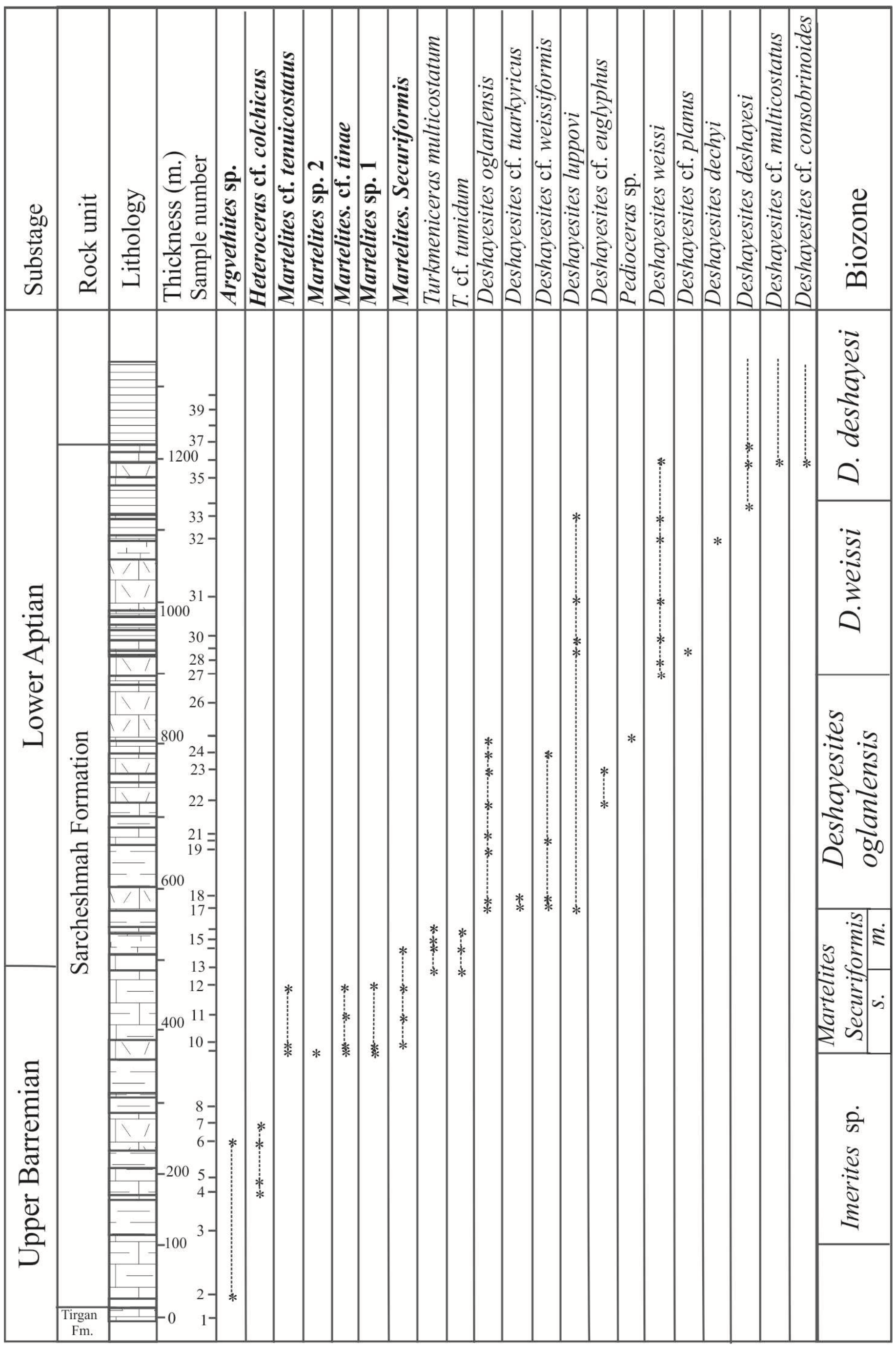


Figure 5. Ammonite range chart of the Sarcheshmeh and Sanganeh Formations in the Takal Kuh section (2), s.= *securiformis* SubZone, m.= *multicostatum* Subzone (Deshayesitidae Family discussed in Raisossadat, 2004).

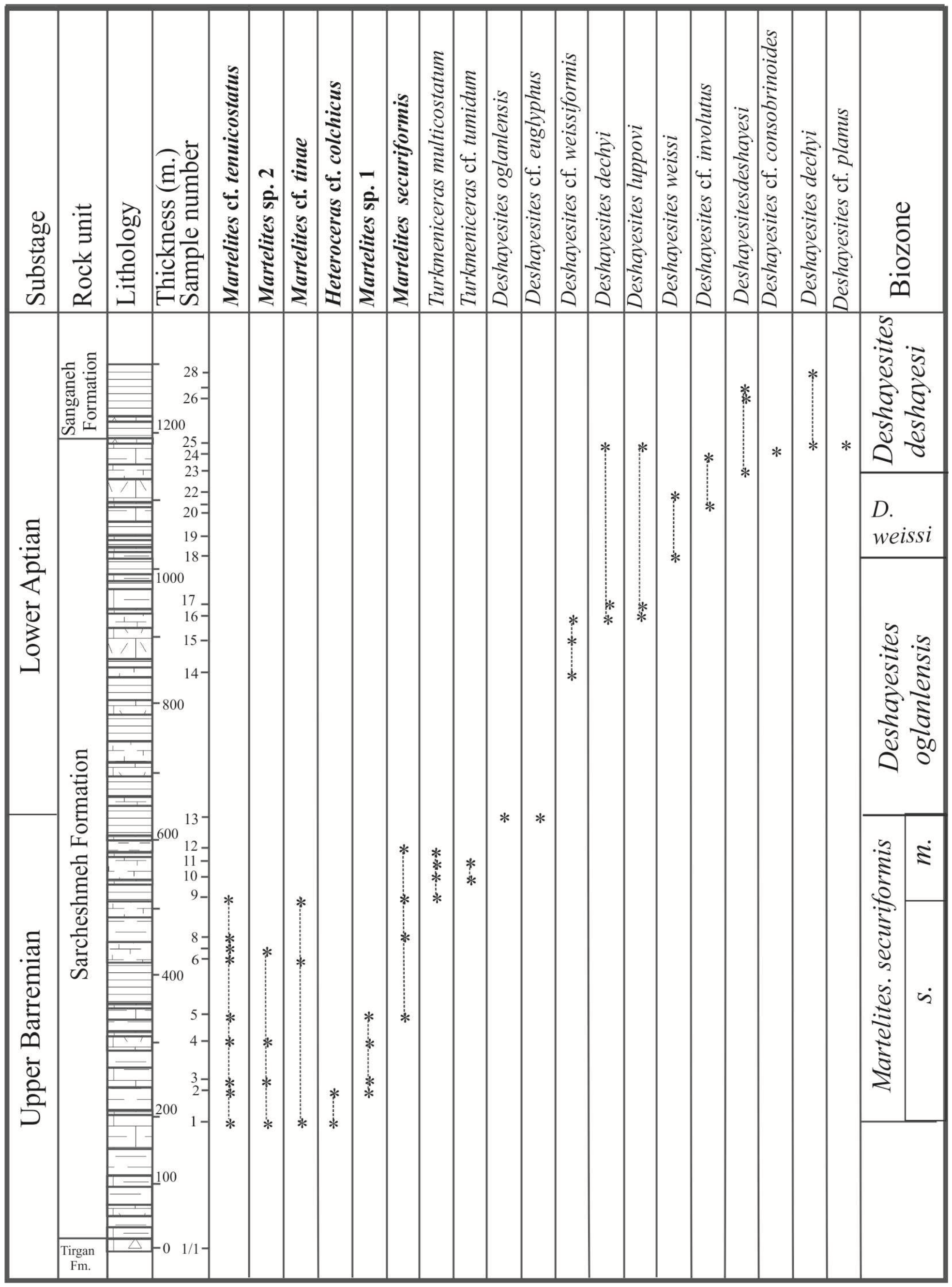


Figure 6. Ammonite range chart of the Sarcheshmeh Formation in the Amand section, s.= *securiformis* Subzone, m.= *multicostatum* Subzone (Deshayesitidae Family discussed in Raisossadat, 2004).

Hence forms in which the helical initial stage passes immediately into a straight or slightly curved shaft, followed by a terminal hook, belong to *Heteroceras*, while those in which the helical stage is followed by one or more planispiral whorls and then a terminal hook belong to *Martelites*. *Paraimerites* differs from *Martelites* (= *Colchidites* pars) by having a pair of tubercles on the venter. Delanoy also suggested that *Eristavia* is a synonym of *Imerites* and should no longer be used.The transition from heteromorph to normally coiled ammonoids has been convincingly traced in a phylogenetic series linking the Barremian Heteroceratidae with Aptian Deshayesitidae (Figure 7). The similarity of ornament, cross section of the whorls and most importantly the development of the suture line during ontogeny of the shell in the last *Martelites* and the first *Turkmeniceras* (Deshayesitidae) confirms that they are related (Wiedmann, 1969; Bogdanova, 1971; Mikhailova, 1979, 1982; Bogdanova & Mikhailova, 1999, 2004; Delanoy, 1997).

The family shows an almost worldwide distribution and is limited to the Upper Barremian. Although the major centre of occurrence is in the Caucasus and Turkmenistan (Kakabadze, 1971, 1975; Kotetishvili, 1988, Kotetishvili *et al.*, 2000), heteroceratids are also recorded from France (Busnardo, 1984; Delanoy, 1997; Hancock, 1991), and from more northerly latitudes in England (Rawson, 1995), Canada (Jeletzky, 1976) and Japan (Obata *et al.*, 1976) as well from the southern hemisphere in Zululand (Klinger *et al.*, 1984) and Argentina (Blasco *et al.*, 1980; Aguirre-Urreta and Klinger 1986). Their widespread distribution makes it possible to correlate deposits in widely scattered areas and representative species are used as index fossils in the Upper Barremian ammonite biozonation (Hoedemaeker *et al.*, 1993, 1995; Kakabadze, 1971, 1983; Tovbina, 1963).

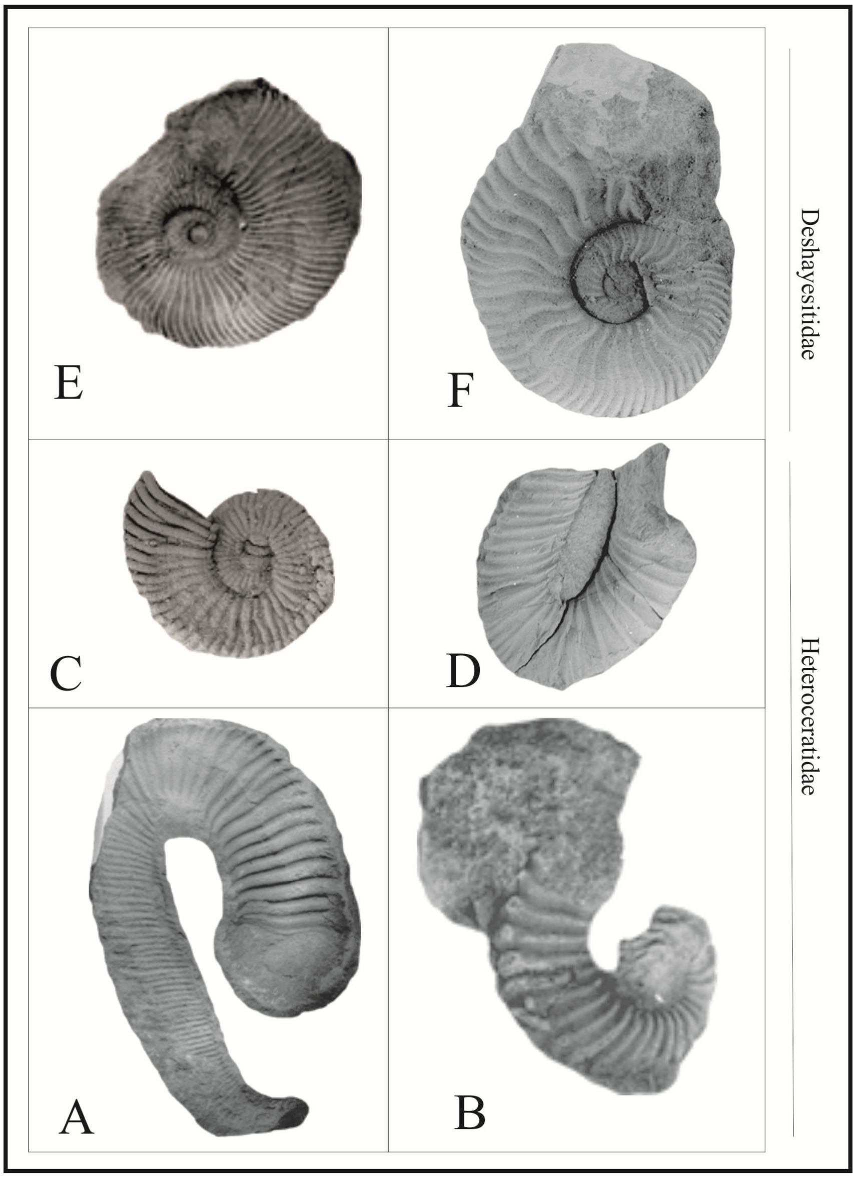


Figure 7. Changes of shell shape in the Heteroceratidae and Deshayesitidae, A) *Heteroceras* cf. *colchicus*, TAK 7/1; B) *Paraimerites* sp., Tk 14-15/3; C) *Martelites* cf. *tinae*, Tk 18-20; D) *Argvethites* sp., Tk 14-15/ 15; E) *Turkmeniceras multicostatum*, Am 10/1; F) *Deshayesites luppovi*, Tk 46/21. All figures in natural size, B-x2.

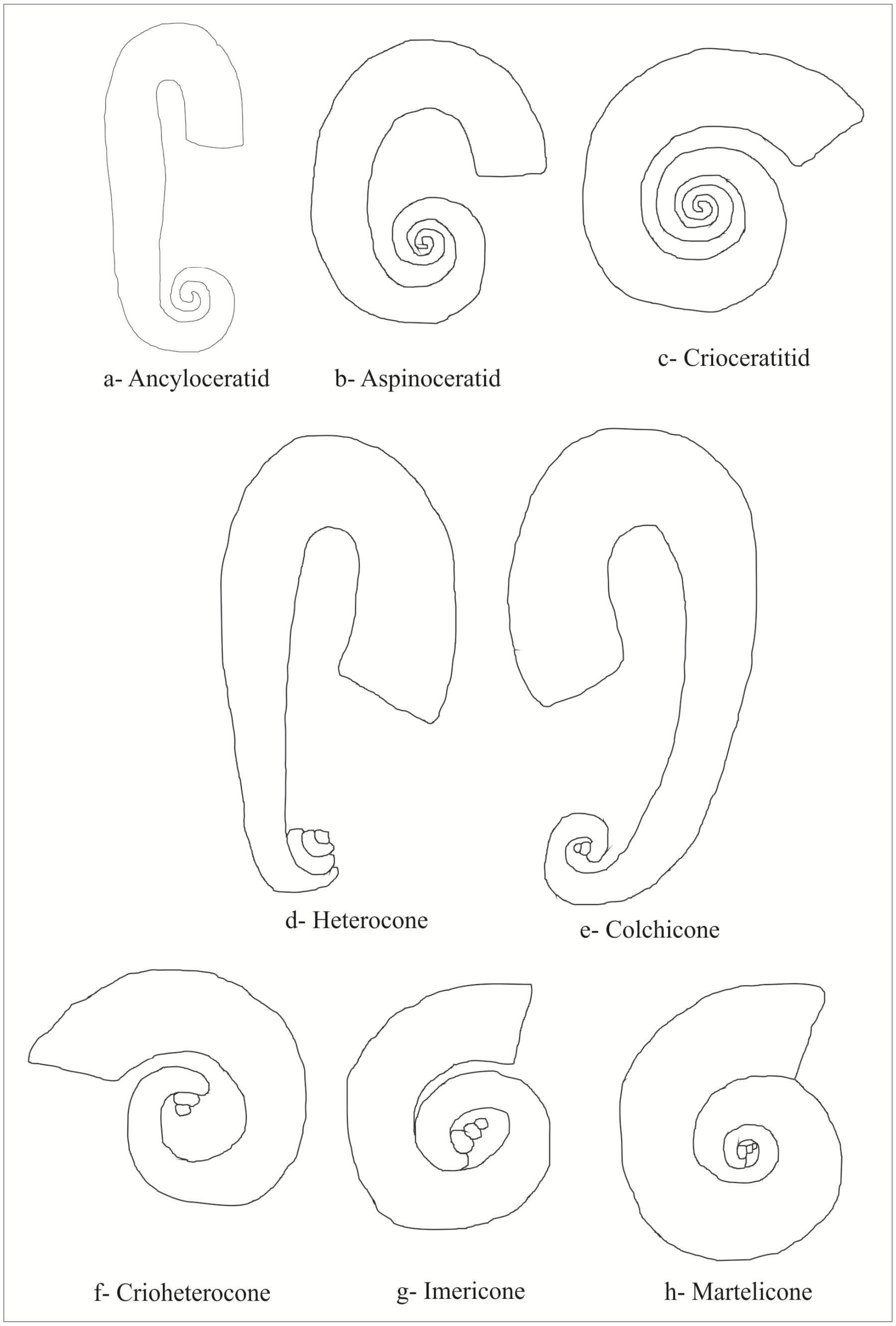


Figure 8. Coiling type of heteromorphs (redrawn from Casey, 1960 and Delanoy, 1997).

Genus *Heteroceras* d'Orbigny 1849

Type species: *Turrilites emericianus* d'Orbigny 1842, by subsequent designation (Meek, 1876, p. 477).

Generic characters: Small to large heteromorph in which the initial whorls are helically coiled with the whorls closely spaced or touching. The remainder of the shell is gently curved (heterocone) to loosely coiled (colchicone) in a more or less plane spiral and has a final hook (Figure 8). The ribs are strong on the umbilical area, and narrow over the ventral region. They are asymmetrical or sinusoidal on the helical whorls.

The mean ribs become radial and straight on the planispiral whorls. Most are single, but some bifurcate on the ventral area. Peristome sinusoidal. Suture ancyloceratid, with four lobes including an asymmetric, trifid lateral lobe.

Discussion: Intraspecific and intrageneric variabilities and their implications for the systematics of Cretaceous heteromorph ammonites were fully discussed by Kakabadze (2004). The lack of tubercles distinguishes *Heteroceras* from *Argvethites*, *Acrioceras* and *Lytocrioceras*, when initial whorls are missing. Kakabadze and Thieuloy (1991) believed that there are some intermediate species between *Heteroceras* and *Colchidites* and it is difficult to determine their taxonomic position. The presence of these intermediate forms caused Delanoy (1997) to include the groups of *C. intermedius* and *C. colchicus* in the genus *Heteroceras*.

Occurrence: *Heteroceras* is reported from the Upper Barremian, *giraudi* zone. *Heteroceras* has been reported from numerous geographic localities such as south-east France (d'Orbigny, 1842, Delanoy, 1992, 1997; Baudouin *et al*., 2012; Busnardo *et al*., 2013), Spain (Company *et al*., 1992), Bulgaria (Nikolov, 1964; Dimitrova, 1967; Ivanov & Idakieva 2013.), Hungaria (Fülop, 1964), Georgia (Rouchadzé, 1933, Kotetishvili, 1970; Kakabadze, 1971, 1975), Colombia (Royo Y Gomez, 1945; Etayo-Serna, 1968; Kakabadze & Thieuloy, 1991; Kakabadze *et al*., 2004), California (Murphy, 1975), Canada (Jeletzky, 1970), Japan (Obata & Ogawa, 1976; Matsukawa, 1983; Obata *et al*., 1984), South Africa (Zululand, Klinger, 1976; Klinger *et al*., 1984; Aguirre Urreta & Klinger, 1986) and Argentina (Aguirre Urreta & Klinger, 1986). In the Boreal Realm it is rare, but a small specimen of the genus has been reported from north-east England (Speeton) (Rawson, 1995).

Age: Late Barremian (Delanoy, 1997, p. 41; Klinger *et al*., 1984).

Heteroceras cf. *colchicus* (Djanelidze 1926)

Figure 9, A-C

cf. 1926 *Colchidites colchicus* Djanelidze, p. 265, pl. 1, fig. 1.

cf. 1971 *Colchidites colchicus* Djanelidze; Kakabadze, p. 54, pl. 6, figs. 1, 2.

cf. 1997 *Colchidites* sp. ex gr. *C. colchicus* Djanelidze; Immel *et al*., p. 174, pl. 8, fig. 5.

cf. 1997*Colchidites* aff. *colchicus* Djanelidze; Dealony, p. 85, pl. 16, fig. 2, text fig. 53.

cf. 2011 *Heteroceras* cf. *colchicus* (Djanelidze); Raisossadat and Shokri, fig. 10D

Holotype: Georgian Institute of Academy of Science, No 1/ 10482, figured by Djanelidze, collected from Nikotsminda, western Georgia.

Material: 30 specimens [TK 14/ 1-3; TK 14-15/ 2-6, 9, 10; TK 15/ 1-3; TK 16; TAK 4/ 1-4; TAK 5/ 1; TAK 6/ 1-9; TAK 7/ 1-2; Am 1/ 3].

Diagnosis: An increase in the size of the ribs and the bifurcate pattern in the second part of the shaft and hook are characteristic for the species.

Description: Most specimens are broken pieces or external moulds, mainly of shafts and hooks, of small to medium size. The most complete is 76 mm long, while the type specimen is 155 mm long (Kakabadze, 1971). The helical stage probably embraces at least 3 whorls. Whorl section sub-rounded to sub-rectangular. Ribs are fine, curved and rather dense on the helical part, then become straight or a little bent and rounded, but still fine and dense, on the shaft. On the hook they become stronger; the secondaries branch or are intercalated on the upper third of the flank. One specimen shows a final stage in which the ribs become single again.

Discussion: Specimens TK 15 compare with material from the Koppeh Dagh in the Munich collections that were described by Immel *et al*. (1997) as *Colchidites* cf. *colchicus*. Following (Delanoy, 1997) *C. colchicus* is placed in *Heteroceras*. However the specimens are also similar to *H. baylei* but differ in the early whorls. *Heteroceras* cf *colchicus* is known with colchicone coiling, and simple, more or less convex, intermediary ribs that appear in the upper third of the flank. While *Heteroceras baylei* has a heterocone form, and ornamentation including generally bifurcated ribs on the helix, single ribs of the shaft and more more strong ribs on the return of the shaft.

Occurrence: Caucasus (Kakabadze, 1971) and Iran.

Distribution: Lower part of the Sarcheshmeh Formation in the Takal Kuh and Amand sections.

Heteroceras spp.

Figure 9, D

Material: 3 specimens [TK 3/ 4; TK 13; TK 14-15/ 1].

Description: The specimens are impressions of shafts and a fragment of a hook. Shafts straight, with fine and dense ribs, more or less straight.

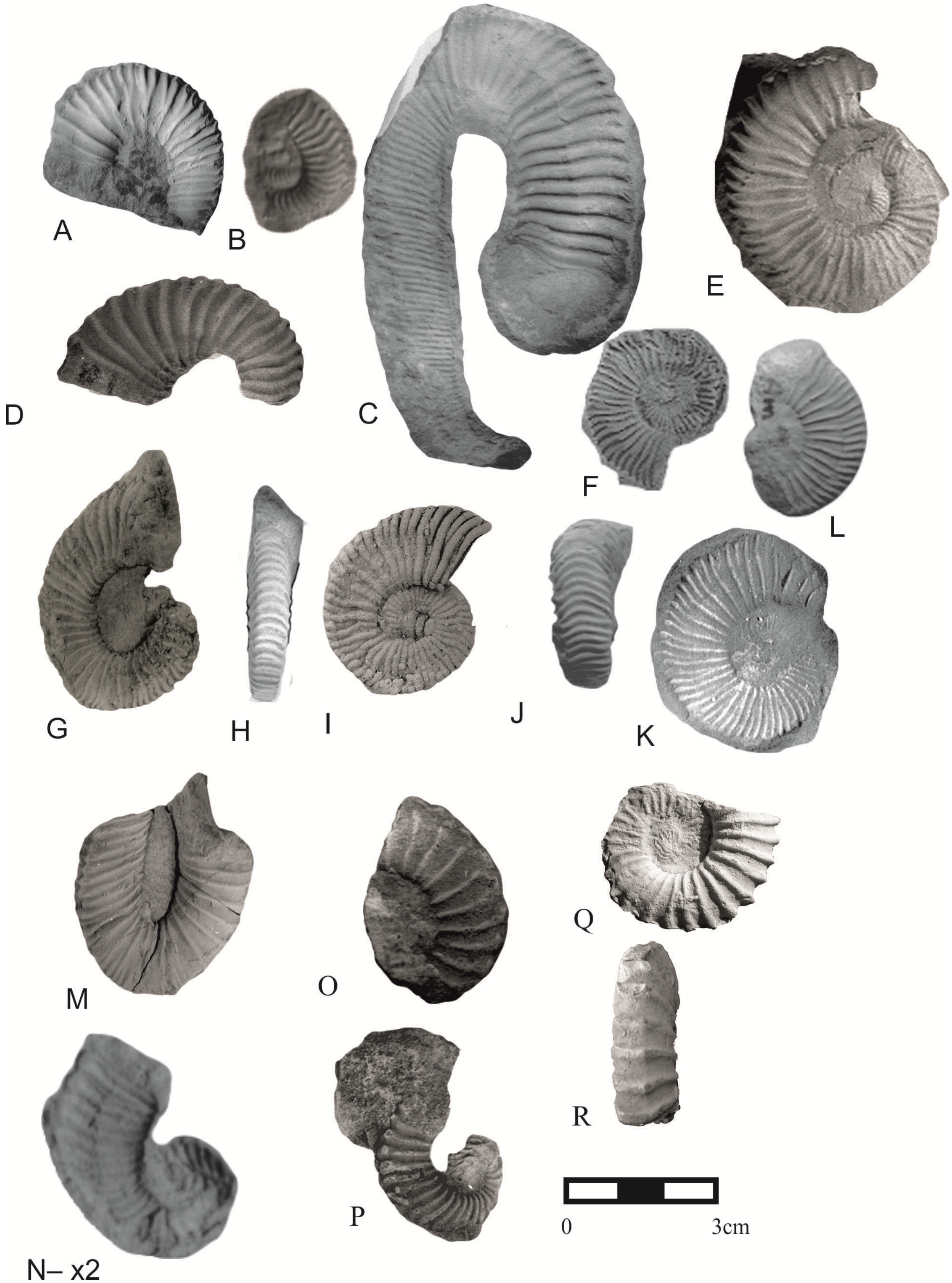


Figure 9- A-C- *Heteroceras* cf. *colchicus*, Sarcheshmeh Formation, Upper Barremian, Takal Kuh section (2), Sample no. TAK 7/ 1 & TAK 6/ 1; Takal Kuh section (1), Sample no. TK 14-15/ 6; D- *Heteroceras* sp., Sarcheshmeh Formation, Upper Barremian, Takal Kuh section (1), Sample no. TK 14-15/ 1.; E-F- *Martelites* cf. *tenuicostatus*, Sarcheshmeh Formation, Upper Barremian, Takal Kuh section

(1), Sample no. TK 18/ 4; Amand section, sample no. Am 2/ 2; G-H- *Martelites securiformis*, Sarcheshmeh Formation, Upper Barremian, Takal Kuh section (2), Sample no. TAK 12/ 4; Takal Kuh section (2), Sample no. TAK 12/ 8; I-J- *Martelites* cf. *tinae*, Sarcheshmeh Formation, Upper Barremian, Takal Kuh section (1), Sample no. TK 18-20/; Amand section, Sample no. Am 1/ 6; K- *Martelites* sp. 1, Sarcheshmeh Formation, Upper Barremian, Takal Kuh section (2), Sample no. TAK 9/ 2; L- *Martelites* sp. 2, Sarcheshmeh Formation, Upper Barremian, Amand section, Sample no. Am 1/ 4; M-N- *Argvethites* sp., Sarcheshmeh Formation, Upper Barremian, Takal Kuh section (1), Sample no. TK 14-15/ 15; Takal Kuh section (2), TAK 6/ 10; O- *Imerites sparcicostatus*, Sarcheshmeh Formation, Upper Barremian, Takal Kuh section (1), Sample no. TK 4/ 1; P- *Paraimerites* sp., Sarcheshmeh Formation, Upper Barremian, Takal Kuh section (1), Sample no. TK 14-15/ 3; Q-R- *Imerites giraudi*, Sarcheshmeh Formation, Upper Barremian, Ostad section, Sample no. Unit 2-1.

TK 14-15/ 1 is an incomplete hook; ribs straight or slightly bent, primary ribs start from umbilical area, some pass into secondary ribs on the other side of the flank, a few secondary ribs are intercalated between primaries.

Discussion: Lack of well preserved shells makes accurate identification impossible, but these specimens differ from other *Heteroceras* in having thicker, less dense ribs and fewer bifurcating ribs. Specimen TK 14-15/ 1 (Pl. 2, Fig. 4) is similar to a specimen figured by Delanoy (1997, p. 51-53, pl. 12, fig. 2, pl. 17, fig. 5, pl. 27, fig. 1) as *Heteroceras* cf. *emerici*, but specimens TK 3 and TK 13 can only be questionably attributed to *Heteroceras*.

Distribution: Lower part of the Sarcheshmeh Formation in the Takal Kuh sections.

Genus *Martelites* Conte 1989

Type species: *Martelites marteli* Conte, 1989, by original designation.

Generic characters: Martelicone (Figure 8). Initial part is turricone, with the whorls in contact and coiled dextrally or sinistrally. Whorl section sub-quadratee to sub-circular, oval or elliptical. Ribs regularly spaced, radial, sinusoidal, convex or concave, alternately simple and bifurcate, thickest across the venter. On the body chamber the ribs are initially similar to those on the phragmocone then become simple. Peristome is sinusoidal. Suture line ancyloceratid (Delanoy, 1997).

Discussion: The genus differs from *Heteroceras* by having one or more planispiral whorls. There is a trend for the number of whorls in the planispiral stage to increase as the helix gradually reduces (Mikhailova, 1979). Djanelidzé (1926) believed that the ancestor of *Heteroceras* d'Orbigny is *Martelites* and there are some intermediate forms between *Heteroceras* and the group of *M. intermedius*.

Occurrence: *Martelites* is recorded from Turkmenistan, the Caucasus, southeast France, Georgia, South Africa, Argentina Cuba, Colombia, Zululand and Patagonia. (Klinger *et al*., 1984; Aguirre-Urreta and Klinger 1986; Conte, 1989; Delanoy, 1997, Wright *et al*., 1996; Kakabadze and Hoedemaeker 2004; Baudouin *et al*., 2012) and Iran.

Age: Late Barremian (Conte, 1989, p. 43; Delanoy, 1997, p. 126).

Martelites cf. *tenuicostatus* (Kakabadze 1971)

Figure 9, E-F

cf. 1971 *Colchidites tenuicostatus* Kakabadze, p. 82, pl. 17, fig. 2; pl. 19, fig. 4.

cf. 1997 *Colchidites tenuicostatus* Kakabadze; Immel et al., p. 174, pl. 8, fig. 8.

Material: 67 specimens [TK 15/ 4; TK 16/ 1; TK 18/ 1-8, 11; TK 18-20/ 4-5; TK 19/ 2, 4; TAK 9/ 3, 6, 7, 9; TAK 10/ 3, 8, 10, 13; TAK 12/ 2, 3, 9, 16-18; Am 1/ 1, 5; Am 2/ 2; Am 3/ 1, 3, 11, 12, 14; Am 4/ 1, 3-6, 8, 10; Am 5/ 1, 2, 5, 7-15; Am 6/ 1, 3; Am 7/ 1-4, 6, 7; Am 8/ 1, 5; Am 9/ 15, 19, 21].

Holotype: Georgian Institute of Academy of Science, No 255/ 76, figured by Rouchadze, collected from Betlevi, western Georgia.

Description: Some specimens are a little crushed. The initial helix is very small, whorls in contact in the planispiral stage. Ribs divisible into primaries which begin at the umbilical margin and secondaries which alternate more or less regularly with primaries; secondaries originate from the middle to one third of the way up the outer flank. TK 18/ 4 has 34 primary ribs at the umbilical margin at 40 mm diameter.

Discussion: The ribs of *M. tenuicostatus* are more curved and more dense than those of *M. securiformis*.

Occurrence: Caucasus (Kakabadze, 1971), Koppeh Dagh (Immel *et al*., 1997).

Distribution: Lower part of the Sarcheshmeh Formation in the Takal Kuh and Amand sections.

Martelites securiformis (Simonovich, Bastevich & Sorokin 1875)

Figure 9, G-H

1875 *Colchidites securiformis* Simonovich, Bastevich and Sorokin, p. 166, pl. 4, fig. 3a-b.

1971 *Colchidites securiformis* Simonovich, Bastevich and Sorokin; Kakabadze, p. 81, pl. 17, fig. 4.
1997 *Colchidites securiformis* Simonovich, Bastevich and Sorokin; Immel et al., p. 172, pl. 8, fig. 9.
2011 *Colchidites securiformis* (Simonovich, Bastevich and Sorokin); Raisossadat and Shokri, fig. 10f

Holotype: Georgian Institute of Academy of Science, No 36/ 1236, figured by Rouchadze, collected from Kutaisy, western Georgia.
Material: 65 specimens [TK 14-15/ 7, 8; TK 16-18/ 1, 2, 4-6, 8, 10, 14, 16; TK 18-20/ 1-3, 7-10; TK 20/ 2, 3, 5,15, 16; TAK 10/ 1, 2, 4-6, 9, 12, 15, 16, 17; TAK 11/ 1-10, 13-15; TAK 12/ 4, 6-10, 12, 15; TAK 14/ 3?, 5?, 8?; Am 5/ 6, 16, 17; Am 8/ 2, 3; Am 12/ 2, 4].
Description: Whorls are in contact: preserved whorls start at about 10 mm diameter and adjacent early whorls are helical, but poorly preserved. Planispiral whorl section rounded to sub-rectangular, venter seems flattened, but does not have a distinct margin. Primaries are straight or a little sinusoidal. They start from the umbilical area, then bifurcate in mid to upper third of the flank; some secondaries not attached to a primary. 40 secondary ribs at 17 mm diameter on the venter.
Discussion: Kakabadze (1971) reported that the first helical whorl in *M. securiformis* is loose and not in contact but this character cannot be examined easily in the Koppeh Dagh examples. The ribs bend forward less in *M. securiformis* than in *M. tenuicostatus*.
Occurrence: Georgia (Kakabadze, 1971) and Iran (Immel *et al*., 1997).
Distribution: Lower part of the Sarcheshmeh Formation in the Takal Kuh and Amand sections.

Martelites cf. *tinae* (Eristavi) 1955
Figure 9, I-J

cf. 1955 *Colchidites tinae* Eristavi, p. 121, pl. 4, fig. 11.
cf. 1971 *Colchidites tinae* Eristavi; Kakabadze, p. 52, pl. 4, fig. 2.
cf. 1997 *Colchidites tinae* Eristavi; Immel et al., p. 174, pl. 8, fig. 7, 10.

Material: 26 specimens [TK 16-18/ 17, 19; TK 18-20/ pocket 2; TK 20/ 12, 13, pocket 2; TAK 9/ 5; TAK 10/ 7, 14; TAK 11/ 11, 12; TAK 12/ 11; Am 1/ 6; Am 6/ 2, 4; Am 7/ 5; Am 9/ 14-16].
Holotype: Georgian Institute of Academy of Science, No 370/ 45, figured by Eristavi, collected from Niktosminda, western Georgia.
Description: Helical part is relatively clear. Whorl section round to sub-rectangular, venter seems flattened, but does not have a distinct margin. Primaries are slightly curved; they start from the umbilical area, then bifurcate in mid to upper third of the flank; some secondaries are not attached to the primary.
Discussion: *M. tinae* has a well-developed helix relative to other described species. The Iranian specimens show this character and are therefore compared with *M. tinae*.
Occurrence: Georgia (Kakabadze, 1971) and Iran (Immel *et al*., 1997).
Distribution: Lower part of the Sarcheshmeh Formation in the Takal Kuh and Amand sections.

Martelites sp. 1
Figure 9, K

Material: 17 specimens [TK 16-18/ 7, 9, 11-13; TK 18/ 9, 10; TK 19/ 1, 3, 5; TAK 9/ 1, 2; TAK 10/11; TAK 12/ 1, 5; Am 2/ 1, 4; Am 3/ 2, 4, 7, 8; Am 4/ 2; Am 5/ 2, 4].
Description: Early whorls are not too clear but planispiral coiling more or less developed. Whorls section sub-quadrate. Primary ribs start from upper part of the umbilical border at a feeble tubercle. Secondaries alternate with primaries; most secondaries are free, commencing on the upper third to quarter of the flank.
Discussion: This species is separated from other *Martelites* described here by having straight ribs and more secondary ribs are intercalated than in other Koppeh Dagh forms. The nearest described form is *Martelites ratshensis* Rouchadze (Kakabadze, 1971, pl. 12, fig. 5, pl. 14, figs. 2, 4, 5).
Distribution: Lower part of the Sarcheshmeh Formation in Takal Kuh and Amand sections.

Martelites sp. 2
Figure 9, L

Material: 11 specimens [TAK 9/ 4, 8, 10, 11; Am 1/ 2, 4; Am 3/ 5, 9, 10; Am 4/ 7, 9].
Description: Early whorls are not clear but planispiral coils well developed. Ribs a little sinusoidal over the flanks and curve on the venter; secondaries either bifurcate or are intercalated or the upper third of the flanks.

Discussion: The nearest described form is *Martelites ellissoae* Kakabadze (1971, pl. 5, fig. 3) which, like the Koppeh Dagh forms, has more strongly curve ribs than other *Martelites*.
Distribution: Lower part of the Sarcheshmeh Formation in Takal Kuh and Amand sections.

Genus *Argvethites* Rouchadze 1933

Type Species: *Heteroceras* (*Argvethites*) *minor* Rouchadze 1933, by original designation.
Generic characters: A small form in which the turricone is attached to a straight shaft, which terminates in a hook. Ventro-lateral tubercles appear on the penultimate or last whorl of the turricone or the base of the shaft and become gradually stronger until the final part of the hook, where they usually disappear. In some cases, they continue to the final part of the hook. The ribs are sinusoidal on the turricone becoming weakly curved on the first part of the hook. Trifurcate ribs exist between bifurcate ribs. Two types of bifurcate ribs are recognised; either the bifurcation point is located at mid-flank and the two secondary ribs cross the venter or bifurcation starts at the level of the ventral tubercles (Wright *et al*., 1996; Delanoy, 1997).
Discussion: *Argvethites* differs from *Heteroceras* by having paired ventral tubercles. According to Kakabadze (1975) a siphonal furrow on the shaft occurs mainly in *Argvethites*. However this character is known from other unrelated heteromorph groups such as *Toxoceratoides* (Aguirre-Urreta and Klinger 1986). Vermeulen (2004, 2005, 2006) believed that there was an evolutionary trend from *Acrioceras* to *Dissimilites* Sarkar, 1955, followed by *Toxoceratoides* and *Argvethites*.
Occurrence: The genus is recorded from *Giraudi* and *Sarasini* zones from Caucasus (Rouchadze, 1933; Kotetshivili, 1970; Kakabadze, 1975) and south-east France (Delanoy, 1992, 1997), Spain (Braga *et al*., 1982) and Czechoslovakia (Vasicek, 1972) and Iran.
Age: Late Barremian (Delanoy, 1997, p. 167).

Argvethites sp.
Figure 9, M-N

Material: TK 14-15/ 14, 15; TK 15/ pocket 2; TAK 2/ 1; TAK 6/10.
Description: Four broken and nearly compressed specimens are in hand. Early coiling is not clear; ribs are straight, radiate and a little bent, bifurcating in curving area and second part of the shaft hook, with two tubercle rows in ventral area.
Discussion: The specimens are accompanied by *Heteroceras* and ~~are~~ differ~~ed~~ by having two rows of tubercles in the ventral region. The incomplete nature of the material makes specific identification uncertain.
Distribution: Lower part of the Sarcheshmeh Formation in the Takal Kuh sections.

Genus *Imerites* Rouchadze 1933

Type Species: *Imerites giraudi* Kilian 1888, by original designation.
Generic characters: Small to medium size, imericone or crioheterocone shell (Figure 8). The initial part of the shell is coiled in a dextral helical spiral; ornamented with simple or bifurcate ribs, starting from the umbilical area. Their relief is more or less reduced over the ventral area, and strong on the flanks; they are generally straight and bituberculate. The remainder of the shell bears simple or fibulate ribs with lateral and ventro-lateral tubercles. Suture lines ancyloceratid (Delanoy, 1997).
Discussion: *Imerites* differs from *Paraimerites* by having lateral tubercles, but this character is not clear in some stages of growth. *Imerites* and *Eristavia* are similar in type of coiling and ventral tubercles but *Eristavia* has some ribs that are limited to the dorsal margin (Kakabadze, 1971). Wright *et al.* (1996) put *Paraimerites* and *Eristavia* as synonyms of *Imerites*. In this paper *Eristavia* is regarded as a synonym of *Imerites*, but *Paraimerites* is retained as a distinct genus because it lacks the lateral tubercles found in *Imerites*. Phylogenetically, *Imerites* and *Eristavia* represent two parallel lineages that probably originated from the *Argvethites* (Kakabadze, 2004). Sarkar (1955) placed *Imerites* in the Hemihoplitidae. But Wright *et al.* (1996) put this genus in the family Heteroceratidae as it had been assigned to this family for a long time. Bert *et al.* (2009) suggested *Imerites* directly derives from the genus *Pseudoshasticrioceras* and again regarded *Imerites* as a representative of the family Hemihoplitidae Spath in the subfamily Gassendiceratinae. The authors believes this subject still needs more attention. In *Imerites*, as in other heteromorphs, there are variations due to dimorphism and growth stage, and also intraspecific variation as it is mentioned by Kakabadze (2004) and Bert *et al.* (2011).

Occurrence: Species of the genus are characteristic of the base of the *Giraudi* zone. The genus is distributed in Mediterranean region (Wright *et al*., 1996). It has been reported from south-east France (Thomel, 1964; Delanoy, 1992, 1997), Bulgaria (Nikolov, 1964; Dimitrova, 1967) Romania (Patrulius, 1969, Patulius & Avaram, 2004), Georgia (Rouchadze, 1933; Kotetshivili, 1970; Kakabadze, 1971) and Turkmenistan (Tovbina, 1963) and Iran (Immel *et al*., 1997).

Imerites sparcicostatus Rouchadze 1933
Figure 9, O

1933 *Imerites sparcicostatus* Rouchadze, p. 253, pl. 21, fig. 1.
1970 *Imerites sparcicostatus* Rouchadze; Kotetishvili, p. 84, pl. 13, fig. 2.
1971 *Imerites sparcicostatus* Rouchadze; Kakabadze: p. 42-43, Tab. II, figs. 3-4.
Material: TK 4/ 1-8; TK 18-20/ 6.
Holotype: Georgian Institute of Academy of Science, No 447/ 1113, figured by Rouchadze, collected from Golsheva, western Georgia.
Description: Most specimens are broken and missing the early or last whorls. Whorl section sub-rectangular, the thickest part of the whorl near the venter. Ribs are straight and widely spaced in last whorls, sharp and radial, becoming thicker towards the body chamber. One row of tubercles on the ventral margin, lateral tubercles are not clear and eroded.
Discussion: The specimens closely match previously figured examples. According to Kakabadze (1971), *I. sparcicostatus* differs from *I. favrei* in having a higher helix and less compact, straighter ribs. The collected samples are attributed to *I. sparcicostatus*, because of their rib pattern and the ribbing density, which is less than in *I. favrei*.
Occurrence: Georgia (Kakabadze, 1971) and Iran.
Distribution: Lowermost part of the Sarcheshmeh Formation in the Takal Kuh section (1) at Koppeh Dagh Basin.

Genus *Paraimerites* Kakabadze 1967

Type species: *Heteroceras densecostatus* Renngarten 1926, by original designation.
Generic characters: Helically coiled at first, then open planispiral whorls. Helical whorls with simple ribs, planispiral whorls with bifurcate ribs and a ventro-lateral tubercle.
Discussion: Kakabadze (1967, 1971) reomoved the group of *Imerites densecostatus* from the genus *Imerites* and placed them in an independent genus, *Paraimerites*. The genus is separated from *Martelites* by the presence of ventro-lateral tubercles and from *Eristavia* and *Imerites* by the lack of lateral tubercles (Klinger, 1976). Delanoy (1997) considered that it is difficult to decide whether *Paraimerites* is a valid genus but used the name without discussion.
Occurrence: The genus is reported from uppermost Barremian *securiformis* subzone of the Caucasus (Kakabadze, 1971), France (Delanoy, 1997) and South Africa (Klinger, 1976; Klinger *et al*., 1984; Aguirre Urreta & Klinger, 1986) and Iran.
Age: Late Barremian (Delanoy, 1997, p. 160).

Paraimerites sp.
Figure 9, P

Material: TK 14-15/ 13, SH 9.
Description: An initial helix is following by a small open planispiral whorl. On the latter each primary rib bears a ventro-lateral tubercle, and secondary ribs are very rare.
Discussion: The material is too poor for firm identification but may be close to *P. planus* Kakabadze (1971, p. 86, pl. 20, fig. 3). Specimen SH9 has been collected from Sheykh section that is situated 80 km. south east of Takal Kuh section.
Distribution: Lower part of the Sarcheshmeh Formation in the Takal Kuh section (1).

Biostratigraphy

The Barremian stage was first defined by Coquand (1861), based on successions in southeast France. One of his cited localities, Angles (Basses-Alpes), was designated by Busnardo (1965) as 'stratotype', though the Barremian Working Group of the Subcommission on Cretaceous Stratigraphy have since suggested that the base of the Barremian should be defined in the Río Argos section of south-east Spain (Rawson, 1996). The typical Barremian ammonite faunas come from the Mediterranean Province. They have been studied extensively in recent years, especially in France (Delanoy, 1992, 1994, 1995, 1997; Vermeulen, 1996; Bert and Delanoy 2009; Bert *et al*., 2009; Bert *et al*., 2011; Baudouin *et al*., 2012; Busnardo *et al*., 2013; Bert *et al*., 2013), Alps (Lukeneder, 2012) Georgia and adjacent areas (Kakabadze, 1971, 1975, 1983; Kotetishvili, 1988; Kotetishvili *et al*., 2000), Romania (Avram, 1983), Czech Republic (Vasicek *et al*., 1983; Vasick, & Skupein, 2002), North Africa (Company *et al*., 2008) and Japan

(Matsukawa *et al*., 2007). Klein and Hoedemaeker (1999) and Hoedemaeker & Rawson (2000) reviewed the biostratigraphy [see Fig. 10] and highlighted some of the remaining problems.

Here subsequent modifications of the Upper Barremian biozonation will be discussed. Most modifications have been made during workshops of the Kilian Group (formerly the Lower Cretaceous Cephalopod Team (a working group of the Subcommission on Cretaceous Stratigraphy (SCS) of IUGS) (Hoedemaeker & Bulot, 1990; Hoedemaeker *et al*., 1993, 1995; Rawson *et al*., 1999; Hoedemaeker & Rawson, 2000; Hoedemaeker *et al*., 2003; Reboulet *et al*., 2006, 2009, 2011, 2014) (Figure 10).

Upper Barremian biozonation

Several markers have been proposed for the base of the Upper Barremian Sub-Stage. In particular, Busnardo (1984) used the first appearance of *Emericiceras* in southeast France. Later, Ancyloceras [now *Toxancyloceras*] *vandenheckii* was suggested for the basal marker in the Mediterranean region (Hoedemaeker & Bulot, 1990; Rawson, 1996) which has been accepted by most of the authors (e.g. Hoedemaeker and Rawson, 2000; Hoedemaeker *et al.*, 2003; Reboulet *et al*., 2009, 2011, 2014). *Toxancyloceras vandenheckii* is recorded from many places in Europe (Klein *et al*., 2007). However later the *Holcodiscus uhligi* Zone (Vermeulen, 2002, 2005) was adopted as the basal marker by Reboulet *et al*. (2006). However, this was soon abandoned (Reboulet *et al*., 2009)

The *Gerhardtia sartousiana* Zone is the second ammonite biozone (e.g. Hoedemaeker & Bulot, 1990; Hoedemaeker & Rawson 2000; Reboulet *et al*., 2014). The former *Hemihoplites feraudianus* Zone (Hoedemaeker & Bulot, 1990; Hoedemaeker & Rawson, 2000) was reduced to a subzone above the sartousiana Subzone (Reboulet *et al*., 2009).

Reboulet *et al*., (2009) placed the remainder of the Upper Barremian in the *Imerites giraudi* Zone, regarding the former *Martelites sarasini* and *Pseudocrioceras waagenoides* zones as subzones. But Ivanov & Idakieva (2013) preferred a subdivision of the interval into a lower *I. giraudi* Zone and an upper *Martellites sarasini* Zone, which was former proposed by Reboulet *et al*. (2006) but later abandoned. Reboulet *et al*. (2014) followed this suggestion.

The *I. giraudi* and *M. sarasini* zones have a wide palaeobiogeographic distribution in France, Spain, Bulgaria, Romania, North Caucasus, Georgia, west of Turkmenistan, and Iran (Aguirre-Urreta & Klinger 1986; Delanoy, 1995, 1997; Aguado *et al*., 1997; Ropolo *et al*., 1999; Kakabadze & Kotetishvili, 2003; Kakabadze *et al*., 2004; Klein *et al*., 2007; Ivanov & Idakieva, 2009, 2013; Zahedipour *et al*., 2014).

Upper Barremian biozonation of the Koppeh Dagh (Kopet Dagh) Basin

Bed-by-bed sampling and measurement of the three stratigraphical sections studied here provides a firm basis for a biozonation for the Upper Barremian of the Koppeh Dagh Basin. The ammonite fauna show very close affinities with those from Mangyshlak and Georgia, and have much in common with those of the west Mediterranean Region and southern England. Thus I accepted to apply the 'standard' biozonation of the Western Mediterranean Province (Hoedemaeker & Rawson, 2000; Reboulet *et al*., 2006, 2009, 2011, 2014). However, the index fossils of some of the standard biozones have not been yet found in Iran. Therfore I preferred to use a local taxon for such cases. The proposed biozonation is summarised in Table 1.

Stage	Substage	Busnardo, 1984; Delanoy, 1997; Ropolo *et al*.,1998, 1999 (France)	Kotetshivili *et al*., 2000 (Caucasus)	Hoedemaeker and Rawson, 2000 (Mediterranean Region)	Reboulet et al., 2014
Aptian	Lower				
			D. weissi- Procheloniceras albrechti-austriae	*Deshayesites weissi*	
		Deshayesites tuarkyricus		*Deshayesites tuarkyricus*	*Deshayesites oglanlensis*
Baremian	Upper	*Pseudocrioceras waagenoides*	*Colchidites securiformis*	*Pseudocrioceras waagenoides*	*Martelites sarasini*
		Martelites sarasini		*Martelites sarasini*	
		Imerites giraudi	*Imerites giraudi*	*Imerites giraudi*	*Imerites giraudi*
		Hemihoplites feraudianus	*Hemihoplites soulieri*	*Gerhardtia sartousiana*	*Gerhardtia sartousiana*
		Gerhardtia sartousiana	*Heinzia sartousiana*		
		Ancyloceras vandenheckii	*Ancyloceras vandenheckii*	*Toxancyloceras vandenheckii*	*Toxancyloceras vandenheckii*

Figure 10. Correlation chart of Upper Barremian ammonite biozones in the Tethyan Realm

New zonal proposal

Lower Barremian

The oldest ammonite recorded from the Cretaceous of the Iranian Koppeh Dagh is a single specimen from the uppermost part of the Tirgan Formation was recorded by Immel *et al*. (1997) and identified as *Paraspiticeras percevali*. This genus is also recorded from Europe and the Caucasus (Avram, 1983; Kotetishvili, 1988).

Upper Barremian

The Upper Barremian ammonites of the Koppeh Dagh Basin are *Barremites*, *Toxoceratoides*, *Heteroceras*, *Argvethites*, *Imerites*, *Paraimerites*, *Martelites*, *Hemihoplites* and *Turkmeniceras*. *Hemihoplite*.

As some index taxa of the standard biozonation have not been found in Koppeh Dagh, two new biozones are suggested for the Upper Barremian in Koppeh Dagh Basin, based on collections from the Takal Kuh and Amand sections (Figure 10 and Table 1).

Imerites giraudi Zone: This zone is an interval zone. The base of the zone is defined by the first appearance of *Imerites*. Other characteristic taxa include *Barremites* cf. *difficilis*, *Argvethites* sp., *Imerites favrei, Imerites sparcicostatus* and *Hemihoplites* sp.

It could be metioned that the *Imerites giraudi* is recorded in Ostad section, 100 kilometers southwest of Takal Kuh sections (Zahedipour *et al*., 2014) (Figure 9, Q-R) and reported in Reboulet *et al.* (2014) (Table 1). This zone appears in the lowermost part of the Sarcheshmeh Formation in the Takal Kuh and Amand sections (Figures 4 and 5). It can be compared with the lower part of the *Imerites favrei*-*Heteroceras astieri* Zone, which represents the whole of the Upper Barremian, in the Caucasus (Kakabadze, 1983, 1989), and the *Hemihoplites feraudianus* and *Imerites giraudi* zones of the West Mediterranean Province (Hoedemaeker *et al*., 1995; Hoedemaeker and Rawson, 2000).

Martelites securiformis Zone: This zone is an assemblage zone. The base of the zone is defined by the first appearance of *Martelites securiformis*. The zone is known in the Takal Kuh and Amand sections (Figures 4-6).

Table 1. The standard biozonation and the proposed biozonation for the Upper Barremian of the Koppeh Dagh basin.

Stage	**Substage**	**Standard biozonation (Reboulet *et al*., 2014)**	**Proposed biozonation**		***Assemblage fauna*** **Recorded in this study** **Recorded by Immel et al., 1997** ***Recorded in both studies***
BARREMIAN	**Upper Barremian**	*Martelites sarasini*	*Martelites securiformis*	*Turkmeniceras multicostatum*	*Turkmeniceras multicostatum*, *T.* cf. *tumidum*, *Martelites securiformis*, *M.* cf. *tinae*, *M.* cf. *tenuicostatus*, *M.* sp. 1, *Barremites* cf. *difficilis*, and *Imerites sparcicostatus*
				Martelites securiformis	*Martelites securiformis*, *M. ratshensis*, *M. tinae*, *M. tenuicostatus*, *M.* cf. *tinae*, *M.* cf. tenuicostatus, *M.* sp. 1, *M.* sp. 2, *Paraimerites* sp., *Heteroceras* cf. *colchicus*, *Argvethites* sp., *Toxoceratoides* sp. and *Barremites* cf. *difficilis*
		Imerites giraudi	*Imerites giraudi*		*Heteroceras* cf. *colchicus*, *H.* sp., *Argvethites* sp., *Imerites favrei*, *I. sparcicostatus* and *Hemihoplites* sp., *Imerites giraudi*
		Gerhardtia sartousiana			
		Toxancyloceras vandenheckii			
	L.Barremian				*Paraspiticeras percevali*

It can be correlated with the *securiformis* Zone of Georgia (Druschitz and Gorbatschik 1979; Kakabadze, 1975; Kotetishvili *et al*., 2000) and the *M. sarasini* and *Pseudocrioceras waagenoides* zones of the West Mediterranean Province. The zone is divided into two subzones, *Martelites securiformis* and *Turkmeniceras multicostatum*.

Martelites securiformis Subzone: The subzone is characterised by the appearance of *Martelites*, but without *Turkmeniceras*. Other present taxa are *Toxoceratoides* sp. (which also occurs below), *Heteroceras* cf. *colchicus*, *Argvethites* sp. and *Paraimerites* sp.

Turkmeniceras multicostatum Subzone: *Turkmeniceras turkmenicum* was suggested as a marker for the uppermost Barremian by Russian palaeontologists (Bogdanova, 1971; Bogdanova and Tovbina 1994; Tovbina, 1963). *Turkmeniceras* is only recorded from the Koppeh Dagh, where it appears along with *Martelites*. The base of the subzone is defined by the first appearance of *Turkmeniceras multicostatum*, where *T.* cf. *tumidum* also occurs. Longer ranging taxa include the last *Barremites* cf. *difficilis*. The subzone can be correlated with the *T. turkmenicum* Subzone of Mangyshlak (Bogdanova and Tovbina 1994) and the *Pseudocrioceras waagenoides* Zone of the west Mediterranean region.

Paleobiogeography

Latitudinal and provincial control of ammonite dispersal is common throughout the Mesozoic. Tectonic movements and sea-level changes (regressions and transgressions) caused connecting seaways to open or close and caused several distinct biochores developing within the realms. Thus numerous subrealms and provinces have been proposed (e.g. Rawson, 1981; Wiedmann, 1988; Hoedemaeker, 1990; Page, 1996; Westermann, 2000, Lehmann *et al*., 2015). Three realms including Boral, Tethyan and Austral Realms have been proposed for Early Cretaceous paleobiogeography. The Boreal Realm embraces the Arctic basins and the seas extending southward to parts of North America, northern Europe and Siberia. The Tethyan Realm includes low latitude areas such as Africa, the Pacific, the Middle East and America. An Austral Realm has also been proposed for high southerly latitudes (Stevens, 1973), based primarily on belemnites. Most paleontologists believed Austral as sub-realm of Tethys. Tethyan faunas are much more diverse than Boreal ones. Along the boundaries of the two realms mixing of ammonite faunas is documented.

There are not many informations about the paleogeography of Koppeh Dagh Basin. It may have lain between the Central Iranian microcontinent and Laurasia (Turan Plate), or possibly between the Cimmerian continent and Laurasia (Sengor, 1990). According to Adamia (1988) the Great Caucasus, Transcaspia (Kopet Dagh), Alborz and Central Iran lay at the north Tethyan margin (Figure 11). The Early Cretaceous palaeolatitude has not been determined but is somewhere between 27^o N (the Triassic position) and 32^o N, which is the Cretaceous position of the Turan plate to the north (Soffel & Forster, 1984).

Recently Barrier and Vrielynck (2008) discussed paleogeographic position of Caucasus and Turkministan (Koppeh Dagh), and marked land, sea ways, and shallow and deep marine environents during Lower Creatceous. Masse (2000) reported a facies change from Urogonian facies to ammonite bearing marls in Caucasus and Turministan during late Barremian- early Aptian. It gradually changed to deeper environment.

Moreover, Mosavinia & Wilmsen (2017) based on previous works believed after closer of Palaeotethys during the Late Triassic impact, the Iran Plate, in northeast of Iran two new basin, Koppeh Dagh and Binalud were formed. Koppeh Dagh basin developed by Middle Jurassic rifting and subsiding continued during Jurassic, Cretaceous and Lower Paleogene. The basin was connected to Caucasus via South Caspian and also extended to southeast.

The distribution patterns of Cretaceous foraminifera, ammonites and rudists show that their dispersion was controlled by climate and sea currents (Addicott, 1970; Neaverson, 1955; Cox *et al*. 1969; Gordon, 1973). Luyendyk *et al*. (1972) and Gordon (1973) suggested a ‘westward flowing circumglobal current system in the Tethys. A new palaeogeographical pattern for the Cretaceous was proposed by Hay *et al*. (1999).

Heteroceratidae and late Barremian paleobiogeography in Koppeh Dagh

During the Berriasian to Hauterivian the sea withdrew from the Koppeh Dagh and partly non-marine (Shurijeh Formation) or very shallow marine (Zard Formation) sediments are deposited.

After this regressive phase there is an extensive transgression in Early Barremian (Haq *et al*., 1988) with onst of the Urgonian facies (*Orbitolina* limestones) which is wide spread in Iran and in Mediterranean areas. The deposition of *Orbitolina* limestones ended in most parts of the Koppeh Dagh before the end of the Barremian. *Paraspiticeras percevali* is the only Early Barremian ammonite recorded from the basin (Immel *et al*., 1997).

The representative of Heteroceratidae family first appear in Caucasus (Kakabadze, 1971, 1975) and then spread around the world from eastern Europe to France, Germany, England, North America (California) to South Africa (Zululand), South America (Colombia, Argentina) and Even Japan (e.g. Klinger, 1976, Klinger *et al*., 1984; Aguirre Urreta & Klinger, 1986; Etayo-Serna, 1968; Kakabadze and Thieuloy 1991; Kakabadze *et al*., 2004).

As mentioned above this dispersion from east to west could be under control of westward paleocurrents and paleogeography pattern during Early Cretaceous (Matsukawa & Obata, 1993, Lehmann *et al*., 2015). Probably the dispersal of the Heteroceratidae occurred in the juvenile stages and not the adult stage when they are sluggish (Klinger *et al*., 1984; Klinger, 1990).

Heteromorph Heteroceratidae have an almost cosmopolitan distribution (Table 2).

They are well-known in many parts of the Tethyan Realm and have recently been recorded from the Boreal Realm (Rawson, 1995) (Figure 11). However, the latest Barremian genera *Argvethites*, *Martelites*, *Imerites* and *Paraimerites* in the Iranian part of Koppeh Dagh indicate a faunal connection with the Mediterranean area via the Caucasus (Kotetishvili, 1988) and France (Delanoy, 1997). *Hemehoplites* also recorded in Koppeh Dagh basin (Immel *et al*., 1997). Both families, Heteroceratidae and Hemihoplitidae, provide faunal links with the Tethyean-Boreal Realms (Lehmann *et al*., 2015).

Barremites is recorded from the Upper Barremian sequences of eastern England, north-west Germany, France, Caucasus, Russia and Japan (Table 2), and north Africa. Mexico (Wright *et al*., 1996) and here from Iran.

In the uppermost part of the Barremian *Turkmeniceras* appears. This earliest deshayesitid is known only from Turkmenistan and the Koppeh Dagh and could be an endemic taxon (Raisossadat, 2004).

In summary, the faunas of the Koppeh Dagh show close relationships with faunas to the Tethyean Realm and Mediterranean Province, and there is some limited evidence from the dispersal of some forms to support with palaeocurrent patterns suggested by Barron and Peterson (1989).

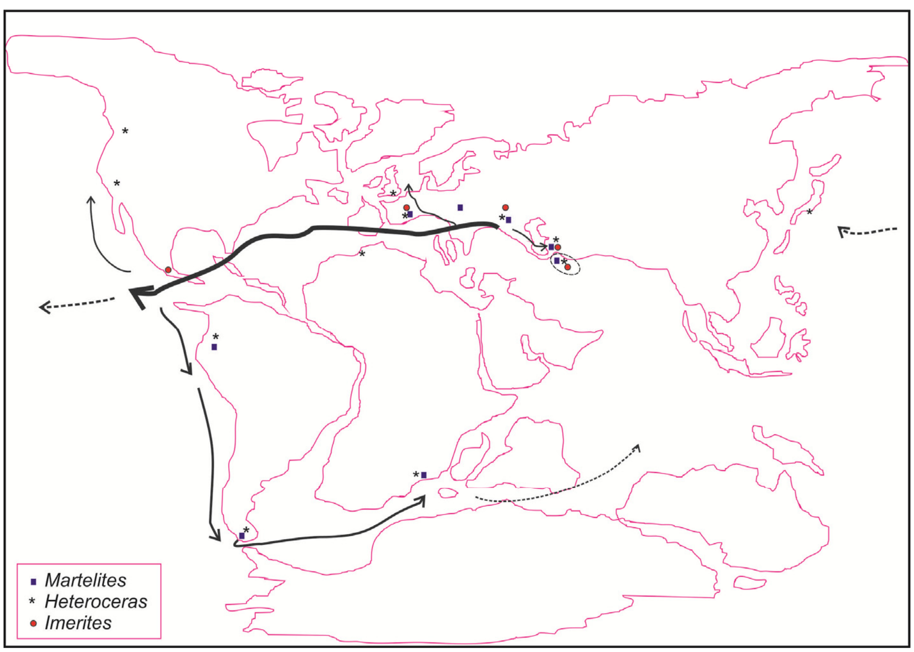


Figure 11. Distribution of *Martelites*, *Heteroceras*, and *Imerites* during Late Barremian and probable migration pass of the Hetroceratidae Family, Ellipsoid dashad is study area.

Table 2. Geographical distribution of selected Late Barremian ammonites of the Koppeh Dagh Basin.

	Koppeh Dagh-Iran (X= Present study)	**Central Iran**	**Turkmenistan**	**Caucasus & Russia C.= Caucasus; R.= Russia**	**Eastern Europe (Carpathians, Romania, Poland)**
Martelites	X, Immel *et al*., 1997	----	Tovbina, 1963; Bogdanova & Prozorovsky, 1999	C. (Kakabadze, 1971, 1989; Kotetishvili, 1988)	Bulgaria (Mandov & Nikolov 1992)
Heteroceras	X	----	Tovbina, 1963; Bogdanova and Prozorovsky, 1999	C. (Rouchadze, 1933, 1938; Kotetishvili, 1970; Egoian, 1965; Kakabadze, 1971, 1975, 1989; Kotetishvili, 1988)	Bulgaria (Nikolov, 1964; Dimitrova, 1967), Romania (Simoniescu, 1898), Hungary (Fülop, 1964) Czechoslovakia (Uhlig, 1883)
Argvethites	X	----	----	C. (Kotetshvili, 1970; Kakabadze, 1975)	Czechoslovakia (Vasicek, 1972)
Imerites	X, Immel *et al*., 1997		(Tovbina, 1963)	Georgia (Rouchadze, 1933; Kotetshvili, 1970; Kakabadze, 1971)	

Conclusions

Heteroceratidae family have an almost cosmopolitan distribution. They are well-known in many parts of the Tethyan Realm and even Boreal Realm. Paleogeographic maps and the presence of representative genera of the family in Koppeh Dagh basin could confirm a sea way connection between Koppeh Dagh and Caucasus. In the uppermost part of the Barremian *Turkmeniceras* appears. This earliest deshayesitid is known only from Turkmenistan and the Koppeh Dagh and could be an endemic. Other cosmopolitan genera such *Barremites* and *Hemihoplites* also recorded in upper Barremian deposits of the basin.

Five ammonite genera and ten species have been identified and described from rhe Barremian of Iranian Koppeh Dagh, most of them for the first time. The genera *Heteroceras, Martelites, Argvethites*, *Imerites* and *Paraimerites* are recorded. The present fauna indicates a Late Barremian age for the lower part of Sarcheshmeh Formation.

Based on the ammonite assemblages, 2 biozones are suggested for the Upper Barremian of the Koppeh Dagh Basin, the *Imerites giraudi* and *Martelites securiformis* Zones. The latter zone is divided into 2 sub-biozones, *Martelites securiformis* and *Turkmeniceras multicostatum.* All the suggested biozones can be correlated with the standard biozonation of the Mediterranean area.

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