

Presence of *Frambocythere* COLIN, 1980, (limnic ostracode) in the Maastrichtian of the Zagros Mountains, Iran: a newly recognized link between southern Europe and the Far East

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Abstract: The limnic ostracode *Frambocythere tumiensis zagrosensis* subsp. nov. (Limnocytheridae, Timiriaseviinae), has been found for the first time in Iran. The strata containing this species are in the lower part of the Tarbur Formation in the interior Fars of the Zagros Mountains. The Late Maastrichtian age is indicated by rudists, larger foraminifers (*Omphalocyclus macroporus*, *Loftusia* spp.) and planktonic foraminifers (*Contusotruncana contusa*-*Racemiguembelina fructicosa* Zone) present in the upper part of the Tarbur Formation. The Maastrichtian age is confirmed by the occurrence in the same strata of the charophytes *Platychara shanii*, *Peckichara cristellata* and *Stephanochara* cf. *producta*. The genus *Frambocythere* COLIN, 1980, was until now known mostly from the Upper Maastrichtian to Middle Eocene of southern Europe, India and China, as well as the Albian of the Democratic Republic of Congo. The presence of *Frambocythere* gr. *tumiensis* in Iran is therefore a newly recognized link between southern Europe and the Far East (China).

Key Words: Limnic ostracodes; Upper Maastrichtian; Iran; Zagros; taxonomy; palaeobiogeography.

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Résumé : Présence de *Frambocythere* COLIN, 1980, (ostracode limnique) dans le Maastrichtien des Monts du Zagros, Iran : un nouveau relais entre l'Europe méridionale et l'Extrême-Orient.- L'ostracode limnique *Frambocythere tumiensis zagrosensis* nov. subsp. (Limnocytheridae, Timiriaseviinae) a été trouvé pour la première fois en Iran. Les niveaux contenant cette espèce proviennent de la partie inférieure de la Formation de Tarbur dans les Fars intérieurs des Monts Zagros. L'âge maastrichtien est donné par les rudistes, les grands foraminifères (*Omphalocyclus macroporus*, *Loftusia* spp.) et les foraminifères planctoniques (Zone à *Contusotruncana contusa*-*Racemiguembelina fructicosa*) dans les niveaux de la partie supérieure de la Formation de Tarbur. L'âge maastrichtien est aussi conforté par la présence dans les mêmes niveaux des charophytes *Platychara shanii*, *Peckichara cristellata* et *Stephanochara* cf. *producta*. Le genre *Frambocythere* COLIN, 1980, n'était jusqu'à présent connu que du Maastrichtien supérieur à l'Éocène moyen en Europe méridionale, Inde et Chine, ainsi que dans l'Albien de la République Démocratique du Congo. La présence de *Frambocythere* gr. *tumiensis* en Iran est donc un nouveau relais entre l'Europe méridionale et l'Extrême-Orient (Chine).

Mots-Clefs : Ostracodes limniques ; Maastrichtien supérieur ; Iran ; Zagros ; taxonomie ; paléobiogéographie.

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1. Geological introduction

The Borujen area is located in the eastern Zagros Mountains, in the interior Fars, which were formed as a result of the closure of the Neotethyan Ocean during the Late Mesozoic and the Cenozoic (Fig. 1).

During the Maastrichtian, an active carbonate platform with numerous rudist build-ups appeared contemporaneous with sea-level change in the eastern part of the Neotethyan realm (Zagros region). This succession, called the Tarbur Formation, extends across the interior Fars and Lurestan and is formed mainly of siliciclastic rocks comprising shales, sandstones and polygenetic conglomerates, and some carbonate units with rudist lithosomes sometimes incorporating corals, other bivalves, gastropods and algae.

The name Tarbur Formation was proposed by JAMES & WYND (1965) for a series of limestones, rudist build-ups and shales overlying the Gurpi and Sachun formations. Although the Tarbur Formation was deemed to be a single formation by JAMES & WYND (1965) and was re-

described as such by other authors (KALANTARI, 1976; VAZIRI MOGHADDAM *et al.*, 2005) from SW Iran, it is represented by varied and complex rock associations. In its type locality in Tarbur village, southern Iran, this formation consists of limestones with larger foraminifers and rudist lithosomes.

In the study area, the Upper Cretaceous sedimentary succession is rather monotonous and consists exclusively of shallow-water carbonates and shales. The oldest sediments of the area crop out at Tang-e-khoshk, which consists of silty shales and thin-bedded limestones of the Lower Cretaceous Gadvan Formation. The studied section, with a thickness of about 1,100 m, is situated NW of the Semirom plain and S of Borujen. It consists of Upper Cretaceous sedimentary rocks, the Gurpi, Amiran and Tarbur formations.

The Gurpi Formation is composed of shales, calcareous shales and sandstones. It contains abundant planktonic microfossils of Santonian-Campanian age. Its lower contact with the Ilam Formation and its upper contact with the Amiran Formation are both gradational.

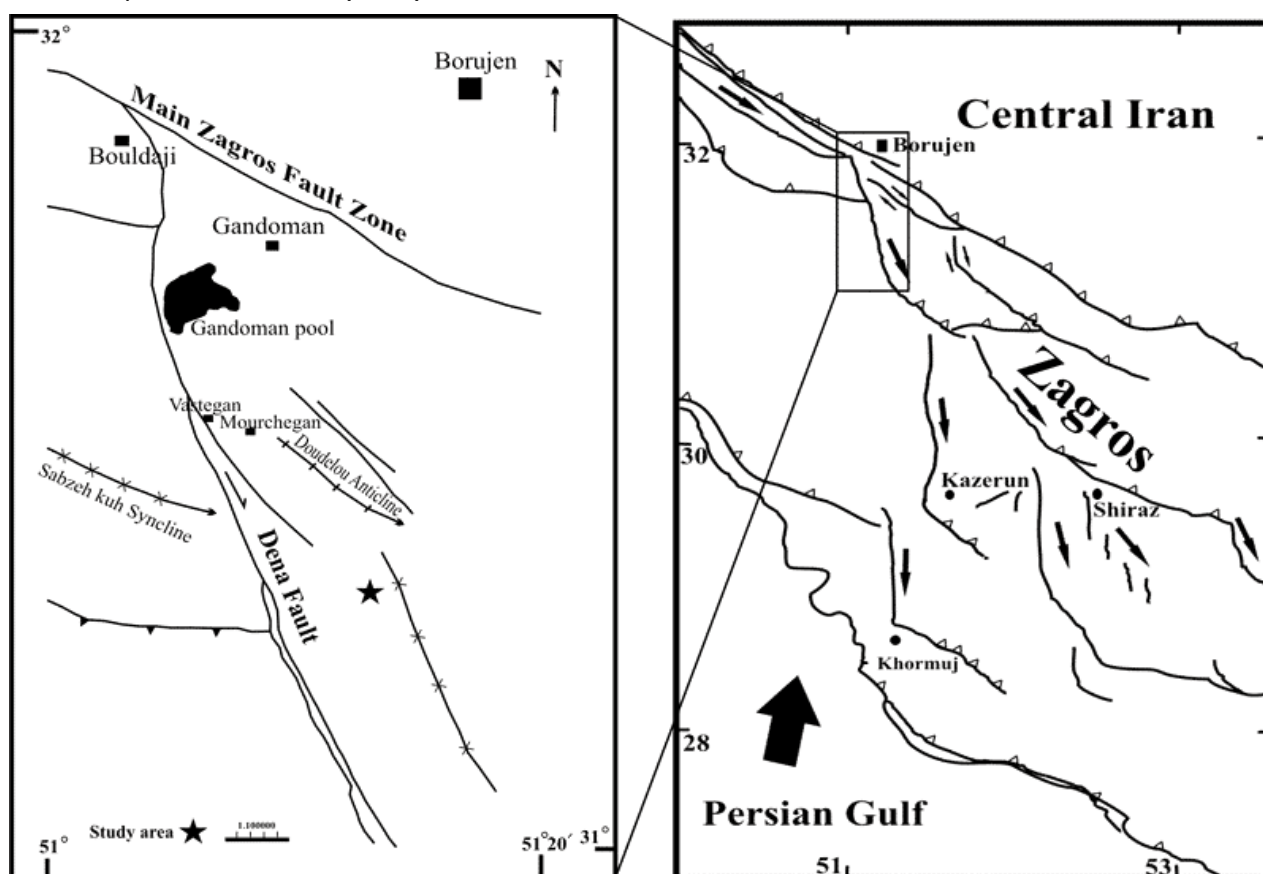


Figure 1: Location map of the studied section, 48 km S of Borujen, Iran.

The main lithology of the Amiran Formation is ophiolite-derived siliciclastic turbidite intercalated with siltstones, carbonate sandstones and shales. The grains include chert, quartz, volcanic and limestone rock fragments and radiolarians. The Amiran Formation is a thickening-upward sequence which contains fining-upward BOUMA cycles indicating deposition by turbidity currents. The formation is of Late Cretaceous age and its upper contact with the Tarbur Formation is gradual. The Amiran Formation is the result of tectonic sedimentary processes related to the Laramian geodynamic event (ALAVI, 2004).

The Tarbur Formation consists of limestones, shales and sandstones with a total thickness of about 920 m. These units generally show lateral changes in thickness, composition, density and facies. The limestones contain a rudist reef facies with larger foraminifers, such as *Loftusia* spp. and *Omphalocyclus macroporus* (LAMARCK, 1816). These limestones were deposited on a carbonate platform that was eroded by a meandering river during a eustatic lowstand. The presence of rudist debris and larger foraminifers indicates a photozoan assemblage and suggests tropical conditions. The base of the formation is made of fine-grained deposits with massive reddish brown shales and very thin-bedded sandstones. This layer proved rich in charophytes and ostracodes, which are important for dating these sediments.

2. Sample locality and stratigraphy

The microfossils described here come from a reddish brown shale exposed 7 km SW of Gerd-bisheh village (beside the Borujen-Lordegan road) about 48 km S of Borujen. In this section, the Tarbur Formation is overlain with an erosional contact by the Shahbazan dolomites of Eocene age. On the basis of lithological variation, we have subdivided the Tarbur Formation into four parts, from base to top:

- Unit 1: green-gray siltstones, sandstones with thin layers of gray-cream sandy limestones;
- Unit 2: reddish brown shales and conglomerates. This is the studied sequence (Figs. 2 - 3);
- Unit 3: thick-bedded limestones and interbedded rudist build-ups with gray shales;
- Unit 4: gray shales.

The exact age of the Tarbur Formation is not well established. JAMES & WYND (1965) assigned a Campanian-Maastrichtian age and other authors (KALANTARI, 1976; VAZIRI MOGHADDAM *et al.*, 2005) dated Unit 3 as Late Maastrichtian based on the occurrence of the larger foraminifers.

Orbitoides media (d'ARCHIAC, 1837), *Siderolites calcitrapoides* LAMARCK, 1801, *Omphalocyclus macroporus* and *Loftusia* spp. Rudists also support a Late Maastrichtian age (KHAZAEI *et al.*, 2010). Unit 4 contains planktonic foraminifers which characterize the *Contusotruncana contusa* - *Racemiguembelina fructicosa* Zone of Late Maastrichtian age.

In the studied level (Unit 2) the absence of stratigraphically important benthic foraminifer taxa (especially *Orbitoides*) precludes better stratigraphic resolution. Unit 2 is certainly Maastrichtian based on the presence of the charophytes *Peckichara cristatella* GRAMBAST & GUTIÉRREZ, 1977, and *Platychara (Chara) shanii* (RAO & RAO, 1939) BATHIA & MANNIKERI, 1976, cf. *Stephanochara producta* LI, 1995 (identification E. MUSACCHIO and in VAZIRI MOGHADDAM *et al.*, 2010). For the first time in Iran, this level has yielded the non-marine ostracode *Frambocythere tumiensis zagrosensis* subsp. nov.

3. Taxonomy, biostratigraphy and palaeobiogeography of the genus *Frambocythere*

a. Taxonomy

Class Ostracoda LATREILLE, 1802
Subclass Podocopa SARS, 1866
Order Podocopida SARS, 1866
Suborder Cytherocopina BAIRD, 1850
Superfamily Cytheroidea BAIRD, 1850
Family Limnocytheridae KLIE, 1938
Subfamily Timiriaseviinae MANDELSTAM, emend COLIN & DANIELOPOL, 1980

Genus *Frambocythere* COLIN, 1980

The genus *Frambocythere* was erected by COLIN (in COLIN & DANIELOPOL, 1980), with the type species *Frambocythere tumiensis* (HELM-DACH, 1978), from the Upper Maastrichtian of Spain. The genus is characterized by its small size (less than 0,600 mm), the presence of two antero-dorsal vertical sulci, ornamentation of small pustules ("raspberry-like"), and posterior conical spines. The right valve is generally larger than the left (inverse overlap) and sexual dimorphism is pronounced, with a strong posterior widening of the posterior half in females, forming a brood cavity. Some morphotypes (or subspecies ?) can be completely smooth, as in *Frambocythere* cf. *tumiensis ferreri* (in BABINOT, 1980) and *Frambocythere tumiensis apleri* (HELM-DACH, 1978), or partly so, as in *Frambocythere tumiensis ferreri* COLIN, 1980 (COLIN, 1991). Up to now, nine species and subspecies have been described and two tentatively assigned to known species (Appendix).

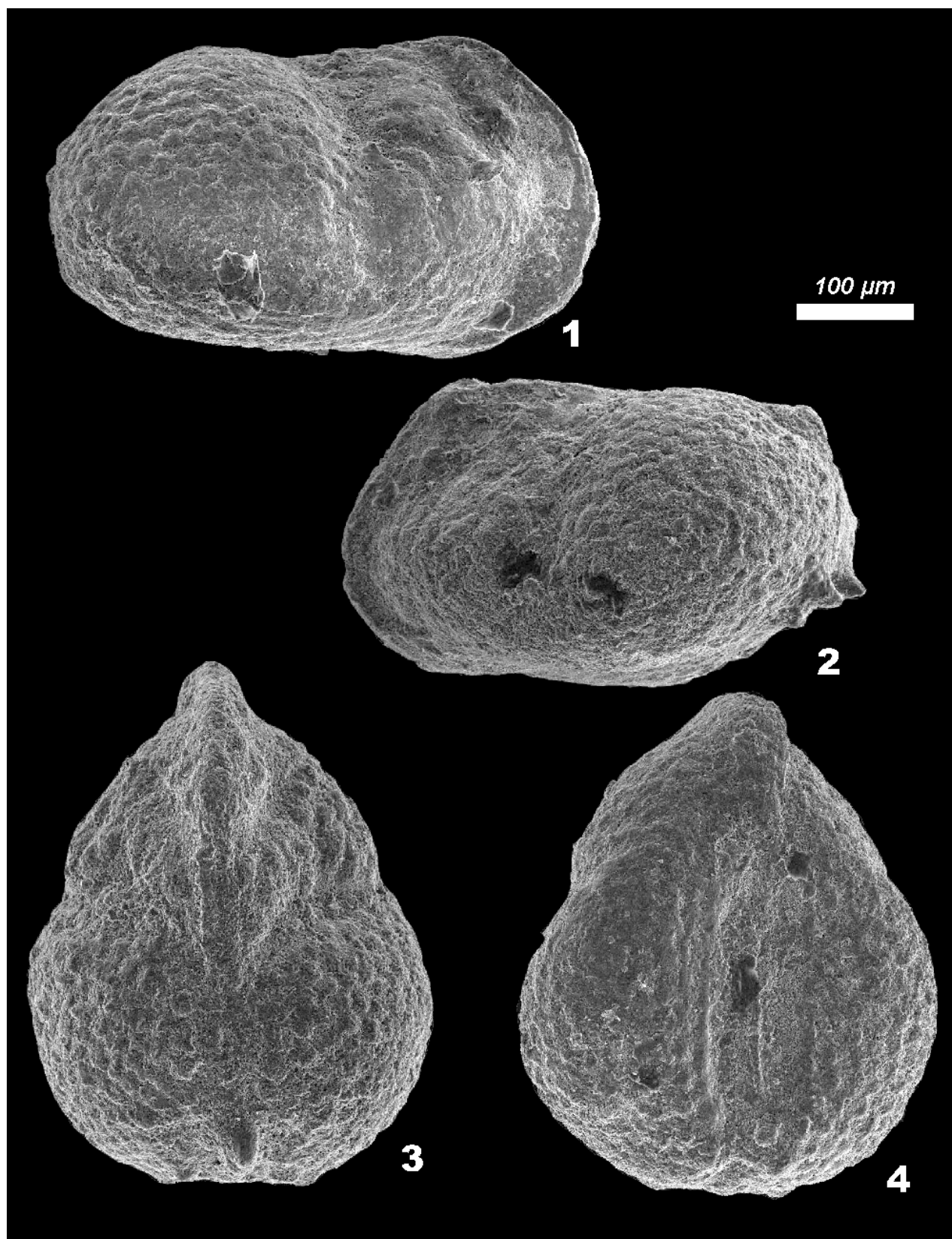


Plate 1: *Frambocythere tumiensis zagrosensis* nov. subsp.
1. Carapace, female, holotype, right lateral view (L = 0.47 mm);
2. Carapace, male, paratype, left lateral view (L = 0.45 mm);
3. Carapace, female, dorsal view (L = 0.47 mm);
4. Carapace, female, ventral view (L = 0.46 mm).

***Frambocythere tumiensis zagrosensis*
subsp. nov.**

(Pl. 1, figs. 1-4)

Derivatio nominis: From the Zagros Mountains, type area.

Holotype: Female carapace (Pl. 1, fig. 1) deposited in the collections of the Geology Department, Faculty of Science, University of Isfahan, Isfahan, Iran. **Paratypes**: four female carapaces deposited in the collections of the Geology Department, Faculty of Science, University of Isfahan, Isfahan, Iran.

ZooBank reference:
urn:lsid:zoobank.org:act:70180DC1-2624-4505-943C-48D1B036A0FF

Type locality: 7 km SW of Gerdbisheh village (besides Borujen-Lordegan road) about 48 km S of Borujen. Lower part of the Tarbur Formation, Upper Maastrichtian.

Diagnosis: Rather elongate subspecies of *Frambocythere* with the characteristic "raspberry-type" pustulose ornamentation. Postero-ventral conical spines only on juveniles and males. Left valve smaller than right valve (inverse overlap).

Dimensions:
Holotype: L = 0.470 mm; h = 0.270 mm.
Paratypes: L = 0.430-0.470 mm; h = 0.240-0.270 mm.

Description: Female carapace sub-rectangular with dorsal and ventral margins more or less parallel. Ventral margin slightly convex. Dorsal margin straight in anterior half, slightly convex in posterior half. Anterior margin equally rounded and compressed. Postero-dorsal margin angular with marked posterior cardinal angle in males. Postero-ventral margin rounded. Two sub-parallel vertical sulci running from dorsal margin downwards, one at mid-length, one shorter in anterior quarter. Surface of valves ornamented with 'raspberry-type' micropustules. Females have no or only one conical postero-ventral spine, whereas males and juveniles have at least two spines (Pl. 1, fig. 2). Right valve overlaps left. Males slightly smaller and with much less inflated posterior region.

Remarks: This subspecies differs from other subspecies of *Frambocythere tumiensis* by its more elongate carapace (females L/h = 1.7-1.80), for example, compared with *Frambocythere tumiensis tumiensis* (females L/h = 1.62-1.70) and *Frambocythere tumiensis ferrerii* (females L/h = 1.64-1.77). It also differs from this last subspecies in that the surface of the valves is entirely pustulose and the postero-dorsal spine is absent. Two other subspecies described from the Upper Maastrichtian intertrappean beds of India, *Frambocythere tumiensis anjarensis* BHANDARI & COLIN, 1999, and *Frambocythere tumiensis lakshmiiae* WHATLEY & BAJPAI, 2000, have more prominent papillae, as does the Early Paleocene subspecies from Belgium, *Frambocythere tumiensis ludi* TAMBAREAU, 1984.

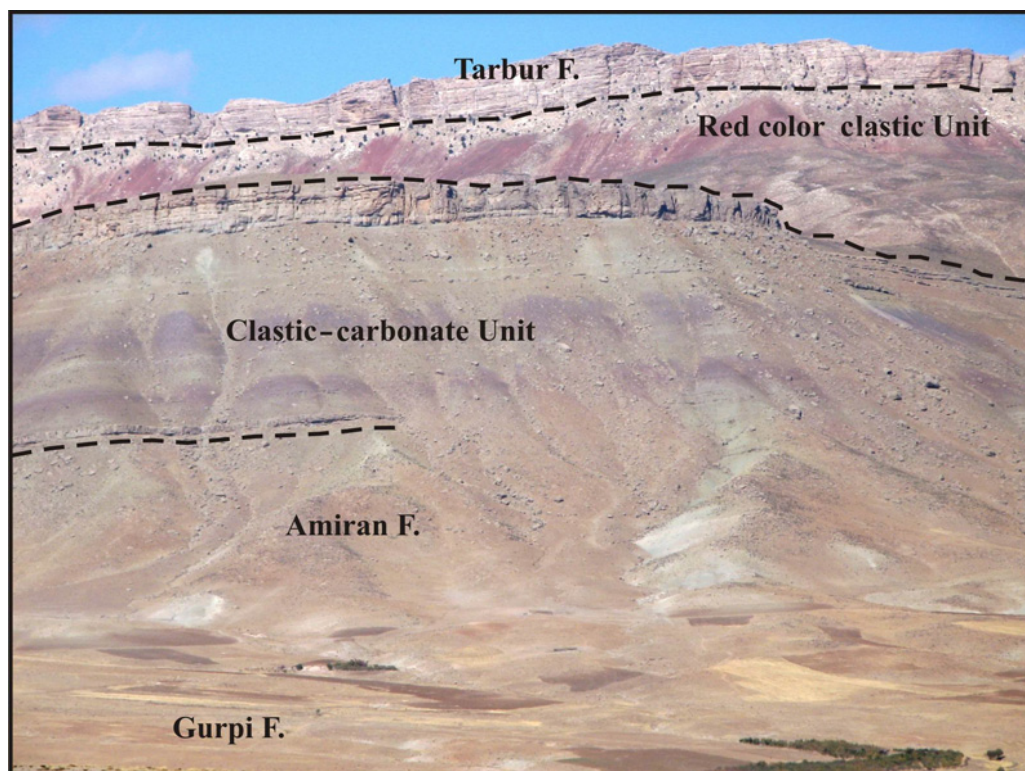


Figure 2: View of the studied section, 48 km S of Borujen, Iran.

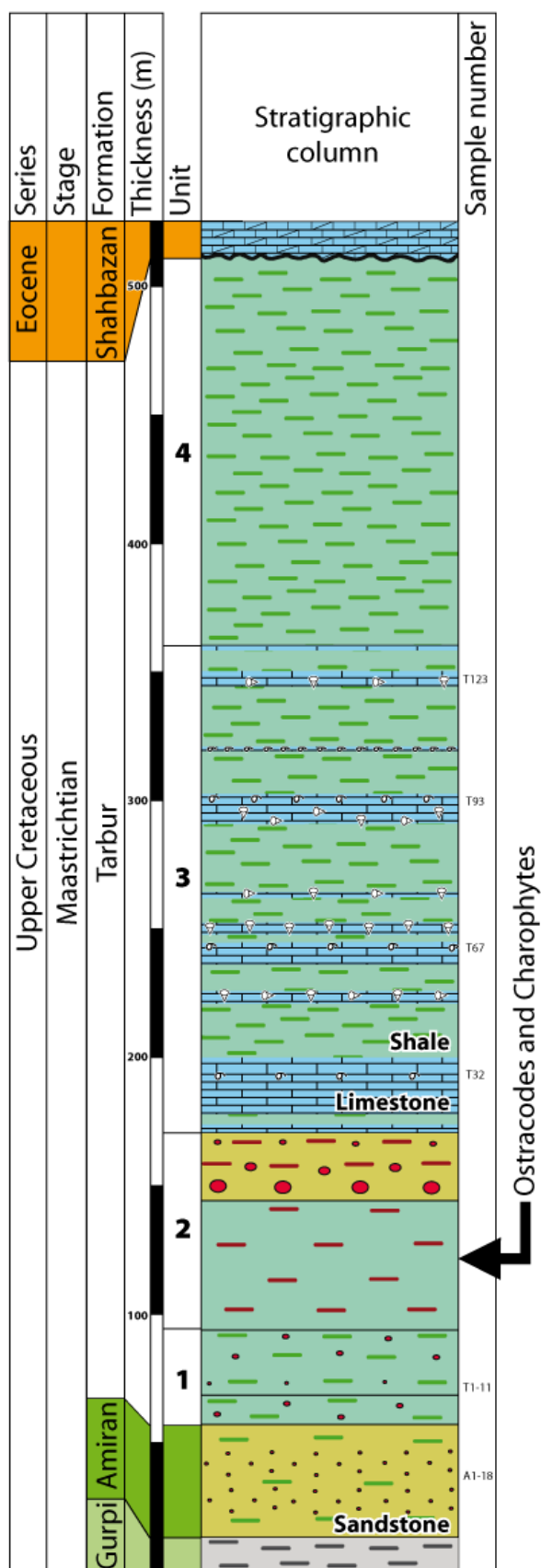


Figure 3: Schematic lithostratigraphic log of the Tarbur Formation.

b. Biostratigraphy and palaeobiogeography

The earliest known species of *Frambocythere* is of Gondwanian origin. It has been reported in the Albian (Loia Formation) of the Democratic Republic of Congo as *Frambocythere pustulosa* (GREKOFF, 1957) and also from the Albo-Aptian of Chad (COLIN, 1993; COLIN & DÉPÊCHE, 1997).

Most other taxa of *Frambocythere* are subspecies of *Frambocythere tumiensis* (HELM DACH, 1978) from northern Spain and are of Late Maastrichtian age, but some subspecies extend into the Danian. Other species are known from the Upper Paleocene and the Lower Eocene as stated by COLIN (2011). From a palaeobiogeographic point of view, the distribution of the various subspecies of *Frambocythere tumiensis* during the Maastrichtian and earliest Danian is remarkable, as already stated by HELMDACH (1979). *Frambocythere tumiensis tumiensis* (HELM DACH, 1978), *Frambocythere tumiensis aepleri* (HELM DACH, 1978), and *Frambocythere tumiensis ferreri* COLIN, 1980, are present in southern Europe, i.e., north-eastern Spain and southern France (BABINOT, 1980; COLIN, 1991; BABINOT *et al.*, 1996), and one subspecies, *Frambocythere tumiensis ludi* TAMBAREAU, 1984, is known from the lowermost Paleocene (Danian) of southern Belgium.

In northwestern India, two species have been described from the Upper Maastrichtian and Lower Palaeocene: *Frambocythere tumiensis anjarensis* BHANDARI & COLIN, 1999, and *Frambocythere tumiensis laskshamiaie* WHATLEY & BAJPAJ, 2000 (BHANDARI & COLIN, 1999; WHATLEY & BAJPAJ, 2000, 2005, 2006; WHATLEY *et al.*, 2002; KELLER *et al.*, 2009). The same year as HELMDACH (1978) described the Spanish species as *Bisulcocypris tumiensis*, in north-west China, YE (*in* Hou *et al.*, 1978), named a species *Bisulcocypris fanghiaensis* from the Upper Maastrichtian. Better SEM illustrations in Hou & GOU (2002) clearly show (COLIN, 2011) that the Chinese species is a subspecies of *Frambocythere tumiensis*, herein named *Frambocythere tumiensis fangjiahensis* (YE *in* Hou *et al.*, 1978).

The presence of a new subspecies of *Frambocythere tumiensis* in the Maastrichtian of Iran is therefore a newly recognised link between southern Europe and the Far East (China). The extremely wide geographical distribution of this species is quite rare amongst fossil Cytherocopa since they very seldom have dessication-resistant eggs (KARANOVIC, 2012). However, MARTENS (1989) raised individuals belonging to the family Limnocytheridae from dried mud and SMITH & HORNE (2004) found a species of *Paralimnocythere* in a temporary pond confirming that limnocytherids have drought-resistant stages. There are also several living Cytherocopa that have very widespread distributions, e.g. *Cytherissa lacustris* (SARS, 1863), *Limnocythere*

inopinata (BAIRD, 1843), *Limnocythere stationis* VÁVRA, 1891, *Leucocythere mirabilis* (KAUFMAN, 1892), and *Cyprideis torosa* (JONES, 1850). Therefore there may be a strong relationship between desiccation-resistant eggs and wide distributions (R.J. SMITH personal communication; MARTENS *et al.* (2008) reported that 90% of freshwater ostracode species are restricted to one zoogeographical region. Half of these are Cypridoidea which have desiccation-resistant eggs. On the other hand, *Darwinula stevensoni* (BRADY & ROBERTSON, 1870), which does not have desiccation-resistant eggs, has a very wide geographical distribution. Birds are thought to be one of the most common means of passive dispersal (PROCTOR, 1964; SYWULA, 1990), especially for ostracodes that do not lay desiccation-resistant eggs such as most Cytherocopina. Other passive dispersal vectors are amphibians (SEIDEL, 1989), fishes (KORNICKER & SOHN, 1971), floating vegetation and stratospheric air currents (SOHN & KORNICKER, 1979). Some Cytherocopina which do not lay desiccation-resistant eggs may disperse in a torpid (dehydrated) state (HORNE, 1993).

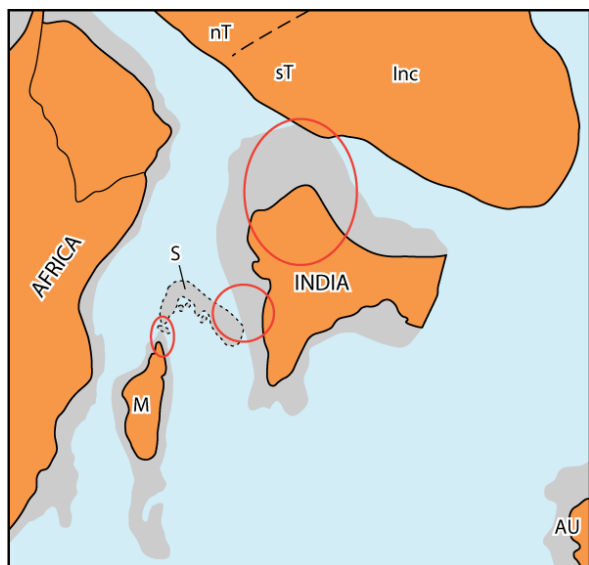


Figure 4: Palaeogeographic relationships of India during the Late Maastrichtian (after RAGE, 2003, modified). Orange: terrestrial areas; light grey; presumed terrestrial connections; M: Madagascar; S: Seychelles Plateau; nT: northern Tibet; sT: southern Tibet; Inc: Indochina.

The presence of *Frambocythere* in the Maastrichtian of India is more difficult to explain since the collision of India with Asia is dated 10 Ma years later, at about 55 Ma (AITCHISON *et al.*, 2007). The most likely scenario is that Laurasian terrestrial taxa, including ostracodes, amphibians and vertebrates, entered India following a presumed terrestrial route as suggested by PRASAD & RAGE (1991), PRASAD & SAHNI (2009) and RAGE (2003) (Fig. 4). This postulate is not accepted by WHATLEY & BAJPAJ (2006) who, on the basis of freshwater ostra-

code faunas, support the isolation of the Indian subcontinent during the Late Cretaceous and the "Out of India" hypothesis with respect to India's zoogeographical relations with Africa and Laurasia.

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Appendix: Check-list of *Frambocythere* species

- *Frambocythere pustulosa* (GREKOFF, 1957): Albion, Loia Formation, Democratic Republic of Congo;
- *Frambocythere tumiensis aepleri* (HELM-DACH, 1978): Upper Maastrichtian of N Spain;
- *Frambocythere tumiensis anjarensis* BHANDARI & COLIN, 1999: Upper Maastrichtian and Lower Danian of NW India;
- *Frambocythere tumiensis fanghiaensis* (YE, 1978), in Hou et al. (1978) and Hou & Gou (2002): Upper Maastrichtian of W China;
- *Frambocythere tumiensis ferreri* COLIN, 1980, in COLIN & DANIELOPOL (1980): Upper Maastrichtian of Spain and SE France;
- *Frambocythere tumiensis lakshmiai* WHATLEY & BAJPAI, 2000: Upper Maastrichtian of NW India;
- *Frambocythere tumiensis ludi* TAMBAREAU, 1984: Danian of Belgium;
- *Frambocythere* gr. *ludi* TAMBAREAU, 1984, in GHEERBRANT et al. (1999): Upper Palaeocene (Thanetian) or Lower Eocene (Ypresian) of Romania;
- *Frambocythere tumiensis tumiensis* (HELM-DACH, 1978): Upper Maastrichtian of N Spain and S France;
- *Frambocythere tumiensis zagrosensis* nov. sp. (this paper): Upper Maastrichtian of Zagros Mountains, Iran;
- *Frambocythere* gr. *tumiensis* (HELM-DACH, 1978), in DUCASSE et al., 1985: Paleocene-Middle Eocene (Lutetian) of the Paris Basin, France;
- *Frambocythere valeroni* TAMBAREAU, 1991, in TAMBAREAU et al. (1991): Lower Eocene (Ypresian) of southern France.