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Berriasian–early Valanginian calcareous shallow-water facies from the Arperos Basin: A proposal from the foraminiferal assemblage of the clasts of the Guanajuato Conglomerate, central Mexico

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Abstract

The Eocene Guanajuato Conglomerate is composed of clasts derived from igneous and metasedimentary sources that can be related to the Upper Jurassic–Lower Cretaceous arc and back-arc assemblages of the El Paxtle and Arperos Basin. Limestone clasts contain a shallow-water platform fauna that includes bivalves, brachiopods, gastropods, echinoderms and foraminifers. Foraminiferal studies were carried out on these limestone clasts. The benthic foraminiferal association is composed of *Pseudocyclammina lituus* (Yokoyama, 1890); *Everticyclammina virguliana* (Koechlin, 1942); *Montsalevia salevensis* (Charollais, Brönnimann and Zaninetti, 1987); *Neotrocholina valdensis* (Reichel, 1955); *Andersolina cherchiae* (Arnaud-Vanneau, Boisseau and Darsac, 1988); *Neotrocholina molesta* (Gorbatchik, 1959); *Pfenderina neocomiensis* (Pfender, 1938); *Nautiloculina bronnimanni* Arnaud-Vanneau and Peybernès, 1978; *Hechtina praeantiqua* Bartenstein and Brand, 1949; *Protopeneroplis* cf. *P. banatica* Bucur, 1993; *Istriloculina* sp., *Moesiloculina* sp., *Protomarsonella* sp., *Ammovertellina* sp. and *Glomospira* sp.

The Tethysian foraminiferal assemblage observed in the limestone clasts indicate the age of the calcareous source as Berriasian–early Valanginian, which is the age of the deposition within the Arperos Basin.

The occurrence of these shallow-water limestone clasts suggests the existence of a shallow-water platform deposit located in the Arperos Basin. This is significant considering that all previous work focused on the deep-water sedimentary rocks (siliciclastic and calcareous). Thus, these clasts are a key to reconstructing the depositional history and architecture of this basin.

Keywords: Tethysian benthic foraminifera, Berriasian–early Valanginian, Guanajuato Conglomerate.

Resumen

El Conglomerado Guanajuato del Eoceno se compone de clastos derivados de rocas de fuentes ígneas y metasedimentarias que pueden estar relacionadas con los conjuntos del Jurásico Superior-Cretácico Inferior de arco y tras arco del Paxtle y la Cuenca Arperos. Los clastos de caliza contienen una fauna de aguas someras de plataforma que incluye bivalvos, braquiópodos, gasterópodos, equinodermos y foraminíferos. Se realizó el estudio de los foraminíferos bentónicos en estas calizas, la asociación se compone de Pseudocyclammina lituus (Yokoyama, 1890); Everticyclammina virguliana (Koechlin, 1942); Montsalevia salevensis (Charollais, Brönnimann y Zaninetti, 1987); Neotrocholina valdensis (Reichel, 1955); Andersolina cherchiae (Arnaud-Vanneau, Boisseau y Darsac, 1988); Neotrocholina molesta (Gorbatchik, 1959); Pfenderina neocomiensis (Pfender, 1938); Nautiloculina bronnimanni Arnaud-Vanneau y Peybernès, 1978; Hechtina praeantiqua Bartenstein y Brand, 1949; Protopeneroplis cf. P. banatica Bucur, 1993; Istriloculina sp., Moesiloculina sp., Protomarsonella sp., Ammovertellina sp. y Glomospira sp.

El conjunto de foraminíferos tethysianos observados en los clastos de caliza indican la edad de la fuente calcárea en el Berriasiano-Valanginiano temprano, que es la edad del depósito en la Cuenca de Arperos.

La presencia de estos fragmentos de calizas de aguas someras sugiere la existencia de un depósito de plataforma somera ubicada en la cuenca de Arperos, es significativo teniendo en cuenta que todo el trabajo previo se centró en las rocas sedimentarias de aguas profundas (siliciclásticas y calcáreas). Por lo tanto estos fragmentos son clave en la reconstrucción de la historia deposicional y arquitectura de esta cuenca.

Palabras clave: Foraminíferos bentónicos tethysianos, Berriasiano-Valanginiano temprano, Conglomerado Guanajuato.

1. Introduction

Eocene continental successions are exposed in the Mesa Central of Mexico (Figure 1). These successions unconformably overlie sheared and folded rocks of the Mesozoic and are in turn overlain by Eocene–Oligocene volcanic rocks of the Sierra Madre Occidental (Edwards, 1955; Aranda-Gómez and McDowell, 1998).

The Eocene continental successions of Central Mexico received different names depending on the locality of the outcrop. In Guanajuato (Figure 1), these continental rocks are designated Guanajuato Conglomerate (GC) (Botsford, 1909; Edwards, 1955; Aranda-Gómez and McDowell, 1998). The GC was first mapped and described by Wandke and Martínez (1928). Later, Guiza (1949) and Edwards (1955) divided the GC into two units, the lower and the upper member, separated by an unconformity.

The GC is 1500 to 2000 m thick (Edwards, 1955) and is composed of limestone, granite, andesite, metasediments, diorite and pyroxenite clasts that indicate the erosion of uplifted blocks of the basal complex of the Sierra de Guanajuato (Arperos Basin). According to Martini *et al.* (2011), the Arperos basin was “developed in a back-arc setting and evolved from continental to open oceanic conditions from the Late Jurassic to the Early Cretaceous.”

The dating of the GC is difficult due to the fact that few fossils have been found. Edwards (1955) recorded small vertebrate bones collected from thinly laminated siltstone within the lower part of the GC. A part of a skull of a tiny rodent more like *Taxymys* (Middle Eocene) was found. Later, Ferrusquía-Villafranca (1987) dated the GC as mid-late Eocene age, based on the mammal remains (*Viverravus* sp. and *Apheliscus*) recovered from the lower member.

Edwards (1955) stated that one cobble contains well-preserved silicified corals identified as *Stylina* (*Heliocoenia*) sp., *Myriophyllia* sp., the *M. trinitatis* group and Drandraraea, and assigned these fossils preliminarily to the Lower Cretaceous but they could possibly be as old as Late Jurassic. Other cobbles of fossiliferous limestone contain eroded sections of corals, pelecypods and bryozoans.

Based on the information reported by Edwards (1955), we are particularly interested in investigating the clasts that contain the shallow–water assemblage.

The objective of the investigation was to conduct a benthic foraminiferal study in order to determine the age and the paleoenvironmental and paleobiogeographical significance of these microfossils found in the limestone clasts.

The benthic foraminifera are stratigraphically useful in the shallow-water environment; the comparison with the biostratigraphic ranges based on them, established mostly in Tethysian basin, enables an accurate dating of the studied foraminiferal assemblage.

In this paper we present data about the specific composition of the foraminiferal assemblage in the limestone clasts that indicate they are derived from a carbonate platform. In addition, taking into account the coarseness, the features, and the present distribution of the GC clasts, it can be assumed that these materials were derived from a source near the city of Guanajuato as previously stated (Edwards, 1955).

2. Geological setting

The Sierra de Guanajuato is located in the southern Mesa Central (Figure 1). The basal complex is composed of the Guanajuato arc and Arperos Basin (Freydier *et al*., 1996; Martini *et al*., 2011).

The Upper Jurassic–Lower Cretaceous Guanajuato arc assemblage is made up of an intrusive complex and a cogenetic eruptive succession. The intrusive complex is made up of gabbro, diorite and tonalite, locally intruded by basaltic and dolerite dike swarms, with scarce wehrlite and olivine clinopyroxenite grading transitionally to interlayered clinopyroxene and metagabbro. The eruptive succession is composed of pillow basalt and hyaloclastite interbedded with volcanic breccia, radiolarian chert, arkose, arkosic greywacke, and scarce rhyodacitic tuff at the top of the sequence (Lapierre *et al*., 1992; Ortiz Hernández *et al*., 1992). The Guanajuato arc has been interpreted as an intraoceanic arc constructed on ocean crust (Lapierre *et al*., 1992; Tardy *et al*., 1991).

The El Paxtle assemblage (Martini *et al*., 2011) is comparable to the arc assemblage described by Lapierre *et al*. (1992) and consists of the El Paxtle and Tuna Manza Formations.

Rocks of the arc assemblage overthrust the Arperos

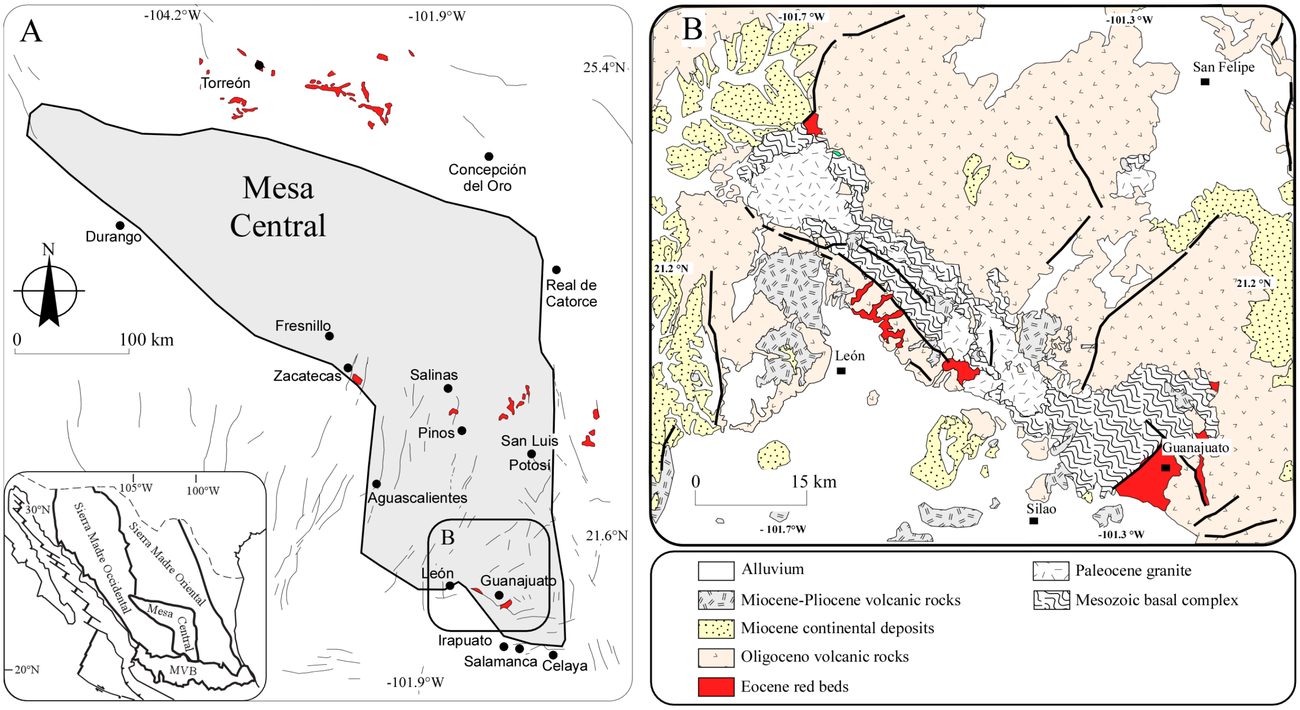

Figure 1. Geographic and geological map.

Basin assemblage, which consists of the Arperos and the Esperanza formations. The Esperanza Formation has been described as polydeformed metavolcaniclastic rocks and limestone (Echegoyén-Sánchez, 1978).

The Arperos Formation is composed of 120 m of pillow basalt hyaloclastite, radiolarian chert, and cherty shale overlain by finely bedded laminated turbidites arranged in a pile of imbricated kilometric scale nappes bounded by mylonitic shear zones (Martini *et al*., 2011). This unit has been dated by whole-rock K-Ar of the pillow basalts to span between 93 and 85 My (Ortiz Hernández *et al*., 2003). In contrast, it has been assigned a Valanginian–Turonian age based on radiolaria (Dávila-Alcocer and Martínez-Reyes, 1988); and a Tithonian–Valanginian age established from a nanofossil study (Corona-Chávez, 1988) has been reported from the sedimentary rocks overlying the pillow basalt.

Martini *et al*. (2011) considered the Esperanza Formation to be a petrotectonic assemblage made up of a volcano-sedimentary succession divided into two formations, the Esperanza and the Valenciana formations.

Rocks of the arc and Arperos Basin assemblages were folded and thrust partially metamorphosed under low-grade greenschist conditions and covered by Albian neritic limestone of the Perlita Formation (Chiodi *et al*., 1988). The available data permit more solid support of the closure of the Arperos Basin in the upper Aptian. Chiodi *et al*. (1988) provided an upper limit (Albian) from fossils in the La Perlita Formation. Martini *et al*. (2011) assigned a lower limit from detrital zircons (118 My).

Volcanic and plutonic activity, as well as sedimentation periods, occurred in the Cenozoic (Nieto-Samaniego *et al*., 1996; Hernández-Silva *et al*., 2000). Thus the GC has been interpreted as a continental molasse deposited on topographic plains, associated with post-Laramide faulting orogeny (Aranda-Gómez and McDowell, 1998).

The Losero Formation unconformably covers the GC and is considered the base of the volcanic succession of Oligocene age. The Losero Formation is composed of lithic arkose to litharenite sandstones (Puy-Alquiza *et al*., 2013). Aranda-Gómez and McDowell (1998) suggest a volcaniclastic origin and Randall *et al*. (1994) propose a volcanic origin deposited in lacustrine conditions.

3. Material and methods

The limestone clasts studied in this work come from the lower member of the GC (Figure 2).

Conglomerate compositions were determined in 12 outcrops, counting pebble populations. In each outcrop 200 pebbles were counted using the method of Dürr (1994). Fifty-two limestone clasts were collected and analyzed by polarized microscope. The benthic foraminifera in the thin sections were observed under a petrographic microscope. Microphotographs were taken with a digital camera.

4. Results

4.1. Guanajuato Conglomerate composition

The GC unconformably overlies the basal complex and is overlain by Cenozoic volcanic rocks. It is interpreted as coalescing alluvial fans deposited at the base of a fault-bounded mountain block (Edwards, 1955; Aranda-Gómez and McDowell, 1998). The GC has been divided into two members (Edwards, 1955). The lower member is composed of polymictic conglomerates with an erosive base intercalated with red sandstone layers and andesitic lavas at the base. The pebbles and cobbles of the conglomerates are composed of limestone, andesite, metasediments, diorite, and pyroxenite clasts.

The upper member is predominantly composed of polymictic conglomerates and breccias. The clast composition of the upper member shows a higher percentage of granite clasts than the lower member (Figure 3).

Limestone clasts were sampled at the base of the lower member of the GC. The limestone clasts in the samples are sub-angular to sub-rounded and measure from 7 to 50 cm. The textures of the limestone clasts are grainstone, packstone and wackestone with bioclasts, with less than 2 % lithoclasts in a micritic matrix. The bioclasts are represented by skeletal fragments of bivalves, brachiopods, gastropods, echinoderms and foraminifera (Figure 4). Non-skeletal material is less than 2 % and is composed of ooids that vary in diameter from 0.25 to 2.00 mm. The clastic material is sub-angular fine sand composed of quartz, plagioclase and andesite lytic grains.


Figure 2. Guanajuato Conglomerate outcrop showing a limestone clast.

4.2. Foraminiferal assemblage

The benthic foraminifera contained in the GC clasts are well preserved and were used to determine the age. The principal age markers are the benthic foraminifera *Pseudocyclammina lituus* (Yokoyama, 1890); *Everticyclammina virguliana* (Koechlin, 1942); *Montsalevia salevensis* (Charollais, Brönnimann and Zaninetti, 1987); *Neotrocholina valdensis* (Reichel, 1955); *Andersolina cherchiae* (Arnaud-Vanneau, Boisseau and Darsac, 1988); *Neotrocholina molesta* (Gorbatchik, 1959); *Pfenderina neocomiensis* (Pfender, 1938); *Nautiloculina bronnimanni* Arnaud-Vanneau and Peybernès, 1978; and *Hechtina praeantiqua* Bartenstein and Brand, 1949, which are discussed below.

Pseudocyclammina lituus (Figure 5ac) was first described by Yokoyama (1890) from the Torinosu Limestone in Japan, late Oxfordian, supposedly. This species was reported by Maync (1959) as early Kimmeridgian, and Kobayashi and Vuks (2006) in the Tithonian–Berriasian in the same locality in Japan. Hottinger (1967) documented the occurrence of *P. lituus* in the Kimmeridgian-Portlandian interval in Morocco. It has also been recorded from the Kimmeridgian of the Albacete province (Spain) by Fourcade (1971) and Fourcade and Neumann (1966); in Croatia this fossil occurs in an association dated as latest Oxfordian to earliest Kimmeridgian (Velić *et al*., 2002). This species has been frequently reported from the Berriasian–Valanginian (Schroeder, 1968; Azema *et al*., 1977). Pélissié and Peybernès (1982) specified the range of the species as Kimmeridgian to Hauterivian, and Bucur *et al*. (1995) defined the range from Kimmeridgian to early Valanginian. *P. lituus* has also been regarded as Oxfordian–Berriasian from the southern part of Crimea (Krajewski and Olszewska, 2007) and Mexico (Ornelas Sánchez and Alzaga, 1994) and late Kimmeridgian-Valanginian from south-western Bulgaria (Ivanova *et al*., 2008).

Everticyclammina virguliana (Figure 5b) is stratigraphically the oldest named species of this genus described by Koechlin (1942) reported from the middle

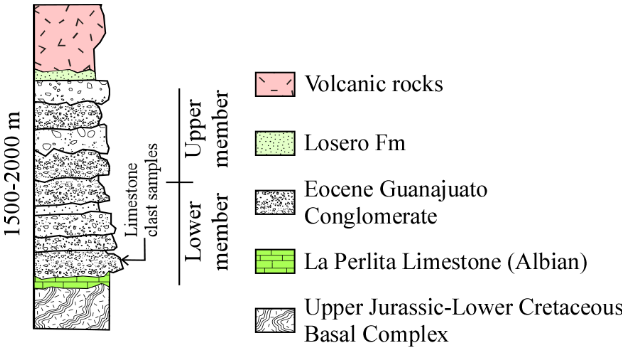

Figure 3. Stratigraphic column of the Guanajuato Conglomerate.

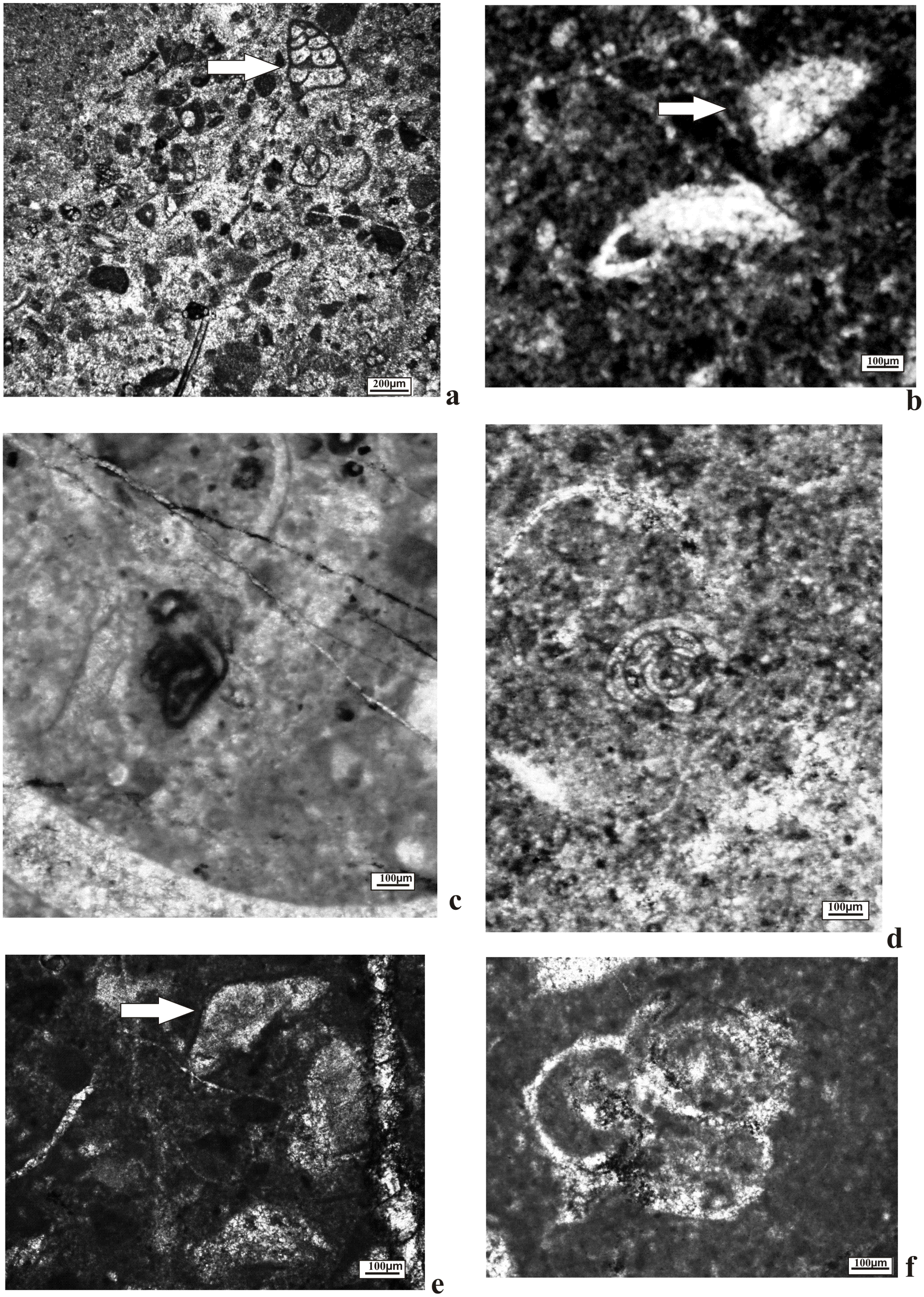

Figure 4. Berriasian–early Valanginian Foraminifera and microfauna from limestone clasts of the Guanajuato Conglomerate. a) *Protomarsonella* sp. Sample R-M25-09A. b) *Andersolina* sp., Sample RM-24-09B. c) *Ammovertellina* sp., Sample RM-24-09C. d) *Glomospira* sp. Sample RM-24-09B. e) *Neotrocholina* cf. *N. molesta* (Gorbatchik, 1959) Sample RM-24-09B. f) Gastropod RM-24-09C.

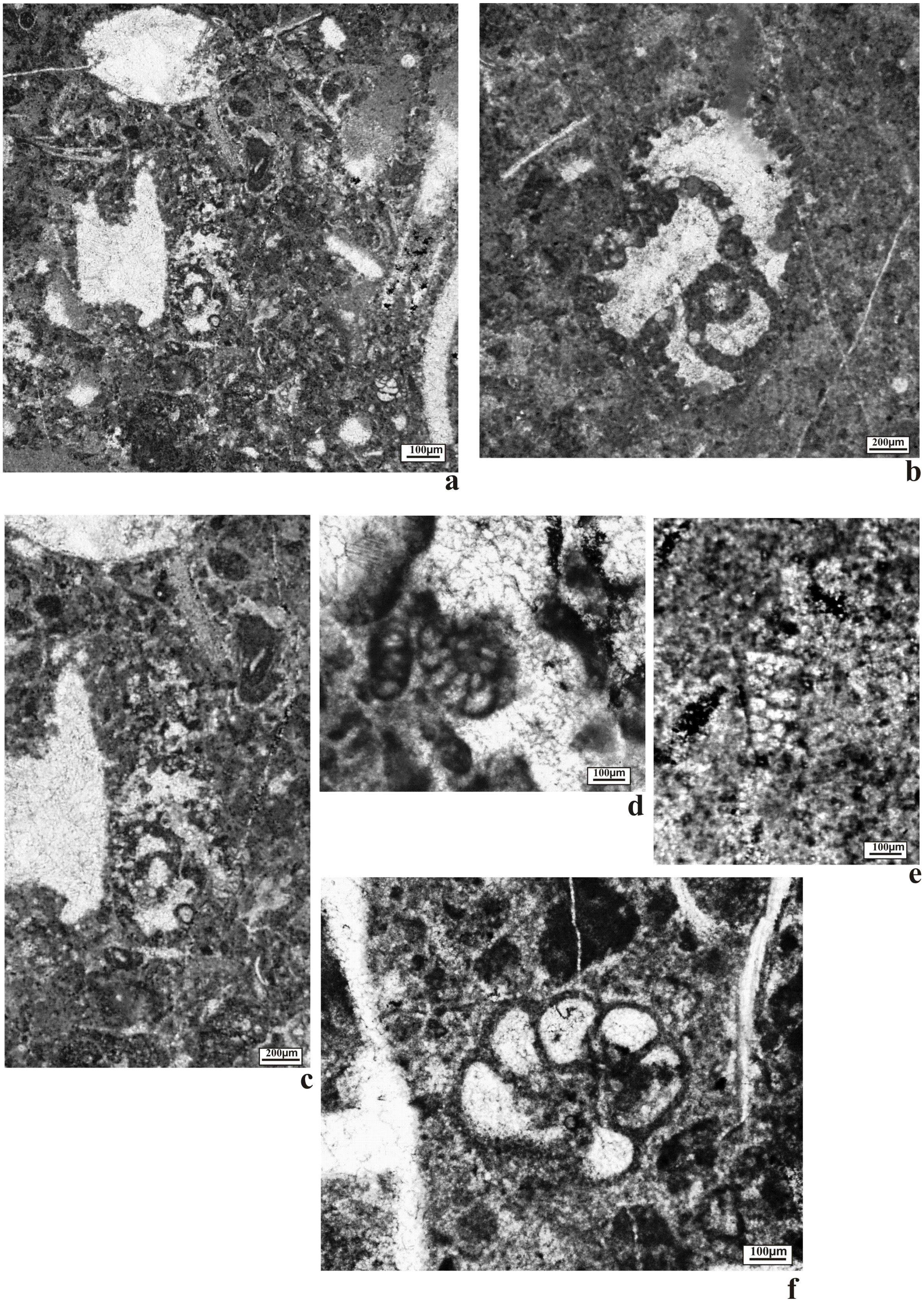

Figure 5. Berriasian–early Valanginian Foraminifera from limestone clasts of the Guanajuato Conglomerate. a, c) *Pseudocyclammina lituus* (Yokoyama, 1890), Sample RM-24-09A. b) *Everticyclammina virguliana* (Koechlin, 1942), Sample RM-24-09A. d) *Nautiloculina bronnimanni* Arnaud-Vanneau and Peybernes, 1978. e) *Montaselevia montsalvensis* (Charollais, Brönnimann and Zaninetti, 1987), Sample RM-24-09A. f) *Pfenderina neocomiensis* (Pfender, 1938), Sample RM-24-09A.

Kimmeridgian, the type specimens from the Berner Jura. Hottinger (1967) recorded this species in the Kimmeridgian of east Morocco. *E. virguliana* was recorded from Portugal where its first occurrence was at the summit of the Oxfordian. Its distribution is from northern Africa and southern Europe to the Middle East (Ramalho, 1985). Banner and Highton (1990) regarded the species as Kimmeridgian to "Portlandian," but in the earliest Cretaceous (Berriasian–Valanginian), *Everticyclammina virguliana,* in equatorial section, is virtually indistinguishable from *E. kelleri*, which is considered to be a Berriasian–Valanginian index.

Montsalevia salevensis (Figure 5e) is regarded as an important age marker. It was illustrated for the first time by Pfender (1938) after being described by Charollais, Brönnimannn and Zaninetti (1986) as *Pseudotextulariella salevensis* from the lower Valanginian of Saleve near Geneva (Switzerland). The species was later reported from the Valanginian by Schroeder (1968) in Spain; by Fourcade and Raoult (1973) in Algeria; by Azema *et al*. (1976) in the western Mediterranean region; and Altiner (1991) in Turkey. Zaninetti *et al*. (1997) in Switzerland, Chiocchini *et al*. (1988) in Italy and Bucur *et al*. (1995) in Serbia recorded the species in the late Berriasian–Valanginian interval. Ivanova and Kolodziej (2004) also recorded the species from the Berriasian–Valanginian, from Stramberk-type limestones, the Polish Carpathians, and from Italy (Bruni *et al*., 2007). Hosseini and Conrad (2008) documented the occurrence of *M. salevensis* from the Berriasian in SW Iran. A Valanginian *M. salevensis* Zone was established by Ivanova (1999) in the Balkans.

Neotrocholina valdensis (Figure 6a) was described from the Valanginian of Switzerland by Reichel (1955). It is considered a good marker of the late Berriasian–early Valanginian of NW Anatolia in Turkey (Altiner, 1991), as well as in Italy (Chiocchini *et al*., 1988), in Romania (Bucur, 1988; Bucur *et al*., 2004a; Bucur and Săsăran, 2005) and Mexico (Riva-Palacio, 1971). Schlanginweit and Ebli (1999) assigned an early Valanginian age to *N. valdensis* in the northern Alps. The known stratigraphic range of *N. valdensis* is late Berriasian–Valanginian; the species has been recorded from the Mirdita zone (Albania) in the lowermost Valanginian (Radoičić, 2005).

Neotrocholina molesta (Figure 6c) was originally described from Cretaceous basal deposits in the Crimea region (Gorbatchik, 1959). Later, it was identified in Ukraine, ranging in age from the Tithonian to Barremian (Krajewski and Olszewska, 2007), which agrees with the stratigraphic range of the species presented by Bucur *et al*. (1995) in Serbia and in northern Iran (Bucur *et al*., 2013). Pop and Bucur (2001) and Bucur *et al*. (2004b) found *N. molesta* in the south Carpathians and Gilău Mountains respectively, in an assemblage dated as Berriasian–Valanginian. According to Arnaud-Vanneau *et al*. (1988) *N. molesta* is known from the Berriasian to Barremian (Albian?) interval.

Andersolina cherchiae (Figure 6b) was described by Arnaud-Vanneau, Boisseau and Darsac (1988). It is regarded as from the Berriasian–early Valanginian in Spain (Ullastre *et al*., 2002). Hosseini and Conrad (2008) in Zagros Basin (SW Iran) considered the species to be in the interval dated as Berriasian in age. Bucur *et al*. (1995) documented the occurrence of the species in Serbia in the upper Berriasian–Valanginian. *A. cherchiae* was also recorded in Austria (Moshammer and Schlanginweit, 1999). Bucur and Săsăran, (2005), and Bucur *et al*. (2004b) in Turkey found a foraminiferal association that contains different species of Andersolina such as *A. cherchiae* and *N. molesta*, which was dated as Early Cretaceous (Berriasian–early Valanginian). Koch *et al*. (2008) regarded the stratigraphical distribution of *A. cherchiae* in Turkey as limited to Berriasian–early Valanginian. Hosseini and Conrad (2008) and Bucur *et al*. (2013) recorded *Andersolina cherchiae* in Iran in an association that they considered as Berriasian age.

Pfenderina neocomiensis (Figure 5f) was illustrated for the first time by Pfender (1938) from the early Valanginian of Provence, and has been frequently reported from the Valangian by Schroeder (1968) and Canerot (1984) in Spain and Bucur *et al*. (1995) in Serbia. These authors stated that the species is considered a good marker for this age.

Azema *et al*. (1977) and Bucur and Oros (1987) reported this species from the late Berriasian–early Valanginian, and Zaninetti *et al*. (1988) recorded the species from the late Berriasian. According to Olszewska (2010), *Pfenderina neocomiensis* has a stratigraphic distribution from the Berriasian to Hauterivian.

Nautiloculina bronnimanni (Figure 5d) was firstly reported by Arnaud-Vanneau and Peybernès (1978) from the Berriasian to upper Albian interval in the French and Spanish Pyrenees. Canerot (1984) in Spain and Altiner (1991) in Turkey recorded the species from the Berriasian to early Valanginian. Arnaud-Vanneau and Masse (1989) recorded *N. bronnimanni* from the Berriasian to Aptian in Switzerland in the Valangian–Hauterivian of the Berdiga Formation in Turkey (Bucur *et al*., 2004a), and the outer Carpathians (Ivanova and Kolodziej, 2010). The species has also been recorded by Radoičić (2005) from the Mirdita zone (Albania) in the lowermost Valanginian. Bucur *et al*. (1995) defined the stratigraphic range of *N. bronnimanni* from the Berriasian to Aptian.

Hechtina praeantiqua (Figure 7a, c) was described by Bartenstein and Brand (1949) from Hannover (Germany) of older Lower Cretaceous. Later, the species was reported from the uppermost Tithonian-Berriasian by Altiner (1991) in Anatolia, Turkey, and from the outer Carpathians (Ivanova and Kolodziej, 2010) and the Berriasian of Bulgaria (Ivanova, 1999). In addition, some miliolids such as *Istriloculina* sp., *Moesiloculina* sp., *Ophthalmidium* sp. and *Spiroloculina* sp. (Figure 7) have been reported.

4.3. Clast Age

Based on the stratigraphic ranges of the larger benthic

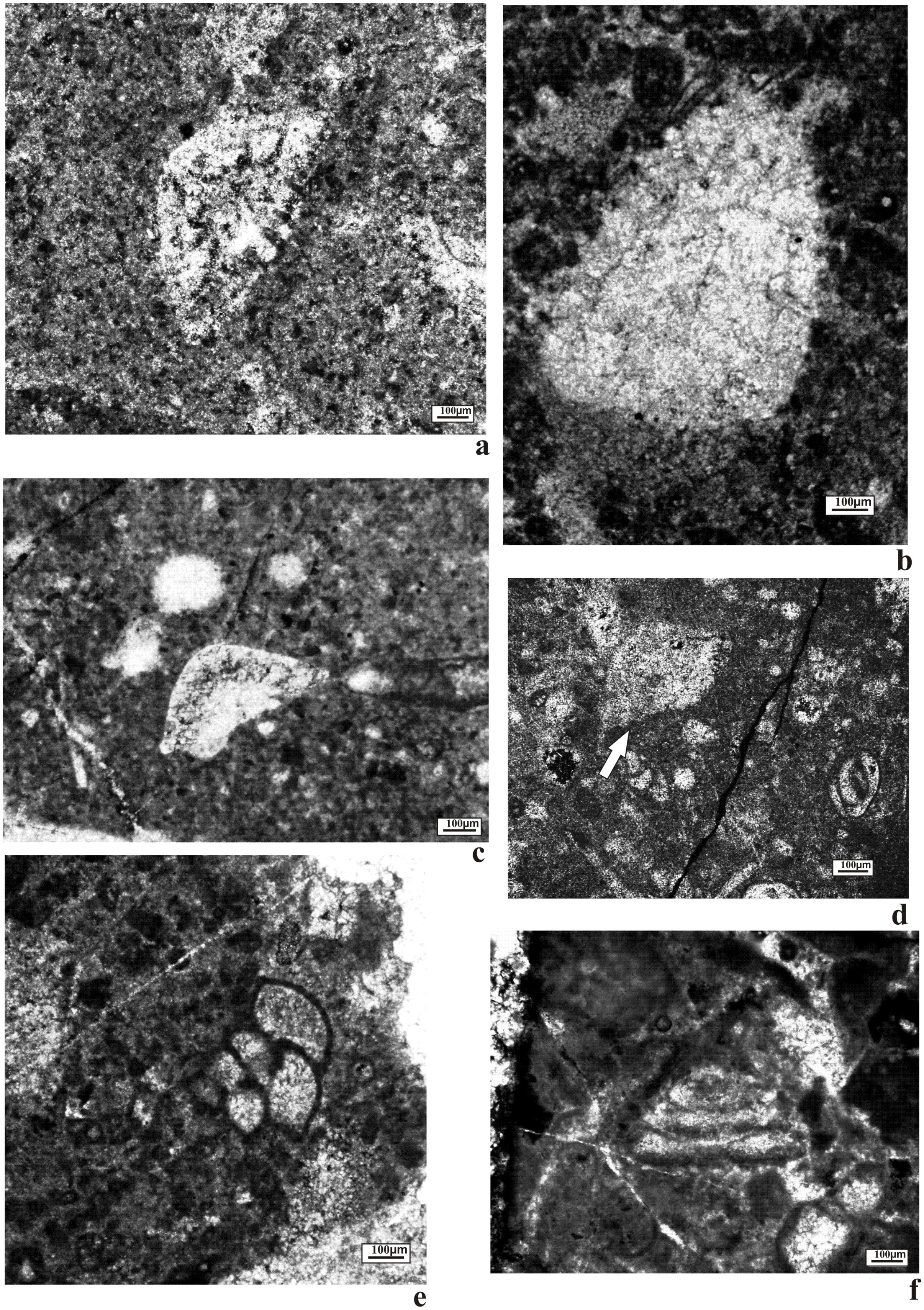

Figure 6. Berriasian–early Valanginian Foraminifera from limestone clasts of the Guanajuato Conglomerate. a) *Neotrocholina valdensis* (Reichel, 1955), Sample RM-24-09B. b) *Andersolina cherchiae* (Arnaud-Vanneau, Boisseau and Darsac, 1988), Sample RM-24-09B. c) *Neotrocholina molesta* (Gorbatchik, 1959), Sample RM-24-09B. d) *Andersolina* sp., Sample RM-24-09B. e) *Textulariopsis* sp., Sample RM-24-09B. f) "*Trocholina*" sp., Sample RM-24-09B.

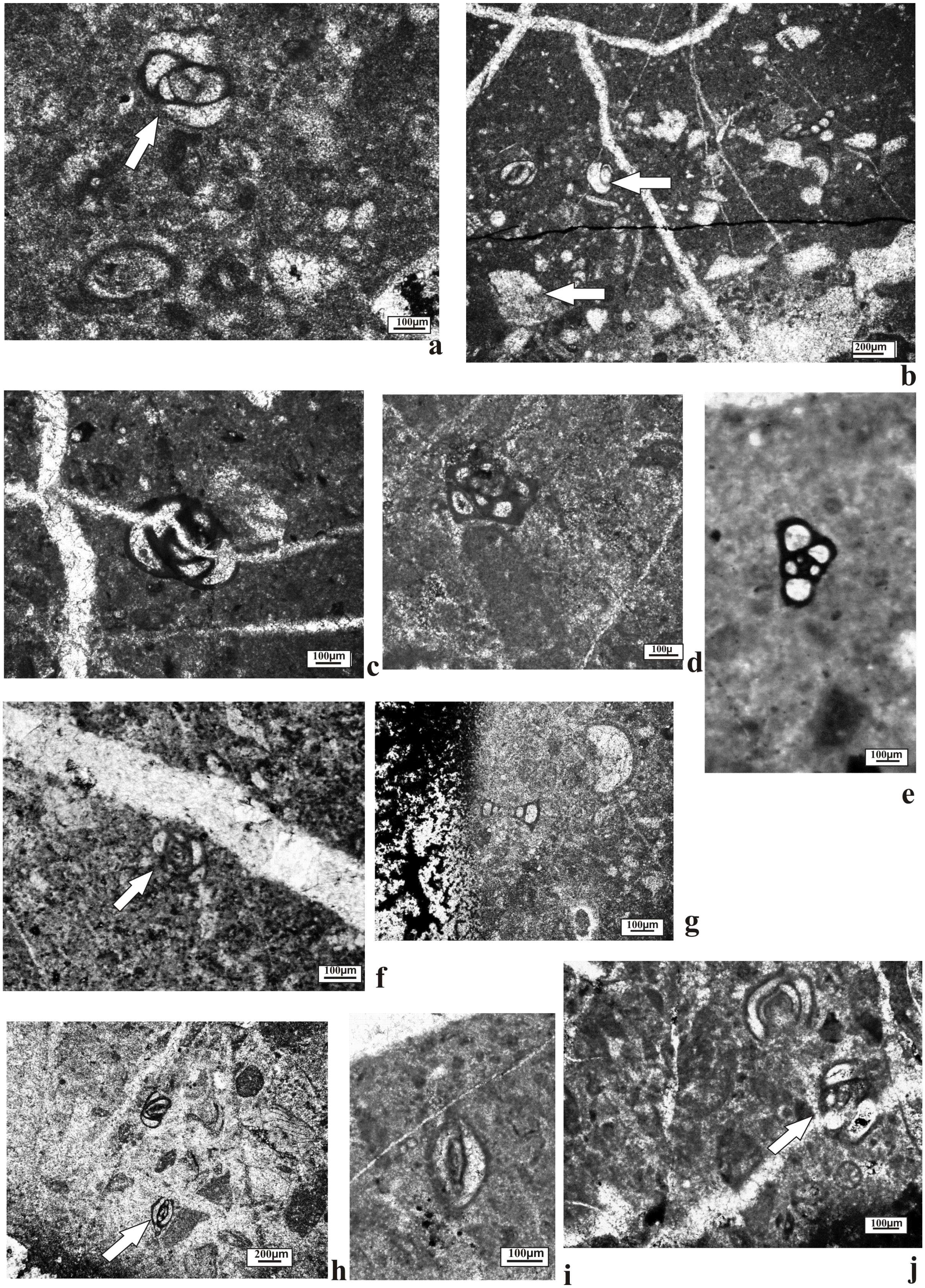

Figure 7. Berriasian–early Valanginian Foraminifera from limestone clasts of the Guanajuato Conglomerate. a, c) *Hechtina praeantiqua* Bartenstein and Brand, 1949, Sample RM-24-09C. b) *Protopeneroplis* cf. *P. banatica* Bucur, 1993, *Istriloculina* sp., Sample RM-24-09A. d) *Moesiloculina* sp., Sample RM-24-09C. e) *Rumanoloculina* sp., Sample RM-24-09C. f) *Spiroloculina* sp., Sample RM-24-09C. g) Miliolid., Sample RM-24-09C. h) *Ophthalmidium* sp., Sample RM-24-09C. i) *Istriloculina* sp., Sample RM-24-09C. j) *Hechtina praeantiqua* Bartenstein and Brand 1949, *Spiroloculina* sp., Sample RM-24-09C.

foraminifera, which are well known in the Tethys Realm we assign a Berriasian-early Valanginian age interval to the limestone clasts collected from the Eocene GC.

The dating of the studied assemblage is consistent with the age assignment in other shallow-water platforms in the Mediterranean areas of Europe and the Middle East.

The Andersolina assemblage is considered typical of the earliest Cretaceous Berriasian–early Valangian (Arnaud-Vanneau, 1985; Bucur *et al*., 1995; Bucur and Săsăran, 2005).

4.4. Clast Paleoenvironment

The foraminiferal assemblage provided a valuable means for interpreting the conditions in which the sediments were deposited.

BouDhager-Fadel (2008) stated that the larger benthic foraminifera that survived the Jurassic–Cretaceous crisis were mostly robust forms such as *Pseudocyclammina* and *Everticyclammina*. These species were observed in the studied material, indicating that they persisted until the Berriasian¬–Valanginian, inhabiting a shallow marine environment (Banner and Whittaker, 1991).

According to Szydlo (2005), the flattened or conical tests belonging to the trocholinid group, such as those of *Andersenolina*, *Trocholina*, *Neotrocholina*, prefer peri-reefal environments (Arnaud-Vanneau *et al*., 1988; Neagu, 1995). According to Mancinelli and Coccia (1999) the palaeoecologic significance of the Trocholinas is that the increase in these benthic foraminifera seems to have been influenced by particular environmental conditions characterized by strong water energy. The *Andersenolina–Neotrocholina* assemblage was found in the samples analyzed. Therefore, we infer that the environment could be similar to that proposed by these authors.

Another foraminiferal association was composed of miliolids such as *Istriloculina* sp., *Moesiloculina* sp., *Quinqueloculina* sp. and *Spiroloculina* sp. This association inhabits a very shallow, low-energy environment with fine sediments, subject to fluctuations of temperature and salinity, as has been suggested by other authors (Gräfe, 2005; Dragastan *et al*., 2005; Amodio, 2006).

4.5. Paleobiogeography

During the Jurassic, with the breakup of Pangea, Laurasia split from Gondwana forming a marine route between the Tethys and the Pacific Ocean. It is possible to establish evidence of this marine connection from the Late Jurassic using the occurrences of coincident faunal assemblages.

Although most of the benthic foraminifera of the Cretaceous had not evolved yet, and with very few new appearances in the Berriasian (5 %), nearly all the benthic foraminifera were Jurassic survivors and the majority was restricted to the Tethys Realm, colonizing all Early Cretaceous reefs. Most forms continued through the Valanginian (BouDagher-Fadel, 2008). All the Berriasian–early Valangian benthic foraminifers identified from the limestone clasts of the GC include Tethysian taxa correlated with other localities in the Mediterranean area. The finding of this Tethysian foraminiferal assemblage provides information about their presence in a zone regarded as being of the Pacific Domain.

5. Discussion

The occurrence of a Berriasian–early Valanginian shallow-water foraminiferal association in the clasts of the GC has not been previously reported in the literature, so the significance of this finding is that it suggests the existence of a shallow-water platform in the Arperos Basin. According to the age assigned to the GC limestone clasts, we propose that the shallow-water limestone could correlate with the top of the volcano-sedimentary association of the Arperos Basin.

In paleogeographic reconstructions, only the presence of basin deposits within the Arperos Assemblage has been considered in the literature; however, Echegoyén Sánchez (1978) described the Esperanza Formation as containing limestone, but without giving a detailed description. Martini *et al*. (2010) reported the Valenciana Formation "as a Lower Cretaceous calcareous debris, which results by erosion of widespread carbonate platform developed on Mexican mainland."

In this paper, we suggest that the shallow-water assemblage of the GC limestone clasts must have come from the calcareous constructions located in the Arperos Basin, since it is the nearest source. The provenance of the clasts being from other platform deposits appears very unlikely because they are distant and of different age. For example, along the Pacific margin, the majority of shallow-water deposits are younger. Several sites with shallow-water deposits have been reported from the states of Guerrero, Michoacán, Jalisco, Colima, Sonora and Baja California. These deposits span from the early Aptian to the Cenomanian (Omaña *et al*., 2012 compilation). In northeastern Mexico, the Cupido Plarform developed in the Barremian-Aptian interval, while the Aurora Formation was deposited in the mid-late Albian (Wilson and Ward, 1993; Lehmann *et al*., 2000). During the Albian, the border around the deep central part of the Gulf of Mexico received widespread carbonate deposition. Examples are the Valles–San Luis Potosí Platform, (Bonet, 1956, Carrillo-Bravo, 1971; Wilson and Ward, 1993; Basáñez-Loyola *et al*., 1993; Omaña *et al*., 2013); the Tuxpan Platform (Wilson and Ward, 1993); and the Córdoba Platfom (Ortuño-Arzate *et al*., 2003). These platforms have been dated as Albian–Cenomanian. In Chiapas, a Late Jurassic shallow-water foraminiferal association was recorded by Michaud (1987) and Ornelas and Hottinger (2006). Deposits of Albian–Cenomanian age (Michaud, 1987; Rosales Domínguez *et al*., 1997) have also been reported from the Sierra Madre limestone platform.

The shallow-water limestone clasts of the CG are in part correlated to the Torinosu Limestone, which represents a carbonate platform deposited in a fore-arc basin developed on the Jurassic–Berriasian accretionary complex in Japan (Matsuoka, 1992), an environment probably similar to that of the limestone clasts studied here.

6. Conclusions

A benthic foraminiferal and lithofacies study was carried out on limestone clasts contained in the mid-Eocene Guanajuato Conglomerate.

We documented the existence of a carbonate shallow-water platform based on the benthic foraminiferal association. In addition, the size and the angular, sub-rounded shape of the clasts indicate that they originated from a nearby source within the framework of the Arperos Basin.

Thirteen benthic foraminiferal species with a wide paleobiogeographic distribution within the Tethys realm were identified from the limestone pebbles of the Guanajuato Conglomerate.

The foraminiferal assemblages of these clasts contain many stratigraphically significant species of benthic foraminifera indicating a late Berriasian to early Valanginian age.

The benthic foraminiferal association enables a paleoenvironmental interpretation of the clasts that suggests two environments in the shallow-water platform, one association that inhabited the high-energy zone and another that occupied a quiet water environment.

The occurrence of these shallow-water limestone clasts suggests the existence of a shallow-water platform deposit of late Berriasian to early Valanginian age correlated to the Arperos Basin deposits.

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