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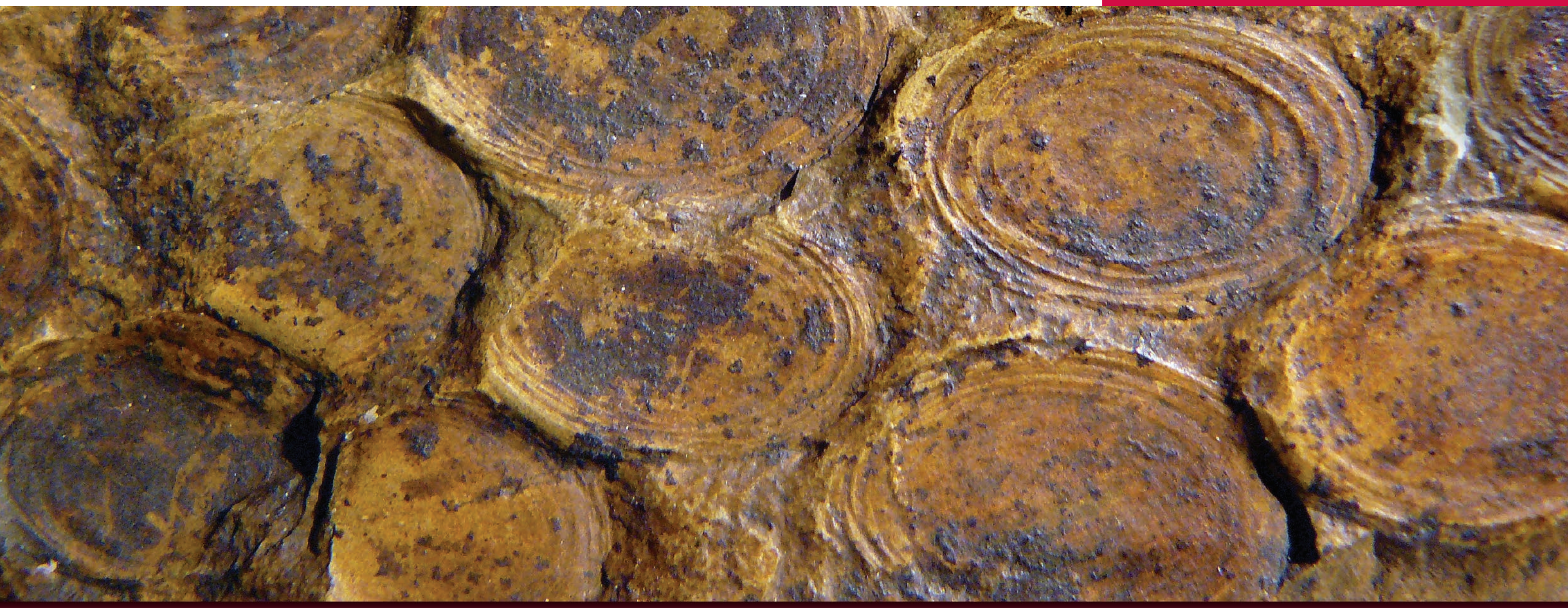

Beltanelliformis brunsae Menner *in* Keller, Menner, Stepanov & Chumakov, 1974: an Ediacaran fossil from Neoproterozoic of Dobrogea (Romania)

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Beltanelliformis brunsae Menner *in* Keller, Menner, Stepanov & Chumakov, 1974 from Dobrogea (detail of the discoid imprints).

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Beltanelliformis brunsae Menner *in* Keller, Menner, Stepanov & Chumakov, 1974: an Ediacaran fossil from Neoproterozoic of Dobrogea (Romania)

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ABSTRACT

Ediacaran fossils are now largely known in different parts of the world. However, some countries are poorly documented on these remains. Thus, rare fossils from the Neoproterozoic Histria Formation of central Dobrogea (Romania) have been reported. Two specimens with discoid imprints are described here in detail and assigned to the typical Ediacaran species *Beltanelliformis brunsae* Menner *in* Keller, Menner, Stepanov & Chumakov, 1974. This palaeontological development confirms both the large geographical distribution of this species and the Ediacaran age of the Histria Formation.

KEY WORDS
Flat discoid imprints,
Ediacaran biota,
Precambrian,
Dobrogea,
Romania.

RÉSUMÉ

Beltanelliformis brunsae *Menner* in *Keller, Menner, Stepanov & Chumakov, 1974 : un fossile édiacarien du Néoprotérozoïque de Dobrogea (Romania).*
Les fossiles édiacariens sont maintenant largement connus à travers le monde. Cependant, certaines régions restent peu documentées sur ces témoignages d'une vie archaïque. Ainsi, seuls de rares fossiles provenant de la Formation Histria du Néoprotérozoïque de Dobrogea centrale (Roumanie) ont été signalés. Deux échantillons portant des impressions discoïdes sont ici décrits en détail et attribués à l'espèce typiquement édiacarienne *Beltanelliformis brunsae* Menner *in* Keller, Menner, Stepanov & Chumakov, 1974. Cette identification permet de confirmer la large répartition de cette espèce et l'âge édiacarien de la Formation Histria.

MOTS CLÉS
Empreintes discoïdes plates,
Biota édiacarien,
Précambrien,
Dobrogea,
Roumanie.

INTRODUCTION

The period corresponding to the Late Precambrian (Neoproterozoic) and the Precambrian-Cambrian boundary is a key moment in the evolution of the biosphere and biodiversity. At this time, the metazoan organisms begin to be organized in complex aquatic ecosystems prefiguring the "Cambrian revolution" from which the modern living aquatic world settles durably with its multiple forms of life (Erwin & Tweedt 2011). The Late Proterozoic fossiliferous deposits distributed throughout the world have brought incomparable information, the most famous being that of Ediacara in Australia, which gave its name to the last period of the Precambrian, the Ediacaran (–635 to –541 million years). Abundant works were dedicated to the identification and creation of a large number of taxa giving an idea of a fairly large biodiversity of the Ediacaran biota. Nevertheless, the interest of scientific community is naturally focused on the Ediacaran "system" with a particular regard on its palaeoecological significance in the ancient biosphere and its place in the general evolution of life (Shen *et al.* 2008; Xiao & Laflamme 2008; Peterson *et al.* 2008; Liu *et al.* 2010, 2015a; Retallack 2010, 2016; Serezhnikova 2010; Grazhdankin 2014; Narbonne *et al.* 2014; Antcliffe *et al.* 2015; Droser & Gehling 2015; Tarhan & Laflamme 2015; Dufour & McIlroy 2016; Bowyer *et al.* 2017; Briggs 2017; Budd & Jensen 2017; Reid *et al.* 2017).

Many deposits have been identified throughout the world enriching the debate, but without really solving the enigmatic aspect of this life so little related to the modern world that will appear very soon after Precambrian-Cambrian boundary (Shu 2008; Erwin & Tweedt 2011). Considering this wide range of opinions, any new discovery obviously provides essential data for the understanding of this disappeared ecosystem. The comprehensive reviews of Ediacaran deposits around the world provide an interesting assessment of the state of knowledge (McCall 2006; Fedonkin *et al.* 2007). However, in Europe, apart from the large outcrops of White Sea in Russia already known, some deposits in Ukraine, and the famous Charnwood site in England, the data are much rarer and scattered among various country, in Northern Europe (Farmer *et al.* 1992; Högström *et al.* 2013), in Spain (Cortijo *et al.* 2015) and in France at the Ediacarian-Fortunian transition (Gougeon *et al.* 2018; Néraudeau *et al.* 2018). The Precambrian sediments of Dobrogea in Romania are also potentially able to contain fossil remains and to provide eventually new lighting about Ediacaran life. Several works have thus mentioned the presence in Central Dobrogea (Fig. 1) of some imprints or traces attributable to elements of the Ediacaran living world (Oaie 1992, 1993, 1998; Oaie *et al.* 2005; Seghedi *et al.* 2005; Seghedi 2012). These organic remains are represented by two kinds of specimens: a "medusoid" imprint identified as *Nemiana simplex* Palij, 1976 for one, and multiple discoid imprints of possible *Beltanelloides* Sokolov, 1965, for the other. Traces of activity were also observed and considered as belong to the *Nereites* MacLeay *in* Murchison, 1839 ichnofacies. Like the other Ediacaran sites the presence of microbial mat at the surface of Precambrian beds was recently highlighted (Saint Martin *et al.* 2011, 2012). The discovery of *Aspidella* Billing, 1872 type discs, which may represent holdfasts of frondose organisms, has made it possible to add new information and to propose an idealized reconstitution based on the knowledge of the moment (Saint Martin *et al.* 2013). However, observations made on the available material and the previous proposed determinations should probably be revised in the light of the most recent works about Ediacaran organisms. In this sense, the present preliminary article proposes to examine a certain type of discoid imprints sampled from the Precambrian terranes of Central Dobrogea, to give update identification from comparisons with known data and to discuss more general consequences.

GEOLOGICAL SETTING

The studied specimens bearing discoid imprints were collected within sediments of the basement in the central Dobrogea area (Fig. 1A). The central Dobrogea is characterized by large outcrops, especially in the valleys, of sediments belonging to Precambrian and more particularly to the Histria Formation (Seghedi & Oaie 1995) corresponding approximately to the "greenschist Formation" denomination of ancient authors (Fig. 1B). The Histria Formation, up to 5000 m thick as estimated from geological and geophysical data, consists of two coarse members of sandstone separated by a thinner member with pelites and siltites (Seghedi & Oaie 1995; Oaie 1999). According to several works (Seghedi & Oaie 1995; Oaie 1999; Oaie *et al.* 2005) considering sedimentological, structural and mineralogical features, the Histria Formation should be accumulated in a foreland basin setting, an interpretation consistent with results of geochemical and detrital zircon distribution data (Żelaźniewicz *et al.* 2001, 2009). Mineralogical, petrographic and sedimentological data show a basin sourced by a continental margin dominated by an active volcanic arc (Oaie *et al.* 2005; Seghedi *et al.* 2005). The low-grade metamorphic ("greenschists") and weakly deformed clastic rocks of the Histria Formation were considered as flyschoid-like sediments (Kraütner *et al.* 1988) corresponding to median to distal turbiditic sequences (Oaie 1998; Oaie *et al.* 2005; Seghedi *et al.* 2005; Balintoni *et al.* 2011).

A Late Proterozoic-Early Cambrian estimated age for the sediments of Histria Formation is documented both by geochemical K/Ar datation in the order of –572 million years (Giuşcă *et al.* 1967) and palynological assemblages (Kräutner *et al.* 1988). On other hand, U/Pb ages based on detrital zircon suggest a maximum Late Ediacaran depositional age (Żelaźniewicz *et al.* 2009; Balintoni *et al.* 2011). In addition, the discovery in the fine-grained members of a "medusoid" imprint identified as *Nemiana simplex* Palij (Oaie 1992, 1993), a typical Ediacaran fossil, has been invoked to confirm

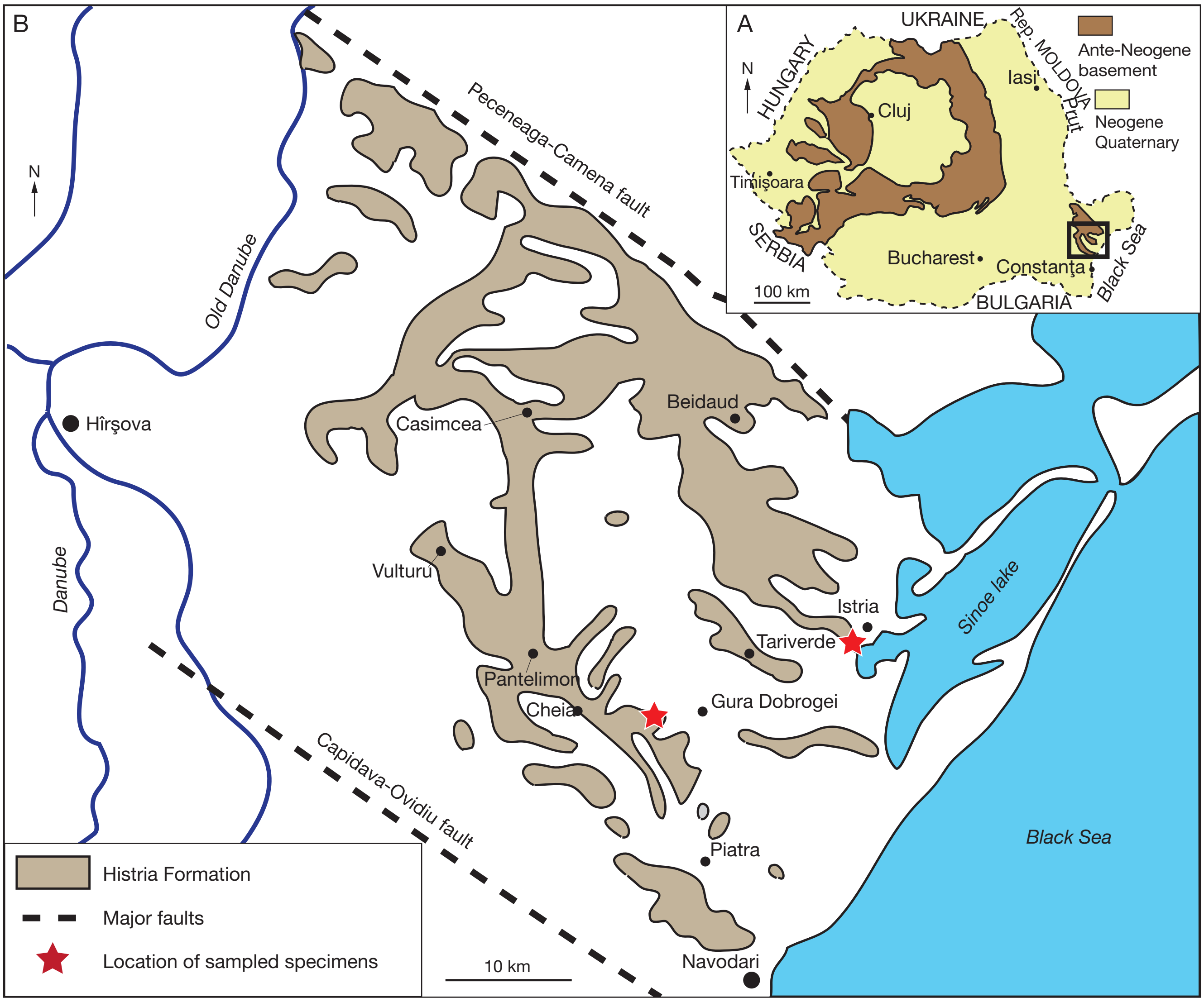

Fig. 1. — **A**, Schematic geological map of Romania and location of the study area (Central Dobrogea); **B**, geologic map of outcropping Neoproterozoic in Central Dobrogea area and situation of the sampling of studied specimens.

this Neoproterozoic age. However, the characteristics of this sample do not quite match with the original conception of this species (Palij 1976; Palij *et al.* 1979). Descriptions or discoveries of other fossil remains undoubtedly belonging to the so-called "Ediacaran Biota" would be an additional argument for confirmation of the proposed ages.

The Histria succession is very rich in sedimentary structures represented by large trains of ripples marks well-preserved on some stratification planes (Oaie 1993, 1998; Oaie *et al.* 2005). The frequent presence of surfaces marked by various wrinkled structures suggests the implication of microbial mats (Saint Martin *et al.* 2011, 2012) resulting in the formation of MISS (Microbially Induced Sedimentary Structures), often described elsewhere in the deposits of the Upper Proterozoic, especially during the Ediacaran period (Arouri *et al.* 2000; Bouougri & Porada 2007; Lan & Chen 2013; Kumar & Ahmad 2014; Parihar *et al.* 2015; Kolesnikov *et al.* 2017; Tarhan *et al.* 2017).

MATERIAL AND METHODS

The specimen 1, actually exposed in the gallery of the National Museum of Geology (Bucharest) and registered under no. P 20.996, was collected near the town of Gura Dobrogei, on the banks of the Casimcea River where the Histria Formation is well outcropping. The Precambrian terranes are here tectonized, deformed by faults and folds (Fig. 2A), and good outcrops are therefore quite rare. However, some features of sedimentation can be observed. As in most of the sediments belonging to the Histria formation, it consists of sequences of sandstone deposits and pelites (Seghedi & Oaie 1995; Oaie 1999) that can be structured into large ripple marks (Fig. 2B). Some surfaces exhibit structures similar to MISS of the *Arumberia* type (Fig. 2C) or elephant skin type (Fig. 2D). Mentioned as representing a "medusoid" imprint (Oaie 1992) close to the genus *Beltanelloides* (Oaie 1993), the specimen 1 has until now never been described in detail, although it is

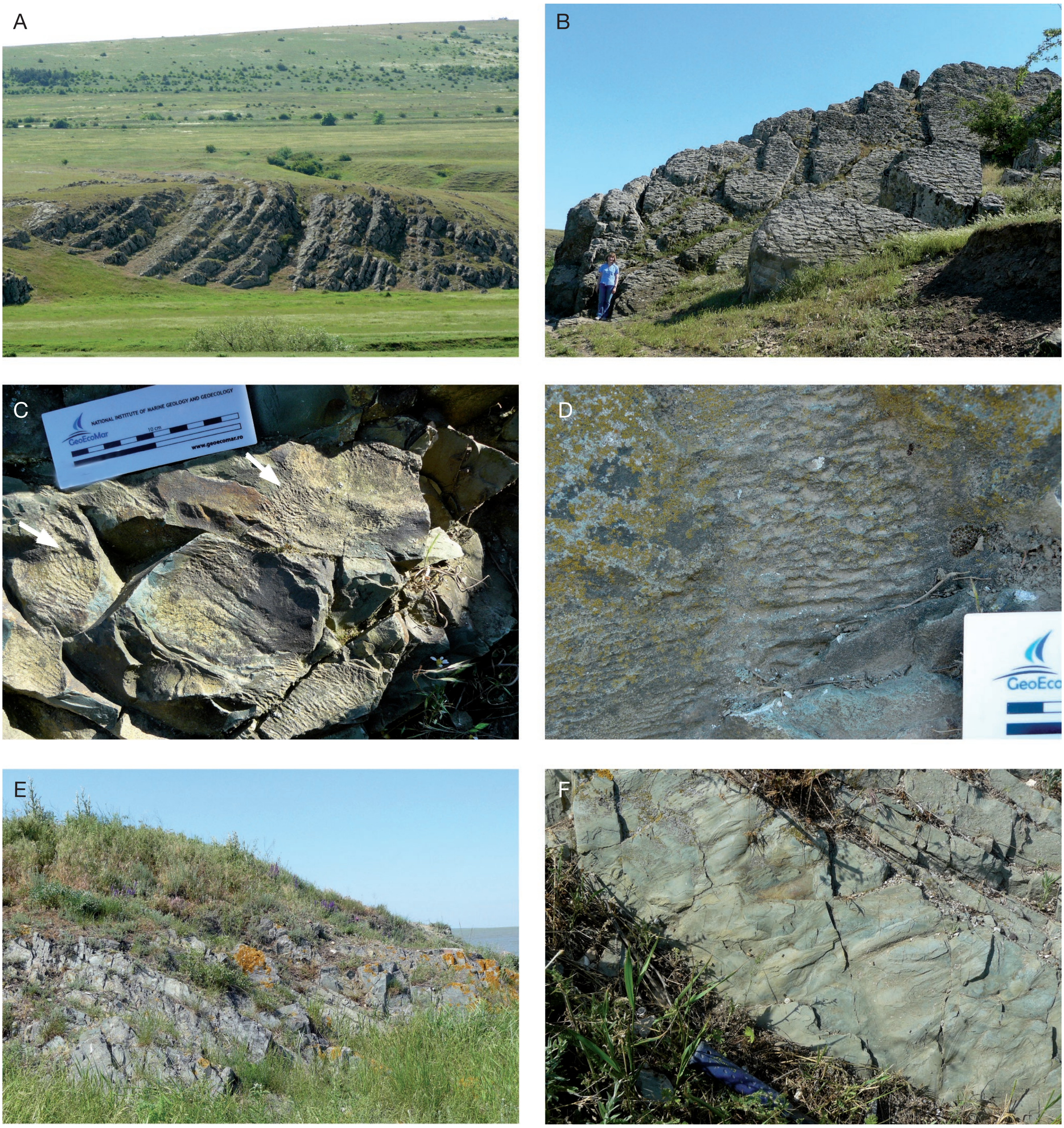

FIG. 2. — **A**-**D**, Outcrop views of the Gura Dobrogei site: **A**, general view of Precambrian straigthened beds; **B**, bed surfaces with large ripples; **C**, MISS (Microbially Induced Sedimentary Structures) of *Arumberia* type (**arrows**); **D**, MISS of "elephant skin" type; **E**, **F**, outcrop views of the Histria site; **E**, view of Precambrian beds; **F**, Bed surface showing linguoid ripple marks.

an important element of appreciation of possible remains testifying an Ediacaran life in Romanian sediments.

The specimen 2, housed in the collections of the Muséum national d'Histoire naturelle, Paris (MNHN.F.A68682), was sampled at outcrops of the Histria Formation on the edge of Sinoe Lake, near the antic town of Histria during a field campaign (2009) carried out as part of a bilateral research program between the MNHN and the Romanian Geoecomar Institute. The Precambrian sediments here vertically straightened outcrop only at a promontory below the ruins on the lake shore (Fig. 2E). There are formed of pelitic successions and only few details of sedimentation are observable. One small surface exhibit ripple marks with a linguoid aspect (Fig. 2F).

In order to appreciate the variations of imprint dimensions, diameter of round imprints or long axis of oval imprints, were measured. Considering the deformations that mostly affect

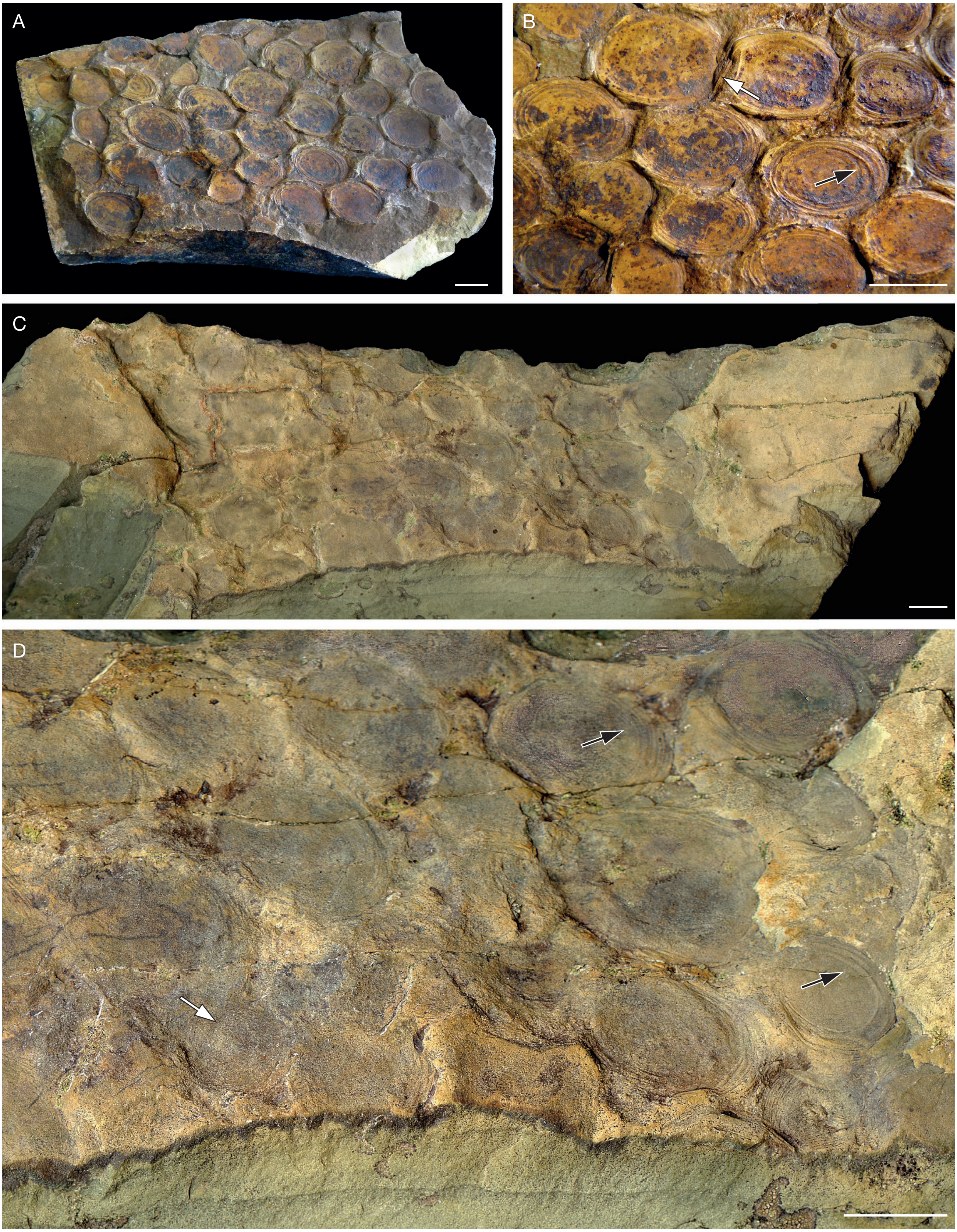

FIG. 3. — *Beltanelliformis brunsae* Menner *in* Keller, Menner, Stepanov & Chumakov, 1974 from Dobrogea: **A**, general view of specimen 1; **B**, detail of the discoid imprints of specimen 1 exhibiting the characteristic small wrinkles at the periphery (**black arrow**). Note some soft deformities of some individuals (**white arrow**); **C**, general view of specimen 2; **D**, detail of the discoid imprints of the specimen 2 (MNHN.F.A68682) exhibiting the characteristic fine wrinkles at the periphery (**black arrows**). Some individuals may partially cover others (**white arrow**). Scale-bar: 1 cm.

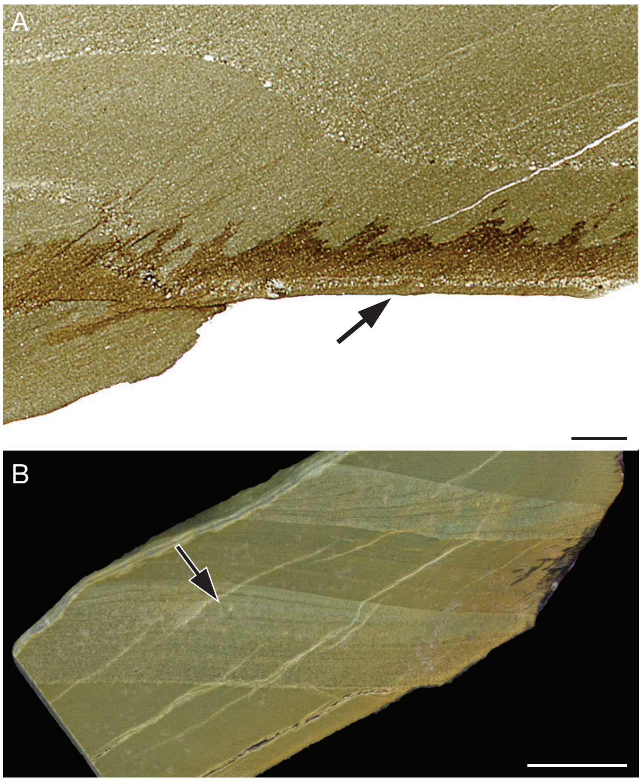

Fig. 4. — **A**, Thin section across the surface bearing *Beltanelliformis brunsae* Menner *in* Keller, Menner, Stepanov & Chumakov, 1974 imprints of specimen 2. The location of an imprint is indicated by the arrow. The imprint is covered and sealed with a thin detrital bed; **B**, polished surface across the sediment covering the imprints with coarser detrital supply structured in micro-HCS (**arrow**). Scale bars: A, 1 mm; B, 1 cm.

the specimen 1, it was considered preferable to measure in addition the surface of each discoid imprint. The surface measurement was so performed using the appropriate functions of the open software Image J.

A section intersecting the surface bearing the imprints and the underlying sediment was made across specimen 2 in order to observe in thin section the main petrographic characteristics.

DESCRIPTION

The specimen 1 is of pelitic nature, roughly rectangular, measuring approximately 14 cm in length and 7 cm in width (Fig. 3A). The oxidized ferruginous surface displays 37 visible discoid flat imprints, of which 22 are integrally preserved and can be measured (Fig. 3B). Each discoid individual is smooth at the centre and shows very fine concentric ridges towards the periphery. Discoid individuals are distributed contiguously or very slightly apart. In some cases, some discoid imprints appear to partially cover the neighboring imprint. All the imprints are affected by a unidirectional deformation according to an elongation giving them an oval shape reflecting the posterior tectonic constraints. Other earlier deformations have undoubtedly affected the surface of the sediment: small differences in elevation are observed between individuals with stretching of the wrinkled peripheral structures (Fig. 3B). The length of the long axis of the oval imprints ranges from 1.34 to 1.94 cm with an average of 1.66 cm. These measures show overall certain homogeneity of size.

The specimen 2 constitutes a block cut according to the dominant fracturation showing both the surface and an oblique section of the original sedimentation (Fig. 3C). The surface of the block, strongly ferruginized to a thickness of about 1 mm, is approximately rectangular with a length of about 20 cm over a width of 7 to 8 cm. Discoid imprints on the surface are usually contiguous and also may overlap slightly one to other. They display the same character as the first specimens with a smooth part in the center and a finely wrinkled periphery (Fig. 3D). Unlike specimen 1, the discoid imprints are very slightly deformed with a roughly circular outline. The diameter is quite heterogeneous with values distributed between 1.03 and 2.50 cm for an average of 1.55 cm. The discoid imprints itself concern only a very thin thickness (Fig. 4A). The sample shows a succession of fine-grained beds and very thin beds of coarser siliciclastic sediment. Within these sequences are individualized two bodies of one centimetre thickness with slightly coarser grains structured in micro-HCS (Fig. 4B). The characteristics of the sedimentation revealed by the polished section show that, like most identical fossils around the world, discoid imprints are represented in positive hyporelief, in bed sole position. Given the outcrop conditions, which essentially show the top surfaces of the beds, it is very difficult, if not almost impossible, to observe these fossils in place. This could explain the small number of found samples.

The measurement of the surfaces shows a disparity of average size between the two samples, the individuals of the specimen 2 showing a greater heterogeneity of distribution and on average a larger surface (Fig. 5). This reflects a fairly large variability in size within a sample or between two samples.

ASSIGNMENT AS *BELTANELLIFORMIS BRUNSAE*

The assignment of the studied samples to the Ediacaran fossils mentioned in the abundant literature dedicated to discoidal impressions comes up against the already old problems of a nomenclature mainly related in fact to taphonomic aspects. If we only refer to remains exhibiting exactly the same characteristics, namely the more or less contiguous presence of flat discoid imprints with fine concentric wrinkles at the periphery and a smooth central part, two main designations have been adopted: *Beltanelliformis brunsae* Menner, *in* Keller, Menner, Stepanov & Chumakov, 1974 (Keller *et al.* 1974; Narbonne & Hofmann 1987; Steiner 1996; Xiao *et al.* 2002; Narbonne 2007; Ivantsov *et al.* 2014; Ivantsov 2017) or *Beltanelloides sorichevae* Sokolov, 1972 (Sokolov 1976, 1997; Glaessner 1984; Sokolov & Iwanowski 1990; Fedonkin 1992; Fedonkin & Runnegar 1992; Fedonkin & Vickers-Rich 2007; Leonov 2007a, b; Leonov & Ragozina 2007; Leonov & Rud'ko 2012). However, the adoption of a systematic status is complicated for several reasons according to the authors' conception and the supposed nature of these fossils: 1) the same designation has been used for variable preservation modes; 2) different names have been assigned to the same type of fossil; 3) different names have been assigned by some authors to fairly similar discoid imprints which are supposed to be different in nature but corresponding for other authors to the same original type of organism. In general, these are rather gregarious forms preserved in a bag-shaped manner or flat imprints, assuming originally a rather globular form. Narbonne & Hofmann (1987) had already distinguished among these discoid remains a "*Beltanelliformis*-type", characterized by the presence of concentric peripheral fine wrinkles, and a "*Nemiana*-type", more globose and smooth, corresponding to two taphonomic processes of the same original organism of undefined nature (Narbonne 2007). On the other hand, Leonov (2007a) attributes these two types of preservation to two different organisms: a "*Beltanelloides*" form that would be attributable to a planktonic spherical organism and a "*Nemiana*" form that would result from the dwelling imprint of a benthic bag-shaped organism. It should be noted that this distinction is based in part on measurements showing a significant difference between the two "morphotypes". The differences in size between our two specimens show that it cannot be a discriminating argument (Fig. 5). The dilemma has been convincingly summarized by the recent comprehensive revision of Ivantsov *et al.* (2014), which demonstrates that, due to the synonymy and anteriority aspects, our fossils must be better related to *Beltanelliformis brunsae*. The name *Beltanelloides sorichevae* is thus not valid, as indicated by Narbonne & Hofmann (1987) and other authors having often pointed out in synonymy the two species (Fedonkin & Runnegar 1992). As a result, the studied specimens are determined as follow (for complete diagnosis and synonymy, refer to Ivantsov *et al.* 2014):

Regnum *incertae*
Genus *Beltanelliformis* Menner *in* Keller, Menner, Stepanov & Chumakov, 1974

Beltanelliformis brunsae Menner *in* Keller, Menner, Stepanov & Chumakov, 1974

Remark

It should be noted that in this work *Beltanelloides sorichevae* Sokolov, 1965 and *Nemiana simplex* Palij, 1976 are clearly synonymized with *Beltanelliformis brunsae*.

DISCUSSION

The problem of systematic assignment is closely linked, not only to the taphonomic processes themselves, but also to the inferred original organic nature of these fossils. Thus, the remains comparable to our specimens could be considered at the same time to be fossil bodies, fossil traces or megascopic compression (Hofmann 1992a, b; Runnegar & Fedonkin 1992, Fedonkin & Runnegar 1992, Runnegar 1992a, b; Jensen *et al.* 2006). Like many other discoidal elements of the Ediacaran biota, *Beltanelliformis* was first considered as "medusoid" organism (Sokolov 1972; Palij *et al.* 1979; Fedonkin 1981; Sokolov & Fedonkin 1984). As mentioned above, "*Nemiana*-type" preservation has been attributed to bag-shaped organisms. For a long time an affinity with benthic coelenterates such as anemones was considered. Various reconstructions have favored this option, these fossils being clearly ranked among the coelenterates (Gureev 1985; Fedonkin 1990, 1992, 1994; Seilacher *et al.* 2005). On other hand, according to Leonov (2007a), the "*Beltanelloides*-type" remains would correspond to spherical floating organisms, formed of a thin and flexible envelope fallen to the bottom and whose compaction would explain the fine concentric lines around the periphery. In the same sense, Ivantsov *et al.* (2014) consider that the presence of basically plastic prediagenetic distortions, as observed for Romanian specimens, suggests that the envelope of *Beltanelloides* was also elastic. If we adopt the idea of a single type of organism, we must reconcile the different types of preservation. Narbonne & Hofmann (1987) proposed a scenario arguing a continuum, but they give no conclusion as to the exact nature of the organism.

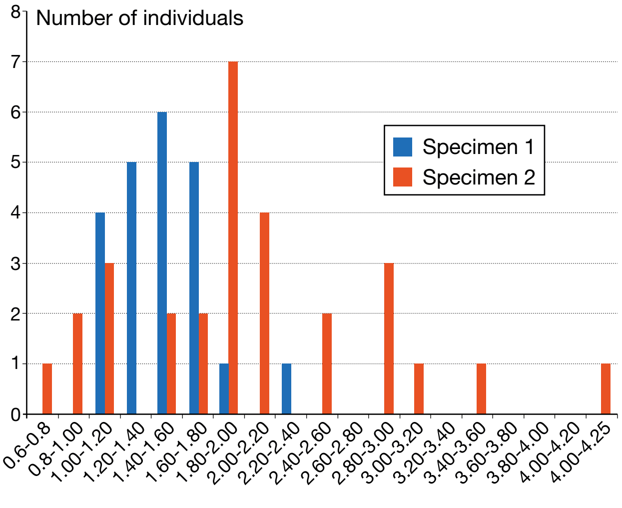

Fig. 5. — Surface measurements of individual discoid imprints for the two specimens.

Flat discoid fossils, like that of Dobrogea, have often been interpreted as compressions of more or less spherical organisms, of which, in some cases, there are only traces or organic films, or more rarely both. As a result, they have been compared with other *Chuaria*-type Ediacaran fossils known as carbon compressions, algal or microbial in origin (Hofmann 1994; Steiner 1996; Steiner & Reitner 2001; Leonov 2004; Ragozina & Leonov 2004; Grazhdankin *et al.* 2005, 2007; Xiao & Dong 2006; Leonov 2007a, b; Leonov & Ragozina 2007; Moczydłowska 2008; Ragozina *et al.* 2016; Bykova 2017; Ye *et al.* 2017), although this affinity is doubtful for other authors (Narbonne & Hofmann 1987). According to Xiao *et al.* (2017), stable carbon isotope values for samples of *Beltanelliformis* preserved as carbonaceous macrofossil do not allow to discriminate between interpretations of this organism as a colonial bacterium or a eukaryotic alga. However, the most recent studies dedicated to biomarkers from *Beltanelliformis* specimens similar to those of Romania, but with a preserved organic film, favor a microbial origin, probably cyanobacterial (Bobrovskiy *et al.* 2016, 2017, 2018).

The known occurrences of *Beltanelliformis brunsae* are apparently limited exclusively to the Ediacaran period (= Vendian), being perhaps the most common and widely distributed Ediacaran fossil worldwide (Narbonne 1998; McCall 2006). In the Precambrian of Russia (Siberia, Urals, White Sea, etc) and Ukraine, this common species seems characteristic of the "Upper Vendian" (see review in Ivantsov *et al.* 2014). In other parts of the world, known occurrences also correspond to the upper Neoproterozoic: Great Britain (Pyle *et al.* 2004; McIlroy *et al.* 2005; Liu 2011), Canada and Newfoundland (Hofmann *et al.* 1983; Liu *et al.* 2015b), China (Zhao *et al.* 2004; Wang *et al.* 2014), Mongolia (Ragozina *et al.* 2016), South America (Aceñolaza & Alonso 2001; Drefahl & Silva 2007; Netto 2012), Namibia (Wood *et al.* 2015), Australia (Xiao *et al.* 2013). However, *Beltanelliformis* has been also reported to be present in even older deposits at about 1GA (Callow *et al.* 2011). The coexistence of *Aspidella* in the Histria Formation of central Dobrogea (Saint Martin *et al.* 2013) argues rather for an Ediacarian age. Consequently, Romanian specimens extend westward the distribution field of the species known in East Europe.

Occurrences of *Beltanelliformis* around the world generally concern sediments deposited in shallow water environment (Narbonne & Hofmann 1987; Fedonkin 1992; Narbonne 1998; Aceñolaza & Alonso 2001; Grazhdankin 2004; Pyle *et al.* 2004; Grazhdankin *et al.* 2005; McIlroy *et al.* 2005; Seilacher *et al.* 2005; Leonov 2007a; Narbonne 2007; Rozhnov 2009; Rozhnov 2010; Liu 2011; Ivantsov *et al.* 2014; Ivantsov 2017; Liu *et al.* 2015b; Netto 2012; Grytsenko 2016; Ragozina *et al.* 2016), sometimes in connection with storm deposits and hummocky cross-stratification (HCS) (Narbonne & Hofmann 1987; Pyle *et al.* 2004; McCall 2006; Narbonne 2007). If the cyanobacterial nature is proved, we can estimate that *Beltanelliformis* occurences would correspond to the photic zone. As a consequence, it should be considered that part of the Histria Formation does not correspond to distal turbidites, as has often proposed, but to shallow environments that may be characterized by storm deposits. This trend is consistent with the extensive microbial mat surfaces observed in the Histria Formation (Saint Martin *et al.* 2011, 2012) and the sedimentological features of the specimen 2.

CONCLUSIONS

The studied specimens unambiguously present exactly the same characteristics as various samples described in the Ediacaran deposits in Podolia, White Sea or Siberia. Although the discussion of their origin is not yet fully decided, recent studies seem to show that the hypothesis of the cyanobacterial colony imprint can be favored. The attribution of these specimens to the Ediacaran morpho-species *Beltanelliformis brunsae* is probably the most acceptable.

The main interesting consequence is the confirmation of the Ediacaran age of the Histria Formation and therefore of the various organic remains known in Central Dobrogea. The deposits of the Histria Formation therefore represent a certain potential for restitution of the Ediacaran life in the Romanian ground. Further systematic field investigations would better measure the abundance and the diversity of the Ediacaran fossils.

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