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Protoarchivolva aurorae n. gen., n. sp. (Gastropoda: Ovulidae) from the Lower Lutetian (Middle Eocene) of Vicenza, Italy

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ABSTRACT A highly unusual member of the family *Ovulidae* has been discovered in the form of a new fossil species from the middle Eocene of Vicenza, Italy. It is closely related to the genus *Archivolva*, so far solely represented by modern species living from the tropical Pacific to the Red Sea through the Indian Ocean. The new genus *Protoarchivolva* n. gen. is introduced, in consideration of its particularly protruding protoconch and other major differences never before observed in contemporary *Archivolva* species. It thus directly echoes the genus *Protocypraedia* of the family Pediculariidae, represented in Europe and Indonesia, and grouping together the most archaic species related to the genus *Cypraedia*.

KEY WORDS Mollusca, Gastropoda, Ovulidae, *Protoarchivolva*, new genus, *Protoarchivolva aurorae*, new species, Eocene, Italy

INTRODUCTION

The superfamily Cypraeoidea C.S. Rafinesque, 1815 from the Eocene of Vicenza, a province of northeastern Italy, has been particularly well studied and has been the subject of numerous publications, including that of Dolin & Pacaud (2009), who offered a critical update, with the description of several new species. The latter study is probably the most comprehensive to date, even if, as the authors themselves declared, it cannot claim to be exhaustive. In fact, for example, *Sphaerocypraea* F.A. Schilder, 1927, which are very rare but nevertheless reported from this period and this region, are not mentioned. Furthermore, several new species have been described since their work was published, thanks in particular to the recent work of Checchi, Zamberlan and Alberti.

The most representative sites in this region covering the Lower to Middle Eocene period are undoubtedly San Giovanni Ilarione, Monte di Malo (Rossi quarry), Valdagno (Grolla quarry) and Nogarole Vicentino (Albanello quarry), whose fossil faunas are extensively documented. Examples of references relating to the inventory of these malacological faunas can be found in Dolin & Pacaud (2009), Pacaud (2008), Zamberlan & Checchi (2014, 2015) or Checchi & Zamberlan (2017), among others. As explained above, the superfamily Cypraeoidea C.S. Rafinesque, 1815 is well represented, including, in the family Cypraeidae C.S. Rafinesque, 1815, the genera *Archicypraea* F.A. Schilder, 1926, *Protoponda* L. Dolin & J.M. Pacaud, 2009, *Gisortia* F. Jousseaume, 1884, and, in the family Eocypraeidae F.A. Schilder, 1924, the genera *Cypropterina* A. De Gregorio, 1880, *Grovesia* L. Dolin & D. Ledon, 2002, *Taviania* L. Dolin & J.M. Pacaud, 2009, *Luponovula* F. Sacco, 1894 and *Sphaerocypraea* F.A. Schilder, 1927. But the most diverse Eocene members from northeastern Italy in this same superfamily are the Pediculariidae J.E. Gray, 1853, with the genera *Cypraedia* W. Swainson, 1840, *Eucypraedia* F.A. Schilder, 1939, *Ficatrivia* L.

Dolin & J.M. Pacaud, 2009, *Protocypraedia* F.A. Schilder, 1927, *Semicypraea* F.A. Schilder, 1936, *Cyproglobina* A. De Gregorio, 1880, *Eotrivia* F.A. Schilder, 1924, *Projenneria* L. Dolin, 1997, and *Transovula* A. De Gregorio, 1880.

All these genera are now extinct and, among the Cypraeoidea, the Ovulidae J. Fleming, 1822 were to our knowledge only represented in Italy in the Pliocene fossil record, notably with the species *Neosimnia pliomajor* F. Sacco, 1894 and *Pseudosimnia passerinalis* J.B. Lamarck, 1810 (Pacaud, 2021). Some Eocypraeidae also appeared in the Pliocene, with several species of *Apiocypraea* F.A. Schilder, 1927 (Fehse, 2004, 2009 and refs. therein), but no *Ovulidae* had ever been reported from the Eocene of Italy, whereas numerous species are known from this stratigraphic stage in France. It should also be added that no extinct genus of Ovulidae was known to date, all those in this family having living species, mostly in warm seas.

In this paper, we describe the first specimen of Ovulidae found in Eocene outcrops, in the Vicenza province, Italy. It is closely related to the genus *Archivolva* F. Lorenz & D. Fehse, 2009, which has never been recorded in Europe, either as a living or fossil species. *Archivolva* differs from all other Ovulidae genera in that its protoconch is located posteriorly instead of being internalized, and is therefore visible on the adult shells of the corresponding species. Previously known with the two species *A. clava* T. Habe, 1991 and *A. lissenungensis* F. Lorenz, 2005, originally placed in the genus *Dentiovula* Habe, 1961, *Archivolva* has proved far more diverse than expected (Lorenz, 2009), with now five living species. Two are endemic to the Red Sea, with *A. kahlbrocki* F. Lorenz, 2009 and *A. alexbrownii* F. Lorenz, 2012, one is endemic to the Maldives, in the Indian Ocean, with the newly described *A. cheripoda* F. Lorenz, 2024, whereas the latter two, *A. clava* T. Habe, 1991 and *A. lissenungensis* F. Lorenz, 2005, have much wider ranges, from Papua New Guinea to Reunion Island through Indonesia, the Philippines and Malaysia (Lorenz, 2009).

However, the uniqueness of the morphospecies considered here prompted us to introduce a new genus, whose character is even more archaic than that which presided over the choice of the name *Archivolva*. In this case, the protoconch is not only pseudoevolute and visible as in living *Archivolva* species (Fehse, 2021), it is evolute, particularly projecting, and thus suggests the creation of *Protoarchivolva* n. gen. In this, we reproduce what has been accepted for *Protocypraedia* F.A. Schilder, 1927 with respect to *Cypraedia*, two neighboring genera in the family Pediculariidae, the former characterized by its protruding protoconch, while the latter has a convolute spire.

MATERIAL EXAMINED

The only known specimen, originating from Albanello quarry, was examined. It is in excellent condition, although with a somewhat rough feel which, combined with the loss of the finest shell details and an unusual surface appearance for an Ovulidae, clearly suggests a recrystallization of the original aragonite into calcite, a more stable crystalline form of the same chemical species $CaCO_3$ (calcium carbonate) of which mollusk shells are made. However, these characteristics did not prevent us from identifying unique features, justifying on a robust basis the simultaneous description of a new species and genus from a single specimen. The holotype is held in the personal collection of the first author (Epinal, France), until new material is found.

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TYPE LOCALITY AND TYPE STRATUM

At Nogarole Vicentino, the Albanello quarry site is a Cenozoic outcrop, from which marble was extracted until its closure in the 1980s. The Ypresian marble is no longer exposed today, having been covered by the environmental restoration work carried out after the quarry closed. On the other hand, the upper limestone section and the tuff, both attributable to the Lower Lutetian, are still visible, themselves covered by nodular limestone of Middle Lutetian age (Borghi & Bottazzi, 2016). Figure 1 is representative of this geological configuration.

The specimen illustrated in this study was found in trappean limestone containing *Velates perversus* J.F. Gmelin, 1791, dated to the Lower Lutetian, *i.e.*, between 48 and 45 My. Given the modest size of the shell, less than 2 cm long, and its thinness, it is quite exceptional that it could have been extracted without damage from the extremely indurated rock in which it was embedded. Sanders *et al*. (2015), quantifying for the first time the "lithification bias" known to distort biodiversity assessment, estimated the loss in the paleobiodiversity record in an indurated facies compared to unconsolidated sediments at nearly 80%. These authors also found that this loss could be as high as 100% for species smaller than 2 mm. The geological particularity of the site, allowing only the hardest shells to be preserved, may explain even further the extreme rarity of the species described in this paper, beyond the sole fineness of its shell. Figure 2 shows the entrance to an excavation in Lower Lutetian calcareous tuff, and an example of a shell trapped in the indurated rock typical of this stratum.

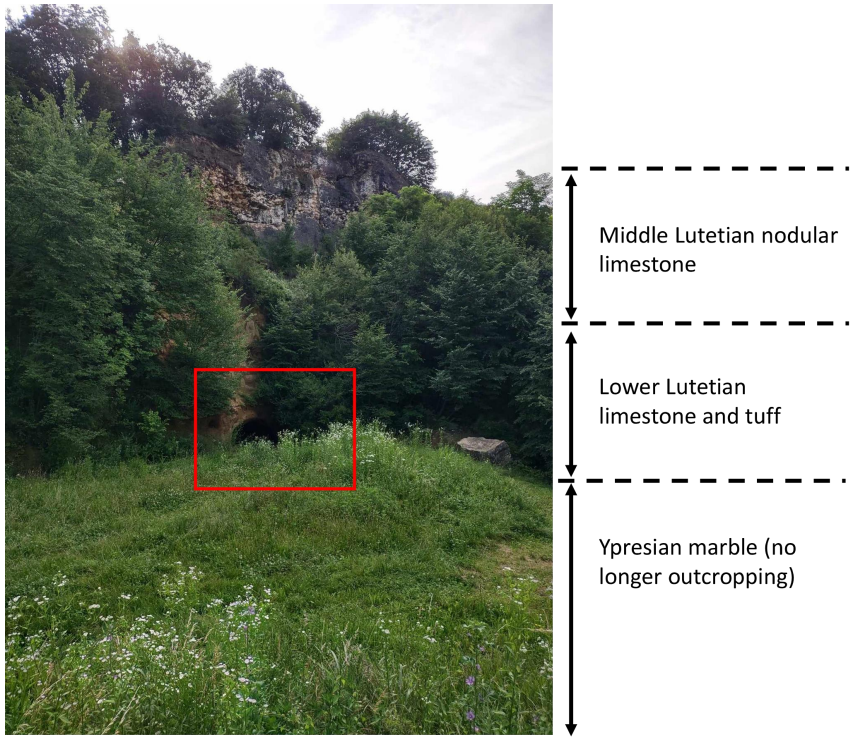

Figure 1. A general view of Albanello quarry, showing the main strata. The red rectangle corresponds to the entrance to the excavation shown in Figure. 2.

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Around the middle of the Eocene, some 50 to 45 My ago, the Nogarole Vicentino site was a shallow basin of the Mediterranean (Northwestern) Tethys, the part of the ocean of the same name that separated the Eurasian continent from Africa and the Arabian Peninsula, the latter two being joined together at the time. The sea level was on average a hundred meters higher than today's after a fairly sudden warming phase, known as PETM (Paleocene-Eocene Thermal Maximum), which began around 56 My ago. Although still 5 to 8 °C warmer than today's climate, cooling was already underway in the Lutetian (Palcu & Krijgsman, 2023). Nonetheless, the European edge of the Tethys was made up of numerous archipelagos with tropical climates. This configuration, particularly favorable to biodiversity, was not so different from that of contemporary Philippines or southern Japan, which are indeed hotspots, a term used to designate regions with a significant reservoir of biodiversity. Moreover, a northward migration of Tethyan forms, notably from the Lutetian of Italy, has been observed, enriching the taxa of the Paris Basin which, at the time, was at the confines of the Atlantic, Northern and Tethyan domains, with which it communicated (Merle, 2008).

Albanello quarry thus appears to be a hotspot like the Paris Basin in the Lutetian period, even if species do not seem to be as numerous due to the lithification bias mentioned above, and characterized by warm, shallow waters in which the new species described here would have evolved.

Figure 2. Excavation in Lower Lutetian calcareous tuff (red rectangle in Figure 1) and typical fossiliferous rock.

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SYSTEMATICS

Class:	Gastropoda Cuvier, 1795
Subclass:	Caenogastropoda Cox, 1960
Order:	Littorinimorpha Golikov & Starobogatov, 1975
Superfamily:	Cypraeoidea Rafinesque, 1815
Family:	Ovulidae Fleming, 1822
Subfamily:	Prionovolvinae Fehse, 2007

Protoarchivolva new genus †
Celzard and Alberti, 2025

Type species. *Protoarchivolva aurorae* n. sp.
Origin. Lower Lutetian (middle Eocene), Italy.
Etymology. This genus is so named because of its prominent protoconch, which adds to the morphology typical of the genus *Archivolva* F. Lorenz & D. Fehse, 2009.
Diagnosis. Shell conical and slender, with broad, smooth and rounded ends; transverse dorsal angular ridge on posterior quarter rounded; labrum very narrow, toothless, posteriorly broadly encircling the body whorl, making a right angle with the coiling axis at the apex; aperture narrow posteriorly to very wide anteriorly; protruding protoconch, located at the posteriormost end of the dorsum, and partially covered by the extension of the labrum to which it is connected.

Protoarchivolva aurorae new species †
Celzard and Alberti, 2025
(Plate 1, Figure A)

Description. Shell medium-sized, thin, conical and with a strikingly straight outline, with its maximum width on the posterior side at 75% of the shell length when viewed dorsally; aperture rather narrow, particularly posteriorly, gradually widening anteriorly until doubling its width before an abrupt narrowing at the anterior canal; labrum narrowly shouldered, smooth, of constant thickness over ¾ of shell length with a thinning at the anterior quarter, almost straight for more than half the shell length but with a very significant curvature around 90% of shell length when viewed ventrally, as it forms an angle of more than 90° at the posterior end; dorsum and ventrum apparently smooth, without visible callosity; anterior terminal wide, spatulate, smooth and blunt, slightly curved upwards when viewed from the side; posterior end very asymmetrical, smooth; anterior canal rather narrow and short; posterior canal and funiculum absent.
Type Material. Holotype, length 18.13 mm, width 8.46 mm, height 7.21 mm. Plate 1 shows the holotype of *Protoarchivolva aurorae* n. gen., n. sp. (Figure A), and the holotype of the modern *Archivolva lissenungensis* F. Lorenz, 2005, for comparison (Figure B).
Etymology. This species is dedicated to Aurora Alberti, daughter of the second author.

DISCUSSION

First, it is important to justify the creation of the new genus *Protoarchivolv*a n. gen., although it has been pointed out several times in this paper that it is very closely related to the genus *Archivolva*. Indeed, the description given above repeats, nearly literally, most of the diagnosis provided by Lorenz & Fehse (2009). However, there are several major differences. The most obvious and unusual is the protruding protoconch, which has no equivalent except in *Protocypraedia* F.A. Schilder, 1927, a genus related to *Cypraedia* W. Swainson, 1840. The comparison *Protocypraedia* / *Cypraedia* has been detailed in a recent work (Celzard, 2024). Although the Ovulidae are closely related, *Cypraedia* are members of another family, Pediculariidae, but the analogy is complete in this case, as the *Cypraedia* shell is always convolute. *Archivolva* was already unique within the Ovulidae in that it was the only genus with a protoconch that was not

completely internalized, but *Protoarchivolva* n. gen. features this peculiarity in an exacerbated and never-before-seen way.

Another remarkable difference with *Archivolva* is that the labrum completely surrounds the last whorl, thus considerably extending the aperture posteriorly, and extends to the apex to join the protoconch. At this point, the edge of the labrum is strictly orthogonal to the coiling axis of the shell. This specificity leads to the closure of the aperture, and thus to the absence of a posterior canal, which is quite exceptional. A final major difference is the total absence of terminal serrations, posterior labral dentition and rostration of the extremities, three distinctive features found in all *Archivolva* species.

Other minor differences can also be observed. For example, the aperture is not as wide at the anterior as in *Archivolva* species, so the labrum lacks the sinuous appearance. The very regular cone shape of the shell is also notable, without the famous distinct bulge found in the posterior quarter of all living *Archivolva* species, with the exception of *A. lissenungensis* F. Lorenz, 2005, whose general shape is the closest to that of *Protoarchivolva* n. gen. This is why this species is shown in Plate 1 Figure B, as it is the most comparable to *Protoarchivolva aurorae* n. gen., n. sp. The genus *Protoarchivolva* n. gen. also lacks a funiculum, which is always present in *Archivolva*, whether inconspicuously (as in *A. clava*) or very markedly (as in *A. kahlbrocki*). Finally, all *Archivolva* species have finely striated shells, even if it is sometimes necessary to observe them very closely to see this. If such striations were present in *Protoarchivolva* n. gen., they are no longer visible due to the calcite recrystallization of the only representative known to date, giving it a particularly coarse, granular surface appearance.

It is worth digressing on this point. The diagenetic loss of aragonite is a well-known phenomenon, partly due to the nature of the soil. Foote *et al.* (2015) have shown, using the Cenozoic mollusks of New Zealand as an example, that "whereas there is no bias against aragonitic taxa in siliciclastic lithologies, calcitic taxa are preferentially favored both in limestones and in carbonate-rich environments regardless of lithology". Thus, according to these authors, it is 8 times more likely to sample calcitic taxa in limestones deposited during carbonate-rich times. To confirm that the extremely coarse surface of the holotype of *Protoarchivolva aurorae* n. gen., n. sp. was indeed due to recrystallization of the shell in the form of calcite, its Raman spectrum was recorded using a laser of wavelength 785 nm filtered at 10% of its power, and a holographic

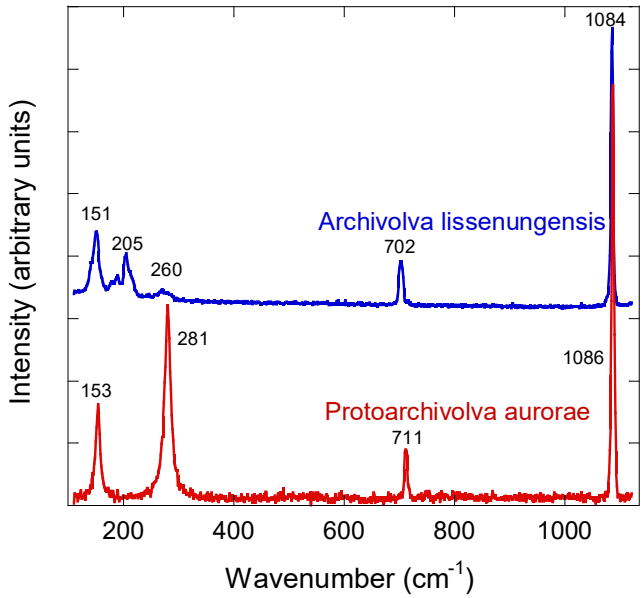

Figure 3. Raman spectra of the shells of *Archivolva lissenungensis* (blue) and the holotype of *Protoarchivolva aurorae* (red). Numerical values indicate the positions of the main bands.

grating of 1800 lines per millimeter. For comparison, the spectrum of a specimen of *A. lissenungensis* was produced under exactly the same conditions, by pointing the laser at the

same area of the columellar lip, close to the anterior end. The spectra are shown in Figure 3, in the wave-number range from 120 to 1120 cm^{-1}.

Raman spectrometry is a non-destructive technique that provides information on the composition and structure of materials. Thus, all the bands appearing in the spectrum of *A. lissenungensis* (notably at 205, 260 and 702 cm^{-1}) correspond strictly to the aragonite phase, with two others (at 151 and 1084 cm^{-1}) also common to calcite (Kupka *et al.*, 2016, Arroyo-Loranca *et al.*, 2020). In contrast, in the holotype of *Protoarchivolva aurorae* n. gen., n. sp. all bands (at 153, 281, 711 and 1086 cm^{-1}) are absolutely characteristic of natural calcite formed under ambient conditions (Liu *et al*., 2017, Wehrmeister *et al*., 2007). No other calcium carbonate phases are present, indicating that the entire shell was indeed transformed into calcite during the fossilization process.

It is also worth recalling that, at least in the Cypraeidae, juvenile specimens are known to have a protruding spire not yet covered by the body whorl, with some exceptions such as the genus *Archicypraea* F.A. Schilder, 1926, which also retains this characteristic when fully grown. Yet the holotype of *Protoarchivolva aurorae* n. gen., n. sp. is actually an adult shell, as evidenced by the thickness of the labrum, which is clearly shouldered. Finally, the vast majority of Cypraeidae have an evolute spire, whereas that of Ovulidae is convolute (Fehse, 2021), now with the notable exception of *Protoarchivolva* n. gen. However, the latter should not be considered as a missing link between the modern Ovulidae and a yet-to-be-determined ancestor in the superfamily Cypraeoidea. Indeed, some Ypresian (56 - 47.8 My) Ovulidae are known and display all the modern characteristics of their genus, such as *Simnia lhommei* Cossmann 1907, from the Cuisian (Upper Ypresian) of the Paris Basin, which is therefore several My older than the new species discussed here. Similarly, *Protocypraedia* from the Lutetian of northern Italy, the Pyrenees or the Paris Basin are not ancestors of *Eucypraedia* either, since, for example, *Eucypraedia martinezi* L. Dolin & O. Aguerre-Chariol, from the Ilerdian (56.0 - 51.0 My) of the Corbières massif (southeastern France), is even more ancient. Interestingly, the Lower Lutetian of the Vicenza province has produced three genera with a protruding protoconch: *Archicypraea*, *Protocypraedia* and *Protoarchivolva*. It is difficult to say what ecological feature of this Eocene period might have favored the appearance of such an appendage, which is not found in other Cenozoic periods.

In short, all these differences with *Archivolva* seem to us to be more than sufficient to claim the status of a new genus, albeit monospecific for the time being, and even based on a single specimen, but with indisputable morphological characters. We felt it prudent to avoid limiting ourselves to the subgenus level, despite the consideration of two well-known counterexamples in the fossil Cypraeidae, whose remarkable characters did not elevate them to full genus status, namely *Megalocypraea* F.A. Schilder, 1927, assimilated to *Gisortia* F. Jousseaume, 1884, and *Palliocypraea* M. Cossmann, 1906, assimilated to *Umbilia* F. Jousseaume, 1884. Indeed, a sub-genus can give the illusion of a well-established classification, especially in the case of fossils, for which the absence of molecular criteria prevents any objectivity on the genus versus sub-genus level. Consequently, since only morphological criteria can be considered, the type species is all that counts, and we hope to have convinced the readers of the importance of the discovery of

Protoarchivolva aurorae n. gen., n. sp. in the advancement of knowledge about the family Ovulidae.

To conclude, the discovery of *Protoarchivolva aurorae* n. gen., n. sp., whose singular characteristics are the subject of this paper, is a first in several respects. For one, it is the first species of Ovulidae from the Eocene of Italy, even though the other members of the superfamily Cypraeoidea are very well represented. It is also the first fossil species closely related to the genus *Archivolva* ever recorded in Europe, the associated species all living in tropical (Indo-Pacific) or sub-tropical (Red Sea) climates. Finally, a number of specific features that distinguish it from the genus *Archivolva* as initially diagnosed by Lorenz & Fehse forced us to propose *Protoarchivolva* n. gen., of which the new species described here is currently the only representative. We drew a clear parallel between *Protoarchivolva* n. gen. and *Protocypraedia*, each justified by the particularly protruding character of the protoconch found in neither *Archivolva* nor *Cypraedia*, respectively, and which according to Schilder (1927) constitutes a distinctive archaic feature. If in addition we consider that *Archivolva* always has crenulated terminal collars, as defined in the original diagnosis, which *Protoarchivolva* does not have, then *Protoarchivolva* should be treated as a full genus and not as a subgenus. *Protoarchivolva* n. gen., monospecific with *Protoarchivolva aurorae* n. gen., n. sp. thus becomes the first extinct genus of Ovulidae ever reported.

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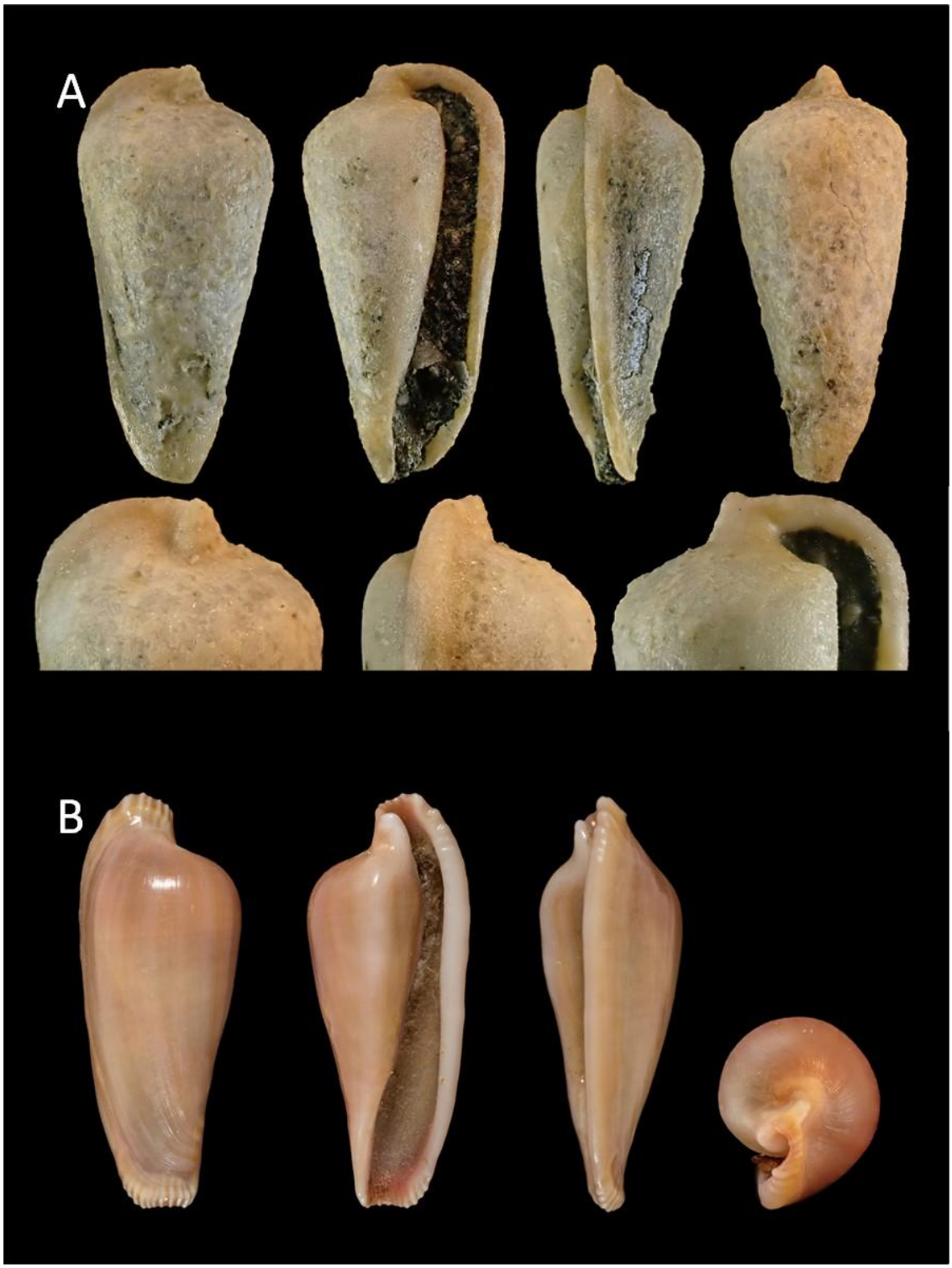

Plate 1. **A=** Holotype of *Protoarchivolva aurorae* n. gen., n. sp.: length 18.13 mm, width 8.46 mm, height 7.21 mm. **B=** Holotype (MNHN-IM-2000-21492) (the 3 photos on the left) of *Archivolva lissenungensis*, from Kavieng, Papua New Guinea: length 17.3 mm. *Archivolva lissenungensis* © Manuel Caballer, CC BY 4.0 (the 4th and right-most photo showing the spire is from a specimen of *Archivolva lissenungensis* in Alain Celzard's collection).