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The mysterious purple mountain slug: first record of *Deroceras juranum* Wüthrich, 1993 (Gastropoda, Agriolimacidae) in France from the High Vosges mountains

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Abstract. The terrestrial slug *Deroceras juranum* Wüthrich, 1993, originally described as endemic to the Swiss Jura, was delineated primarily on the basis of its distinctive dark purple colouration and subtle penial-complex characters, which distinguished it from the closely related species *Deroceras rodnae* Grossu & Lupu, 1965, but the taxonomic status of *D. juranum* has since been revised, initially as a synonym and rare dark morph of the cream-coloured *D. rodnae*, and later as a distinct, colour-varying species based on sarcobelum characters and mating behaviour. Field-work in 2022 and 2024 around Lac de la Lauch in the High Vosges, France, allowed sampling of seven specimens with morphological and anatomical characters fully matching the original description of *D. juranum*. Comparative anatomical studies with topotypes from the Swiss Jura confirmed this nominal assignment, particularly with regard to reproductive anatomy, including sarcobelum characters consistent with those reported in subsequent literature. The recent discovery of the *juranum* morphotype in the Vosges mountains, possibly the dominant homozygous genotype, extends its range westwards and raises the question of the validity of the previous records of *D. rodnae* s.l. from eastern France. The High Vosges mountains currently represent the extreme north-western limit of the distribution of *D. juranum*, which is documented at its eastern edge as far as Austria and the Czech Republic. Further research is needed to determine the true taxonomic identity of the cream-coloured morph in the Vosges and French Jura which has been called *D. rodnae*.

Key words. Cryptic species, *Deroceras rodnae* species group, slug alpha-taxonomy

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Introduction

The genus *Deroceras* Rafinesque, 1820 (Eupulmonata: Agriolimacidae) is one of the most diverse groups of terrestrial slugs, encompassing over 109 species distributed throughout temperate regions worldwide (Wiktor 2000; MolluscaBase Eds 2024). However, species boundaries within the genus remain problematic due to uniform external morphology and significant intraspecific variability that often overlaps with interspecific variability (Zając & Stec 2020), a classic and recurring problem in the alpha-taxonomy of terrestrial and freshwater gastropods. Consequently, species delimitation within *Deroceras* relies on detailed genital anatomy, mating behaviour and, increasingly, molecular approaches to resolve cryptic diversity and assess evolutionary relationships (Hutchinson & Reise 2009; Reise *et al.* 2011; Araiza-Gómez *et al.* 2017). However, the molecular data remain sparse, and phylogenetic relationships have only been clarified for a handful of nominal species (Hutchinson *et al.* 2020; Zając & Stec 2020). This taxonomic handicap particularly limits, for example, the ability to identify pest slugs with potentially significant economic and environmental impacts, and to identify species of high conservation value (Gregoric *et al.* 2013; Rowson *et al.* 2014).

Deroceras juranum Wüthrich, 1993 is one of these enigmatic species in the western part of Europe. Originally

described as endemic to the Swiss Jura, *D. juranum* was distinguished from *Deroceras rodnae* Grossu & Lupu, 1965 by its dark-purple coloration, larger body size (up to 70 mm in life), and subtle differences in genital morphology, notably a flattened, fan-shaped penial stimulator. Its known distribution was historically restricted to cool and humid environments at altitudes above 900 m in the southern range of the Swiss High Jura Mountains (Wüthrich 1993).

However, Reise (1997) suggested that the dark purple *D. juranum* is not a distinct species, but rather a Mendelian colour morph of the cream-coloured *D. rodnae*. Based on comparative analyses of genital anatomy, mating behaviour, breeding experiments and allozyme genetic analyses of Swiss specimens, she hypothesised that the purple colouration is controlled by a single gene locus, with the purple allele dominant over the cream allele. The purple morph could confer a selective advantage at higher altitudes. Therefore, Reise (1997) concluded that the cream and purple populations occurring in the Swiss Jura belong to the same species and that *D. juranum* is a junior synonym of *D. rodnae*, a view shared by Wiktor (2000).

However, Hutchinson & Reise (2009) showed that the apparently extensive range of *D. rodnae*, from eastern France to Romania, actually includes two very similar but distinct species with a parapatric distribution. The eastern part is inhabited by the cream-coloured *D. rodnae* s.s., while the taxon in the western part, including the Swiss Jura, was called *D. juranum* but in a broader sense than Wüthrich (1993) and including both the dark-purple *D. juranum* and cream-coloured individuals.

These authors emphasised that *D. rodnae* s.s. and *D. juranum* differ in their reproductive behaviour—the latter is characterised by prolonged courtship, downward penile eversion forming a double-helix, and sarcobelum movements around the partner's flanks—as well as anatomical divergences in the size and shape of the sarcobelum and penial glands. Their results were supported by preliminary and unpublished molecular analyses. More recent results by Hutchinson *et al.* (2020) based on the COI mitochondrial gene appear to confirm *D. rodnae* and *D. juranum sensu* Hutchinson & Reise (2009) as separate taxa. Based on Hutchinson & Reise (2009), MolluscaBase Eds. (2024) recognized both *D. rodnae* s.s. and *D. juranum* as separate species, with the latter treated in the sense of Hutchinson & Reise (2009) and including both cream and purple Mendelian individuals, not in the narrower sense of Wüthrich (1993). So far, outside the Swiss Jura the purple morphotype has only been found in Austria (Jordaens *et al.* 1998).

The recent discovery of the dark purple "*juranum*" morphotype in the Vosges mountains is the first unambiguous record of this nominal species in the north-eastern France. The aim of this study is to make a comparative analysis of the anatomical features of the collected French specimens with those of the type locality in the Jura, as well as with descriptions available in the literature and to characterise the habitat of *D. juranum* in the Vosges.

Materials and Methods

The Vosges, in north-eastern France, is a low mountain range which, together with the Palatinate Forest on the German side, forms a single geo-morphological unit covering some 8,000 km². Running from south-west to north-east, the Vosges mark the western boundary of the Upper Rhine Valley, with the Black Forest forming its eastern edge. The High Vosges, comprising the southern and central parts of the massif, extend for approximately 50 km and reach a maximum elevation of 1,424 m. The first significant high relief on the path of oceanic perturbations, this mountain range is subject to both oceanic and continental influences, dominated by westerly winds, with average annual temperature and precipitation at the highest elevations of 4 °C and 1,800–2,000 mm, respectively (Sell *et al.* 1998). Above 1,000–1,100 m, natural habitats are dominated by almost pure beech (*Fagus sylvatica* L.) stands, while at lower altitudes mixed mountain forests of fir (*Abies alba* Mill.), beech and occasionally maple (*Acer pseudoplatanus* L.) dominate (Sell *et al.* 1998). Lac de la Lauch is a glacial lake situated at an altitude of 923 m near the Grand Ballon massif, the highest peak in the Vosges. It was dammed at the end of the 19th century and turned into a reservoir. The surrounding natural habitats are classified as an area of ecological, faunistic, and floristic interest (ZNIEFF, Cirque glaciaire du Lac de la Lauch, National ID: 420030132) and are part of an Integral Biological Reserve (World Database on Protected Areas ID: 18167; National ID: FR2400170) due to the presence of habitats of community interest as defined by the EU Habitats Directive (92/43/EEC) including Asperulo-Fagetum beech forests (habitat type 9130), siliceous rocky slopes with chasmophytic vegetation (habitat type 8220) and Tilio-Aceron forests on slopes, screes and ravines (habitat type 9180).

After the first opportunistic discovery of the "*juranum*" morphotype around Lac de la Lauch in 2022 (collected by AS), more extensive visual searches were carried out in the surrounding habitats from May to July 2024 (Fig. 1A, B). A total of seven individuals were collected, of which two

Figure 1. Habitat and specimens of *Deroceras juranum* in the Vosges Moutains. **A,** view of the beech-fir forest on a scree slope near Lac de la Lauch. **B,** another view of the beech-fir forest near Lac de la Lauch. **C,** specimen sampled the 2024-07-14 [MHNEC 20241203]. **D,** same specimen showing sole colouration. **E**, Yin-yang position during courtship *sensu* Reise (2004). **F,** Detail of sarcobela position during courtship behaviour with hooked ventral margin of the sarcobelum base as described by Hutchinson & Reise (2009: fig. 8I). Abbreviations: Ba = base of the sarcobelum, spcA = specimen A, spcB = specimen B, SaA = sarcobelum of specimen A, SaB = sarcobelum of specimen A, To = tongue of the sarcobelum.

were captured and reared. These two individuals mated on 18 July 2024 (Fig. 1C–F), one day after capture, followed by the hatching of five offspring on 14 September 2024, all with dark-purple bodies. On 19 December 2024, these individuals were 4 cm long and reached 5 cm in early March 2025.

For anatomical studies, animals were drowned in water for about 12 hours and then preserved in 75% ethanol. All dissections were performed under a stereomicroscope using narrow, pointed forceps. The reproductive systems were removed and photographed using a digital camera mounted on the stereomicroscope. Line drawings were prepared by hand from these photographs. The terminology used here to describe the different parts of the reproductive system follows Wiktor (2000), and the nomenclature of all the taxa cited in this article follows MolluscaBase (https://www.molluscabase.org, accessed on March 2025). All specimens collected are deposited either at the Musée d'Histoire naturelle et d'Ethnographie de Colmar (MNHEC) or at the Naturhistorisches Museum Bern (NMBE).

Systematics and Results

Class Gastropoda Cuvier, 1795

Order Stylommatophora A. Schmidt, 1855

Family Agriolimacidae H. Wagner, 1935

Genus *Deroceras* Rafinesque, 1820

***Deroceras juranum* Wüthrich, 1993**

Type locality. "Chasseral Nordhang (Kanton Bern), oberer Teil der bewaldeten Schlucht der Combe Grède (Naturschutzgebiet), nahe beim Aussichtsfelsen 'La Corne', auf ca. 1320 m Höhe ü.M." [English translation: north slope of the Chasseral (Canton Bern), upper part of the wooded gorge of the Combe Grède (nature reserve), near the near the panoramic rock of "La Corne", at an altitude of approx. 1320 m a.s.l.].

Type material. Holotype Senckenberg Research Institute (SMF 309794); paratypes Naturhistorisches Museum Bern (NMBE 564364/14), coll. Wüthrich N°2281, 25.IX.1960.

Material examined. Switzerland • 1 adult and 3 offspring (topotypes, MHNEC 20241201); Canton of Bern, Nods, Chasseral; 26.VIII.1991; Gérard Hommay leg. France (new record) • 1 juvenile specimen (MHNEC 20241202); Haut-Rhin, Linthal, Lac de la Lauch, footpath right of dam at the end of the dike, on moss; 47.9340°N, 007.0458°E; elevation 940 m; 11.VI.2022; Aurore Stoffer leg. • 2 adults (NMBE MOLL-0585606a); Haut-Rhin, Linthal, Lac de la Lauch, footpath right of dam at the end of the dike, on *Petasites hybridus* leaf and in the litter; 47.9340°N, 007.0458°E; elevation 940 m; 26.V.2024; Aurore Stoffer, Gérard Hommay & Jean Guhring leg. • 1 adult (NMBE MOLL-0585606b); Haut-Rhin, Linthal, Lac de la Lauch, Biologic reserve, on *Petasites hybridus* leaf near the footpath under the old quarry; 47.9340°N, 007.0490°E; elevation 874 m; 9.VI.2024; Gérard Hommay leg. • 3 adults (one of them died quickly and was not preserved) and their 5 offspring (MHNEC 20241203), Haut-Rhin, Linthal, Lac de la Lauch, forest zone on scree-slope, 47.9329°N, 007.0489°E; elevation 990 m, 14.VII.2024; Aurore Stoffer leg.

External morphology and anatomy. The external morphology and anatomy of the sampled specimens conform to the diagnostic characteristics of Wüthrich (1993). Living adult specimens of *D. juranum* reach 50–70 mm in length, and preserved specimens typically measure 25–35 mm (Wüthrich 1993). The body colour is uniformly dark purple to bluish black, with a darker powdery appearance in the furrows, but without dark spots or reticulation; there is pale area around the pneumostome (Fig. 1C, D), and the sole is tripartite, with bluish-grey lateral areas. The mucus is transparent, but milky-white after irritation of the animal.

The following descriptive anatomy was based on three specimens from the Lac de la Lauch and on four specimens from the type locality in Switzerland. The penis is divided into two parts (Fig. 2A, B). The proximal part is inflated and spherical; the distal part is narrower and more or less coiled. The retractor muscle of the penis is short, strong, and joins the distal part of the penis near the junction with the vas deferens (Fig. 2B). There are two or three penial glands, which are more or less elongate and lobed; these are located near the insertion of the retractor muscle on the penis (Fig. 2C). The area between the retractor muscle of the penis and the insertion of the vas deferens is more or less pigmented (Fig. 2C) and with the emergence of some fine muscles running to the distal part of the penis (Fig. 2B).

The sarcobelum, when retracted into the proximal part of the penis, has two distinct parts, the tongue and its base (Fig. 2D). The tongue or stimulator *sensu* Hutchinson & Reise (2009), also called the primary stimulator by Wüthrich (1993) or the real stimulator by Reise (1997), is fan-shaped or lanceolate, more or less elongate, and often folded in two (forming a Z-like structure). The tongue may be more or less pigmented. The base, *sensu* Hutchinson & Reise (2009) but called the second stimulator by Wüthrich (1993), consists of a flat, broad, and more or less cone-shaped structure,

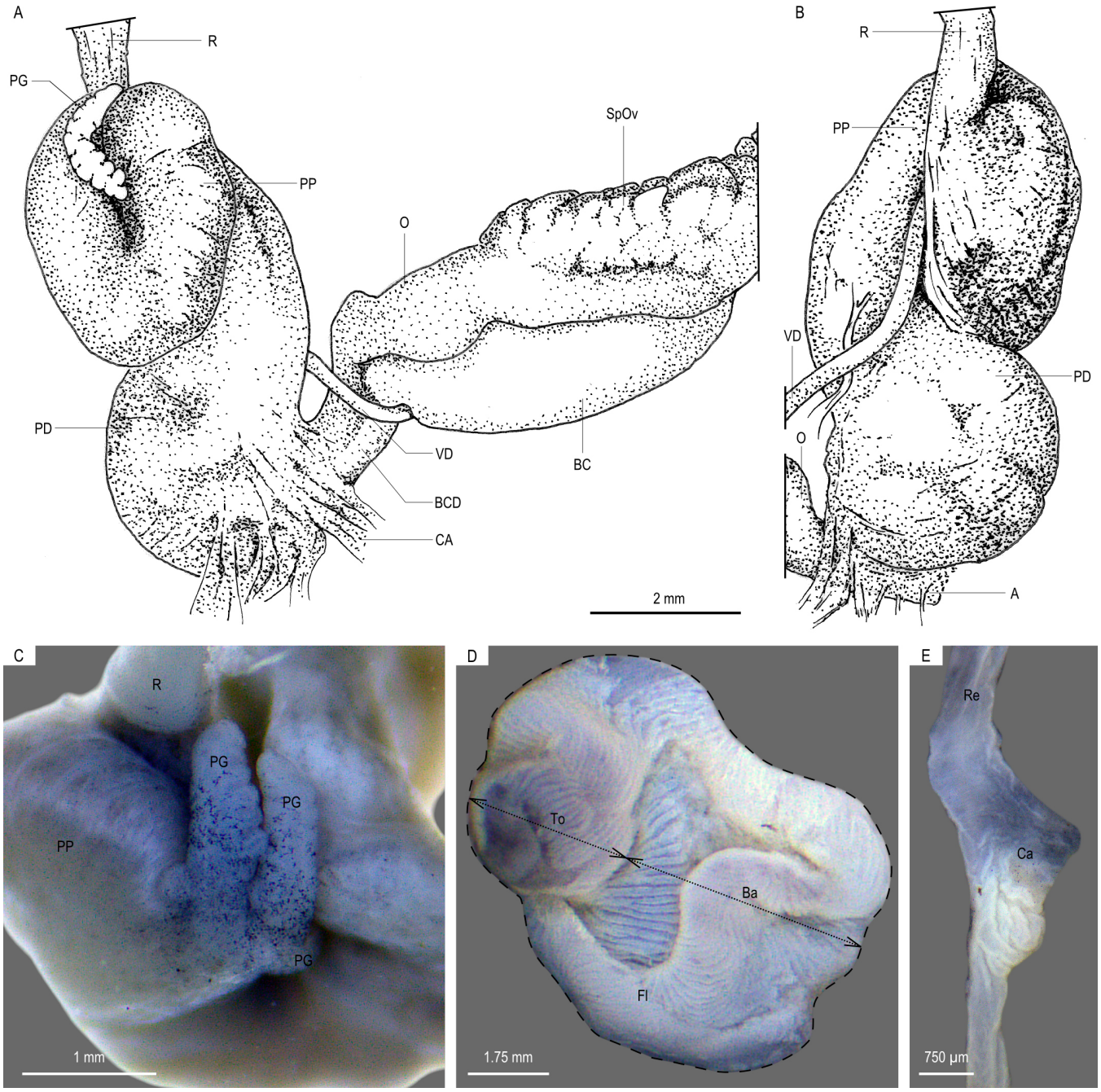

Figure 2. Anatomy of a specimen of *Deroceras juranum* Wüthrich, 1993 from the Vosges Moutains near the "Lac de la Lauch". **A**, distal part of the reproductive system, ventral view of the penal complex. **B**, distal part of the reproductive system, dorsal view of the penial complex. **C**, penial glands. **D**, sarcobelum. **E**, rectal caecum. Abbreviations: A = atrium, Ba = base of the sarcobelum, BC = bursa copulatrix, BCD = duct of bursa copulatrix, Ca = rectal caecum, CA = conjunctive adhesion, Fl flange of the sarcobelum, O = oviduct, PD = distal part of penis, PG = penial gland, PP = proximal part of penis, VD = vas deferens, R = penis retractor muscle, SpOv = spermoviduct, To = tongue of the sarcobelum, Re = rectum.

which widens distally. When contracted, the base forms a low fold which forms a thick, lip-like flange more or less connected to the tongue. This structure is diagnostic of *D. juranum*, which differs from *D. rodnae*, and corresponds to the hind part of the everted sarcobelum during courtship (Reise 1997).

The caecum is short, slightly elongated and appears as a flat blind sac overlying the rectum (Fig. 2E).

Habitat. Specimens (MHNEC 20241203, NMBE MOLL-0585606a) were sampled among moss/dead wood and *Petasites* leaves in a mixed beech-fir forest (EUNIS 41.2) on a north-facing scree slope with small underflow at an altitude of 990 m. Specimens (MHNEC 20241202, NMBE MOLL-0585606b) were also sampled in the moss and *Petasites*-dominated vegetation that develops along the dam fortifications at the edge of the beech-fir forest, corresponding to formations of hygrophilous mountain megaphorbia (EUNIS E5.5). These habitats generally develop on damp, rich soils, often disturbed by human activities.

Discussion

All the specimens from the Vosges collected around Lac de la Lauch show morphological and anatomical characters corresponding to the diagnostic characters and habitats requirements described by Wüthrich (1993) and subsequently by Hutchinson & Reise (2009), allowing the name *Deroceras juranum* to be applied unambiguously. Hutchinson & Reise (2009) proposed several key differences between *D. juranum* and *D. rodnae*, particularly in their courtship and copulatory behaviour, as well as in the morphology of the sarcobelum. In *D. juranum*, the base of the sarcobelum is broad and has a low fold that can connect to the elongated fan-shaped stimulator, whereas in *D. rodnae* the base is significantly shorter and resembles a small, teat-like protuberance. According to Reise (1997), body colour is suspected to be determined by Mendelian inheritance, with dark colouration dominant and lighter colour homozygous and recessive. Based on these observations, Hutchinson & Reise (2009) appled the name *juranum* to putative Mendelian populations characterised by a creamy or dark colouration, ranging from the Alps and the Swiss Jura northwards through southern Germany to the vicinity of Vienna (Jordaens *et al.* 1998) and the Czech Republic further east, whereas *D. rodnae* s.s. occupies the Carpathian and Sudeten mountains. Čejka *et al.* (2020) and Vašát (2019) documented *D. juranum* from the Czech Republic at two separate populations in northern and southern Bohemia, whereas they found that *D. rodnae* occurs east of the Elbe River and inhabits primarily the Carpathian part of the country.

The recent discovery of the *juranum* morphotype in the Vosges Mountains, possibly the dominant homozygous genotype *sensu* Reise (1997), extends its range westwards and raises the question of the validity of the previous records of *D. rodnae* s.l. from eastern France. Indeed, the latter has only been recorded in France from a few localities in the Vosges (Bichain *et al.* 2019, 2021), including Mittlach in Haut-Rhin (Regteren Altena 1970), Château du Nideck in Oberhaslach in Bas-Rhin (Schmid 1971) and the French Jura (De Winter 1991). The lack of a detailed description of the sarcobelum in these publications precludes retrospective assignment of these specimens to the *juranum* light morph *sensu* Hutchinson & Reise (2009), i.e. the homozygous recessive genotype suggested by Reise (1997). However, our discovery of purple specimens of *D. juranum* from the Vosges mountains supports the most likely option, that the early records of *D. rodnae* from eastern France are *D. juranum*.

The High Vosges, and possibly the French Jura, currently represent the western limit of the species' range. According to Bichain & Ryelandt (2021), about 15 other species of terrestrial and freshwater gastropods reach their westernmost limit in north-eastern France, which represents a transition zone between Atlantic and continental climates. Indeed, this geographical area represents a physical and biogeographical boundary, marking the western limit of the range of some central and eastern European snail and slug species. France, therefore, has a major responsibility for the conservation of these taxa at the edge of their range, and in particular for this population with the rare *D. juranum* dark genotype.

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