Re-assessment of ammonoid specimens from the Early Carboniferous *Protocanites* Beds of the Badenweiler-Lenzkirch Zone (Schwarzwald, Central Variscan Belt): Age constraints for a lithostratigraphic key bed

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Abstract

The *Protocanites* Beds of the Black Forest Massif (Germany) form an important lithostratigraphic key bed, as the index fossils contained in this formation enable correlation within large areas of the internal Zone of the central Variscan Belt of Europe. Furthermore, the formation provides significant information on the geodynamic evolution of the Moldanubian Zone. The stratigraphic age of the

formation has been a subject of controversy in the past; a Devonian to Viséan age has been proposed. In order to determine the age of the *Protocanites* Beds, two ammonoid specimens from the *Protocanites* Beds of Schönau are re-described here. They belong to *Becanites abnobensis* and *Pericylcus princeps* and fix the stratigraphic position of the *Protocanites* Beds to the early Late Tournaisian.

Keywords Black Forest Massif . Tournaisian . Ammonoidea . biostratigraphy . correlation

Introduction

Deciphering the geological framework within the internal zone of the central European Variscan Belt is very difficult (for the latest review, see Franke et al. 2000), as reliable biostratigraphic age determinations are rare and lithostratigraphic correlation is often questionable due to the lack of unambiguous marker beds and intensive tectonic dislocations. One of the scarce marker horizons within the Moldanubian Black Forest Massif are the *Protocanites* Beds with their type locality at the city of Schönau im Wiesental;

this formation was proven to serve as a lithostratigraphic key. Geochemical analysis together with sedimentological and petrographic investigations of this formation (Güldenpfennig 1997, 1998) led to a plate tectonic model (Loeschke et al. 1998) for the Moldanubian Black Forest Massif, in which the Badenweiler-Lenzkirch Zone was interpreted as a major Variscan suture Zone. However, the age of the *Protocanites* Beds and consequently the onset of subduction was controversial when taking the plate tectonic model proposed by Loeschke et al. (1998) into account.

Usually, the *Protocanites* Beds were interpreted as Early Carboniferous in age (Burgath and Maass 1973; Güldenpfennig 1997 with additional references therein; see Sittig 1961). However, Hann and Sawatzki (1998) suggested a general Devonian age of the formation on the basis of palynological investigations of this important marker horizon. The considerable contrast between the classical stratigraphic age assignment and new age determinations makes it necessary to reinvestigate and to re-evaluate the name-giving ammonoid from the type locality of the *Protocanites* Beds.

Geological setting

The Black Forest (Schwarzwald) is part of the Variscan Belt of Europe, which formed in Devonian -Carboniferous times by the collision of Gondwana, Laurussia and microplates in between (Franke 2000; Franke et al. 1995; Matte 1991). While the northernmost part (the Baden-Baden Zone) belongs to the Saxothuringian Zone, the central and southern areas are assigned to the Moldanubian Zone (sensu Kossmat 1927). The Black Forest Massif itself can be subdivided into four fault-bound tectonic units:

(1) The Baden-Baden Zone (BBZ) hosts accreted crustal fragments of distinct tectonometamorphic evolution (Wickert et al. 1990) and greenschist facies metasediments (Sittig 1965) of Cambro–Ordovician age (Montenari and Servais 2000; Montenari et al. 2000).

(2) The Central Schwarzwald Gneiss Complex (CSGC) contains metapsammitic gneisses and migmatites, which have undergone different metamorphic conditions (for a overview, see Kalt et al. 2000). During the Variscan convergence, the CSGC was tectonically juxtaposed against the Baden-Baden Zone in the north and also thrusted over the Badenweiler-Lenzkirch Zone (BLZ) to the south.

(3) The Badenweiler-Lenzkirch Zone (Fig. 1c) is an approximately E-W-trending thrust and fault zone of 40 km length and 3 to 4 km width (Maass et al. 1991; Sittig 1981; von Bubnoff 1912, 1921). It comprises metasedimentary units (e.g., Altherr and Maass 1977; Werling and Altherr 1987; Wimmenauer et al. 1981; Ziegler and Wimmenauer 2001), for which a Wenlock to Pridoli age is proven (Montenari et al. 2000), and non-metamorphic volcanosedimentary successions of Late Devonian (Kneidl et al. 1982; Weyer 1962) to Early Carboniferous age (Sittig 1961; Vöhringer 1960; Spiegelhalter 1910).

(4) To the south, the Badenweiler-Lenzkirch Zone is bordered against the Southern Schwarzwald Gneiss Complex (SSGC) by an E–W-trending and steeply N-dipping fault. The SSGC consists of metaluminous to slightly peraluminous biotite granites and two-mica granites of peraluminous composition (Kalt et al. 2000). Besides the granites, it hosts also a gneiss-leptynite complex and the Wehra-Wiesetal Diatexite (Wimmenauer 1984).

The *Protocanites* Beds (also termed *Protocanites* Greywackes) are part of the non-metamorphic volcanosedimentary sequences of the Badenweiler-Lenzkirch Zone. They have a thickness of more than 500 m (Kneidl et al. 1982) and occur within the entire, marine parts of the zone where they can serve as an important

lithostratigraphic marker formation. The formation can be correlated within the Badenweiler-Lenzkirch Zone as well as with the time-equivalent deposits of the Moldanubian Southern Vosges Basin (France) and the north-eastern part of the French Massif Central (Eisele et al. 2000; Leloix et al. 1999; e.g., Maass 1988; Maass et al. 1991). Wilser (1933) coined the term for relatively immature, medium grain-sized greywackes, which yielded the index ammonoid (first determined *Prolecanites* cf. *Lyoni* by Spiegelhalter 1910) at the quarry near the forestry office of Schönau im Wiesental. While earlier workers (Metz and Rein 1958; Schäfer 1957; e.g., von Bubnoff 1919) compared and correlated the *Protocanites* Beds with the metamorphosed succession of the Gschwend-Sengalenkoopf Series (sensu Altherr and Maass 1977), Sittig (1963, 1969) was the first who recognized their significance as an independent lithostratigraphic element.

Detailed petrographic and geochemical investigations of the *Protocanites* Beds and the tectonically emplaced Late Devonian shales (Kneidl et al. 1982; Weyer 1962) were carried out by Güldenpfennig and Loeschke (1991) and Güldenpfennig (1997, 1998) concluding that the *Protocanites* Beds are deposits representing only a limited time interval. The restricted period of their

occurrence together with the remarkable horizontal distribution emphasize their importance as a lithostratigraphic key horizon.

The stratigraphic age of the *Protocanites* Beds

There is a variety of age determinations for the *Protocanites* Beds of the Badenweiler-Lenzkirch Zone. Starting with Spiegelhalter (1910), the formation was attributed to the Early Carboniferous. Vöhringer (1960) suggested, in his new description of the subspecies "*Protocanites supradevonicus abnobensis*", an age of the younger part of the *Gattendorfia* Stufe (= Early Tournaisian) or a little younger. Thanks to the discovery of a specimen of *Pericylcus princeps* (de Koninck 1844) in the *Protocanites* Beds at Schönau in 1961, a Tournaisian age of the greywackes could be confirmed (Sittig 1967). Later authors then used this stratigraphic date (e.g., Güldenpfennig 1997; Maass 1988, 2006; Güldenpfennig 1998; Güldenpfennig and Loeschke 1991; Maass et al. 1991; Huth and Zedler 2019; Maass 2005; Kneidl et al. 1982).

Hann and Sawatzki (1998) carried out palynological investigations on the *Protocanites* Beds and questioned the previous age determination of the

Protocanites Beds. They recovered palynomorphs (acritarchs and chitinozoans) of Ordovician, Silurian, and also Devonian age from five samples, but only one of them (Präg, Sägentobel) yielded Devonian taxa. They concluded an undifferentiated Devonian time for the deposition of the *Protocanites* Beds, whilst the Ordovician and Silurian fossils were regarded as recycled (Hann and Sawatzki 1998, p. 186, 188). In subsequent papers, Hann et al. (2003), Vaida et al. (2004) and Hegner et al. (2005) regarded the *Protocanites* greywackes as Late Devonian to Early Carboniferous in age, while Brockamp et al. (2015), without providing evidence, suggested an early Viséan age. Already earlier, Schaltegger (2000) suggested a Tournaisian to Viséan age of the *Protocanites* Greywacke that overlays Frasnian green and yellow shales.

The co-occurrence of the ammonoid genera *Becanites* and *Pericyclus* allows a precise age determination. While *Becanites* has a longer stratigraphic range from the Early to the Late Tournaisian, *Pericyclus* provides a constraint age of early Late Tournaisian. *Becanites* is known from the *Gattendorfia* Limestone of Dzikowiec in Lower Silesia (unpublished material), Middle Tournaisian strata such as the Bordalete Formation of South Portugal (Korn 1997) and the Oued Znaïgui Formation of the Anti-Atlas of Morocco (Korn et al. 2007) as well as early Late Tournaisian strata such as the Upper Kahla Formation of Gourara of

western Algeria (Korn et al. 2010b) and the Teguentour Formation of the Mouydir of southern Algeria (Korn et al. 2010a).

The genus *Pericyclus* appears to be restricted to a limited early Late Tournaisian time interval. It was originally described from rare finds in the Calcaire de Calonne of Belgium (Delépine 1940; de Koninck 1844) and the Oued Znaïgui Formation of the Anti-Atlas of Morocco (Korn et al. 2003, 2007; Korn and Klug 2015). The most diverse assemblages with up to twenty species including several species of *Pericyclus* are in the Upper Kahla Formation of Gourara of western Algeria (Korn et al. 2010b) and the Teguentour Formation of the Mouydir of southern Algeria (Korn et al. 2010a). In summary, the co-occurrence of the two ammonoids allows only a stratigraphic attribution in the early Late Tournaisian, i.e., with a geochronological age of approximately 350 Ma according to the geological time scale (Davydov et al. 2012).

The second precise stratigraphic date in the lower portion of the greywacke, which is based on conodonts (Kneidl et al. 1982; Weyer 1962), provides an Early to Middle Famennian age. This means a geochronological age of approximately 365 Ma according to the geological time scale (Becker et al. 2012), i.e., much younger than the youngest zircons from the greywackes of the Badenweiler-Lenzkirch Zone, dated 384–371 Ma (Gruler et al. 1999).

Palaeontological descriptions

Genus ***Pericyclus*** von Mojsisovics, 1882

Pericyclus princeps (de Koninck, 1844)

Figure 2c

1844 *Ammonites princeps* de Koninck: 579, pl. 51, figs. 2, 3.

1880 *Goniatites princeps* de Koninck—de Koninck: 116, pl. 49, figs. 1, 2.

1940 *Pericyclus princeps* (de Koninck)—Delépine: 38, pl. 1, figs. 12-15.

Description. The single poorly preserved specimen GZG 190-1 (Geowissenschaftliches Museum, Georg-August-Universität Göttingen) with a conch diameter of about 47 mm is embedded on a large slab of shaley greywacke. It is slightly crushed and laterally deformed, so that the dimensions and proportions of the conch can only be estimated. The width of the umbilicus is one third of the conch diameter. Only one volution can be studied; this bears

about 45 rather sharp riblets. They cross the flanks in slightly anterior direction and turn, in the ventrolateral area, further back to form a deep ventral sinus.

Genus ***Becanites*** Korn, 1997

Becanites abnobensis (Vöhringer, 1960)

Figures 2a, b, 3

1910 *Prolecanites* cf. *Lyoni* (Meek and Worthen)—Spiegelhalter: 506, text-figs. 1, 2.

1960 *Protocanites supradevonicus abnobensis* Vöhringer: 173, text-fig. 52.

Description. Unfortunately, the original specimen could not be traced so far and may have been lost. Only two plaster casts (kept in the geological collection of the Albert-Ludwigs-Universität Freiburg) are available. They are from the same specimen of which Spiegelhalter (1910) had already published a photograph. The casts of the specimen were produced before and after the suture line preparation by Vöhringer (1960).

The specimen had a conch diameter of 60 mm and was widely umbilicate (umbilicus approximately half of the conch diameter) with almost circular whorl cross sections. The whorl overlap rate is very low. Smooth shell remains were

attached. Since the suture line cannot be studied in the plaster casts, one relies on the figure provided by Vöhringer (1960) (reproduced here in Fig. 3b). In his suture line drawing, a slightly pouched, lanceolate external lobe can be seen, which is shorter than the adventive lobe. This adventive lobe and also the lateral lobe that is located on the flank, closely resemble the external lobe in their lanceolate shape. Only the sizes of the lobes are different, the adventive lobe being the deepest. All the three lobes and the two saddles in between them have the same width.

Conclusions

The *Protocanites* Beds of the Badenweiler-Lenzkirch Zone (southern Schwarzwald) are a stratigraphically important key horizon; the formation allows correlation within large areas of the internal Zone of the central Variscan Belt of Europe and North Gondwana. However, their age classification has been the subject of controversy over the last 60 years. In order to clarify the stratigraphic position of the *Protocanites* Beds, we describe two ammonoid

specimens that originate from the type locality of the formation in the quarry near the forestry office of Schönau im Wiesental:

(1) Plaster casts of the probably lost holotype of *Becanites abnobensis* (Vöhringer 1960), first described as *Prolecanites* cf. *Lyoni* by Spiegelhalter (1910), which are permanently kept in the geological collection of the Albert-Ludwigs-Universität Freiburg.

(2) A specimen of *Pericyclus princeps* (de Koninck, 1844), found in 1961 and first mentioned by Sittig (1967), kept in the collection of the Geowissenschaftliches Museum, Georg-August-Universität Göttingen (GZG).

Based on the co-occurrence of these ammonoids, the age of the *Protocanites* Beds can be precised to a short stratigraphic interval (*Pericyclus-Progoniatites* genus zone) in the early Late Tournaisian (Fig. 4).

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Figure captions

Fig. 1 Geological map of the Badenweiler-Lenzkirch Zone, the Black Forest and its position within the mid-European Variscan Belt. **a** Relationship between the Schwarzwald and the mid-European Variscan Belt (modified after Franke 1989). AM = Armorican Massif; MC = Massif Central; VG = Vosges; SW = Schwarzwald; BM = Bohemian Massif; RH = Rhenohercynian Zone; ST = Saxothuringian Zone; MO Moldanubian = Zone. **b** Geological outline and main characteristics of the Schwarzwald (modified after Kalt et al. 2000). BBZ = Baden-Baden Zone; NSGM = Northern Schwarzwald Granite Massif; CSGC = Central Schwarzwald Gneiss Massif; BLZ = Badenweiler-Lenzkirch Zone; SSGC = Southern Schwarzwald Gneiss Massif. **c** Simplified geological framework of the Badenweiler-Lenzkirch

Zone with particular emphasis on the city of Schönau with the type locality of the discussed *Protocanites* Beds (modified after Burgath and Maass 1973).

Fig. 2 Ammonoids from the *Protocanites* Beds of the quarry near the forestry office of Schönau im Wiesental (Schwarzwald). **a, b** *Becanites abnobensis* (Vöhringer, 1960), plaster casts of the holotype (before and after preparation of the suture line). **c** *Pericyclus princeps* (de Koninck, 1844), specimen GZG 190-1. Scale bar units = 1 mm.

Fig. 3 Suture lines of early representatives of prolecanitid ammonoids. **a** *Eocanites supradevonicus* (Schindewolf, 1926) from the Early Tournaisian Hangenberg Limestone of Ober-Rödinghausen (Rhenish Mountains); from Korn (1994). **b** *Becanites abnobensis* (Vöhringer, 1960) from the *Protocanites* Beds of Schönau (Schwarzwald), magnification not stated; from Vöhringer (1960). **c** *Becanites algarbiensis* (Pruvost, 1914) from the Bordalete Formation of Bordeira (South Portugal); from Korn (1997). **d** *Protocanites lyoni* (Meek and Worthen, 1860) from the Rockford Limestone of Rockford (Indiana); from Miller and Collinson (1951). Scale bar units = 1 mm.

Fig. 4 Tournaisian ammonoid genus zones with representative species occurring in North African occurrences (Bockwinkel and Ebbighausen 2006; Ebbighausen et al. 2010; Korn et al. 2010a, 2010b).

Figure 1:

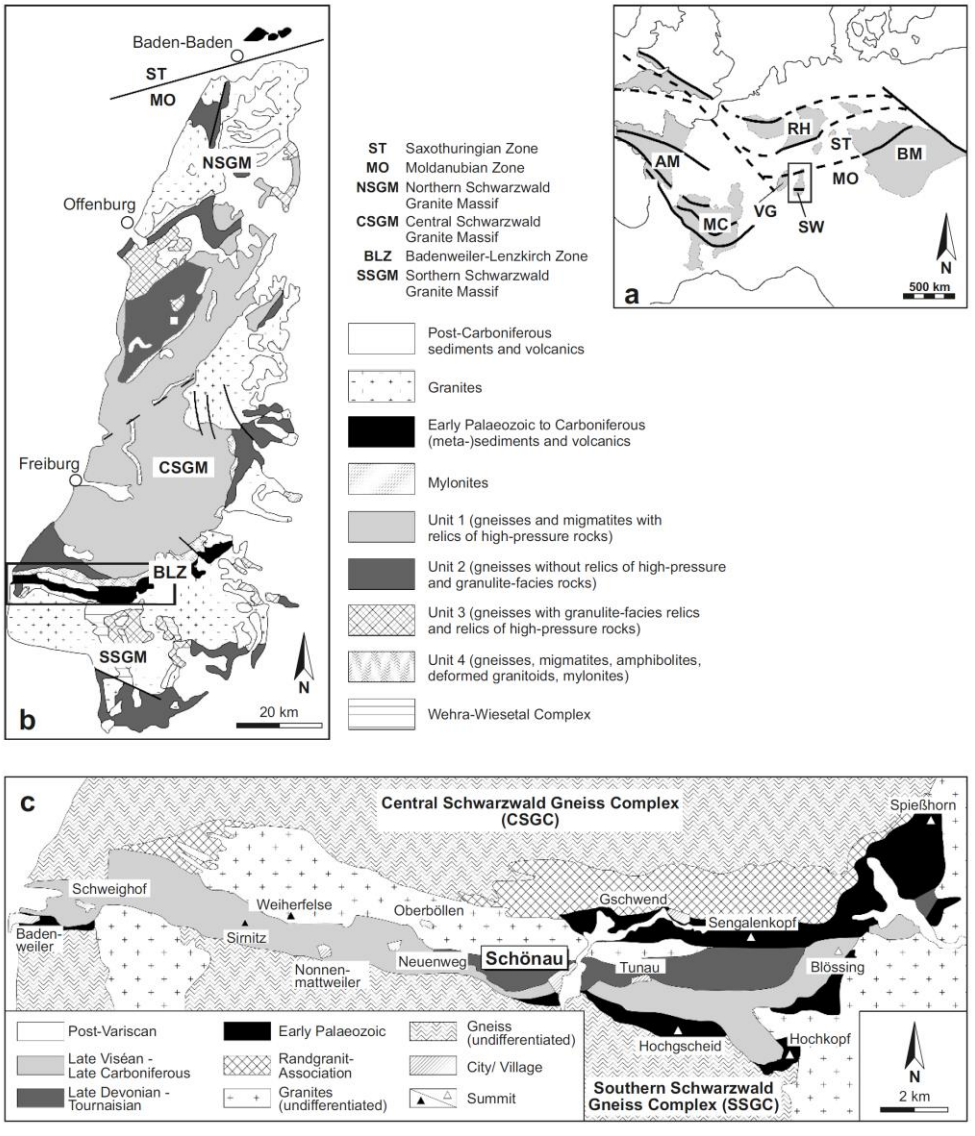

Baden-Baden
ST
MO
NSGM
Offenburg
Freiburg
CSGM
BLZ
SSGM
N
20 km
b
ST Saxothuringian Zone
MO Moldanubian Zone
NSGM Northern Schwarzwald Granite Massif
CSGM Central Schwarzwald Granite Massif
BLZ Badenweiler-Lenzkirch Zone
SSGM Sorthern Schwarzwald Granite Massif
Post-Carboniferous sediments and volcanics
Granites
Early Palaeozoic to Carboniferous (meta-)sediments and volcanics
Mylonites
Unit 1 (gneisses and migmatites with relics of high-pressure rocks)
Unit 2 (gneisses without relics of high-pressure and granulite-facies rocks)
Unit 3 (gneisses with granulite-facies relics and relics of high-pressure rocks)
Unit 4 (gneisses, migmatites, amphibolites, deformed granitoids, mylonites)
Wehra-Wiesetal Complex
RH
ST
BM
AM
MO
MC
VG
SW
N
500 km
a
c
Central Schwarzwald Gneiss Complex (CSGC)
Spießhorn
Schweighof
Weiherfelse
Oberböllen
Gschwend
Sengalenkopf
Baden-weiler
Sirnitz
Neuenweg
Schönau
Tunau
Blössing
Nonnen-mattweiler
Hochgscheid
Hochkopf
Southern Schwarzwald Gneiss Complex (SSGC)
Post-Variscan
Late Viséan - Late Carboniferous
Late Devonian - Tournaisian
Early Palaeozoic
Randgranit-Association
Granites (undifferentiated)
Gneiss (undifferentiated)
City/ Village
Summit
N
2 km

Figure 2:

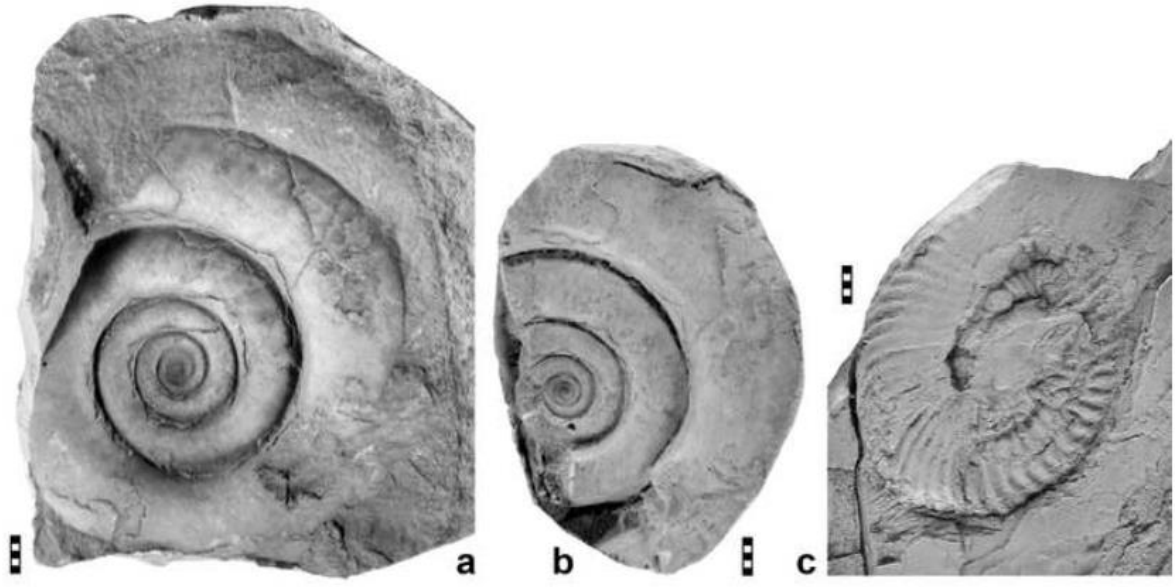


Figure 3:

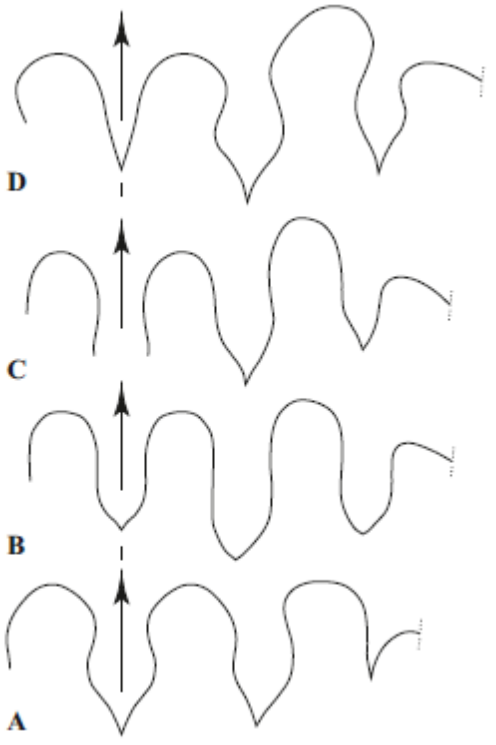
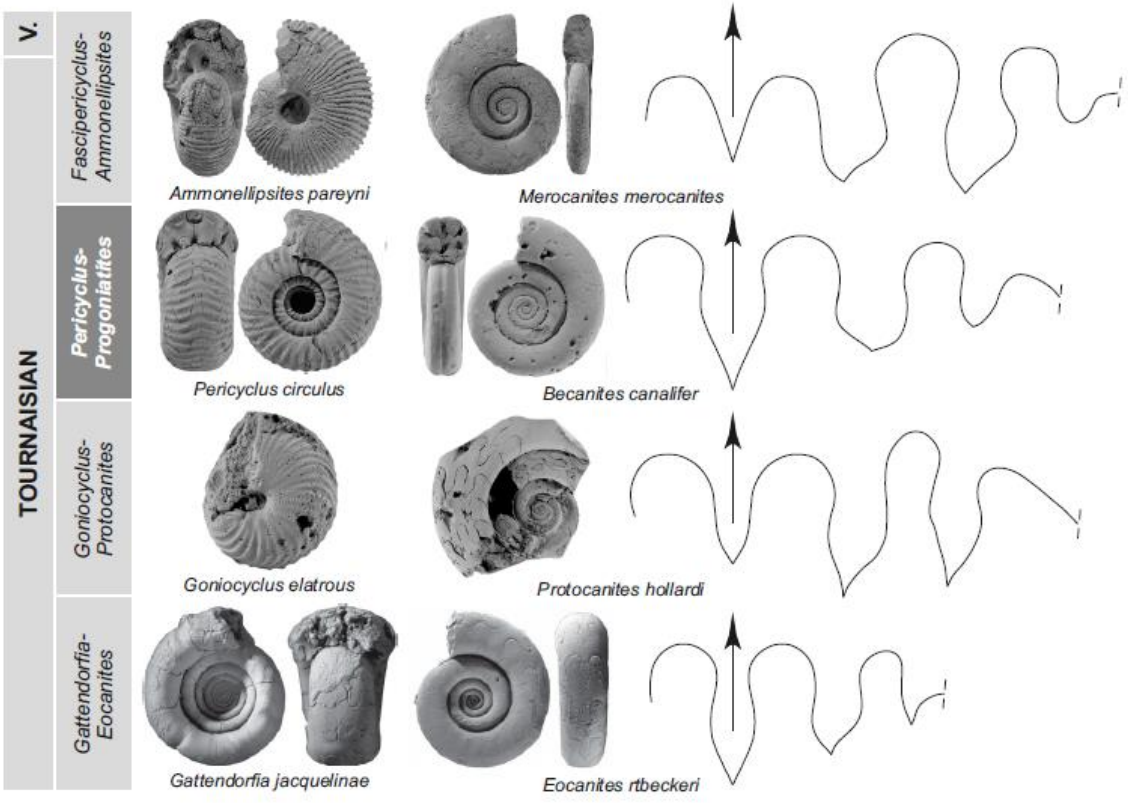


Figure 4:


V.
TOURNAISIAN
Fascipericyclus-Ammonellipsites
Pericyclus-Progoniatites
Goniocyclus-Protocanites
Gattendorfia-Eocanites
Ammonellipsites pareyni
Merocanites merocanites
Pericyclus circulus
Becanites canalifer
Goniocyclus elatrous
Protocanites hollardi
Gattendorfia jacquelinae
Eocanites rtbeckeri