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CALLOVIAN AND KIMMERIDGIAN FOSSILS AND STRATIGRAPHY OF THE BLUE NILE BASIN (CENTRAL WESTERN ETHIOPIA)

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Abstract: A refined, stratigraphic and biostratigraphic framework for Ethiopia has a strong bearing on the Jurassic sedimentary evolution, not only for the Horn of Africa, but also for the North African region. The present contribution provides an updated Callovian–Kimmeridgian stratigraphy and biostratigraphy, on the basis of the occurrences of age-diagnostic ammonites from Dejen (Blue Nile Basin; central western Ethiopia). Here, the late Callovian (Lamberti Zone) ammonite *Pachyceras* cf. *lalandeanum* (d'Orbigny) is associated with the nautiloid *Paracenoceras* cf. *giganteum* (d'Orbigny). The early Kimmeridgian *Orthosphinctes* aff. *tiziani* (Oppel) is associated with the nautiloids *Paracenoceras* cf. *kumagunense* (Waagen) and *P.* cf. *ennianus* (Dacqué) and a large gastropod *Purpuroidea gigas* (Étallon). The previously recorded middle Callovian ammonite *Erymnoceras* cf. *coronatum* (Bruguière) is associated with the now recorded *P. gigas* (Étallon). Additionally, the age of the Antalo Limestone Fm is also reassessed on the basis of the ammonite records from the three basins – Ogaden, Blue Nile and Mekele. The Ogaden Basin strata span from the late Callovian to the late Tithonian (from ammonite records), the Blue Nile Basin from the early Callovian to the late Tithonian (calcareous nannofossils) and the Mekele Basin from the uppermost middle Oxfordian to the early Kimmeridgian (ammonite records). However, the upper age assignments should be considered tentative, as much of the previously recorded Oxfordian–Kimmeridgian ammonite fauna needs taxonomic re-evaluation and precise resampling. Contextually, it should be mentioned that in all the three sedimentary basins, the top part of the Antalo Limestone Fm did not yield any ammonites.

Key words: *Orthosphinctes*, *Pachyceras*, *Paracenoceras*, Jurassic, Blue Nile Basin, Ethiopia.

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INTRODUCTION

The Ethiopian Jurassic (Fig. 1) is marked by the near absence of marker (age-diagnostic) ammonite species, thus hindering precise biostratigraphic correlation at both the intra- and interbasinal levels (see Jain, 2019a; Jain *et al*., 2020). Ethiopia is the typical area for the ammonite Ethiopian Province (Uhlig, 1911; Arkell, 1956; Hillebrandt *et al*., 1992; Enay and Cariou, 1997) and an important passageway between the north (Europe: Submediterranean/Mediterranean provinces) and the south (Somalia, Kenya, Tanzania, Madagascar, India and Nepal) of the Tethys (Fig. 2). Previous reports of Ethiopian cephalopod (ammonites and nautiloids) from the Antalo Limestone Fm by Dacqué (1905, 1914), Venzo (1942, 1959), Scott (1943) and Zeiss (1971, 1974) were based on unlocalized (with no precise sampling location or contained lithology) specimens with no lithological sections or precise stratigraphic sampling positions. Other reports by Zeiss (1984), Russo *et al*. (1994) and Bosellini *et al*. (2001) mentioned them, but with no supporting illustrations. For the Ethiopian Jurassic, only three records have associated stratigraphic information; for ammonites, the reports are from the Mekele (Martire *et al*., 2000) and Blue Nile basins (Jain *et al*., 2020), and for the nautiloid, from the Blue Nile Basin (Jain, 2019a). The Antalo Limestone Fm (ALF) has yielded Oxfordian–Kimmeridgian ammonites from the Mekele (Martire *et al*., 2000), Callovian from the Blue Nile (Zeiss, 1974; Jain *et al*., 2020) and Callovian–Tithonian from the Ogaden basins (Dacqué, 1905, 1914; Scott, 1943; Venzo, 1942, 1959). The upper Bathonian nautiloid record comes from the underlying Gohatsion Fm, exposed in the Blue Nile Basin (Jain, 2019a). Recently, Jain and Singh (2019) attempted to fill this age gap within the Blue Nile Basin biostratigraphy on the basis of the record of marker calcareous nannofossils species from Mugher (Fig. 1C) and dated

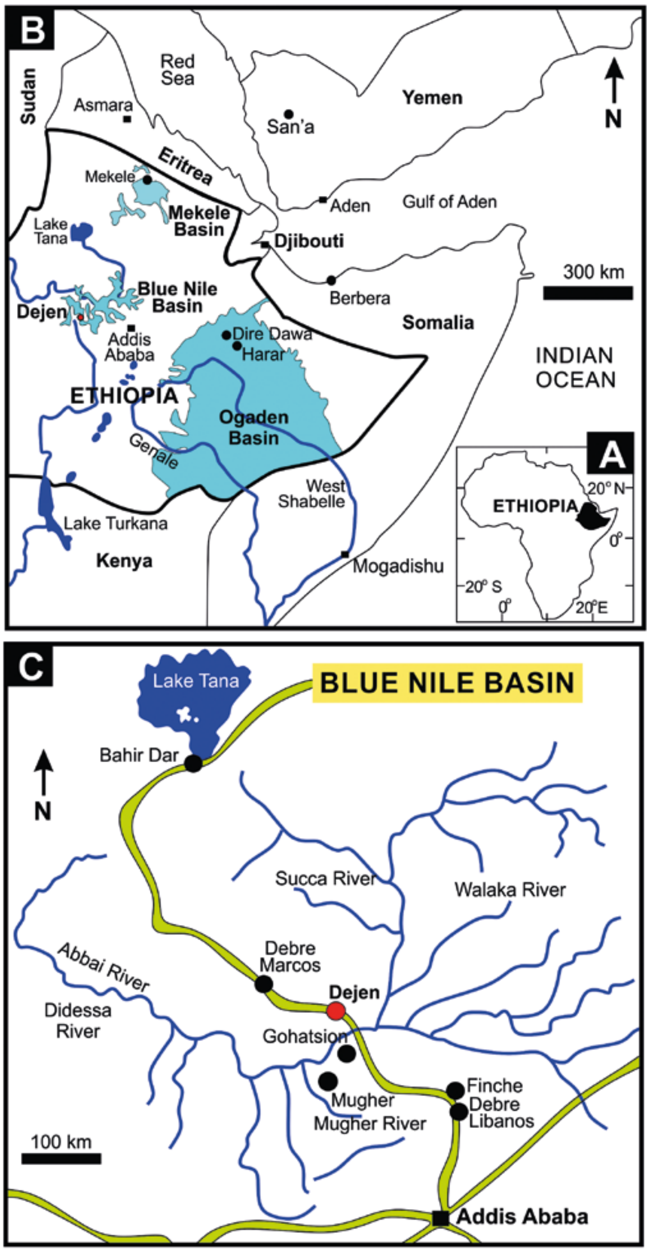

Fig. 1. Locality map. **A.** Map of Africa showing the location of Ethiopia (in black). **B.** Map of Ethiopia showing the three sedimentary basins (Ogaden, Blue Nile and Mekele) with important Jurassic localities (excluding the capital Addis Ababa). **C.** Detailed localities in and around Dejen (the study area) discussed in the text. Mugher R. – Mugher River.

the Antalo Limestone Fm between early Callovian and late Tithonian. The lower Callovian assemblage included the presence of *Lotharingius velatus*, *Pseudoconus enigma* and *Watznaueria ovata* (see Jain and Singh, 2019 for details). *L. velatus* ranges from the NJ8b calcareous nannofossil Subzone to the NJ12a Subzone and is correlated with the late Aalenian Concavum to the early Callovian Bullatus ammonite zones (see also Bown and Cooper, 1989). *P. enigma* spans from the base of NJ11 to the top of NJ12a subzones (= Bajocian to the early Callovian ammonite Bullatus Zone). The first occurrence of *W. ovata* is only at the base of the Callovian and is correlated with the lower part of the ammonite Bullatus Zone (see Bown, 1998). Thus, the base of the Antalo Limestone was assigned an early Callovian age and correlated with the western European Bullatus Zone (Jain and Singh, 2019). The top part of the ALF yielded the dominance of genus *Nannoconus* within the calcareous nannofossil assemblage that also yielded the late Tithonian marker *Polycostella beckmannii* (see Jain and Singh, 2019). Nannoconids mark the advent of the Tithonian (see Bown, 1998; Burnett, 1998) and *P. beckmannii* is a Zonal marker for the NJT15b Subzone (late Tithonian) and ranges up until the end of the Tithonian (Bown and Cooper, 1998; Casellato, 2010). Hence, on the basis of the presence of *P. beckmanii* and the predominance of *Nannoconus* within the assemblage, a broad late Tithonian age was proposed for the top part of the ALF, exposed at Mugher (Fig. 1C; Jain and Singh, 2019). The Bathonian nautiloid *Paracenoceras* aff. *prohexagonum* Spath from Mugher (Jain, 2019a) comes from the underlying Gohatsion Fm. The Bathonian age is tentative (as nautiloids are not age-diagnostic), but is based on palaeobiogeographic considerations, where the oldest *P. prohexagonum* Spath record comes from definite early Bathonian strata in Saudi Arabia and the youngest from the middle–late Bathonian of the Kachchh Basin, western India (Jain, 2020). Ethiopia being an intermediate region (Fig. 2); hence, a safe late Bathonian age was assigned (Jain, 2019a). This age designation was later reaffirmed, as the base of the overlying ALF also yielded a typical earliest Callovian assemblage of calcareous nannofossils (Jain and Singh, 2019).

The present study, on the basis of five sections at Dejen (~150 km southwest of Mugher), (a) documents a detailed stratigraphy and associated fossils, (b) describes new ammonite, nautiloid, and gastropod discoveries in the Antalo Limestone Fm, and (c) refines the biostratigraphy of the Blue Nile Basin (Fig. 1). Additionally, the age of the Antalo Limestone Fm is reassessed on the basis of the published ammonite fauna from the three Jurassic basins, the Ogaden, Blue Nile and Mekele basins (Fig. 1).

GEOLOGICAL SETTING AND STRATIGRAPHY

The J–Cr rocks in the central western Ethiopian Blue Nile Basin (Fig. 1; N08°45′ to 10°30′; E36°30 to 39°00′) cover an estimated area of 55,000 km^2. In the Dejen area (N10º00′ to 10º10′ to E38º05′06″ to 38º15′; Fig. 1C), five sections were studied by means of five transects (Fig. 3), namely Gohatsion-Abay (Fig. 4A), Gilgele (Fig. 4B), Filiklik (Fig. 4C), Kurar (Fig. 4D), and Dejen (Fig. 4E). Towards Dejen (Kurar and Filiklik sections, Fig. 4D, E), the basal part of the ALF grades into more clayey sediments and is represented by variegated shales and clay-limestone intercalations (GPS location 10°02′39.7″N, 38°13′53.7″E; see Fig. 5). A composite, lithostratigraphic synthesis of these sections exposed in the Dejen area was constructed for the Blue Nile Basin, accompanied by the stratigraphic occurrences of the major faunal elements (Fig. 6).

In the Blue Nile Basin, the basal Precambrian Crystalline Basement is overlain unconformably by the 300-m-thick Adigrat Sandstone Fm (ASF; Figs 6, 7). The ASF is made

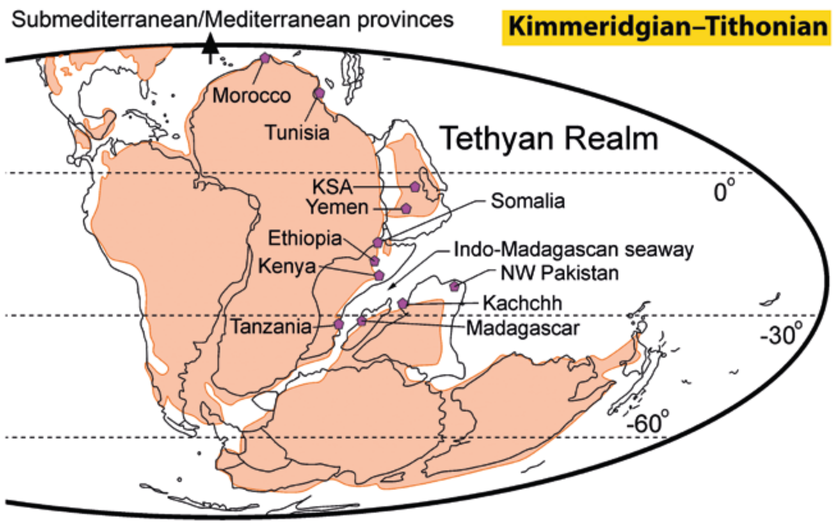

Fig. 2. Kimmeridgian–Tithonian palaeogeographic map, showing major Jurassic localities of the southern margin of Tethys discussed in the text (modified after Enay and Cariou, 1997).

up of sub-horizontal layers of fine-grained sandstones, with intercalations of minor reddish shales and siltstones that grade upwards into medium- to coarse-grained sandstones with planar cross-bedding and followed by reddish, coarse-grained sandstones (Fig. 6) with minor glauconitic siltstone/mudstone beds at the top (Fig. 7A, B). Additionally, the upper level contains several channel-fills and pebbles with rare, large wood fragments (Fig. 7C, D). But in general, the thickness, facies architecture, stratigraphic position and depositional environment (fluvial vs. marine) of the ASF is very poorly constrained, as also is its age (Permian to Jurassic) (see Mohr, 1964). The age of the ASF is based on either regional correlation or the ages of the underlying and overlying formations. For the former (regional correlation), either a Triassic–Early Jurassic age was suggested (Mohr, 1964; Russo *et al.*, 1994) or a Permo–Triassic age (Beauchamp and Lemoigne, 1974). Others proposed a broad Triassic age for its lower unit (Merla and Minucci, 1938; Beyth, 1972) or a Carboniferous–Mesozoic age for the entire unit (Kazmin, 1975). Dawit (2014) studied the palynoflora of the underlying "Fincha Sandstone" (exposed at Fincha; ~150 km south east of Dejen; Fig. 1D) and assigned the Fincha Sandstone to span from Lower Permian (Artinskian–Kungurian) to the Upper Triassic (Carnian–Norian). For the latter (i.e., ages of the underlying and overlying formations), Assefa (1980, 1981) assigned a Liassic (latest Triassic to Early Jurassic, i.e. Rhaetian to Toarcian) to ?Bathonian age to the overlying Gohatsion Fm, which was based on the presence of the alga *Palaeodasycladus mediterraneus* (Pia) that otherwise ranges from the Early Triassic (Rhaetian) to the Late Jurassic (Toarcian) (see Jain, 2019a for more details). Hence, on the basis of the record of *Paracenoceras* aff. *prohexagonum* Spath described by Jain (2019a), a more conservative age of late Bathonian was proposed for the middle to upper parts of the Gohatsion Fm exposed at Mugher, until better finds of marker taxa, ammonites or of other groups, would prove otherwise. Hence, a broad Jurassic age for the ASF was proposed (see also Jain, 2019a, b; Jain and Singh, 2019; Jain *et al.*, 2020).

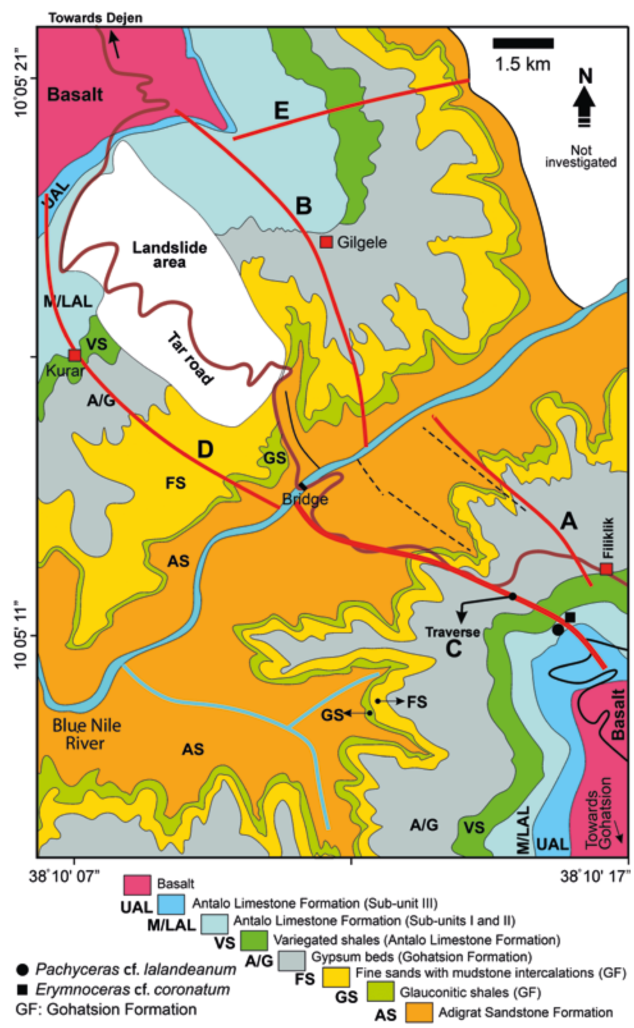

Fig. 3. Geological map showing the five traverses (A–E; see also Fig. 4) undertaken for the studied sections. Traverse C (near Filiklik) yielded *Pachyceras* cf. *lalandeanum* (d'Orbigny) and the nautiloid *Paracenoceras giganteum*. Traverse D yielded *Orthosphinctes* aff. *tiziani* (Oppel), nautiloids *Paracenoceras ennianus* (Dacqué) and *P. kumagunense* (Waagen), and the gastropod *Purpuroidea gigas* (Étallon). Bottom panel gives the general stratigraphy with Adigrat Sandstone Fm at the base.

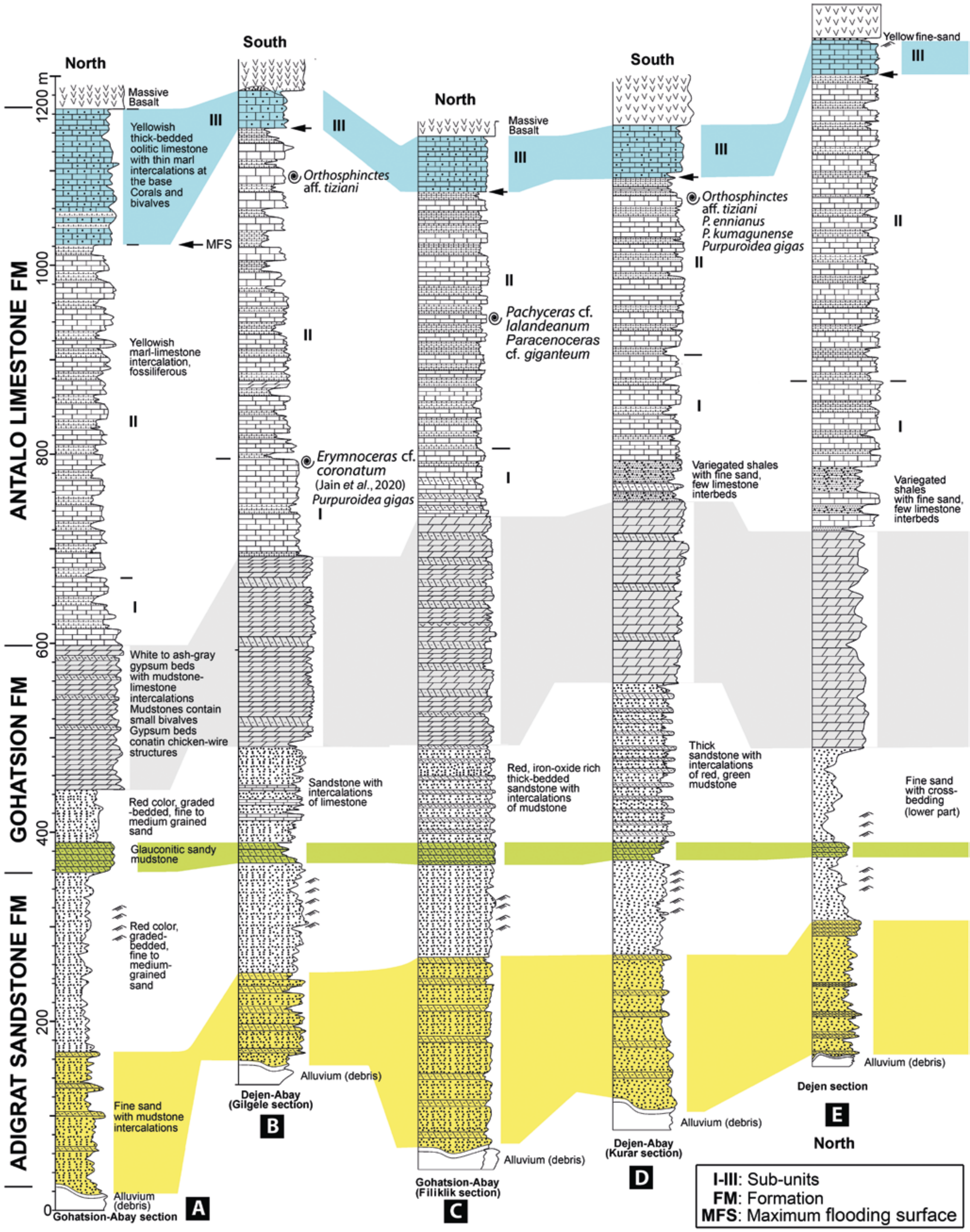

Fig. 4. Lithological and faunal details of the five sections (A to E) studied (see Fig. 3 for corresponding traverses). The recorded ammonites, nautiloids and the gastropod also are noted . The Antalo Limestone Fm has three lithological subunits, I, II and III (see text for explanation).

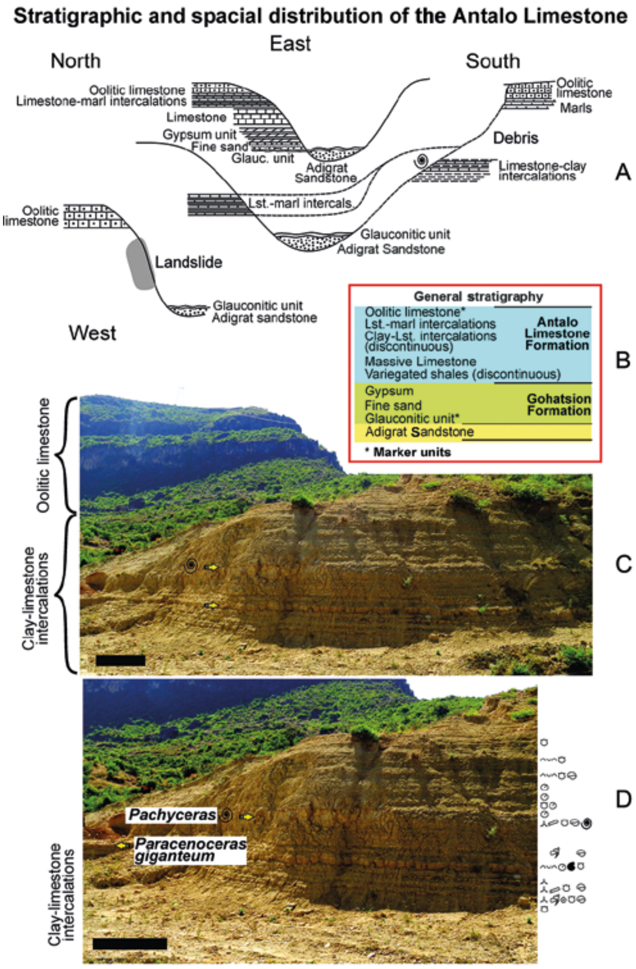

Fig. 5. Stratigraphic position of the investigated sections **(A)**, inferred local stratigraphy **(B)** and lithological details marking the occurrences of the ammonite *Pachyceras* cf. *lalandeanum* (d'Orbigny), the nautiloid *Paracenoceras giganteum*, and other faunal elements **(C, D)** based on traverse D (see Fig. 3). The ammonite symbol records the occurrence of the *Pachyceras* cf. *lalandeanum* (d'Orbigny). Index for symbols is given in Figure 6. Scale bar for C, D = 1 m.

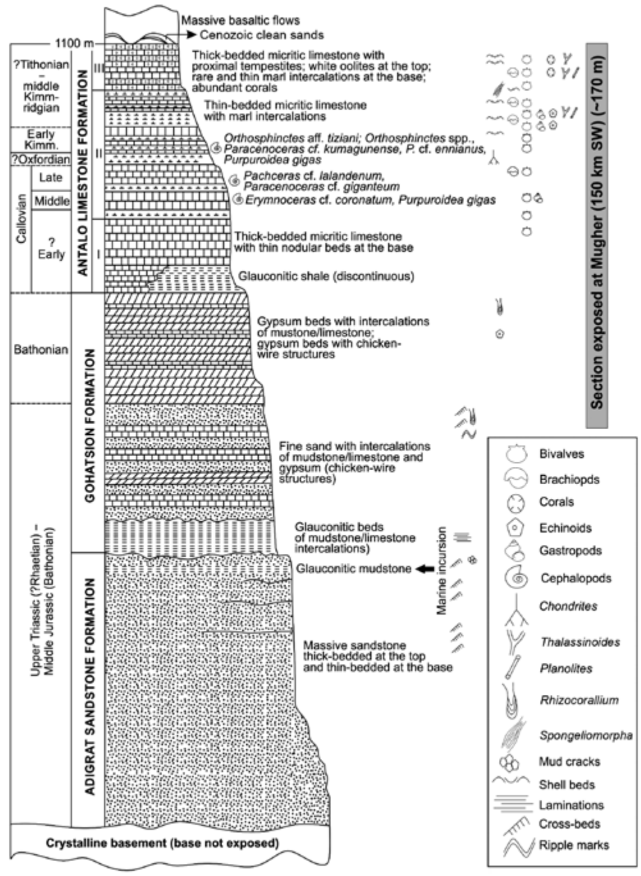

Fig. 6. General stratigraphy of the Blue Nile Basin (this study) with associated fossil content (see text for explanation).

The ASF is followed by the Gohatsion Fm (GF); its basal part is made up of a distinctive 30-m-thick glauconitic mudstone (= Glauconitic beds) with no macrofauna (Figs 4, 6). Following the Glauconitic beds are maroon-coloured, medium-grained and cross-bedded sandstones with ripple marks, with thin intercalations of mudstones (Figs 4, 6) that are barren of any macrofauna. These are succeeded by massive and monotonous gypsum beds that are, in places, intercalated with thin beds of limestone (micritic), mudstone and siltstone (Figs 4, 6) that contain rare bivalves, shell beds and/or pavements of very small bivalves (*Corbiculina*, *Nucinella* and lucinids) and gastropods (*Protocerithium*). These gypsum-dominated beds (450 m thick) variously have been named the Abbei Beds by Mohr (1964), the Shale and Gypsum Unit by Jespen and Athearn (1961) and more recently as the Gohatsion Fm by Assefa (1981). The GF at Mugher (~150 km south of Dejen; see Fig. 1D) recently was dated as Bathonian, on the basis of palaeobiogeographical constrains, namely the discovery of a nautiloid *Paracenoceras* aff. *progexagonum* Spath (Jain, 2019a). Therefore, a similar age also is proposed for this formation, exposed at Dejen (Fig. 6A).

Immediately above the GF is the 400-m-thick ALF, with its basal part consisting of variegated shales with no macrofauna (Figs 4, 6A). In the Blue Nile Basin, three sub-units are identified (Figs 4, 6). The sub-unit I (Figs 4, 6) is a thick-bedded limestone with a scarce macrofauna, consisting largely of bivalves (predominantly *Gryphaea* and *Lopha*) and rare brachiopods. The upper part of the sub-unit I in the Gilgele section (Fig. 4B) has yielded the Middle Callovian ammonite *Erymnoceras* cf. *coronatum* (Bruguière) (Jain *et al*., 2020). The succeeding marl-limestone alternations (sub-unit II; Figs 4, 6) contain ammonites (this study), gastropods, abundant bivalves and rare brachiopods (Fig. 6). The late Callovian *Pachyceras* cf. *lalandeanum* (d'Orbigny) comes from the middle part of sub-unit II in the Filiklik section (Fig. 4C). The upper part of sub-unit II, a thick-bedded micritic limestone with thin intercalations of marl, has yielded the late Oxfordian–early Kimmeridgian *Orthosphinctes* aff. *tiziani* (Oppel) in the Kurar section (Fig. 4D), associated with brachiopods and the abundant trace fossils *Rhizocorallium* (Fig. 8A–C), *Thalassinoides* (Fig. 8D, E), *Planolites* (Fig. 8D, E), and *Spongeliomorpha* (Fig. 8F, G). Associated with *Pachyceras* is the trace fossil *Chondrites* [Fig. 8H, I: *C. intricatus* (Brongniart) and Fig. 7J: *C. targionii* (Brongniart); see also Fig. 5C, D]. These intercalated marls gradually decrease in thickness towards the

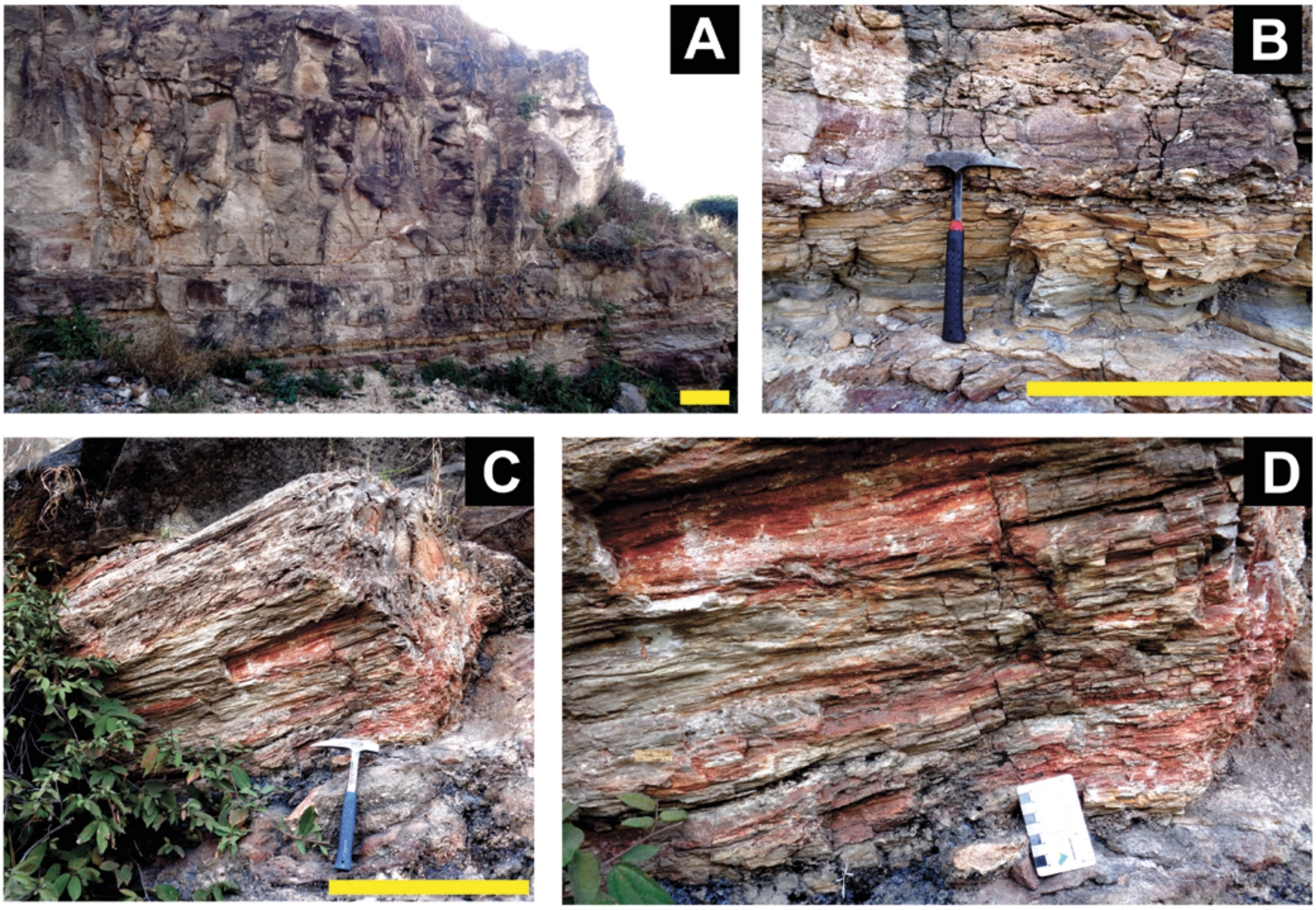

Fig. 7. Major lithology units of the Adigrat Sandstone Formation exposed around Dejen area, Blue Nile Basin (see also Fig. 5). **A, B.** Top of the Adigrat Sandstone Formation with a blowup of the olive-green mudstone beds (B). **C, D.** Large wood fragment noted near the top of the Adigrat Sandstone, a few metres below the olive-green mudstone unit (A, B). Hammer measures 33 cm. Scale bar for A = 1 m, for B, C = 50 cm.

top of the section (Figs 4, 6). A detailed basin analysis, using the distribution of trace fossils is under way and will be published elsewhere.

The ALF is succeeded by the barren and fluvial Mugher Muddy Sandstone Fm (MMSF) at Mugher (see Jain, 2019a; Jain and Singh, 2019; Radwańska and Jain, 2020). However, at Dejen, the ALF is directly overlain by massive basaltic flows (Figs 4, 6A). It is noteworthy that the top oolitic part of the ALF did not yield any ammonites (Figs 4, 6A).

MATERIALS AND REPOSITORY

All specimens are housed in the repository of the Department of Geology, Adama Science and Technology University, Adama (Ethiopia) under the log AF001–AF020. Table 1 provides measurements of the samples illustrated.

SYSTEMATIC PALAEONTOLOGY

Superfamily Stephanoceratoidea Neumayr, 1875
Family Pachyceratidae Buckman, 1918
Genus *Pachyceras* Bayle, 1878

Type species: *Ammonites lalandeanus* d'Orbigny, 1848.

Pachyceras cf. *lalandeanum* (d'Orbigny, 1848)
Fig. 9

1848 *Ammonites lalandeanus* – d'Orbigny, p. 477, pl. 175, figs 1–5.

1974 *Pachyceras* cf. *lalandeanum* (d'Orbigny) – Zeiss, pl. 37, figs 2–4.

1976 *Pachyceras lalandeanum* var. *lalandeanum* – Charpy, p. 40, pl. 1, fig. 2a, b; pl. 5, fig. 3.

1994 *Pachyceras lalandeanum* (d'Orbigny) – Thierry in Fischer, p. 155, pl. 67, fig. 3; pl. 68, figs 1–3.

Material: One poorly preserved specimen (no. AF020) from the middle part of sub-unit II of the Antalo Limestone Fm from Traverse C (Fig. 3), Filikilik section (Fig. 4C). GPS location 10°02′39.7″N, 38°13′53.7″E.

Description: Shell fragmentary, small (36 mm in diameter), evolute (Umbilicus/diameter; U/D = 0.24) and compressed (Whorl thickness/Whorl height; T/H = ~0.86). Blunt primary ribs divide into 2 prorsiradiate secondary ribs with an interviewing intercalatory; the rib-division is at the lower third of the flank height. The secondaries are blunt and widely spaced and number 20 per half whorl. They are initially bent backwards near the umbilical region (lower third of flank height), but thence become prorsiradiate. Umbilicus shallow with rounded umbilical edges and low vertical umbilical walls. Flanks are somewhat arched to the extent that the venter is narrow, but rounded. Secondaries cross the narrowly rounded venter straight and without interruption. The suture line is barely visible.

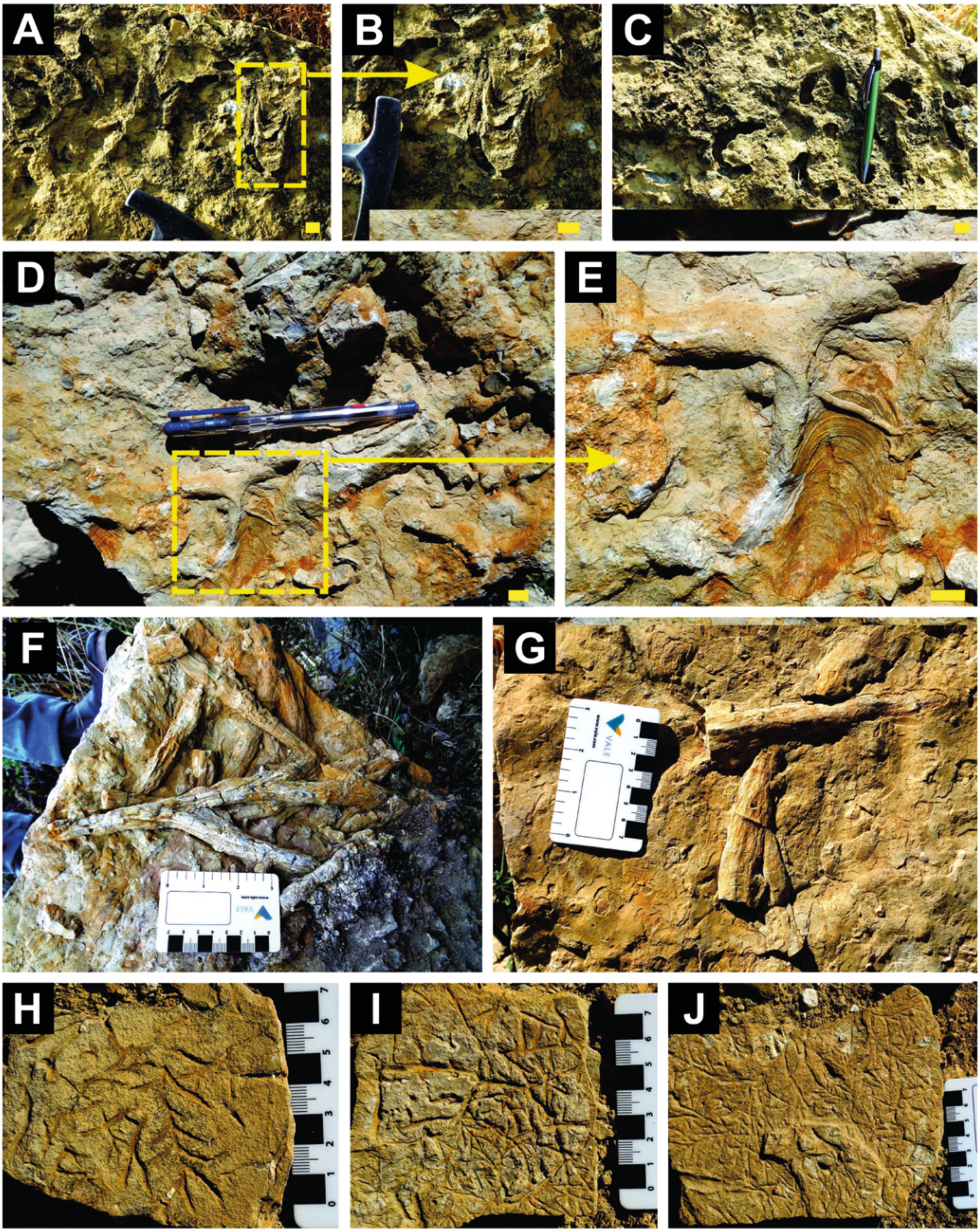

Fig. 8. Trace fossils from around the Dejen area, Blue Nile Basin. **A–C.** *Rhizocorallium* isp. (possibly *R. jenense*), GPS location 10°02′39.7″N, 38°13′53.7″E, elevation: 1,999 m a.s.l. **D, E.** *Thalassinoides* isp., GPS location 10°07′45.3″N, 38°10′51.0″E, elevation: 1,964 m a.s.l. **F, G.** *Spongeliomorpha* isp., GPS location 10°02′33.3″N, 38°14′27.7″E, elevation: 2131 m a.s.l. **H, I.** *Chondrites intricatus* (Brongniart), specimen nos. AF018-AF019. **J.** *Chondrites targionii* (Brongniart), specimen no. AF020, GPS location 10°02′39.7″N, 38°13′53.7″E, elevation = 1,999 m a.s.l. A–G: see Fig. 5; H–J: see Fig. 4D. Scale bar for A–E = 1 cm.

Table 1

Measurements. D: Diameter measured. H: Maximum height of whorl at given diameter. T: Maximum width of whorl between ribs or nodes at given diameter. U: Width of umbilicus atgiven diameter. T/H: Whorl thickness. U/D: Coiling ratio. P: Primaries and S: Secondaries.

Species	Specimen no.	Measurement						Per whorl	
		D	H	T	U	T/H	U/D	P	S
Paracenoceras cf. *kumagunense* (Waagen)	AF004	58	30.5	45.9	11.7	1.5	0.2	–	–
Paracenoceras cf. *ennianus* (Dacqué)	AF012	~130	42.4	51.3	~16.9	1.2	~0.13	–	–
Pachyceras cf. *lalandeanum* (Orbigny)	AF020	36	18	~16	8.8	~0.86	0.24	–	20

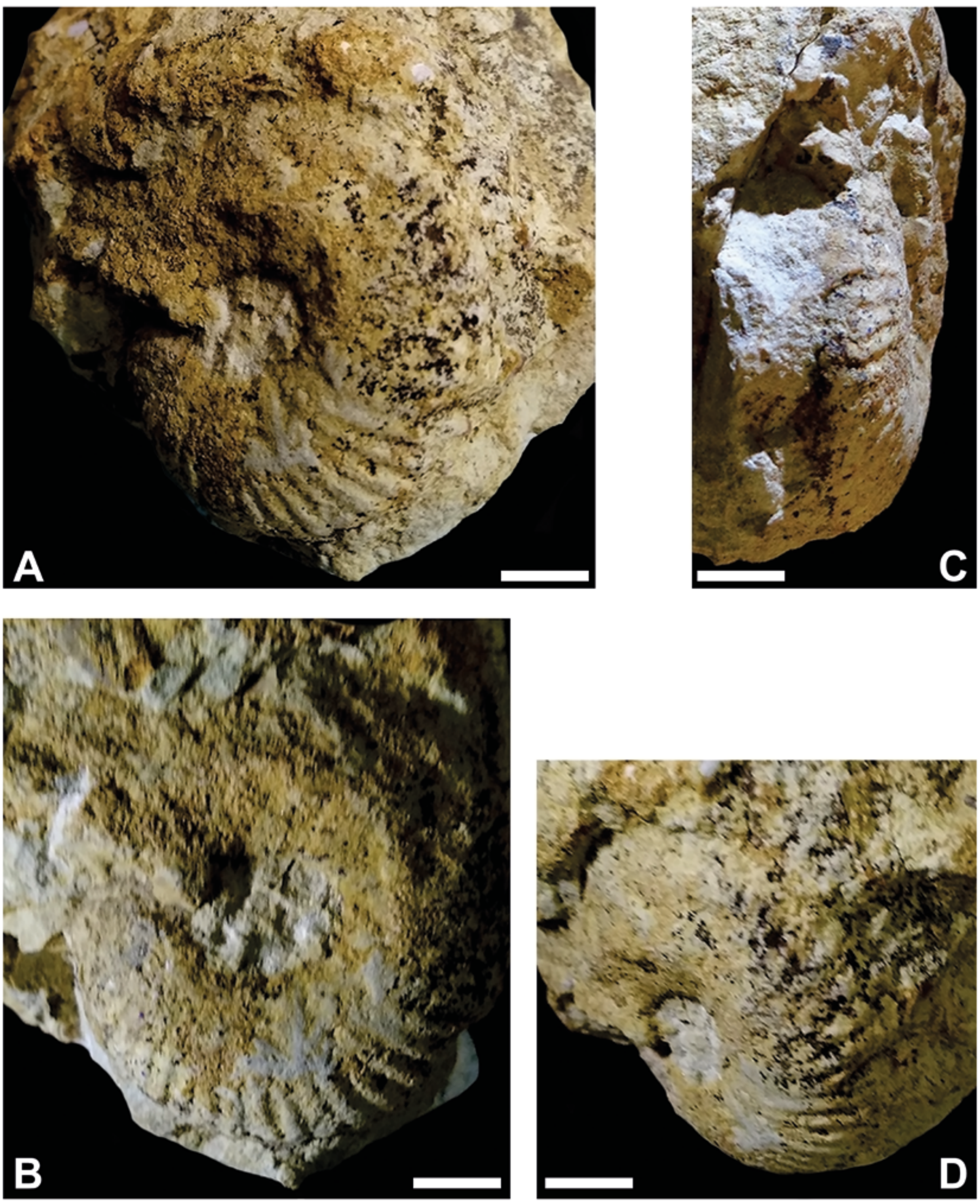

Fig. 9. *Pachyceras* cf. *lalandeanum* (d'Orbigny), specimen no. AF020. **A, B** and **D.** Lateral views showing the pattern of ribbing. **C.** Ventral view. The present specimen was collected from a thin limestone bed within the limestone-clay intercalation (see Figs. 5C-D). The specimen comes from traverse C (see Fig. 3) and section C (see Fig. 4).

Remarks: Zeiss (1974, pl. 37, figs 2–4) recorded a fragmentary and unlocalized specimen of *Pachyceras* cf. *lalandeanum* (d'Orbigny) from the Blue Nile Basin and considered it to represent the juvenile stage of *Pachyceras lalandeanum* with close morphological similarity to *Pachyceras* cf. *schloenbachi* (Roman) in Imlay (1970, pl. 1, figs 18, 19) and also to the Indian (Kachchh) *Pachyceras distinctum* Spath (1928, p. 222, pl. 20, fig. 5). Spath (1928, p. 221) earlier had considered the latter to be "the Indian equivalent of the European *P. lalandeanum*" (see also Thierry, 1980, p. 761). Charpy (1976, p. 40) reinterpreted Zeiss's form as a microconch and a variety of *P. lalandeanum*.

In terms of general morphology, the Ethiopian specimen (Fig. 9) closely resembles the late Callovian Lamberti Zone *Pachyceras lalandeanum* var. *lalandeanum* from Villers-sur-Mer, Upper Normandy, France (Charpy, 1976, p. 40, pl. 1, fig. 4a–c). Among the smaller microconchiate forms, another closely comparable specimen is the Indian *Pachyceras arenosum* (Waagen, 1875, p. 121, pl. 36, fig. 5a–c; Thierry, 1980, pl. 1, figs 1, 2). However, *P. arenosum*, is more involute. The other comparable form is *P. lalandeanum* var. crassum (Charpy, 1976, p. 49, pl. 1, fig. 5), but it is considerably more evolute. Both *P. arenosum* and *P. lalandeanum* var. *crassum* also have a denser, concave and relatively more prorsiradiate ribbing pattern with a distinct and higher attenuation of ornamentation, around the umbilical region. Another closely comparable form is the Russian *P. efimovae* (Mitta, 1992, fig. 1a–e), but it differs in being somewhat more inflated, more involute, and is less densely ribbed, with a straighter secondary ribbing pattern.

Age: *Pachyceras lalandeanum* (d'Orbigny) is characteristic of the late Callovian Lamberti Zone (Cariou and Hantzpergue, 1997).

Superfamily Perisphinctoidea Steinmann, 1890
Family Ataxioceratidae Buckman, 1921
Subfamily Ataxioceratinae Buckman, 1921
Genus *Orthosphinctes* Schindewolf, 1925

Type species: *Ammonites tiziani* Oppel, 1863

Orthosphinctes aff. *tiziani* (Oppel, 1863)
Fig. 10

1863 *Ammonites tiziani* – Oppel, p. 246.

1997 *Orthosphinctes* aff. *tiziani* (Oppel) – Schweigert and Callomon, p. 20, pl. 4, fig. 1.

2007 *Orthosphinctes* aff. *tiziani* (Oppel) – Głowniak and Wierzbowski, p. 109, fig. 66/1, 2.

2010 *Orthosphinctes* aff. *tiziani* (Oppel) – Seyed-Emami and Schairer, p. 273, fig. 8d, e.

Material: Five fragmentary specimens were recorded from the top part of sub-unit II of the Antalo Limestone Fm (Figs 4, 6). One (specimen no. AF005) from the Gilgele section (Fig. 4B), GPS location 10°07′45.3″N, 38°10′54.3″E; and four specimens (nos. AF001a, and AF002a illustrated in Fig. 10; AF001b illustrated in Fig. 10; AF002b not illustrated) from the Kurar section (Fig. 4D), GPS location 10°07′34.7″N, 38°09′25.7″E.

Description: Shell fragmentary with a maximum diameter of 68 mm (Fig. 10). Ornamentation on the inner whorl is very fine, dense, and rectiradiate (Fig. 10A, C), whereas that on the outer whorls is coarser, distant and somewhat prorsiradiate (Fig. 10). Ribbing is strictly biplicate (Fig. 10); the primary ribs branch regularly just below the ventrolateral shoulder into two secondary ribs of the same thickness (Fig. 10D).

Points of rib-bifurcation are hidden by the subsequent whorl. Secondary ribs are progressively and slightly longer in the outer whorls. Owing to the somewhat crushed and fragmentary nature of the material, the style of the primary ornamentation is tentative but primary ribs appear to originate from the inner part of the umbilical margin in a rursiradiate manner and then turn forward, branching at the outer third of whorl height (between 64–68% of whorl height). A single constriction (shallow and relatively broad) that runs parallel to the ribs is noted in the outer whorl of the larger specimen (Fig. 10D).

Remarks: The Ethiopian specimens (Fig. 10) show a recurrent sculpture among Oxfordian and Kimmeridgian platycone and moderately evolute ammonites – namely, quasi-exclusive bifurcate and blunt, rather than sharp ribs with shallow inter-rib spaces and with some shallow constriction(s) parallel to the ribbing. Among the early Kimmeridgian taxa, several genera developed such conservative sculpture on the inner whorls (see also Pandey *et al*., 2013). In the better known European planulate ammonites, the sculpture, with its ribs mainly bifurcating in forward-directed secondaries and shallow constrictions parallel to the ribbing, points to the morphologically conservative genera of *Orthosphinctes* Schindewolf and *Discosphinctoides* Olóriz (= *Lithacoceras* Hyatt; Enay and Howarth, 2019). However, in the latter, the rib-bifurcation is almost at the middle of the flank height (see Scherzinger and Mitta, 2006). Broadly, the sculptural pattern varies between radial and bifurcate ribs with a variable occurrence of simple ribs as in early Kimmeridgian *Dichotomosphinctes*, to more oblique ribbing with the occurrence of scarce intercalatory ribs in the late Kimmeridgian *Discosphinctoides*.

The present fragmentary specimens (Fig. 10) show great similarity with the Polish *Orthosphinctes aff. tiziani* (Oppel), as figured by Głowniak and Wierzbowski (2007, p. 109, fig. 66.1, 2; particularly with the smaller specimen, fig. 66.1) and also with the one figured by Matyja and Wierzbowski (1997, pl. 6, fig. 1; although this form has considerably more intercalatories, in contrast to the present samples that rarely show one). The *O.* aff. *tiziani* specimens from the Submediterranean Europe, such as the one illustrated by Schweigert and Callomon (1997, p. 20, pl. 4 and pl. 5, fig. 1; particularly with pl. 4, fig. 1), are also closely comparable. The Iranian *O.* aff. *tiziani*, illustrated by Seyed-Emami and Schairer (2010, p. 273, fig. 8d, e; in particular fig. 8d), are very similar to the present specimens.

Age: *Othosphinctes tiziani* (Oppel) comes from exactly the same level as Oppel's type material, latest Hauffianaum Subzone of the Bimammatum Zone (early Kimmeridgian; see also Schweigert and Callomon, 1997). Additionally, *Orthosphinctes*, ranges from the Bimmamatum Zone up to the lowermost Platynota Zone (early Kimmeridgian), the same age also assigned here (pers. comm., Günter

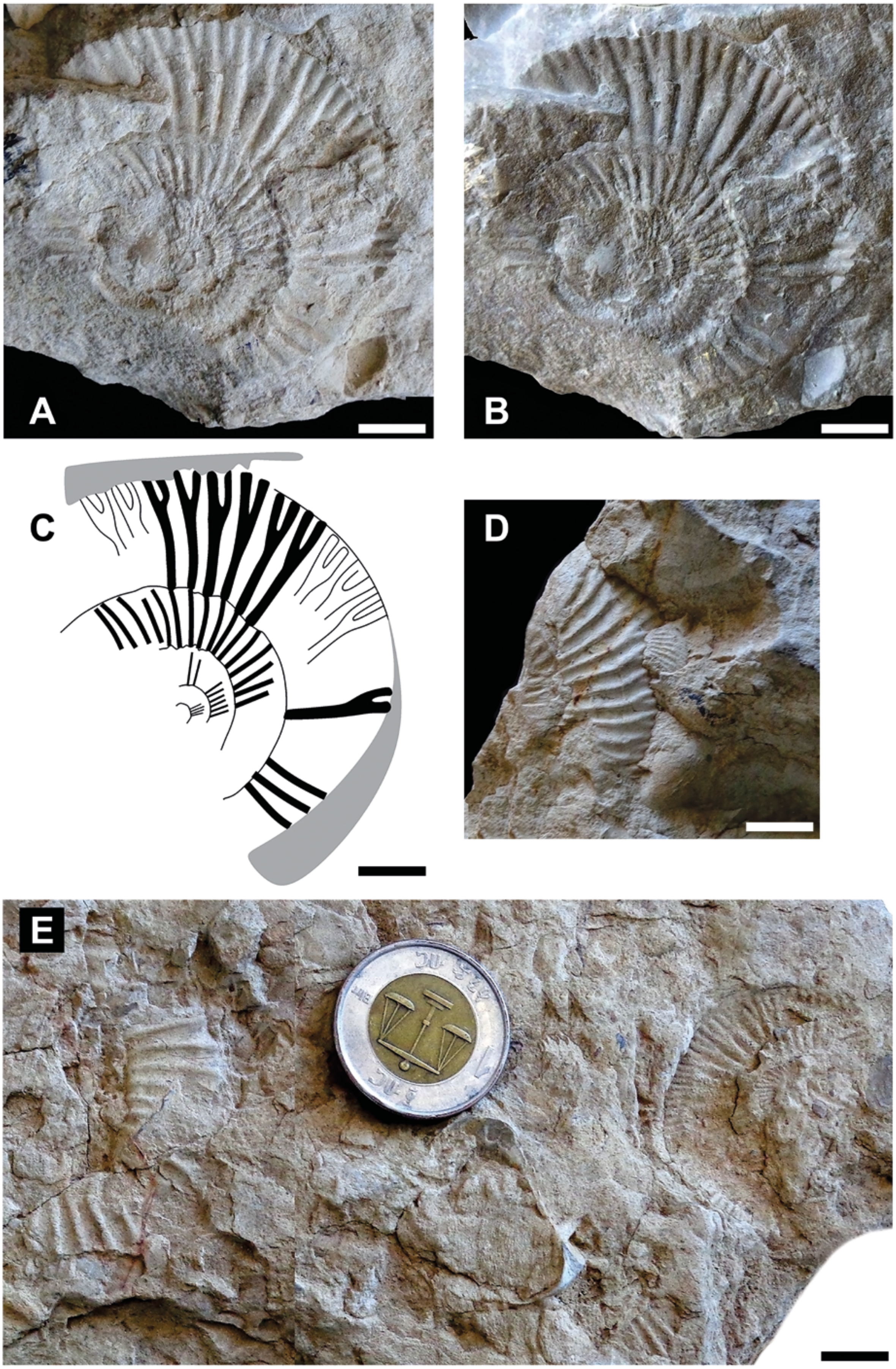

Fig. 10. *Orthosphinctes* aff. *tiziani* (Oppel). **A–C.** Specimen no. AF001a (Kurar section, Fig. 3D); C is the line diagram of A. **D.** Specimen no. AF002a (Kurar section, Fig. 3D). **E.** Slab with specimens of *Orthosphinctes* spp.; specimen no. AF001b (Kurar section, Fig. 3D). GPS location for all specimens: 10°07′34.7″N, 38°09′25.7″E, elevation: 2004 m a.s.l.

Schweigert). In general, *Orthosphinctes tiziani* characterizes the Bimammatum Zone (see Atrops, 1982, 1994; Atrops and Meléndez, 1993; Myczyński *et al*., 1998; Głowniak and Wierzbowski, 2007; Parent *et al*., 2012; Pandey *et al*., 2013) and also occurs widely in Germany, Switzerland, France, northern Italy, Spain, Portugal, Poland, southern England, Romania, northern Africa, northern Turkey, and Uzbekistan (Enay and Howarth, 2019). Thus, until records from Ethiopia of closer to complete *Orthosphinctes* are available and/or those of other, associated marker taxa, an early Kimmeridgian age is assigned to the occurrence of *Orthosphinctes tiziani* (Oppel).

Superfamily Nautilitoidea De Blainville, 1825
Family Paracenoceratidae Spath, 1927
Genus *Paracenoceras* Spath, 1927

Type species: *Nautilus giganteus* d'Orbigny, 1843, p. 163.

Paracenoceras cf. *kumagunense* (Waagen, 1873)
Fig. 11A–E

1873 *Paracenoceras kumagunense* Waagen, p. 19, pl. 3, fig. la, b.

1925 *Paracenoceras* cf. *kumagunense* (Waagen) – Spath, p. 23.

1927 *Paracenoceras kumagunense* (Waagen) – Spath (*in* Spath, 1927–1933), p. 26, pl. 4, fig. 2 (= Waagen's holotype refigured), pl. 4, fig. 3a, b.

Material: One specimen (no. AF004) from the top part of sub-unit II of the Antalo Limestone Fm (Figs 4, 6), the Kurar section (Fig. 3D). GPS location 10°07′34.7″N, 38°09′25.7″E.

Description: The phragmocone is small (58 mm) with a maximum estimated shell diameter of 110 mm (judging by the presence of the umbilical seam) (Fig. 11A). Umbilicus has steeply sloping umbilical walls at the phragmocone stage; the umbilical shoulder is distinct and rounded. At the end of the phragmocone, and the beginning of the body chamber, there is a sudden whorl inflation, resulting in very high and steep (and slanting) umbilical walls (Fig. 11A, D). The umbilical shoulder increasingly becomes collared (the previously rounded umbilical shoulder now forms a flat and distinct band; see Fig. 11A, B). Maximum whorl thickness is always at the umbilical shoulder. Flanks at the early part of the visible phragmocone stage are somewhat flat but with increasing shell diameter become converging towards the deeply sulcate venter. The ventrolateral margin forms a distinct and rounded curve and joins the deep sulcate venter (Fig. 11C). The venter at the visible part of the phragmocone stage is somewhat flat (~40 mm; see Fig. 11D) but becomes subsulcate by ~50 mm shell diameter; it is deeply sulcate, thereafter, >60 mm (see Fig. 11C). Whorl section is not visible but appears to be subtrapezoidal. The suture line shows a broad and shallow lateral lobe, followed by a well-marked umbilical saddle (Fig. 11E).

Remarks: The most closely comparable form is *Paracenoceras kumagunense* (Waagen) [Waagen, 1873, p. 19, pl. 3, fig. la, b; Spath, 1927, p. 26, pl. 4, fig. 2 (= Waagen's Holotype refigured)] and *P.* cf. *kumagunense* (Waagen) Spath (1927, p. 26, pl. 4, fig. 3a, b). Spath's (1927, p. 27) observation on *P. kumagunense* of the change in the shape of venter, from tabulate to subsulcate to sulcate, is clearly visible in the present specimen (Fig. 11C, D). The other comparable form is the Kimmeridgian–Tithonian *Paracenoceras hexagonoides* (Spath, 1927, p. 28, pl. 4, fig. 4a, b). However, at comparable diameters, it has a much rounded, broader and less sulcate venter, besides being much more inflated and with much flatter flanks (Spath, 1927, pl. 4, fig. 4a, b). Spath (1927, p. 27) suggested a close morphological grouping between *P. kumagunense* and the *hexagonoides-giganteum-ennianus* group, but the lack of complete specimens presently do not allow any finer resolution.

Age: The present specimen is associated with the early Kimmeridgian *Orthosphinctes* aff. *tiziani* (Oppel) and is dated accordingly. In western India (Kachchh), the species ranges from the upper part of early Callovian (Semilaevis-Opis zones; see Jain, 1998) to the late Oxfordian (Bifurcatus Zone; see Pandey *et al*., 2012).

Paracenoceras cf. *ennianus* (Dacqué, 1905)
Fig. 11F-H

1905 *Nautilus ennianus* – Dacqué, p. 144, pl. 17, fig. 5a, b (refigured here as 13D, E).

non 1943 *Paracenoceras ennenianum* (Dacqué) – Scott, pl. 24, fig. 2, pl. 25, fig. 1.

Material: One specimen (no. AF012) from the top part of sub-unit II of the Antalo Limestone Fm (Fig. 4), Kurar section (see Fig. 4D). GPS location 10°07′34.7″N, 38°09′25.7″E.

Description: Shell septate and moderate-sized, with a maximum estimated shell diameter of 130 mm. Umbilicus funnel-shaped, with high and slanting umbilical walls and a rounded umbilical edge (Fig. 11E). Flanks gently converge and are interrupted by a broad sulcus on the outer third of whorl height, which is bordered by a somewhat rounded and elevated ridge (Fig. 11A, B). The ventrolateral margin is rounded and also is bordered by a rounded and elevated ridge, leading to a deeply sulcate venter (Fig. 11F); the sulcus somewhat increases in depth with increasing shell diameter. Suture line present but not completely visible; only a broad and deep lateral lobe is discernable.

Remarks: The pronounced lateral sulcus distinguishes the present specimen from all other known paracenoceratids, except for the septate *Paracenoceras ennianus* (Dacqué, 1905, p. 144, pl. 17, fig. 5a, b) that has similar morphological characters and dimensional proportions. Dacqué's (1905) specimen is still septate at 200 mm shell diameter, indicating a maximum estimated shell diameter close to ~330 mm. In terms of the suture line (broad and deep lateral lobe), the present specimen closely resembles *Paracenoceras* cf. *giganteum* (d'Orbigny) (see fig. 18.4 in Dacqué, 1905). Spath (1927, p. 27) suggested that a close morphological relationship exists between *P. kumagunense* and the *hexagonoides-giganteum-ennianus* group, but the lack of complete specimens and their scarcity in numbers do not allow any finer resolution. The other closely comparable form is *Paracenoceras kumagunense* (Waagen), which has a similar sulcate venter but lacks the one present on the flanks. Additionally, *P. kumagunense*

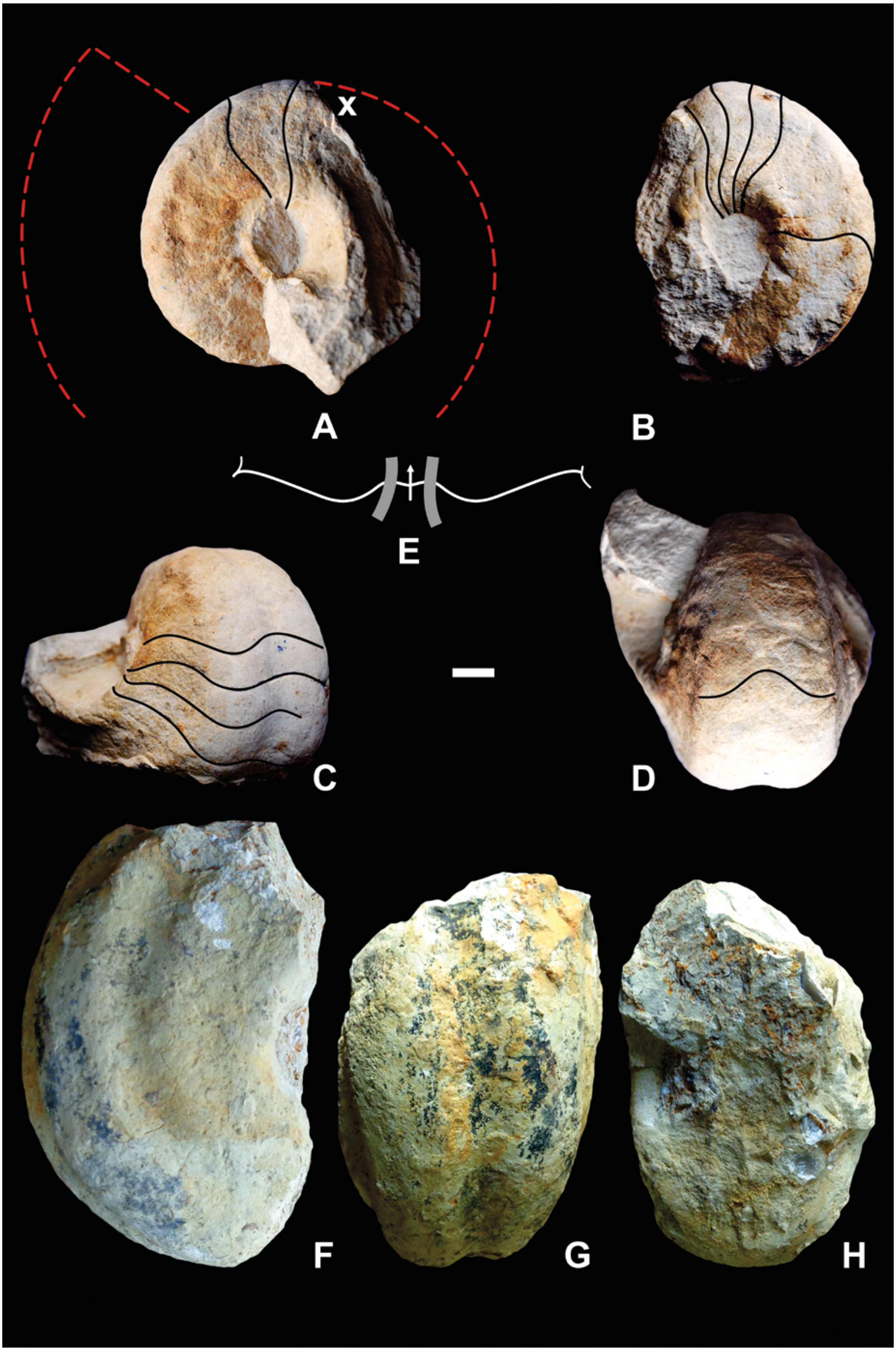

Fig. 11. Nautiloids from Dejen (Blue Nile Basin). **A–E.** *Paracenoceras* cf. *kumagunense* (Waagen), specimen no. AF004, Kurar section (see Fig. 4D), GPS location 10°07′34.7″N, 38°09′25.7″E, elevation: 1996 m a.s.l. **F–H.** *Paracenoceras* cf. *ennianus* (Dacqué), specimen no. AF012, Kurar section (see Fig. 4D), GPS location 10°07′34.7″N, 38°09′25.7″E, elevation: 2,014 m a.s.l. Scale bar = 1 cm.

is somewhat more inflated and evolute (compare with Fig. 11A–D of present work; see also Waagen, 1873–75, p. 19, pl. 3, fig. la, b; Spath, 1927, p. 26, pl. 4, fig. 2). Scott (1943) illustrated an unlocalized specimen from Kurtcha (20 km southwest of Harrar; 9°16′49.8″N, 42°04′03.7″E; northwestern Ogaden Basin; see Fig. 1), which he identified as *P. ennianus*. However, this Harrar specimen (Scott, 1943, pl. 25, fig. 1) lacks the characteristic broad sulcus on the outer third of the whorl height, is much more compressed, and has a more sinuous suture line and an occluded umbilicus. It closely resembles the lower Aptian (Lower Cretaceous) *Heminautilus lallierianus* (d'Orbigny, 1841) see also Baudouin *et al*. (2016). Interestingly, Bosellini *et al*. (1999) documented the presence of marine Aptian sediments in the Harrar region (see Fig. 1B; Ethiopia). Accordingly, it is likely that Scott's specimens may well be an Aptian *Heminautilus*. More rigorous sampling is needed.
Age: Dacqué (1905, p. 144) recorded *Paracenoceras ennianus* from Atschabo near Harro Rufa (150 km south of Harar; northwestern Ogaden Basin; Fig. 1B), associated with unlocalized perisphinctids and aspidoceratids (Dacqué, 1905, p. 122) and assigned it to the Kimmeridgian. The recorded aspidoceratid species include *Aspidoceras somalicum* of Dacqué (1905, 149, pl. 17, fig. 1), *A. iphiceroides* Waagen (Dacqué, 1910, p. 24, pl. 1, fig. 8; pl. 4, fig. 4), *A. kilindianum* Dacqué (1910, p. 25, pl. 1, fig. 9; pl. 3, fig. 6) and *A. bispinosum* (Zieten) by Venzo (1959, p. 164, pl. 12, fig. 4; pl. 14, figs 3, 4). All these have been synonymized under *A. longispinum* (Sowerby) (Howarth (1998, p. 65) and dated to span from the late Kimmeridgian Beckeri Zone to the early Tithonian Hybonotum Zone (Howarth, 1998). In the Indo-Madagascan region, the bituberculate aspidoceratins span from the middle Kimmeridgian to the early Tithonian (see Enay, 2009). In Ethiopia, *Paracenoceras ennianus* is associated with the characteristic early Kimmeridgian *Orthosphinctes* aff. *tiziani* (Oppel) and hence, is dated accordingly.

Paracenoceras cf. *giganteum* (d'Orbigny, 1848)
Fig. 12A–D

1994 *Paracenoceras giganteum* (d'Orbigny) – Tintant *in* Fischer, p. 38, pl. 9, fig. 3, pl. 10, fig. 3, pl. 11, fig. la–c, text–fig. 13a–c.

Material: One specimen (no. AF005) from the middle part of sub-unit II of the Antalo Limestone Fm, the Filikilik section (see Fig. 4C). GPS location 10°02′39.7″N, 38°13′53.7″E.
Description: As the shell is fragmentary, the diameter of the phragmocone cannot be approximated (Umbilicus = ~42 mm; Height = 135; Thickness = 180; T/H = 1.33), but it appears to be large (~200 mm). Whorl section is subtrapezoidal with slightly concave flanks (Fig. 12B, C) that tend to become somewhat straight (Fig. 12A, B). Venter is narrow and deeply sulcate, with a distinct rounded and somewhat higher ventrolateral edge (Fig. 12A, C). Suture has a deep lateral lobe (Fig. 12D) and a well-marked umbilical saddle (Fig. 12B). The siphon is subdorsal (Fig. 12A).
Remarks: In its large size, suture line and general morphology (particularly whorl section and sulcate venter), the present specimen closely resembles *Paracenoceras giganteum* (d'Orbigny); its shell diameter reaches up to 470 mm (see Fischer, 1994, p. 38, pl. 9, fig. 3, pl. 10, fig. 3, pl. 11, fig. la, c, text-fig. 13a, c). Another closely comparable form is *P. kumagunense* (Waagen), but it differs considerably in possessing a much rounded and less sulcate venter with flatter sides and a distinctly rounded to subdued ventrolateral edge [see Waagen, 1873–75, p. 19, pl. 3, fig. la, b; Spath, 1927, p. 26, pl. 4, figs 2, 3a, b (cf.)]. *P. hexagonoides* Spath has a sulcate venter, but the venter is much subdued and broader with considerably flatter flanks (Spath, 1927, p. 28, pl. 4, fig. 4a, b).
Age: *Paracenoceras giganteum* (d'Orbigny) spans from the early Kimmeridgian (Bimammatum Zone) to the middle Kimmeridgian (lower part of the Acanthium Zone), where the lectotype also was recorded (see Fischer, 1994, p. 38). In the present study, it is associated with the late Callovian *Pachyceras* cf. *lalandeanum* (d'Orbigny), and is dated accordingly. This is the earliest record of this species.

Class Gastropoda Cuvier, 1795
Superorder Caenogastropoda Cox, 1960
Suborder Littorinimorpha Golikov and Starobogatov, 1975
Family Purpuroideidae Guzhov, 2004
Genus *Purpuroidea* Lycett, 1848

Type species: *Murex*? *nodulatus* Young and Bird, 1828.

Purpuroidea gigas (Étallon, 1861)
Fig. 13A–K

1980 *Purpuroidea* aff. *gigas* (Étallon) – Hirsch, pl. 10, figs 14, 15.

Material: Two specimens (AF025 and AF026) were recorded. One specimen (AF025) from the top part of sub-unit I of the Antalo Limestone Fm, Gilgele section (see Fig. 4B), GPS location 10°07′45.3″N; 38°10′54.3″E; one specimen (AF026) the top part of sub-unit II of the Antalo Limestone Fm, Kurar section (see Fig. 4D), GPS location 10°07′34.7″N, 38°09′25.7″E.
Description: The specimens are large, multispiral, with no umbilicus and a siphonostomatous aperture, bearing a short half-closed, siphonal canal. Spire is low, whorls are convex, and lack prominent carinae. The sutural ramp is broad, with rounded tubercles on the angulation of last whorl (i.e., at the shoulder of the whorl), where they also show maximum shell width. There is slight variation in the degree of inflation of the last whorl (compare Fig. 13D, I).
Remarks: The present specimens in their low spire, convex whorls, broad sutural ramp, and weak and round tubercles on the angulation of last whorl, closely match *Purpuroidea gigas* (Étallon, 1861) aff. *gigas*: Hirsch (1980, pl. 10, figs 14, 15). There are no other comparable forms. *Purpuroidea lapierrea* (Buvignier) occurring in Oxfordian sediments, and *Purpuroidea glabra* Morris and Lycett in the Bathonian are more trochiform, slender and have higher whorls with irregularly spaced spiral cords (Morris and Lycett, 1850; Fischer, 2001). The coeval middle Callovian *Purpuroidea*? *gradata* Hirsch (1980, pl. 11, figs 4, 5) has a more gradate shell that is covered with thick spiral cords,

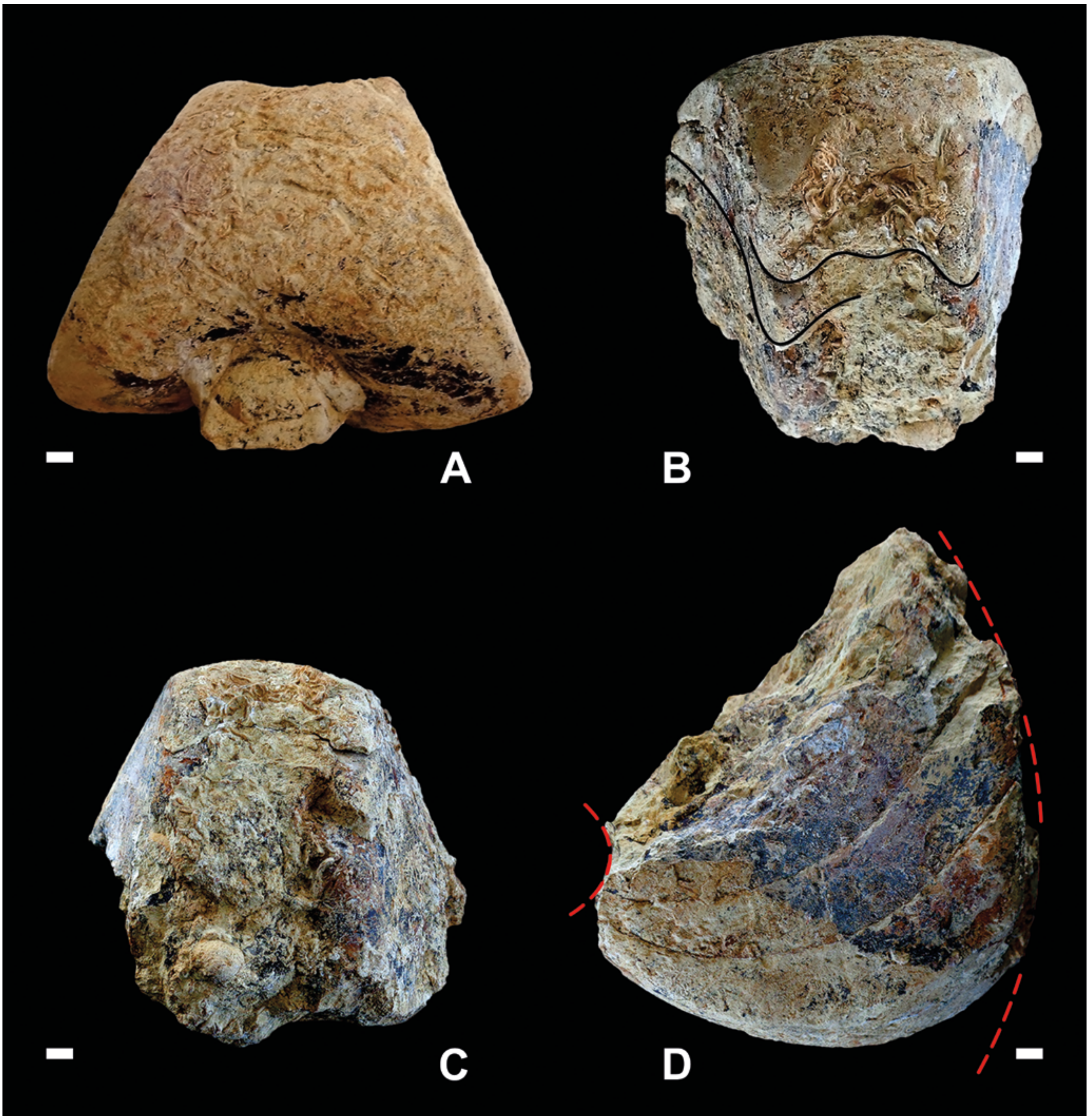

Fig. 12. *Paracenoceras* cf. *giganteum* (d'Orbigny), specimen no. AF005, Filikilik section (see Figs. 3C and 5C, D). GPS location 10°02′39.7″N, 38°13′53.7″E, elevation: 1,999 m a.s.l. Scale bar = 1 cm.

intercepted by spiral furrows; it also lacks the spinose tubercles/nodes on last whorl and the aperture is circular, unlike any other specimens of *Purpuroidea* (Hirsch, 1980).

Age: The type of *Purpuroidea gigas* (Étallon, 1861) comes from the upper Kimmeridgian of France (Étallon, 1861). Other occurrences are from the Kimmeridgian of Tunisia (Étallon, 1861) and the lower Oxfordian of northern Saini (Egypt) and Israel (Hirsch, 1980). In the present study, *P. gigas* comes from two horizons; the basal specimen (Fig. 13A, F) is associated with the middle Callovian *Erymnoceras* cf. *coronatum* and the upper one (Fig. 13G, K) with the early Kimmeridgian *Orthosphinctes*. Hence, a broad middle Callovian–early Kimmeridgian age is assigned to them.

DISCUSSION

The cephalopod (ammonites and nautiloids) records from the Ethiopian Jurassic are stratigraphically discontinuous and rare in their occurrences; those that have been documented are largely restricted to the "Kimmeridgian" interval (Dacqué, 1905; Scott, 1943; Venzo, 1942, 1959; Zeiss, 1974, 1984), which needs serious systematic re-evaluation. It is against this backdrop of sporadic occurrences that precise chronostratigraphic assignments and time-correlations cannot be achieved presently for the Ethiopian Jurassic. However, these sporadic finds need to be documented and placed within a stratigraphic framework, so that a template

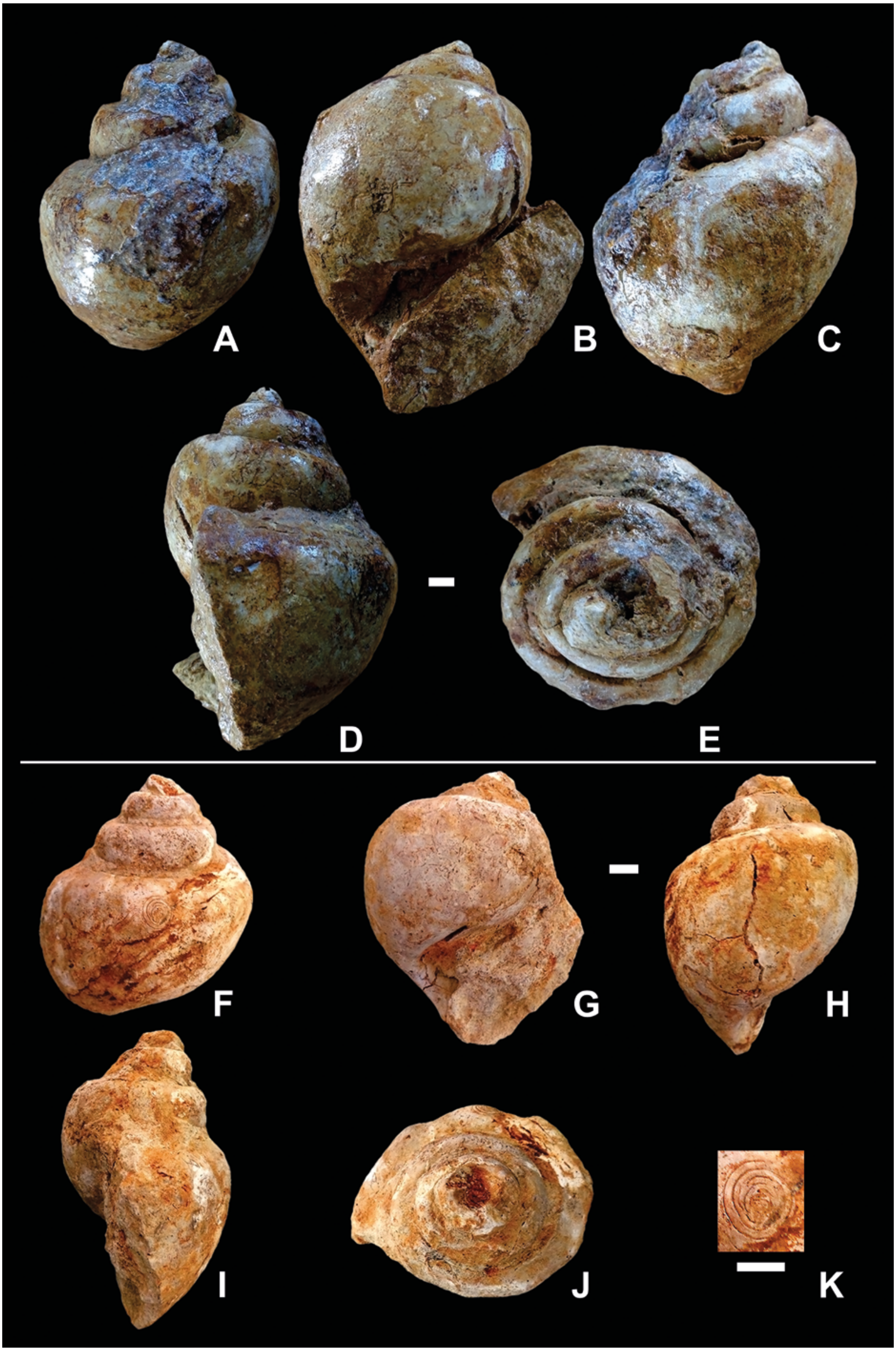

Fig. 13. *Purpuroidea gigas* (Étallon), specimen nos. AF025 (**A–F**) and AF026 (**G–K**). One specimen (AF025) from the Gilgele section (see Fig. 4B), GPS location 10°07′45.3″N; 38°10′54.3″E, elevation: 1964 m a.s.l.; one specimen (AF026) from the Kurar section (see Fig. 4D), GPS location 10°07′34.7″N, 38°09′25.7″E; elevation: 2,004 m a.s.l. **L.** *Cycloserpulid* on Fig. 13G. Scale bar = 1 cm.

is established for future, finer-resolution biozonation. This contribution is such an attempt.

The single example of a Bathonian nautiloid comes from the underlying gypsum-dominated GF (Jain, 2019a), whereas the rest of the cephalopod record comes from the overlying carbonate-dominated ALF (Dacqué, 1905; Scott, 1943; Venzo, 1942, 1959; Zeiss, 1974, 1984; Jain *et al*., 2020). The ALF has been bracketed to lie between early Callovian and late Tithonian on the basis of the occurrences of age-diagnostic, calcareous nannofossils (Jain and Singh, 2019). This intervening age interval (Callovian to Tithonian) in part, was recently occupied in part by the find of a typical middle Callovian ammonite, *Erymnoceras* cf. *coronatum* (Bruguière) (Jain *et al*., 2020; see Fig. 14). The present study addresses the late Callovian (*Pachyceras* cf. *lalandeanum* (d'Orbigny) and the early Kimmeridgian (*Orthosphinctes* aff. *tiziani* (Oppel) time interval (see Fig. 14).

The occurrences of the ammonite records (this study) and those from the Mekele (Martire *et al*., 2000) and Ogaden (Dacqué, 1905, 1914; Venzo, 1942, 1959; Scott, 1943; Zeiss, 1974) basins are discussed briefly below with respect to their biostratigraphic potential for the Jurassic sediments of Ethiopia (Fig. 14).

Middle Callovian

The occurrence of *Erymnoceras* cf. *coronatum* (Bruguière) at Dejen (Blue Nile Basin) marks the first record of definite middle Callovian strata for the Ethiopian Jurassic (Jain *et al*., 2020). This record, albeit discontinuous, succeeds the lower Callovian nannofossil record of the nearby Mugher area (150 south of Dejen; see Fig. 1D). No other middle Callovian fossils have been documented.

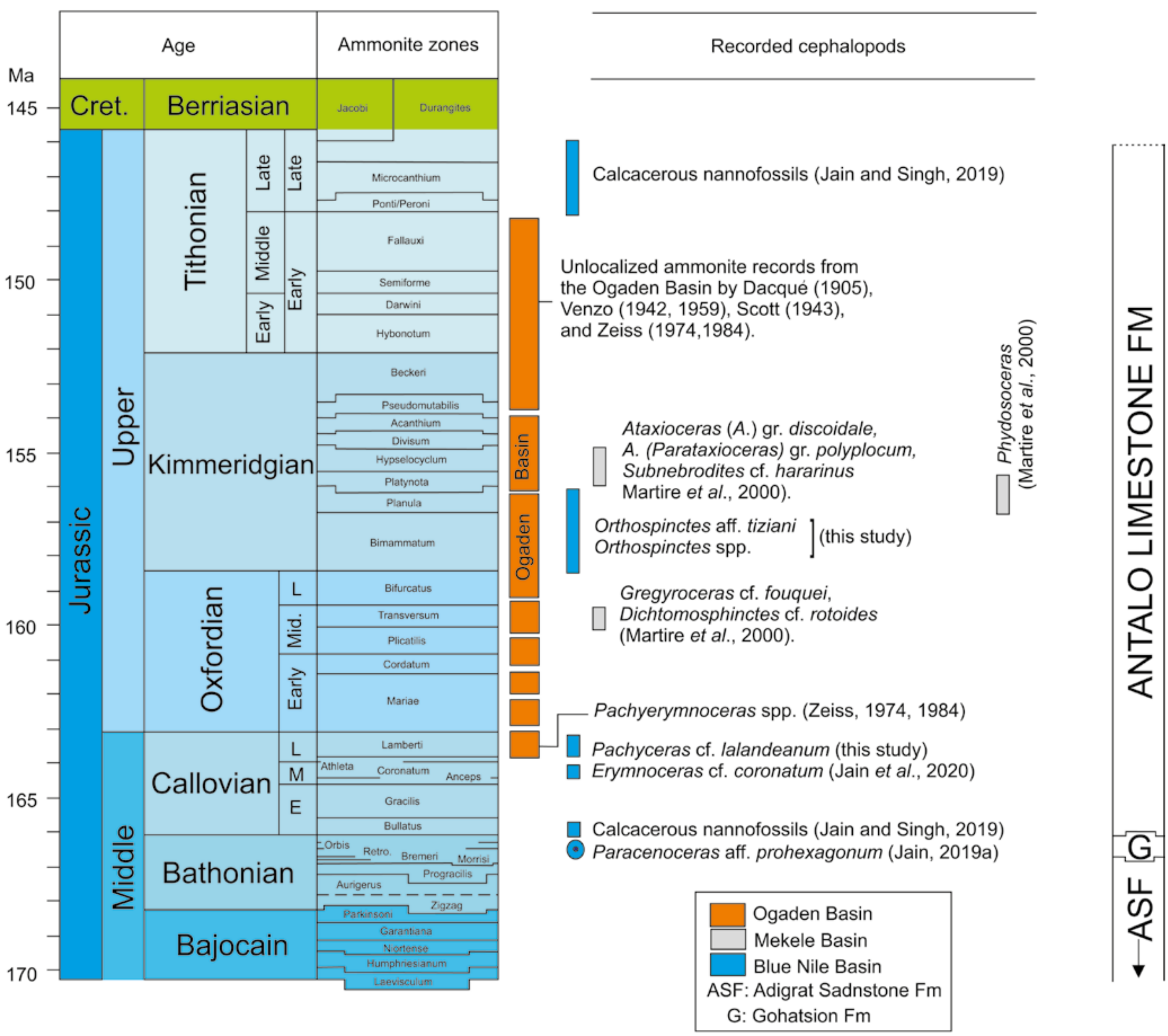

Fig. 14. Standard ammonite zones (after Cariou and Hantzpergue, 1997) and occurrences of cephalopods (ammonites and nautiloids) from the three sedimentary basins of Ethiopia, Ogaden, Blue Nile and Mekele (see text for further explanation and see also Fig. 1B for the location of the three basins). All ages are after Gradstein *et al.* (2012; see also GTS, 2012).

Late Callovian

Zeiss (1974) in the Ogaden Basin recorded three late Callovian *Pachyerymnoceras* specimens – *Pachyerymnoceras* sp. from Burcaf (SE of Harar; southwestern Ogaden Basin; see Fig. 1D), *P. jarryi* var. *ethiopicum* Zeiss (76 km north of Gabredarre, 6°43′60″N, 44°16′60″E; 500 km southeast of Harar) and *P. imlayi* Zeiss (60 km south of Giggia = Jijiga; 100 km east of Harar). Later, Zeiss (1984) mentioned that the Burcaf specimen is "closely related to *P. jarryi*", as figured by Imlay (1970, figs 1, 2) from the late Callovian of Jebel Tuwaiq, Saudi Arabia, and *P. jarryi* var. *ethiopicum* Zeiss is a close match for the late Callovian juvenile specimens of *P. philbyi*, as illustrated by Gill *et al*. (1985) from Israel. Both *P. imlayi* Zeiss and *P. jarryi* var. *ethiopicum* Zeiss came from the Gabredarre Fm (Zeiss, 1974, p. 270), a distinctive 150-m-thick oolitic and marly limestone unit, interbedded with gypsum and shales that otherwise had been given an Oxfordian–?Berriasian age (see Mohr, 1964; Merla *et al*., 1973). However, *Pachyerymnoceras* is restricted to the middle–late Callovian interval (Spath, 1927–1933; Cariou and Enay, 1999; Jain, 2017). Hence, more collections are needed to evaluate fully the aforementioned records. However, these records and their odd stratigraphic position are not discussed any further, as the present contribution limits itself to the reports from the Blue Nile Basin (Fig. 1).

Zeiss (1974) recorded a fragmentary specimen of *Pachyceras* cf. *lalandeanum* (d'Orbigny) from the Blue Nile Basin (Fig. 1) from a *"... site located about 5.5 km southeast of road bridge near the village of Cassi. The layer is located in the upper part of the approx. 470 m of Adigrat sandstone… about 15 m below its upper limit, and is represented by a 5 m thick layer*" (Zeiss, 1974, p. 270). If Zeiss's text is followed to the letter, then "*5.5 km SE from the bridge along the road*" is a location ~1 km west of the village of Filiklik (Fig. 3) and the strata there belong to the Bathonian Gohatsion Fm (gypsum beds) and also are too far from the Adigrat Sandstone Fm, mentioned in the text (see Fig. 3). The road, coming up from the bridge and passing the area, is disturbed by landslides, causing disruption of the stratigraphic succession. Hence, it appears that the specimen is unlocalized and finding its original horizon is almost impossible. This is compounded by the fact that there is also no mention of the containing lithology or an associated lithological section. In Europe, *Pachyceras lalandeanum* (d'Orbigny) occurs in the late Callovian Lamberti Zone (Charpy and Thierry, 1977; Lewy, 1983; Gill *et al*., 1985; Fischer, 1994; Fig. 14). In Kachchh (western India), i.e., along the peri-Gondwana margin (see Fig. 2), *P. lalandeanum* has been mentioned (but not illustrated) as occurring in the Poculum Subzone, Lamberti Zone (Krishna and Ojha, 1996). Contextually, between European occurrences (i.e. largely from France = Submediterranean Province) and India (see Fig. 2), *P. lalandeanum* also has been recorded from Israel (north Africa) from the top of the late Callovian Athleta (Gill *et al*., 1985) and Lamberti zones (Lewy, 1983; see fig. 8). Thus, for Ethiopia, on the basis of both the underlying occurrence of the middle Callovian *Erymnoceras* cf. *coronatum* (Bruguière) Jain *et al*. (2020) and the overlying late Callovian occurrence of *P. lalandeanum* (Zeiss, 1974, 1984), a late Callovian (Lamberti Zone) age can be inferred, indicating the presence of late Callovian interval in both the Blue Nile and Ogaden basins (see Fig. 14).

Middle Oxfordian

Martire *et al*. (2000) from the Mekele Basin (Fig. 1B), mentioned (but did not illustrate) the presence of *Gregoryceras* cf. *fouquei* and *Dichotomosphinctes* cf. *rotoides* from the lower part of their sub-unit A2 of the Antalo Limestone Fm, exposed in the Agabe section, some ~60 m above the basal Adigrat Sandstone Fm. It should be noted that *Dichotomosphinctes* cf. *rotoides* [= *Perisphinctes* (*Dichotomoceras*) *rotoides*] is the index fossil of the Rotoides Subzone, Transversarium Zone, uppermost middle Oxfordian (see Gygi, 2001; Głowniak, 2006) and *G. fouquei* is restricted to the Rotoides Subzone (see Bert *et al*., 2009). *Gregoryceras fouquei* (Kilian) has been recorded widely from France, Germany, Italy, Spain, Bulgaria, Algeria, Tunisia, Iran, Chile, and Kachchh (western India; see Bert *et al*., 2009). Głowniak (2006) re-interpreted *Dichotomosphinctes* as an early representative of *Dichotomoceras* that occurs widely in England, France, Germany, Switzerland, Poland, western India (Kachchh), Ethiopia, Kenya, and Japan (see Enay and Howarth, 2019).

Dacqué (1905), Scott (1943), Venzo (1942, 1959) and Zeiss (1974, 1984) recorded unlocalized Oxfordian ammonite discoveries from the Ogaden Basin. In the list of ammonites presented by Venzo (1959), of particular interest (in terms of an age-diagnostic species) is the record of *Perisphinctes* (*Kranaosphinctes*) *subevolutus* (Waagen) (= *Pachyplanulites subevolutus* (Waagen); Venzo 1959, pl. 1, fig. 3). It is a long-ranging species that spans from the early Oxfordian Cordatum Zone to the middle Oxfordian Transversarium Zone and commonly occurs in Madagascar (Collignon, 1959) and western India (Kachchh; Pandey *et al*., 2012). Of interest is also the reference to *Orthosphinctes tiziani* by Zeiss (1971, tab. 1); he also re-interpreted Venzo's *Dichotomosphinctes jabolii* (1959, pl. 1, fig. 7) as an *Orthosphinctes*. More recently, Pandey *et al*. (2013, p. 109), while describing the Oxfordian–Kimmeridgian ammonite fauna from the Kachchh Basin (western India) re-interpreted *Lithacoceras mombassanum* (Dacqué in Venzo, 1959, pl. 2, fig. 4; pl. 3, fig. 1) as "another example of evolute, macroconchiate *Orthosphinctes*" and noted that the "middle Kimmeridgian" age given by Venzo (1959) for the ammonite fauna at Harar (northern Ogaden; Ethiopia) and the one by Collignon (1959) from Madagascar (i.e., Collignon's *Hybonoticeras hybonotum-Aspidoceras acanthicum* biozones) were actually earliest Tithonian. Hence, a thorough re-evaluation of the ammonite fauna by the aforementioned authors from Ethiopia is needed urgently, as also is re-sampling.

Early Kimmeridgian

Martire *et al*. (2000), from the Mekele Basin (Fig. 1B), also mentioned the presence of *Physodoceras* in the upper part of the sub-unit, A2 of the Antalo Limestone Fm, exposed in the Agabe section. *Physodoceras* occurs in the early Kimmeridgian (Planula to Platynota zones; Schweigert, 2020) and occurs widely in Europe, Russia, Kenya, Madagascar, India, Nepal, Mexico, USA (Texas), and Cuba (see Enay and Howarth, 2019).

Venzon (1959) reviewed the occurrences of the genus *Physodoceras* from the Ogaden Basin, on the basis of the unlocalized collections of Dacqué (1905) and Scott (1943), and recorded several species at Harar (*P. altenense* (d'Orbigny), *P. supraspinosum* (Dacqué), *P. dogouense* Scott, *P. sub-dogouense* Vcnzo, *P. microplum* (Oppel), *P. gortanii* (Vcnzo), *P. gregoryi* (Spath) and *P. browni* Scott) and assigned to them an early Kimmeridgian age. Recently Schweigert (2020) noted that Dacqué's *P. altenense* (d'Orbigny) from Harar closely resembles the Submediterranean *P. circumspinosusm* recorded in the early Kimmeridgian Platynota Zone (uppermost parts).

Martire *et al*. (2000), from the same level (A2) of the Antalo Limestone Fm exposed in the Agabe section, also mentioned the presence of the early Kimmeridgian (Hypselocyclum Zone) "*Ataxioceras* (*A*.) gr. *discoidale*". From the nearby Mekele section, Martire *et al.* (2000) also mentioned the presence of *Subnebrodites* cf. *hararinus* (Venzo) and "*Ataxioceras* (*Parataxioceras*) gr. *polyplocum*" from the coeval C2 sub-unit. *Subnebrodites* is restricted to the early Kimmeridgian Planula Zone and occurs widely in France, Switzerland, Germany, Poland, Romania, Italy, Spain, Portugal, Morocco, Algeria, and Tunisia (see Enay and Howarth, 2019), whereas *Ataxioceras* (*Parataxioceras*) occurs stratigraphically higher in the upper part of the Platynota to the Hypselocyclum zones (Fig. 14) and occurs widely in Germany, Switzerland, Spain, Poland, Portugal, Bulgaria, northern Africa, northern Turkey and Mexico (see Enay and Howarth, 2019). However, Martire *et al*. (2000) recorded these two stratigraphically distinct forms together. Thus, in the Mekele Basin, the exposed Antalo Limestone Fm spans from the middle Oxfordian (Rotoides Subzone, Transversarium Zone) to the early Kimmeridgian (Hypselocyclum Zone; see Fig. 14). None of these forms have been recorded so far from the Blue Nile Basin (this study).

In the Ogaden Basin (from Harar), *Katroliceras* has been noted by Venzo (1959), who assigned it a Kimmeridgian age. Later, Zeiss (1971) gave it an early Tithonian age and correlated it with his *Subplanites scarsellai* Zone. Zeiss (2003) also noted the occurrence of *Katroliceras* at Harar and correlated its occurrence with the early Tithonian Hybonotum Zone (see Fig. 14). Venzo (1959) recorded *Subplanites scarsellai* Venzo and *Subplanites* cf. *rueppellianus* (Quenstedt) and assigned them to the early Tithonian (Hybonotum Zone; see Parent, 2003). *Katroliceras somalicum* Valduga (see Valduga, 1954) was listed as being among the Ethiopian ammonites, identified by Venzo (1959) from his "Kimmeridgian" deposits northwestwards from Harar and subsequently by Zeiss (1971) from the northern Ogaden. Zeiss (1971) interpreted *K. somalicum* as belonging to the *Hybonoticeras kachhense* Zone of the latest Kimmeridgian and correlated the same with the Beckeri Zone of the Submediterranean Tethys (see Fig. 14). As such, the genus *Katroliceras* ranges from the latest early Kimmeridgian to the latest Tithonian (see Krishna and Pathak, 1993). Later, Dacqué (1905, p. 122) from Atschabo near Harro Rufa (100 km southwest of Harar, Ogaden Basin), recorded several unlocalized perisphinctids, associated with bituberculate aspidoceratids. In the Indo-Madagascan region, the bituberculate aspidoceratines predominate (Spath, 1933; Collignon, 1959) and span from the middle Kimmeridgian to the early Tithonian (Enay, 2009). Later, Howarth, (1998, p. 65,) while describing the ammonite fauna from Kenya, synonymized unlocalized Harro Rufa specimens of *Aspidoceras somalicum* of Dacqué (1905, 149, pl. 17, fig. 1), *A. iphiceroides* Waagen (of Dacque 1910, p. 24, pl. 1, fig. 8; pl. 4, fig. 4), *A. kilindianum* Dacqué (1910, p. 25, pl. 1, fig. 9; pl. 3, fig. 6) and *A. bispinosum* (Zieten) of Venzo (1959, p. 164, pl. 12, fig. 4; pl. 14, figs 3, 4) under *A. longispinum* (Sowerby). *A. longispinum* spans from the late Kimmeridgian Beckeri Zone to the lower Tithonian Hybonotum Zone (Howarth, 1998). Thus, on the basis of the available ammonite data that need serious re-evaluation and re-sampling, a broad late Callovian (*Pachyerymnoceras* sp. by Zeiss, 1976, 1984) to early Tithonian age is proposed for the Antalo Limestone Fm exposed in the Ogaden Basin.

Thus, in summary, for the Antalo Limestone Fm, the calcareous nannofossil and ammonite records in the Blue Nile Basin provide an age bracket between the early Callovian and the late Tithonian, in the Mekele Basin between the late Callovian and the early Kimmeridgian (ammonite records) and in the Ogaden Basin from the middle Oxfordian to the early Tithonian (ammonite records). However, it should be mentioned that (a) these for now must be considered tentative age assignments, as much of the ammonite fauna needs taxonomic re-evaluation, and that (b) the top part of the Antalo Limestone Fm in all the three basins has not yielded any ammonites.

CONCLUSIONS

New ammonites, nautiloids and gastropods from the Antalo Limestone Fm exposed at Dejen are described and their relevance to the biostratigraphy of the Blue Nile Basin is discussed. On this basis, the main conclusions of the present contribution are:

In the Blue Nile Basin, the Antalo Limestone Fm exposed at Mugher is dated as between early Callovian and late Tithonian, on the basis of calcareous nannofossils. At Dejen (this study; Blue Nile Basin), on the basis of the occurrence of ammonites, a middle Callovian to early Kimmeridgian age is recognized. The age of the Antalo Limestone Fm is reassessed from the three Jurassic basins – the Ogaden, Blue Nile and Mekele basins. The Ogaden basin is dated as between late Callovian and early Tithonian (ammonite records) and the Mekele Basin from the latest middle Oxfordian to the early Kimmeridgian (ammonite records).

The top part of the Antalo Limestone Fm, in all the three sedimentary basins – Ogaden, Blue Nile and Mekele – has not yielded any ammonites.

The ammonite record from Dejen (Blue Nile Basin) includes the middle Callovian *Erymnoceras* cf. *coronatum* (Bruguière), the late Callovian *Pachyceras* cf. *lalandeanum* (d'Orbigny) and the early Kimmeridgian *Orthosphinctes* aff. *tiziani* (Oppel).

Erymnoceras cf. *coronatum* is associated with the gastropod *Purpuroidea gigas* (Étallon), *Pachyceras* cf. *lalandeanum* is associated with the nautiloid *Paracenoceras* cf. *giganteum* (d'Orbigny), and *Orthosphinctes* aff. *tiziani* (Oppel) with another nautiloid species of *P.* cf. *kumagunense* (Waagen) and *P.* cf. *ennianus* (Dacqué), along with *P. gigas* (Étallon).

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