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Integration of Darriwilian (Middle Ordovician) $\delta^{13}C_{org}$ chemostratigraphy with graptolite biostratigraphy in the classical Röstånga area in northwestern Scania (southern Sweden)

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Abstract. The largely covered Middle Ordovician succession in the classic geological Röstånga area in northwestern Scania has not been studied for some 80 years. A new drill core through a succession ranging from the lower–middle Darriwilian to the lower Sandbian has provided a unique opportunity to investigate the graptolite biostratigraphy and the $\delta^{13}C_{org}$ chemostratigraphy, and clarify their stratigraphic relations, through this ~90 m thick interval, which is developed within a black shale facies. The lithology, biostratigraphy and chemostratigraphy are closely similar to those of the coeval strata in the Fågelsång area, south-central Scania, including the presence of the Fågelsång Phosphorite, which was previously unrecorded in the Röstånga area. The new data are particularly important in providing evidence of the relations between graptolite biostratigraphy and $\delta^{13}C_{org}$ chemostratigraphy. The Fågelsång-3 and Röstånga-2 drill core successions are currently the only Darriwilian sequences in the world where these relations have been well established.

Key words: outer shelf, black shale, Ordovician, regional correlation, chemostratigraphy, phosphorite, Baltoscandia.

INTRODUCTION

An important area for the study of Darriwilian graptolite biostratigraphy not only in Scania (Skåne), southern Sweden, but in the entire Baltoscandia is at the village of Röstånga, which is located approximately 35 km north of the city of Lund (Fig. 1). Although the Middle Ordovician outcrops in that region are of insignificant size, shallow diggings through unexposed intervals, such as those carried out by Hadding (1913) and Ekström (1937), have provided important information on some Middle Ordovician stratigraphic intervals. The pioneer work on the Middle Ordovician of the Röstånga area was carried out a very long time ago (e.g. Tullberg 1880, 1882, 1883; Moberg 1910; Hadding 1913; Ekström 1937) and virtually no new studies of the Lower and Middle Ordovician of this area have been published for decades. The principal reason for this scientific inactivity may have been that the existing small outcrops were judged unlikely to yield significant new information. Hence, in order to establish a useful standard succession for the Röstånga area, there was an urgent need for a new drill core through the Darriwilian succession. The usefulness of such a new drill core was illustrated by a recent drilling (Röstånga-1) through the Upper Ordovician and lower Silurian that has yielded a wealth of new information (e.g. Bergström et al. 1999, 2014, 2016; Pålsson 2002; Maletz et al. 2014).

A new core drilling, here referred to as Röstånga-2, through the Darriwilian succession, was carried out in 2016. The purpose of the present report, which is preliminary in some respects, is to summarize the principal stratigraphical results of this drilling, especially the relations between the graptolite biostratigraphy and the $\delta^{13}C_{org}$ chemostratigraphy through the Darriwilian succession. It is of special interest that comparable stratigraphic data have recently become available from a similar drilling (Fågelsång-3) that penetrated the Darriwilian succession in the Fågelsång area

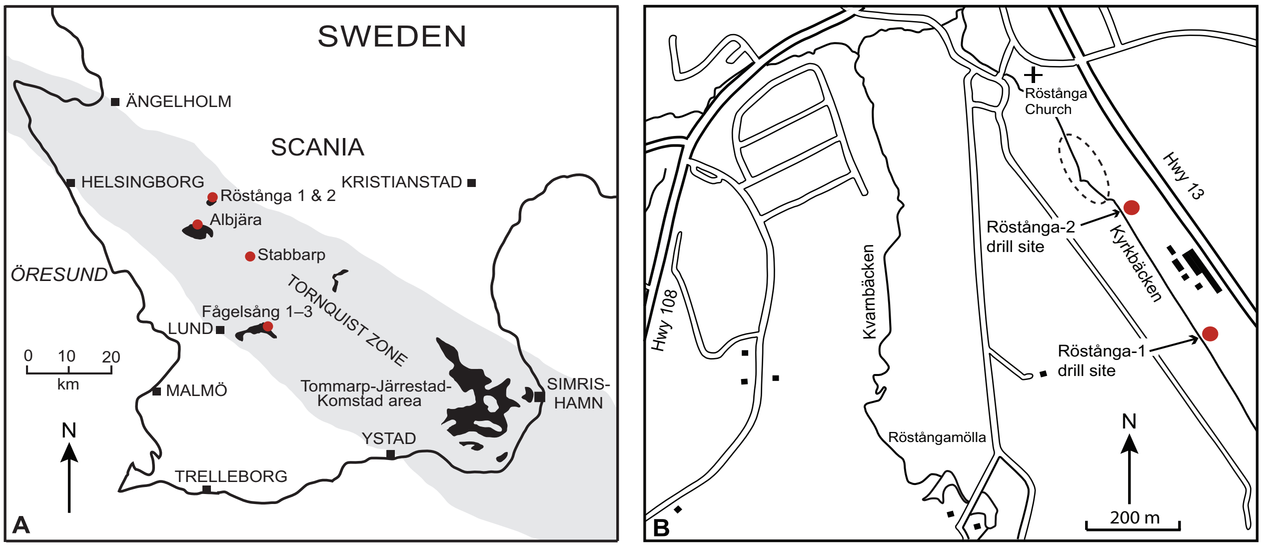

Fig. 1. A, sketch map of Scania (Skåne), southern Sweden, showing Ordovician outcrop areas (black) and the geographic position of localities discussed in the text. Modified after Maletz et al. (2020, fig. 1). **B**, detailed map of the Röstånga area west of Highway 13 showing the location of the Röstånga-1 and Röstånga-2 drill sites and the Church Brook (Kyrkbäcken). The small exposures of Darriwilian strata, where Hadding (1913) and Ekström (1937) made their excavations, are along the west side of the brook (stippled oval) a short distance northwest of the Röstånga-2 drill site. Modified after Maletz et al. (2020, fig. 1).

in south-central Scania (Bergström et al. 2018; Maletz & Ahlberg 2020). The drilling at Röstånga is important in providing an opportunity to assess the validity of the relations between graptolite biostratigraphy and $\delta^{13}C_{org}$ chemostratigraphy recognized by Bergström et al. (2018, 2020) in the Fågelsång succession. Although different in some respects, these two key successions exhibit notable similarities, which suggests that they are representative of the outer shelf–upper slope deposition across this part of Baltoscandia during Darriwilian time. Both these successions are located in the Scanian Confacies Belt of Jaanusson (1976, 1995) in which the dominant lithology is graptolite-bearing fine-clastic sediments that were deposited in deeper water than the coeval cold-water carbonates (see Lindskog & Eriksson 2017 and references therein) with diverse shelly faunas that were laid down in the central parts of the Baltoscandic platform.

PREVIOUS WORK ON THE DARRIWILIAN SUCCESSION AT RÖSTÅNGA

Early studies of this part of the Ordovician in the Röstånga region were carried out during the second half of the nineteenth century by, among others, Linnarsson (1875, 1879) and Tullberg (1880, 1882, 1883). In an informative summary of previous work together with much new information, Moberg (1910) provided a still useful guide to the Lower Palaeozoic geology of the area. Subsequently, two of Moberg's students, namely Hadding (1913) and Ekström (1937), published important new information about the Röstånga Darriwilian succession with special regard to the graptolite biostratigraphy. To get data from normally unexposed intervals, both Hadding and Ekström made several excavations along the Church Brook (Kyrkbäcken; Fig. 1B). Whereas Hadding's work extended from the middle Darriwilian *Pterograptus elegans* Zone of the Almelund Shale to well into the Sandbian Sularp Shale, his studies primarily focused on the latter unit (Lower Dicellograptus Shale or Undre Dicellograptusskiffern of Hadding). Ekström's study was concentrated on the middle–upper Darriwilian Almelund Shale (Upper Didymograptus Shale of Ekström), from the *Nicholsonograptus fasciculatus* Zone (the *Didymograptus bifidus* Zone of Ekström) to the *Pseudamplexograptus distichus* Zone (the *Glossograptus hincksi* Zone of Ekström) for a distance of about 80 m along the Church Brook. Since the time of Ekström's (1937) studies, which were based on field work from 1913 to about 1920, very few new data have been published on the Darriwilian succession at Röstånga. This is in contrast to the significant amount of work that in recent years has been devoted to the Katian and Hirnantian part of the succession (cf. Pålsson 1996, 2002; Bergström et al. 1997, 1999, 2010, 2011, 2018; Badawy et al. 2014; Maletz et al. 2014). A major reason for this is the lack of outcrops of especially the Lower Ordovician that still remains essentially unknown in this area.

LITHOLOGY AND LITHOSTRATIGRAPHIC CLASSIFICATION OF THE RÖSTÅNGA-2 DRILL CORE SUCCESSION

The Röstånga-2 core drilling, which took place on a field 30 m east of the Church Brook and 370 m southeast of Röstånga Church (Fig. 1), resulted in a 116.11 m long core succession, reaching a depth of 116.91 m (Fig. 2). The drilling was carried out in September 2016 by the Engineering Geology Group of the Department of Measurement Technology and Industrial Electrical Engineering at Lund University using an Atlas Copco CT20 drill rig (*Riksriggen*). The core diameter is 82 mm down to 12.10 m and 62 mm between 12.10 and 116.91 m. The cored sequence has a dip of ~34–43 degrees and core loss was minimal. Using an average dip of ~38 degrees, the calculated stratigraphical thickness of the penetrated succession may be approximately 90 m. This may not represent the true thickness of the study succession as a few bedding plane surfaces may be interpreted as possibly representing fault planes. However, the completeness of the graptolite zone succession suggests that there are no major gaps in the succession, but it cannot be excluded that there are some fault-generated minor duplications or deletions of one or several intervals. Nevertheless, it is difficult to avoid the conclusion that the Darriwilian sequence at Röstånga is significantly thicker than that at Fågelsång, possibly by as much as 50%.

Virtually the entire core succession is a rather monotonous black to grey shale with a few thin beds of fine-crystalline impure limestone mixed with siliciclastic material (Fig. 2). The core interval from 111.10–116.91 m, that is, roughly the stratigraphically lowermost 5 m of the study succession, is light to medium-grey mudstone. Both graptolite biostratigraphy and chemostratigraphy suggest that this interval may represent a transition to the early Darriwilian carbonate unit known as the Komstad Limestone that is rather widely distributed in Scania (see Bergström et al. 2018 for a comparison with the corresponding interval in the Fågelsång area). Moberg (1910) recorded this unit in boulders from a locality at Röstånga, but later authors (e.g. Ekström 1937, p. 23) have expressed doubts about its *in situ* occurrence in this area (see also Nielsen 1995, p. 13). An occurrence of the Komstad Limestone at Röstånga appears not unlikely in view of the fact that it has a thickness of 2.75 m in the Albjära drill core (cf. Maletz 2005), which was drilled at a site approximately 8 km southwest of Röstånga (Fig. 1A). It seems that deepening the drill hole of Röstånga-2 a few metres would clarify if the Komstad Limestone is present at this site.

The drill core succession up to a depth of 19.7 m is classified as the Almelund Shale (Fig. 2). Most interestingly, its top is marked by a few centimetres thick phosphorite bed (Fig. 3) that appears to have the same stratigraphic position as the prominent Fågelsång Phosphorite in the Fågelsång succession (cf. Bergström et al. 2000). This partly conglomeratic bed has not been identified with certainty in northwestern Scania, but Tullberg (1883) recorded a lithologically similar bed in a drill core from Stabbarp, which is approximately half-way between Röstånga and Fågelsång (Fig. 1A). Hadding (1913, p. 82) noted that phosphorite lenses and beds occur at several levels in the Fågelsång succession (cf. Bergström et al. 2000) and he felt that in the absence of biostratigraphy, it was premature to identify the Stabbarp bed with what is now referred to as the Fågelsång Phosphorite. At any rate, this prominent bed apparently represents a period of very slow net deposition, erosional reworking and/or sea floor phosphogenesis during the earliest part of the Upper Ordovician Sandbian Stage (cf. Finney & Bergström 1986). As is the case in the Fågelsång succession, the Almelund Shale succession in the new drill core contains a small number of thin K-bentonite beds.

The topmost 19.7 m of the drill core, that is, the interval above the Fågelsång Phosphorite, includes dark shale with a couple of thin K-bentonite beds. Following the lithostratigraphy of the Fågelsång succession (Bergström et al. 2002), it is herein classified as the Sularp Shale.

GRAPTOLITE BIOSTRATIGRAPHY OF THE RÖSTÅNGA-2 SUCCESSION

The graptolite biostratigraphy of the Röstånga-2 core was recently described by Maletz et al. (2020), who showed that the cored succession ranges from the middle part of the Darriwilian Stage into the lowermost Sandbian Stage (Fig. 2). It is conceivable that also the basal part of the Darriwilian Stage is present in the Röstånga area, but in the absence of outcrops of this interval, the only way to verify this idea is by a new drilling, or by deepening the Röstånga-2 drill hole.

Assuming that the Röstånga phosphorite bed, identified as the Fågelsång Phosphorite, is coeval with that bed at Fågelsång (Bergström et al. 2000), the top of the Darriwilian Stage in the Röstånga succession would be somewhat below the phosphorite bed. According to Bergström et al. (2000) and Bergström & Ahlberg (2004), the base of the *Nemagraptus gracilis* Zone should be found in the uppermost part of the Almelund Shale, as it was defined in the GSSP section at Fågelsång.

The graptolite faunas of the Almelund Shale in the Röstånga-2 drill core show the presence of the Darriwilian *Holmograptus lentus*, *Nicholsonograptus fasciculatus*, *Pterograptus elegans*, *Pseudamplexograptus distichus* and *Jiangxigraptus* (formerly *Dicellograptus*) *vagus* zones (Maletz et al. 2020), that is, the same graptolite zone succession as at Fågelsång (Fig. 2). The index fossil of the

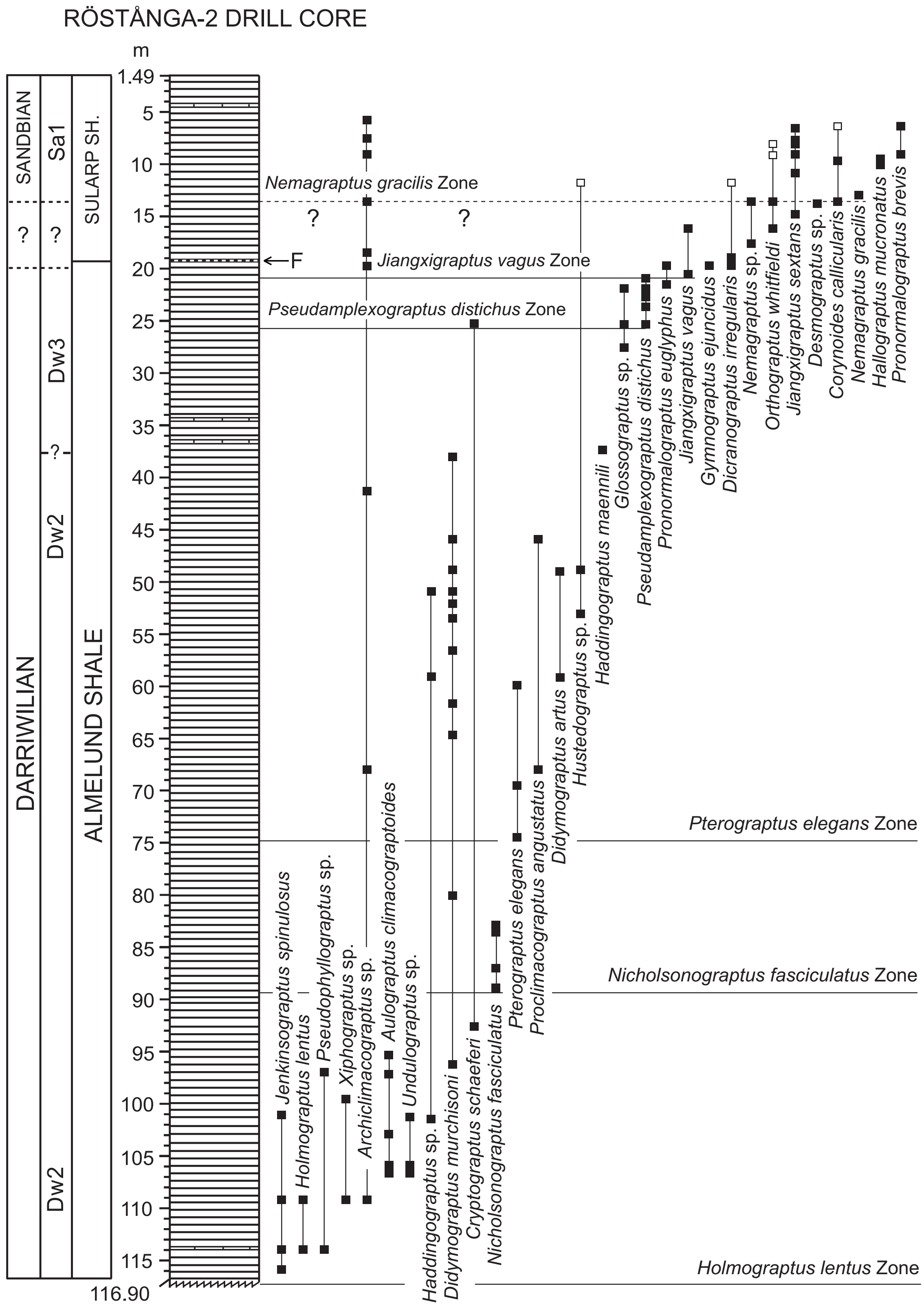

Fig. 2. Lithological succession, formation classification and graptolite species ranges through the Darriwilian–lower Sandbian succession in the Röstånga-2 drill core. Note the presence of the Fågelsång Phosphorite bed (F) just above the 20-m level. Stage slices (Dw2, Dw3, Sa1) from Bergström et al. (2009). Biostratigraphy and ranges of graptolites based on Maletz et al. (2020, fig. 2).

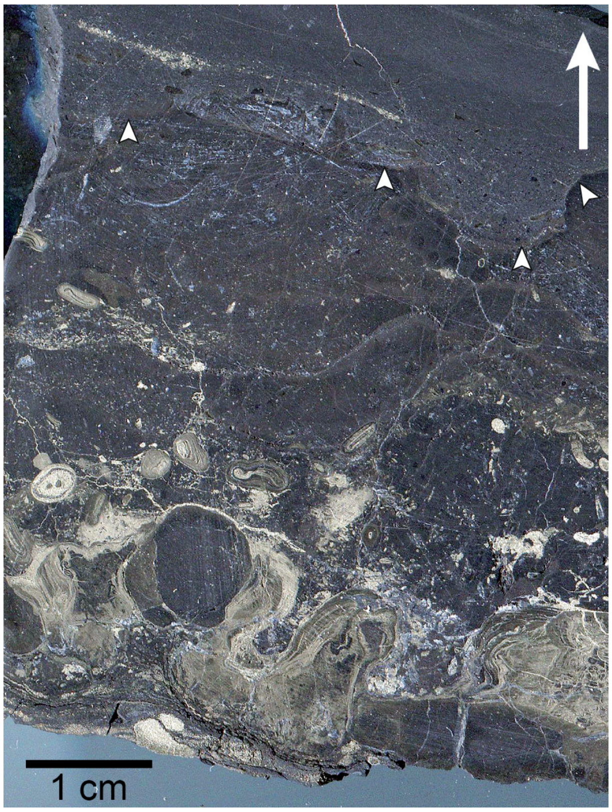

Fig. 3. Photo of the Fågelsång Phosphorite from just above the 20-m level in the Röstånga-2 drill core. This is the first record of this lithologically characteristic bed in the Röstånga area. The arrow is placed just above the top surface of the bed. Note the conglomeratic nature of especially the lower part of this bed and the apparent disconformity surface in its upper part (marked by arrowheads).

basal Darriwilian *Levisograptus austrodentatus* Zone has not yet been found in Scania, but the index species of two of its subzones have been recorded just below the Komstad Limestone at Fågelsång (Bergström et al. 2018; Maletz & Ahlberg 2018, 2020). The corresponding lowermost Darriwilian strata are not yet known from Röstånga.

The lowermost portion of this drill core, which includes the drill core depth from 89.1 m to 116.25 m, is referred to the *Holmograptus lentus* Zone. Using an average dip of 38 degrees, the stratigraphical thickness of this interval is calculated to be ~21.5 m. Graptolites are generally not very well preserved in this interval, but the fauna includes, apart from the zone index, pendent didymograptids, phyllograptids identified as *Pseudophyllograptus* sp. and *Aulograptus climacograptoides* (see Maletz et al. 2020).

The base of the overlying *Nicholsonograptus fasciculatus* Zone is placed at the level of the first occurrence of the zone index, which is at a core depth of 89.1 m. The top of this zone is taken at the level of the first occurrence of *Pterograptus elegans,* which is at a core depth of 74.88 m. Using 38 degrees as the average dip of these strata, the total stratigraphical thickness of this zone is ~11 m. Graptolites recorded from this zone include, among others, *Cryptograptus schaeferi*, *Proclimacograptus angustatus* and specimens of *Haddingograptus* and *Archiclimacograptus* (Maletz et al. 2020).

As just noted, the base of the overlying *Pterograptus elegans* Zone is taken to be at the core level of 74.88 m. In this drill core, this zone ranges up to a core level of 26.02 m and has a calculated total stratigraphical thickness of ~39 m. Most of this zone along the Church Brook was excavated by Ekström (1937), who estimated its thickness there to be ~15 m, which includes a several-metre-thick unexposed interval. The graptolite fauna of this zone includes slender didymograptids, such as *Didymograptus artus*, and more robust specimens, such as *Didymograptus murchisoni*.

The base of the overlying *Pseudamplexograptus distichus* Zone is placed at the level of the first occurrence of the zone index species at a core depth of 26.02 m. The top of the zone is marked by the first appearance of the zone index *Jiangxigraptus vagus* at a core depth of 20.7 m. The stratigraphical thickness of this zone is ~4.4 m. In the past, this interval has frequently been referred to as the *Glyptograptus teretiusculus* Zone, but the extended vertical range of the zone index species into both older and younger strata, along with the unclear morphology of the type specimens of this species (cf. Jaanusson 1960, p. 322), have made it appropriate to abandon this species as a zonal index. Herein, we follow Maletz et al. (2007), Chen et al. (2016), Maletz & Ahlberg (2020) and Maletz et al. (2020) in using *Jiangxigraptus vagus* as a zone designation. In the Röstånga-2 drill core, the graptolite fauna of this zone is relatively diverse and includes, among others, *Dicranograptus irregularis* and *Gymnograptus ejuncidus* (see Maletz et al. 2020).

The top of the *Jiangxigraptus vagus* Zone is currently not well defined in the Röstånga-2 drill core succession because the stratigraphically oldest specimens of the index of the next higher graptolite zone, the *Nemagraptus gracilis* Zone, have been found well above the base of the Sularp Shale at the 13.22 m drill core level (Maletz et al. 2020). Taking the zone base at that level would be in conflict with the conditions at Fågelsång where the base of this zone is 1.4 m below the base of the Fågelsång Phosphorite (Bergström et al. 2000). As is the case at Fågelsång, the graptolite fauna of the uppermost part of the Almelund Shale is poor and the species found in the new drill core are not diagnostic of a specific zone. However, judging from the $\delta^{13}C$ chemostratigraphy and a comparison with the carbon isotope curve from Fågelsång (Bergström et al. 2018, 2020), it would appear that the base of the *Nemagraptus gracilis* Zone corresponds to a

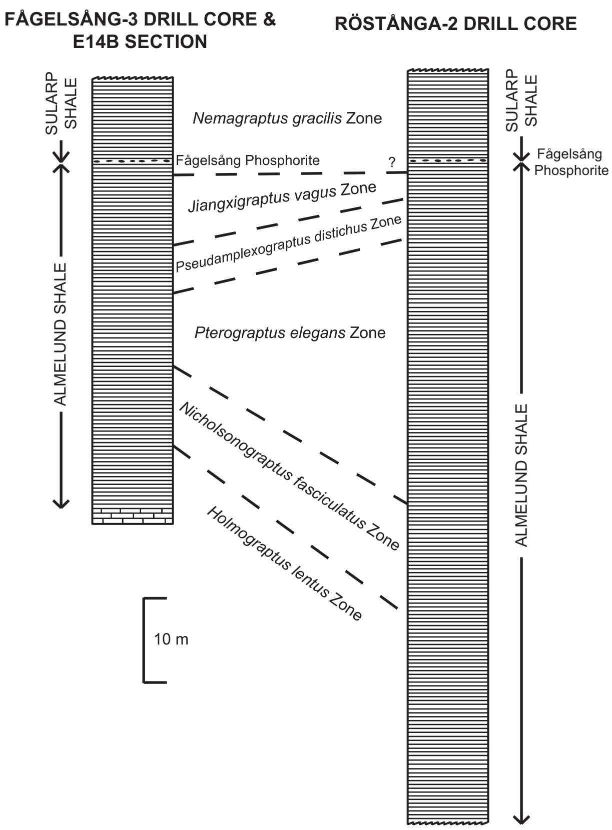

Fig. 4. Comparison between the estimated stratigraphical thickness of the middle–upper Darriwilian graptolite zones at Fågelsång (based on the Fågelsång-3 drill core and locality E14b) and the Röstånga-2 drill core. The calculated thicknesses are based on an assumed average dip of 10 degrees at Fågelsång and 38 degrees at Röstånga. As noted in the text, the precise level of the base of the *Nemagraptus gracilis* Zone remains undetermined in the Röstånga-2 drill core due to the absence of zone index graptolites in the uppermost Almelund Shale and lowermost Sularp Shale. As shown in this figure, the calculated thicknesses of the various graptolite zones in the two successions are similar except those of the *Pterograptus elegans* and *Holmograptus lentus* zones, which appear much thicker in the Röstånga-2 drill core. As noted in the text, this may be an artifact due to strata duplication by faulting.

level well below the first occurrence of the zone index in also the Röstånga-2 drill core.

It should be noted that the Darriwilian graptolite faunas from Röstånga have much in common with the coeval ones from Fågelsång (cf. Maletz & Ahlberg 2020) and there is also a close similarity to the graptolite faunas of the Albjära drill core faunas recorded by Maletz (1995). The latter core was estimated to include about 75 m of the Almelund Shale (identified as the Elnes Formation by Maletz 1995). Based on Ekström's (1937) records, the middle–upper Darriwilian interval has yielded 29 graptolite species at Röstånga and 33 species at Fågelsång among which 27 (93%) are in common. Although these figures may change somewhat after a modern revision of the faunas, there is no doubt that these faunas have essentially the same composition. This is not surprising in view of the relatively close distance between these areas and their closely similar depositional environments.

In view of the great similarity between the Darriwilian graptolite faunas from Röstånga and Fågelsång, it is obviously of interest to compare the thickness of the graptolite zones in the two regions (Fig. 4). Obviously, without consideration of the dip, such a thickness comparison is meaningless. As is shown in the literature (e.g. Hede 1951), the dip varies through the Fågelsång Darriwilian succession but we have adopted a figure of 10 degrees as an average in our attempt to calculate the stratigraphical thickness of the graptolite zones in our study successions in that area. As shown in Fig. 4, the stratigraphical thickness of the *Pseudamplexograptus distichus* and *Nicholsonograptus fasciculatus* zones is about 4–7 m and 10 m, respectively in the two successions, whereas the *Pterograptus elegans* Zone has a stratigraphical thickness of about 8 m in the Fågelsång-3 drill core, but close to 40 m in the Röstånga-2 succession. We consider the latter figure to be greatly inflated and probably an artifact of thickness duplication by faulting, although this is not obvious from the isotope curve shown in Fig. 5. It should be noted that in Ekström's (1937) excavations along the Church Brook, the total estimated thickness of this graptolite zone would be no more than ~15 m, including an estimated 5 m thick unexposed interval. This estimated thickness of the *Pterograptus elegans* Zone is not much different from that in the Fågelsång-3 drill core indicated above.

$\delta^{13}C_{ORG}$ CHEMOSTRATIGRAPHY OF THE RÖSTÅNGA-2 SUCCESSION

Samples and laboratory analysis

Among 233 samples collected from the drill core interval 1.49–116.90 m, 230 yielded useful carbon isotope data (Table 1). Assuming an average dip of 38 degrees, the sampled interval would have a stratigraphical thickness of approximately 90 m. In most cases sampling took place at 50 cm drill core intervals which corresponds to a stratigraphical thickness of 40 cm. The samples were subjected to the same laboratory treatment as those from the Fågelsång-3 drill core as described by Bergström et al. (2018). Carbon isotope analyses of organic carbon were performed using a Flash EA 2000 elemental analyser connected online to a ThermoFisher Delta V Plus mass spectrometer at the Geocentre of Northern Bavaria,

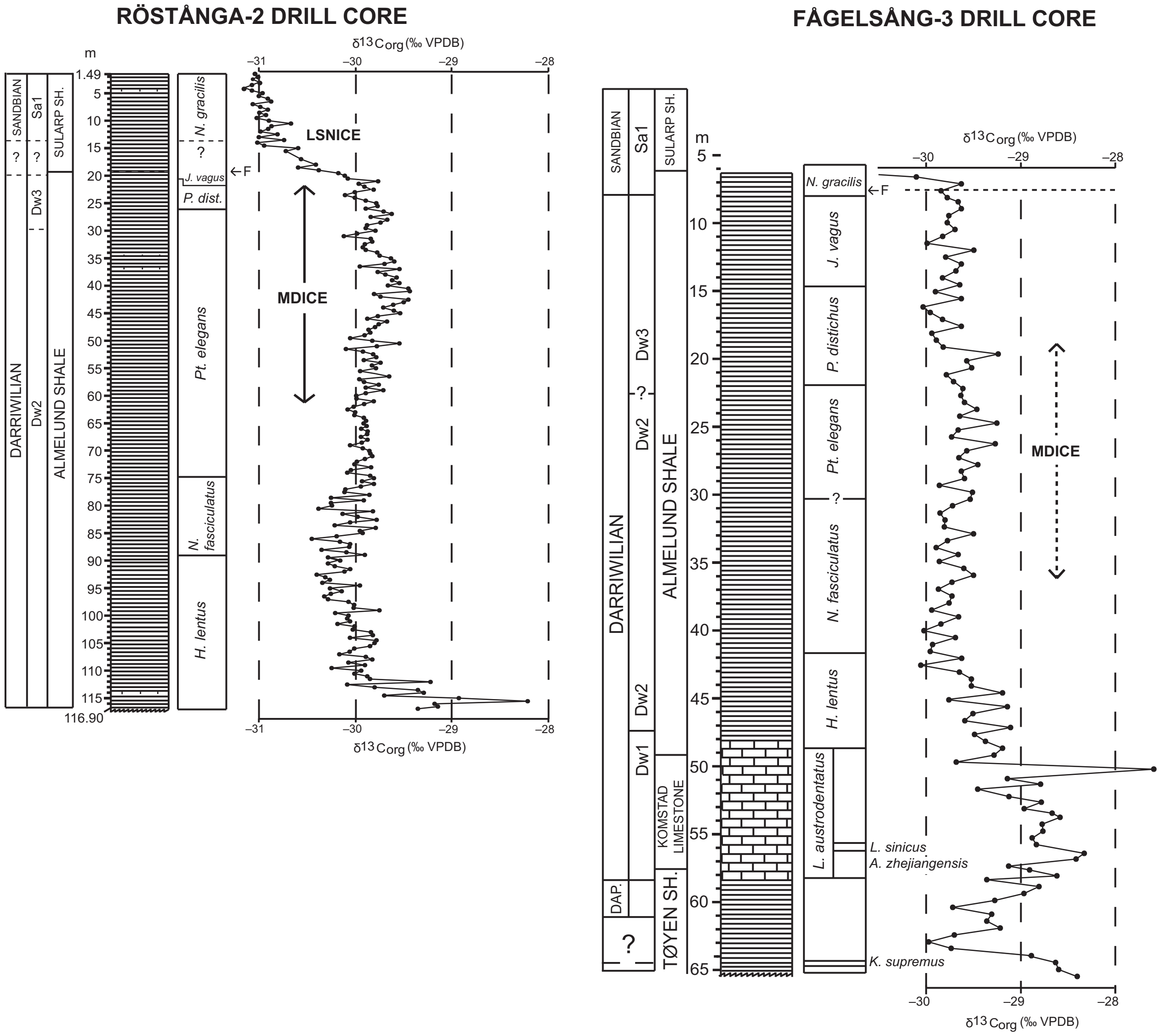

Fig. 5. The $\delta^{13}C_{org}$ isotopic curve and graptolite biostratigraphy through the Röstånga-2 drill core (to the left) and comparison between the $\delta^{13}C_{org}$ curves through the Darriwilian dark shale successions in the Röstånga-2 and Fågelsång-3 drill cores. Note the presence of the Fågelsång Phosphorite (F) just above the 20-m level in the Röstånga-2 drill core. The m-levels refer to the drill core depth and not the stratigraphical thickness. A subdued MDICE has been recorded in the isotope curves of both drill core successions, but the base and top of the MDICE are not precisely marked in the Fågelsång-3 core. In the Röstånga-2 core, the MDICE ranges upwards from the lower–middle *Pterograptus elegans* Zone to near the top of the Darriwilian sequence. In the Fågelsång succession, the MDICE appears to start slightly earlier. Also note the presence of the negative LSNICE in the *Nemagraptus gracilis* Zone in the Sularp Shale in the uppermost portion of the Röstånga-2 drill core. Both isotope chemostratigraphy and graptolite biostratigraphy suggest that the bottom of the Röstånga-2 drill core succession corresponds to a stratigraphic level in the *Holmograptus lentus* Zone somewhat above the Komstad Limestone in the Fågelsång-3 succession. As indicated in the text, the presence of this distinctive carbonate unit in the Röstånga area remains uncertain. *P. dist., Pseudamplexograptus distichus*.

Friedrich-Alexander University of Erlangen-Nürnberg in Erlangen, Germany. All carbon isotope values are reported in the conventional δ-notation in per mil relative to VPDB (Vienna-PDB). The accuracy and reproducibility of the analyses were monitored by replicate analyses of laboratory standard calibrated to the international standards USGS 40 and 41 and was ±0.05 (1 std. dev.).

Three unusually high values (–16.78‰, –26.47‰ and –14.80‰) at 16.00, 16.51 and 17.50 m, respectively, are anomalous and may be explained by carbonate in the

Table 1. List of study samples from the Röstånga-2 drill core showing $\delta^{13}C_{org}$ (‰ VPDB) data

Sample (core depth, m)	$\delta^{13}C_{VPDB}$ (‰)	Sample (core depth, m)	$\delta^{13}C_{VPDB}$ (‰)	Sample (core depth, m)	$\delta^{13}C_{VPDB}$ (‰)	Sample (core depth, m)	$\delta^{13}C_{VPDB}$ (‰)
1.49	–31.04	31.01	–30.12	60.00	–29.98	88.51 (II)	–30.10
1.99	–31.01	31.51	–29.84	60.50	–29.98	89.00	–29.91
2.50	–31.06	32.01	–29.82	61.00	–29.81	89.50	–30.29
3.02	–30.99	32.50	–29.90	61.50	–29.91	90.00	–30.16
3.51	–31.08	33.01	–29.92	62.01	–30.02	90.48	–30.28
4.01	–31.14	33.52	–29.89	62.50	–30.08	91.01	–30.21
4.50	–31.07	34.01	–29.78	63.00	–30.00	91.49	–30.05
5.02	–30.97	34.51	–29.74	63.49	–30.01	92.01	–30.11
5.51	–31.00	34.99	–29.63	64.00	–29.91	92.50	–30.40
6.02	–30.91	35.50	–29.60	64.50	–29.89	93.00	–30.31
6.51	–30.87	36.00	–29.70	64.99	–29.91	93.48	–30.27
7.01	–31.06	36.42	–29.95	65.51	–29.88	94.00	–30.34
7.51	–30.98	37.00	–29.54	66.00	–29.94	94.50	–29.96
8.02	–30.91	37.50	–29.77	66.52	–29.87	95.00	–30.25
8.51	–30.99	38.00	–29.69	67.00	–29.88	95.52	–30.14
9.01	–30.93	38.50	–29.57	67.49	–29.94	96.03	–30.25
9.51	–31.02	38.98	–29.62	68.00	–29.87	96.52	–30.32
10.00	–30.90	39.50	–29.54	68.50	–29.93	96.99	–30.28
10.49	–30.67	40.00	–29.66	69.00	–30.06	97.49	–30.07
10.99	–30.87	40.52	–29.46	69.50	–29.92	98.00	–30.01
11.49	–30.89	41.00	–29.43	70.00	–29.86	98.48	–30.02
12.00	–30.97	41.52	–29.80	70.50	–29.85	99.01	–29.76
12.51	–30.81	42.00	–29.73	70.99	–29.83	99.48	–30.20
12.99	–31.01	42.51	–29.45	71.50	–29.90	99.98	–30.07
13.50	–30.74	43.01	–29.50	72.02	–29.99	100.50	–30.08
14.02	–31.02	43.50	–29.61	72.50	–30.01	101.00	–30.05
14.49	–30.94	44.00	–29.71	73.00	–29.83	101.50	–30.18
15.01	–30.59	44.49	–29.60	73.50	–30.05	102.00	–30.01
15.52	–30.72	45.00	–29.53	74.00	–30.08	102.50	–30.03
16.00	–16.78	45.51	–29.77	74.50	–29.85	103.00	–29.84
16.51	–26.47	46.00	–29.87	75.00	–29.81	103.50	–29.82
17.00	–30.57	46.50	–29.67	75.50	–29.93	104.00	–30.06
17.50	–14.80	47.00	–29.76	76.03	–29.81	104.50	–29.78
18.00	–30.41	47.48	–29.79	76.56	–29.95	105.00	–29.80
18.49	–30.59	48.00	–29.87	76.98	–30.10	105.50	–29.85
19.00	–30.37	48.50	–29.85	77.50	–30.11	106.00	–30.02
19.53	–30.18	49.00	–29.90	78.00	–29.85	106.50	–30.06
20.01	–30.11	49.50	–30.05	78.50	–30.25	107.00	–30.17
20.50	–30.07	50.01	–29.82	79.00	–29.91	107.51	–29.89
21.00	–29.77	50.50	–29.64	79.50	–30.25	108.01	–29.83
21.50	–29.96	51.00	–29.78	80.00	–30.24	108.50	–30.07
21.98	–29.91	51.49	–30.10	80.50	–30.38	108.98	–29.91
22.50	–29.84	51.99	–29.92	81.00	–29.82	109.50	–30.24
22.98	–30.01	52.50	–29.81	81.50	–30.13	110.00	–29.94
23.50	–30.11	53.00	–29.78	82.00	–29.97	110.51	–30.01
24.02	–30.01	53.50	–29.91	82.50	–29.78	111.00	–29.88
24.50	–29.89	54.00	–29.74	83.00	–30.06	111.50	–29.85
25.00	–29.78	54.50	–29.82	83.50	–30.21	112.00	–29.23
25.49	–29.76	55.00	–29.78	84.02	–29.79	112.50	–30.07
26.00	–29.89	55.50	–29.95	84.50	–29.95	113.01	–29.80
26.50	–29.72	56.00	–29.78	85.00	–29.92	113.50	–29.35
27.00	–29.62	56.50	–29.65	85.50	–30.19	113.99	–29.31

Continued on the next page

Table 1. *Continued*

Sample (core depth, m)	$\delta^{13}C_{VPDB}$ (‰)	Sample (core depth, m)	$\delta^{13}C_{VPDB}$ (‰)	Sample (core depth, m)	$\delta^{13}C_{VPDB}$ (‰)	Sample (core depth, m)	$\delta^{13}C_{VPDB}$ (‰)
27.50	–29.84	57.00	–29.96	85.99	–30.45	114.47	–29.70
28.00	–29.67	57.50	–29.91	86.50	–30.15	114.97	–28.93
28.50	–29.73	58.00	–29.76	86.99	–30.05	115.50	–28.21
29.00	–29.88	58.50	–29.89	87.51	–30.06	116.00	–29.17
29.50	–29.89	59.00	–29.71	88.00	–30.34	116.49	–29.14
30.00	–29.79	59.50	–29.89	88.51 (I)	–30.10	116.90	–29.35
30.49	–29.98						

sample after decarbonatization or an effect of the source and type of organic matter. These anomalous high values are excluded from the curve shown in Fig. 5.

Results

The stratigraphically closely controlled $\delta^{13}C_{org}$ curve is illustrated and compared with the isotope record from the Fågelsång-3 drill core in Fig. 5. Although at first look appearing rather smooth and without prominent isotopic excursions, the $\delta^{13}C_{org}$ curve exhibits some notable features. Also, it is of significant interest to compare this isotope curve with that of the approximately same stratigraphic interval from the Fågelsång-3 drilling (see Bergström et al. 2018). In the lower 5 m of the Röstånga-2 drill core, which corresponds to the lower half of the *Holmograptus lentus* Zone, there is a marked decrease in the isotopic values from –29‰ to –30‰. Based on graptolite biostratigraphy, this negative trend would correspond to a similar trend in the lower *Holmograptus lentus* Zone around a core depth of 45 m in the Fågelsång-3 succession. This is important because it indicates that the lower end of the Röstånga-2 drill core does not reach down into strata corresponding to the Komstad Limestone. As is the case in the Fågelsång-3 drill core, the isotopic values are relatively uniform through the upper portion of the *Holmograptus lentus* Zone to about the middle of the *Nicholsonograptus fasciculatus* Zone. Above that level and up to the middle part of the *Pterograptus elegans* Zone, the isotope curve shows baseline values of approximately –30‰. This interval is followed by an obvious but minor increase in isotopic values that continues up into the upper part of the *Pseudamplexograptus distichus* Zone. As in the case of the Fågelsång-3 carbon isotope record, this interval of raised isotopic values is interpreted to represent the Middle Darriwilian Isotopic Carbon Excursion (MDICE). This positive excursion is the most prominent one in the lower Middle Ordovician and identified not only in Baltoscandia but also in China, North America and Argentina (cf. Albanesi et al. 2013; Wu et al. 2017; Lindskog et al. 2019). In both the Fågelsång succession and Röstånga-2 drill core (Fig. 6), this excursion interval is followed by several metres with declining isotopic values just above the Fågelsång Phosphorite. In a recent study, Bergström et al. (2020) identified this negative excursion as equivalent to what Kaljo et al. (2007) in Estonia referred to as the 'Upper Kukruse low', which occurs in the *Baltoniodus variabilis* Subzone of the *Amorphognathus tvaerensis* conodont Zone and in the lower part of the *Nemagraptus gracilis* graptolite Zone. In their study of the chemostratigraphy of the Tartu-453 drill core from southern Estonia, Bauert et al. (2014) renamed this isotopic perturbation the Lower Sandbian Negative Isotope Carbon Excursion (LSNICE). This excursion has potential as a useful stratigraphic marker for the lower Sandbian. As shown in Fig. 6, the onset of the LSNICE is displayed in the uppermost part of the Röstånga-2 drill core where it shows isotopic values down to at least –30.5‰, which is of nearly the same magnitude as the isotopic values of the corresponding interval at Fågelsång. Although it has not been linked to any known global biogeochemical event, it may be noted that the LSNICE appears to be geographically widespread. For instance, in the Yichang area, China, it is displayed in the *Nemagraptus gracilis* Zone of the Zhenjin and Jieling sections (Ma et al. 2015).

In summary, the isotope chemostratigraphy is in agreement with the interpretation that there is a close similarity between the Röstånga and Fågelsång successions in the interval around the base of the Sandbian Stage, and the carbon isotope record supports the idea that the base of the *Nemagraptus gracilis* Zone corresponds to a level well below the appearance of the zone index in the Röstånga-2 drill core.

CONCLUDING REMARKS

Although the widely cited study by Underwood et al. (1997) on the $\delta^{13}C_{org}$ chemostratigraphy of the Ordovician–Silurian boundary interval at Dob's Linn, South Scotland, was published more than 20 years ago, and has been followed by several $\delta^{13}C_{org}$ investigations of Upper Ordovician (e.g. Bergström et al. 2014) and

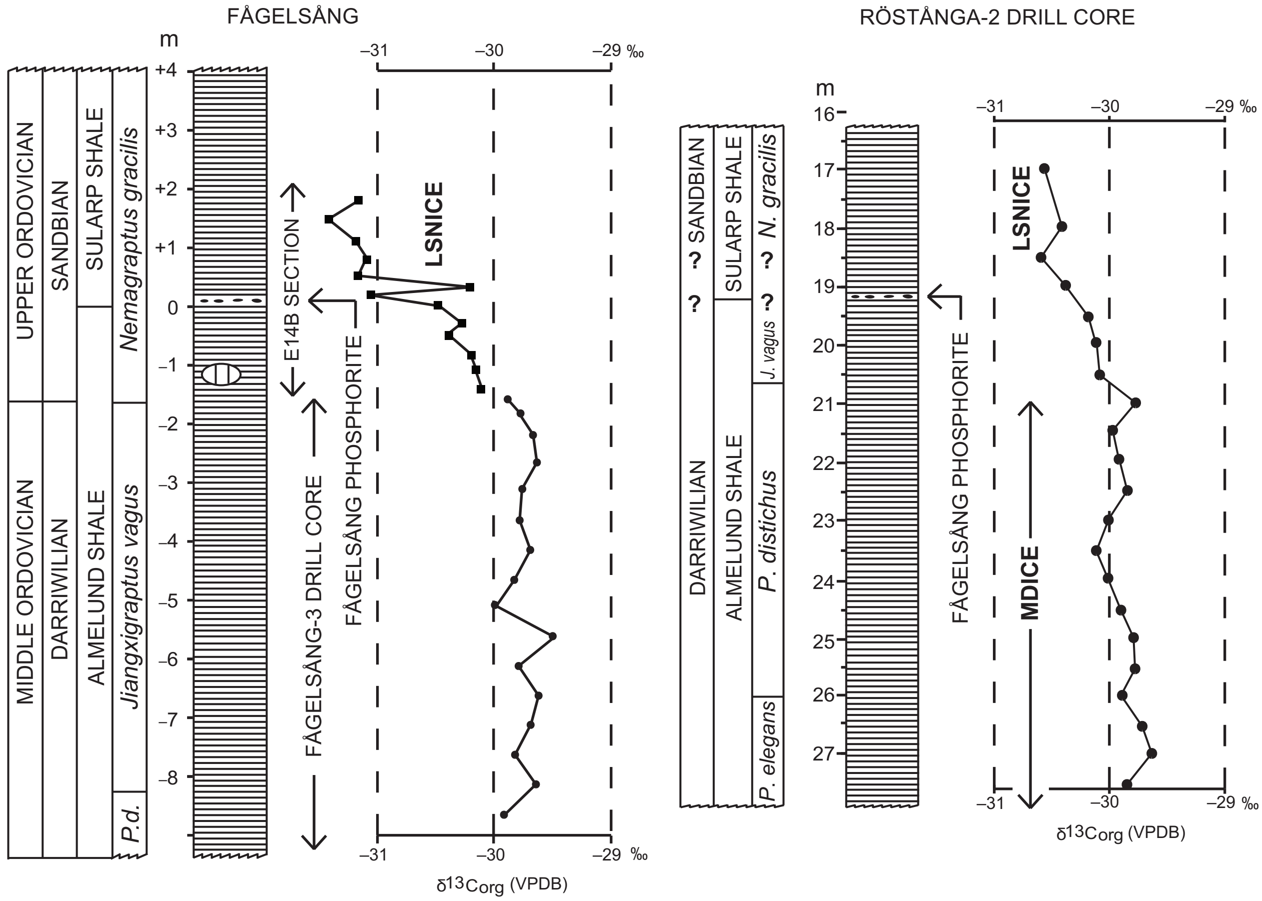

Fig. 6. Comparison of the uppermost Darriwilian–lowermost Sandbian interval (from the top of the *Pseudamplexograptus distichus* Zone to the lower *Nemagraptus gracilis* Zone) in the Röstånga-2 drill core and at Fågelsång. The latter is a composite of part of the Fågelsång-3 drill core (Bergström et al. 2018, fig. 5) and the E14b outcrop (Bergström et al. 2020, fig. 5), this outcrop section being the GSSP of the Global Sandbian Stage. Note the general similarity between the isotope curves. Three apparently anomalous data points just above the Fågelsång Phosphorite in the Röstånga-2 drill core (see Table 1) are omitted in this figure. The isotope curves suggest that in terms of $\delta^{13}C$ chemostratigraphy, the base of the Sandbian Stage occupies a position between the positive curve perturbation referred to as MDICE and the negative one known as LSNICE. *P. d., Pseudamplexograptus distichus*.

Darriwilian carbonate successions (e.g. Young et al. 2016), such studies of Ordovician graptolite-bearing dark shale successions are still far less common than those based on the $\delta^{13}C_{carb}$. This is especially the case in the Darriwilian interval where, as far as we are aware, Zhang et al. (2010) and Bergström et al. (2018) are the only such graptolite shale studies so far published anywhere in the world. Unfortunately, in the Honghuayuan, Tongzi Province, South China section investigated by Zhang et al. (2010), the Darriwilian interval is quite thin and stratigraphically incomplete and thus, their few Darriwilian $\delta^{13}C$ values are not useful for a comparison with the Scanian $\delta^{13}C_{org}$ records. In Bergström et al. (2018) a comparison was made with a $\delta^{13}C_{carb}$ succession in the Siljan region, Province of Dalarna, south-central Sweden, and the results obtained in that study are applicable also to the Röstånga-2 drill core sequence. An investigation of the $\delta^{13}C_{org}$ chemostratigraphy of the GSSP of the Darriwilian Stage at Huangnitang, Changshan Province, China (cf. Chen & Bergström 1995) would be of considerable interest although the $\delta^{13}C_{carb}$ study of that succession by Munnecke et al. (2011) yielded only chemostratigraphically inconclusive results.

The principal results of the present study may be summarized as follows:

1. A new drill core through the Darriwilian and lowest Sandbian interval at Röstånga has made it possible to classify the approximately 90 m thick succession in terms of the currently used Baltoscandic graptolite zone classification (Maletz et al. 2020).
2. The dominantly shaly lithology of the study interval is closely similar to that of coeval strata at Fågelsång. For

the first time, the distinctive Fågelsång Phosphorite is identified at Röstånga, where it appears to occupy the same stratigraphic position just above the base of the Sandbian Stage as at Fågelsång. This suggests that this characteristic bed may have a much wider geographic distribution than has been known previously.
3. Based on 230 samples the $\delta^{13}C_{org}$ chemostratigraphy has been established through the entire Röstånga-2 drill core. Two excursions are recognized, namely the positive MDICE in the middle–upper Darriwilian and the negative LSNICE in the lower Sandbian. As a whole the chemostratigraphy is closely comparable to that of the coeval interval at Fågelsång.
4. The Röstånga-2 chemostratigraphy has been tied to the graptolite biostratigraphy. The relations between these stratigraphies are basically the same as at Fågelsång.
5. Both the graptolite biostratigraphy and the chemostratigraphy indicate that the end of the Röstånga-2 drill core is somewhat above the stratigraphic interval corresponding to the lower Darriwilian Komstad Limestone. Hence, it remains uncertain if the latter calcareous unit is present at Röstånga.
6. To date, the Röstånga-2 and Fågelsång-3 drill cores represent the only stratigraphically reasonably complete Darriwilian shale successions in the world in which the $\delta^{13}C_{org}$ chemostratigraphy is directly tied to the graptolite biostratigraphy.

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REFERENCES

Albanesi, G. L., Bergström, S. M., Schmitz, B., Serra, F., Feltes, N. A., Voldman, G. C. & Ortega, G. 2013. Darriwilian (Middle Ordovician) $\delta^{13}C_{carb}$ chemostratigraphy in the Precordillera of Argentina: Documentation of the Middle Darriwilian Isotope Carbon Excursion (MDICE) and its use for intercontinental correlation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **389**, 48–63.

Badawy, A. S., Mehlqvist, K., Vajda, V., Ahlberg, P. & Calner, M. 2014. Late Ordovician (Katian) spores in Sweden: oldest land plant remains from Baltica. *GFF*, **136**, 16–21.

Bauert, H., Ainsaar, L., Põldsaar, K. & Sepp, S. 2014. $\delta^{13}C$ chemostratigraphy of the Middle and Upper Ordovician succession in the Tartu-453 drillcore, southern Estonia, and the significance of the HICE. *Estonian Journal of Earth Sciences*, **63**, 195–200.

Bergström, S. M. & Ahlberg, P. 2004. Guide to some classical Ordovician and Cambrian localities in the Fågelsång area, Scania, southern Sweden. *Erlanger geologische Abhandlungen – Sonderband*, **5**, 81–90.

Bergström, S. M, Huff, W. D., Kolata, D. R., Yost, D. A. & Hart, R. 1997. A unique Middle Ordovician K-bentonite bed succession at Röstånga, S. Sweden. *GFF*, **119**, 231–244.

Bergström, S. M., Huff, W. D., Koren′, T., Larsson, K., Ahlberg, P. & Kolata, D. R. 1999. The 1997 core drilling through Ordovician and Silurian strata at Röstånga, S. Sweden: preliminary stratigraphic assessment and regional comparison. *GFF*, **121**, 127–135.

Bergström, S. M., Finney, S. C., Chen, X., Pålsson, C., Wang, Z. H. & Grahn, Y. 2000. A proposed global boundary stratotype for the base of the Upper Series of the Ordovician System: The Fågelsång section, Scania, southern Sweden. *Episodes*, **23**, 102–109.

Bergström, S. M., Larsson, K., Pålsson, C. & Ahlberg, P. 2002. The Almelund Shale, a replacement name for the Upper *Didymograptus* Shale and the Lower *Dicellograptus* Shale in the lithostratigraphical classification of the Ordovician succession in Scania, Southern Sweden. *Bulletin of the Geological Society of Denmark*, **49**, 41–47.

Bergström, S. M., Chen, X., Gutiérrez-Marco, J. C. & Dronov, A. 2009. The new chronostratigraphic classification of the Ordovician System and its relations to major regional series and stages and to $\delta^{13}C$ chemostratigraphy. *Lethaia*, **42**, 97–107.

Bergström, S. M., Young, S. & Schmitz, B. 2010. Katian (Upper Ordovician) chemostratigraphy and sequence stratigraphy of the United States and Baltoscandia: A regional comparison. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **296**, 217–234.

Bergström, S. M., Schmitz, B., Young, S. A. & Bruton, D. L. 2011. Lower Katian (Upper Ordovician) $\delta^{13}C$ chemostratigraphy, global correlation, and sea-level changes in Baltoscandia. *GFF*, **133**, 31–47.

Bergström, S. M., Eriksson, M. E., Young, S. A., Ahlberg, P. & Schmitz, B. 2014. Hirnantian (latest Ordovician) $\delta^{13}C$ chemostratigraphy in southern Sweden and globally: a refined integration with the graptolite and conodont successions. *GFF*, **136**, 355–386.

Bergström, S. M., Eriksson, M. E., Schmitz, B., Young, S. A. & Ahlberg, P. 2016. Ordovician $\delta^{13}C_{org}$ chemostratigraphy, K-bentonite stratigraphy, and biostratigraphy in southern Scandinavia: a reappraisal. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **454**, 175–188.

Bergström, S. M., Ahlberg, P., Maletz, J., Lundberg, F. & Joachimski, M. M. 2018. Darriwilian (Middle Ordovician) chemostratigraphy linked to graptolite, conodont and trilobite biostratigraphy in the Fågelsång-3 drill core, Scania, Sweden. *GFF*, **140**, 229–240.

Bergström, S. M., Schmitz, B., Terfelt, F., Eriksson, M. E. & Ahlberg, P. 2020. The $\delta^{13}C$ chemostratigraphy of Ordovician global stage stratotypes: geochemical data from the Floian and Sandbian GSSPs in Sweden. *GFF*, **142**, 23–32.

Chen, X. & Bergström, S. M. 1995. The base of the *austrodentatus* Zone as a level for the global subdivision of the Ordovician System. *Palaeoworld*, **5**, 1–117.

Chen, X., Zhang, Y., Goldman, D., Bergström, S. M., Fan, J., Wang, Z., Finney, S. C., Chen, Q. & Ma, X. 2016. *Darriwilian to Katian (Ordovician) Graptolites from Northwest China*. Zheijiang University Press, Hangzhou, China, 354 pp.

Ekström, G. 1937. Upper Didymograptus Shale in Scania. *Sveriges Geologiska Undersökning (Geological Survey of Sweden)*, **C403**, 1–53.

Finney, S. C. & Bergström, S. M. 1986. Biostratigraphy of the Ordovician *Nemagraptus gracilis* Zone. In *Palaeoecology and Biostratigraphy of Graptolites* (Hughes, C. P. & Rickards, R. B., eds), *Geological Society Special Publication*, **20**, 47–59.

Hadding, A. 1913. Undre Dicellograptusskiffern i Skåne jämte några därmed ekvivalenta bildningar. *Lunds Universitets Årsskrift, N.F. 2*, **9(15)**, 1–90.

Hede, J. E. 1951. Boring through Middle Ordovician–Upper Cambrian strata in the Fågelsång district, Scania, Sweden. 1. Succession encountered in the boring. *Lunds Universitets Årsskrift, N.F. 2*, **46**(7), 1–85.

Jaanusson, V. 1960. Graptoloids from the Ontikan and Viruan (Ordov.) limestones of Estonia and Sweden. *Bulletin of the Geological Institutions of the University of Uppsala*, **38**, 289–366.

Jaanusson, V. 1976. Faunal dynamics in the Middle Ordovician (Viruan) of Balto-Scandia. In *The Ordovician System: Proceedings of a Palaeontological Association Symposium* (Bassett, M. G., ed.), pp. 302–326. University of Wales Press, Cardiff.

Jaanusson, V. 1995. Confacies differentiation and upper Middle Ordovician correlation in the Baltoscandian basin. *Proceedings of the Estonian Academy of Sciences, Geology*, **44**, 73–86.

Kaljo, D., Martma, T. & Saadre, T. 2007. Post-Hunnebergian Ordovician carbon isotope trend in Baltoscandia, its environmental implications and some similarities with that of Nevada. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **245**, 138–155.

Lindskog, A. & Eriksson, M. E. 2017. Megascopic processes reflected in the microscopic realm: sedimentary and biotic dynamics of the Middle Ordovician 'orthoceratite limestone' at Kinnekulle, Sweden. *GFF*, **139**, 163–183.

Lindskog, A., Eriksson, M. E., Bergström, S. M. & Young, S. A. 2019. Lower–Middle Ordovician carbon and oxygen isotope chemostratigraphy at Hällekis, Sweden: implications for regional to global correlation and palaeoenvironmental development. *Lethaia*, **52**, 204–219.

Linnarsson, G. 1875. Anteckningar från en resa i Skånes silurtrakter 1874. *Geologiska Föreningens i Stockholm Förhandlingar*, **2**, 260–284.

Linnarsson, G. 1879. Iakttagelser öfver de graptolitförande skiffrarne i Skåne. *Geologiska Föreningens i Stockholm Förhandlingar*, **4**, 227–257.

Ma, X., Wang, Z.-H., Zhang, Y.-D., Song, Y. Y. & Fang, X. 2015. Carbon isotope records of the Middle–Upper Ordovician of the Yichang area, South China. *Palaeoworld*, **24**, 136–148.

Maletz, J. 1995. The Middle Ordovician (Llanvirn) graptolite succession of the Albjära core (Scania, Sweden) and its implication for a revised biozonation. *Zeitschrift für Geologische Wissenschaften*, **23**, 249–259.

Maletz, J. 2005. Early Middle Ordovician graptolite biostratigraphy of the Lovisefred and Albjära drill cores (Scania, southern Sweden). *Palaeontology*, **48**, 763–780.

Maletz, J. & Ahlberg, P. 2018. The Lower Ordovician Tøyen Shale succession in the Fågelsång-3 drill core, Scania, Sweden. *GFF*, **140**, 293–305.

Maletz, J. & Ahlberg, P. 2020. Graptolite biostratigraphy of the Ordovician Almelund and Sularp Shale formations of the Fågelsång-3 drill core, Scania, Sweden. *GFF*, **142**, 33–51.

Maletz, J., Egenhoff, S., Böhme, M., Asch, R., Borowski, K., Höntzsch, S. & Kirsch, M. 2007. The Elnes Formation of southern Norway: Key to the Middle Ordovician biostratigraphy & biogeography. *Acta Palaeontologica Sinica*, **46**(suppl.), 298–304.

Maletz, J., Ahlberg, P., Suyarkova, A. & Loydell, D. K. 2014. Silurian graptolite biostratigraphy of the Röstånga-1 drill core, Scania – a standard for southern Scandinavia. *GFF*, **136**, 175–178.

Maletz, J., Ahlberg, P. & Lundberg, F. 2020. Ordovician graptolite biostratigraphy of the Röstånga-2 drill core (Scania, southern Sweden). *GFF*, https://doi.org/10.1080/11035897.2020.1739743

Moberg, J. C. 1910. Guide for the principal Silurian districts of Scania (with notes on some localities of Mesozoic beds). 4. Röstånga (with Lake Odensjön) and Skäralid. *Geologiska Föreningens i Stockholm Förhandlingar*, **32**, 105–132.

Munnecke, A., Zhang, Y. D., Liu, X. & Cheng, J. F. 2011. Stable carbon isotope stratigraphy in the Ordovician of south China. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **307**, 17–43.

Nielsen, A. T. 1995. Trilobite systematics, biostratigraphy and palaeoecology of the Lower Ordovician Komstad Limestone and Huk Formations, southern Scandinavia. *Fossils and Strata*, **38**, 1–374.

Pålsson, C. 1996. Middle–Upper Ordovician trilobites and stratigraphy along the Kyrkbäcken rivulet in the Röstånga area, southern Sweden. *GFF*, **118**, 151–162.

Pålsson, C. 2002. Upper Ordovician graptolites and biostratigraphy of the Röstånga 1 core, Scania, S. Sweden. *Bulletin of the Geological Society of Denmark*, **49**, 9–23.

Tullberg, S. A. 1880. Om lagerföljden i de kambriska och siluriska aflagringarne vid Röstånga. *Geologiska Föreningens i Stockholm Förhandlingar*, **5**, 86–101.

Tullberg, S. A. 1882. Skånes graptoliter. 1. Allmän öfversigt öfver de siluriska bildningarne i Skåne och jämförelse med öfriga kända samtidiga aflagringar. *Sveriges*

Geologiska Undersökning (Geological Survey of Sweden), **C50**, 1–44.

Tullberg, S. A. 1883. Ueber die Schichtenfolge des Silurs in Schonen, nebst einem Vergleiche mit anderen gleichalterigen Bildungen. *Zeitschrift der Deutschen geologischen Gesellschaft*, **35**(2), 223–269.

Underwood, C. J., Crowley, S., Marshall, J. D. & Brenchley, P. J. 1997. High-resolution carbon isotope stratigraphy of the basal Silurian stratotype (Dob's Linn, Scotland) and its global correlation. *Journal of the Geological Society, London*, **154**, 709–718.

Wu, R. C., Calner, M. & Lehnert, O. 2017. Integrated conodont biostratigraphy and carbon isotope chemostratigraphy in the Lower–Middle Ordovician of southern Sweden reveals a complete record of the MDICE. *Geological Magazine*, **154**, 334–353.

Young, S. A., Gill, B. C., Edwards, C. T., Saltzman, M. R. & Leslie, S. A. 2016. Middle–Late Ordovician (Darriwilian–Sandbian) decoupling of global sulfur and carbon cycles: Isotopic evidence from eastern and southern Laurentia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **458**, 118–132.

Zhang, T., Shen, Y. & Algeo, T. J. 2010. High-resolution carbon isotopic records from the Ordovician of South China: links to climatic cooling and the Great Ordovician Biodiversification Event (GOBE). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **289**, 102–112.

Darriwili (Kesk-Ordoviitsiumi) $\delta^{13}C_{org}$ kemostratigraafia koos graptoliitide biostratigraafiaga klassikalisel Röstånga alal Skåne maakonna loodeosas Lõuna-Rootsis

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Suures osas mattunud Kesk-Ordoviitsiumi läbilõige geoloogiliselt klassikalisel Röstånga alal Skåne maakonna loodeosas on olnud viimased 80 aastat uurimata. Uus puursüdamik avas unikaalse võimaluse uurida Alam-Kesk-Darriwili kuni Alam-Sandby lademe graptoliitide biostratigraafiat ja $\delta^{13}C_{org}$ kemostratigraafiat ning selgitada nende kihtide stratigraafilisi suhteid umbes 90 m paksuses mustade kiltade intervallis. Uuritud kihid on litoloogiliselt, biostratigraafiliselt ja kemostratigraafiliselt väga sarnased samavanuste kihtidega Fågelsångi alal Skåne kesk-lõunaosas, sealhulgas ka nn Fågelsångi fosforiidikihi esinemise poolest, mida varem kirjeldatud Röstånga alal polnud. Uued andmed on eriti olulised graptoliitide biostratigraafia ja $\delta^{13}C_{org}$ kemostratigraafia omavahelise seostamise küsimuses. Fågelsång-3 ja Röstånga-2 puursüdamike läbilõiked on praegu ainsad Darriwili lademe läbilõiked maailmas, kus need seosed on hästi tuvastatud.