Guide to some classical Ordovician and Cambrian localities in the Fågelsång area, Scania, southern Sweden

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Introduction

One of the most well-known outcrop areas of Ordovician rocks in Baltoscandia is near the settlement of Fågelsång about 8 km east of Lund in south-central Scania (Skåne). In scattered outcrops in the valleys of the Sularp Brook and the Fågelsång (Rögle) Brook there are more than 50 recorded exposures of fossiliferous Ordovician and Cambrian strata. The geology of these rocks have been studied for more than 250 years. The succession consists mainly of deeper-water shales and mudstones deposited in a foreland basin not far from the southern margin of the Baltic plate. Carbonate units, although important paleontologically, are very subordinate in the Ordovician succession, being represented in outcrops by only two units, the Early Ordovician (Tremadocian) Bjørkåsholmen Formation (formerly *Ceratopyge* Limestone) and the early Middle Ordovician (Darriwilian) Komstad Limestone. In addition, there are limestone nodules in the Middle-Upper Ordovician Almelund Shale. A thin Upper Ordovician limestone, the Skagen Limestone, is known only from drillings. Most of the Middle and Upper Cambrian succession, which is poorly exposed and best known from drillings, consists of shales and mudstones (Westergård, 1942, 1944; Axheimer and Ahlberg, 2003), the only relatively prominent limestone unit being the Middle Cambrian Andrarum Limestone. There are also richly fossiliferous limestone nodules in the Upper Cambrian shales.

The dominant fine-clastic lithology in the Fågelsång succession differs markedly from the calcareous lithology in the coeval shallower-water platform deposits in the more central portions of Baltoscandia, such as in the Province of Västergötland and on the Island of Öland. On the other hand, the Scanian fine-clastic Ordovician sequence is in important respects similar to that in the Oslo Region, south-eastern Norway. This regional facies differentiation across Baltoscandia has served as a basis for the recognition of so-called confacies belts (Jaanusson, 1976). Such individual facies belts (Fig. 1) are characterized by regional similarities in both lithology and fauna and they evidently represent specialized conditions in the depositional environment.

Although many of the old outcrops in the Fågelsång area are now covered or destroyed and hence not available for study, the Ordovician and Cambrian successions can be pieced together based on existing exposures combined with several drill-cores. For the Ordovician, the principal drillings include the Fågelsång core (Hede, 1951), the Koängen core (Nilsson, 1977), and two cores drilled at the Lindegård farm 0.5 km north of the Sularp Brook (Glimberg, 1961; Nilsson, 1980). The Almbacken core (Axheimer and Ahlberg, 2003) has provided important data on the unexposed upper Lower and Middle Cambrian succession in the Fågelsång area, and a core drilled 300 m south of Södra Sandby church (Westergård, 1942, 1944) has yielded substantial information about the Middle Cambrian-Lower Ordovician (Tremadocian) sequence.

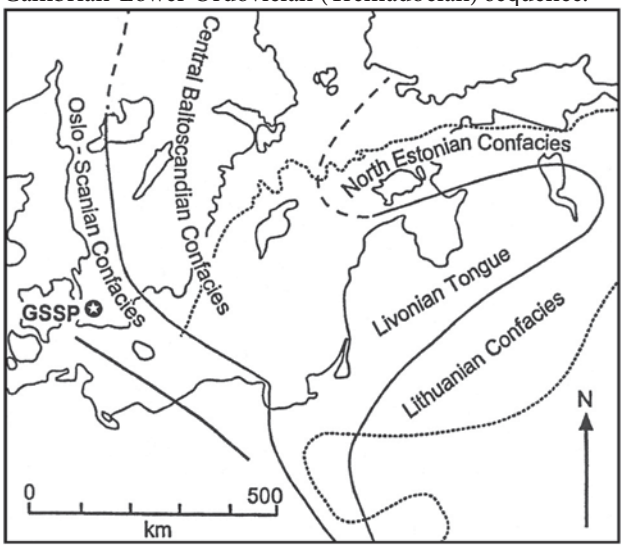

Fig. 1. Geographic location of the Fågelsång Upper Ordovician GSSP in terms of the Baltoscandian confacies belts. (Slightly modified after Jaanusson, 1995).

Most of this succession is stratigraphically condensed as shown by the fact that the remarkably complete Ordovician sequence has a total thickness of only about 145 m. An instructive illustration of this stratigraphic condensation is provided by the thickness of the graptolite zones between the early Middle Ordovician Komstad Limestone and the top of the Upper Ordovician *Dicranograptus clingani* Zone in the partly overlapping Fågelsång and Koängen cores:

Dicranograptus clingani Zone.....*12.75 m*
Diplograptus foliaceus (formerly *Diplograptus multidens*) Zone.....*30.46 m*
Nemagraptus gracilis Zone.....*6.74 m*
Hustedograptus teretiusculus Zone.....*6.95 m*
Transition beds.....*1.80 m*
Didymograptus murchisoni Zone (including the *Pterograptus elegans* and *Didymograptus clavulus* Zones of Hede (1951).....*14.10 m*

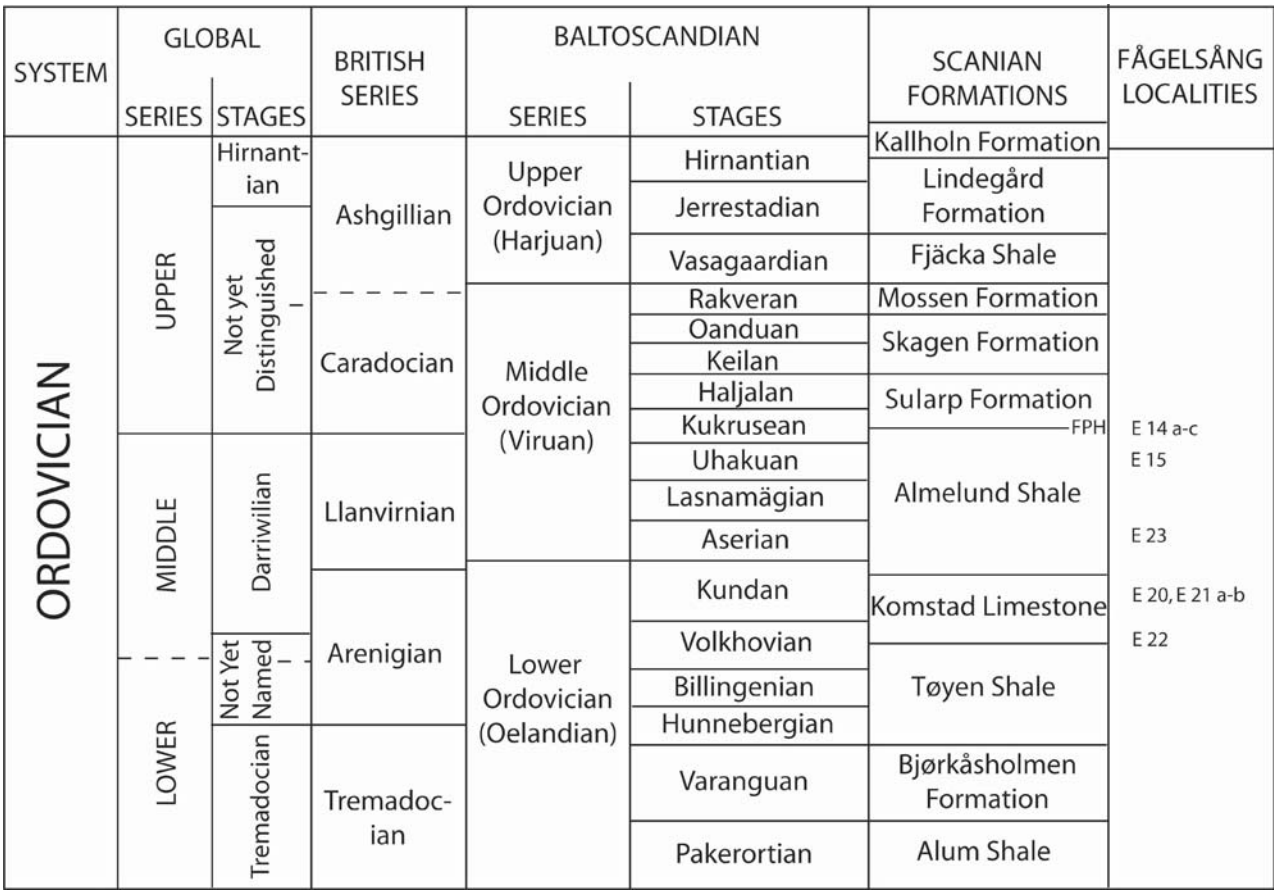

Fig. 2. Chronostratigraphic and lithostratigraphic classification of the Ordovician sequence in Scania and stratigraphic position of the outcrops discussed herein. Local stratigraphic gaps and a couple of lithostratigraphic units with a very restricted geographic distribution are not shown. FPH denotes the Fågelsång Phosphorite that marks the boundary between the Almelund Shale and the Sularp Formation.

Didymograptus 'bifidus' (*?artus*) Zone.....*2.17 m*
Total about *75 m*

The Middle and Upper Cambrian succession is extremely condensed but stratigraphically virtually complete as shown by the drillings at Södra Sandby and Almbacken. The sequence consists of dark-grey to black, organic-rich mudstones and shale (alum shale) with lenses and beds of dark-grey limestone. The limestone intercalations and concretions are in Swedish often referred to as *orsten.* In the Fågelsång area the Middle Cambrian (including the *Agnostus pisiformis* Zone) is about 41.5 m thick, and the Upper Cambrian (Furongian Series) is about 50 m. The Middle Cambrian Andrarum Limestone is about 1.20 m thick in the Södra Sandby drill-core and 1.55 m thick in the Almbacken drill-core (Westergård, 1944; Axheimer and Ahlberg, 2003).

The Fågelsång Ordovician succession is unique in Baltoscandia in having a virtually complete succession of graptolite zones, and this graptolite zone sequence has long served as a standard for national and international biostratigraphic comparisons. Being located close to Lund, this sequence has since the 1700s been studied by many generations of geologists from Lund University as well as by field trip groups and scientists from elsewhere in Sweden and abroad. Pioneer Ordovician investigations carried out by, among others, Stobaeus (1734), Wahlenberg (1818), Hisinger (1837, 1840), Törnquist (1865,1875), and Linnarsson (1875, 1879) were followed by more detailed studies by Moberg (e.g. 1910) and his students, especially Strandmark (1902), Olin (1906), Westergård (1909), Hadding (1913), Funkquist (1919), and Ekström (1937). Later investigations include Hede (1951), Nilsson (1953, 1977, 1980), Lindström (1953, 1955), Glimberg (1961), Bergström and Nilsson (1974), Nielsen (1995), Bergström et al. (1995, 1997, 1999, 2000, 2002), and Stouge and Nielsen (2003). For a summary of the current lithostratigraphic and chronostratigraphic classification of the Ordovician succession, see Fig. 2.

In recent years, the Fågelsång sequence has attracted particular international attention because an important part of it has been designated the GSSP for the base of the global Upper Ordovician Series. After a decision in 1996 by the International Subcommission on Ordovician Stratigraphy (ISOS) that the base of the Upper Ordovician shall be the level of first appearance of the morphologically distinctive and geographically widespread graptolite *Nemagraptus gracilis* (Fig. 7), a Subcommission Working Group conducted a world-wide search for a suitable GSSP for this important boundary. After extensive assessments

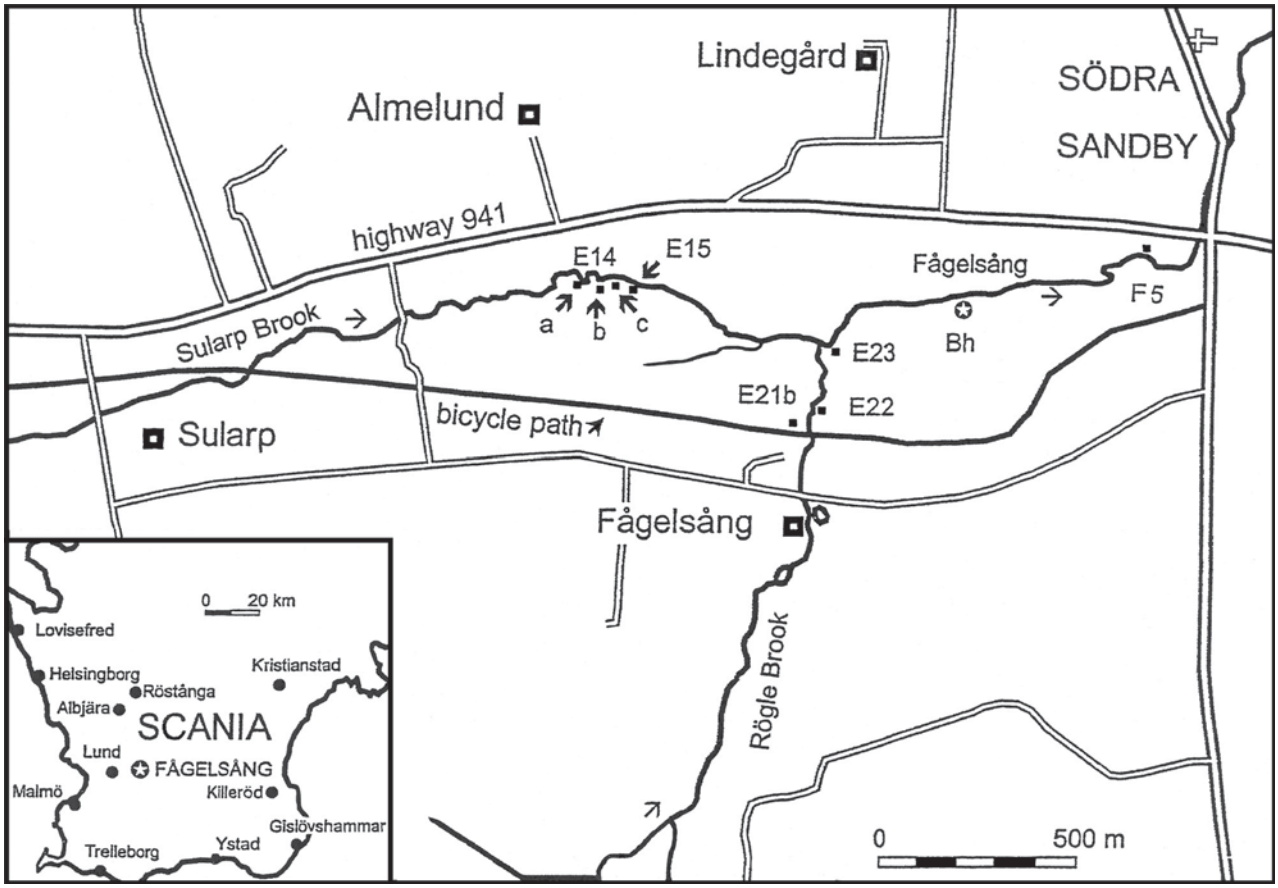

Fig. 3. Sketch-map of the Fågelsång area showing location of important outcrops of Ordovician (E localities) and Cambrian (F5 locality) strata. The GSSP of the Upper Ordovician Series is at the E14b locality.

in the field and much discussion, three sections emerged as principal GSSP candidates, namely that at Calera, Alabama that at Dawangou in northwestern China (Tarim), and that at Fågelsång. After further investigations and discussions, it was concluded that all things considered, the Fågelsång outcrops at locality E14 are the best sections currently known anywhere in the world for this boundary; they have excellent biostratigraphic control based on graptolites, conodonts, and chitinozoans, are easily accessible, and are unlikely to be destroyed by human activities in the future. This locality was approved by the ISOS as GSSP in 2001, and this decision was formally ratified by the International Commission on Stratigraphy in 2002. Dedication ceremonies with unveiling of an information sign and hammering of a "golden spike" into the shale wall at the boundary level took place in May, 2003 with participation of geologists from more than a dozen countries.

Description of Ordovician localities

Several of the classical, and most important, Ordovician localities in the Fågelsång area are easily reached by following a public footpath running northward from the parking area just west of the Fågelsång settlement along the west side of the Fågelsång (Rögle) Brook to the Sularp Brook (Fig. 3). The following localities are situated near this footpath, as well as along the Sularp Brook (locality designations after Moberg, 1910) and can conveniently be visited in the order described below.

Localities E20 and E21a–b

A short distance north of the former railroad, and just west of the footpath from the Fågelsång parking area, there are three, long disused and partly water-filled, small quarries exposing the early Middle Ordovician Komstad Limestone (Fig. 3). The Komstad Limestone is the only prominent limestone unit in the otherwise shale-dominated Fågelsång Ordovician succession, and it reflects a period of shallowing of the depositional environment. Because a coeval regression can be recognized in many other successions round the world, it is likely that this shallowing event is not due to local uplift but rather represents a period of negative eustatic sea level change. This regression is known internationally as the Whiterock regression.

For centuries and up to about 1860, these small quarries furnished limestone that was used locally as building and tombstone material. Because of faulting, estimates of the total thickness of the Komstad Limestone at this site are uncertain but it is of the order of 7–8 m (Stouge and Nielsen, 2003). Although some beds are moderately fossiliferous, fossils are not easily collected these days without excavations. However, collecting during more than 150 years has resulted in the recovery of a diverse fauna that is dominated

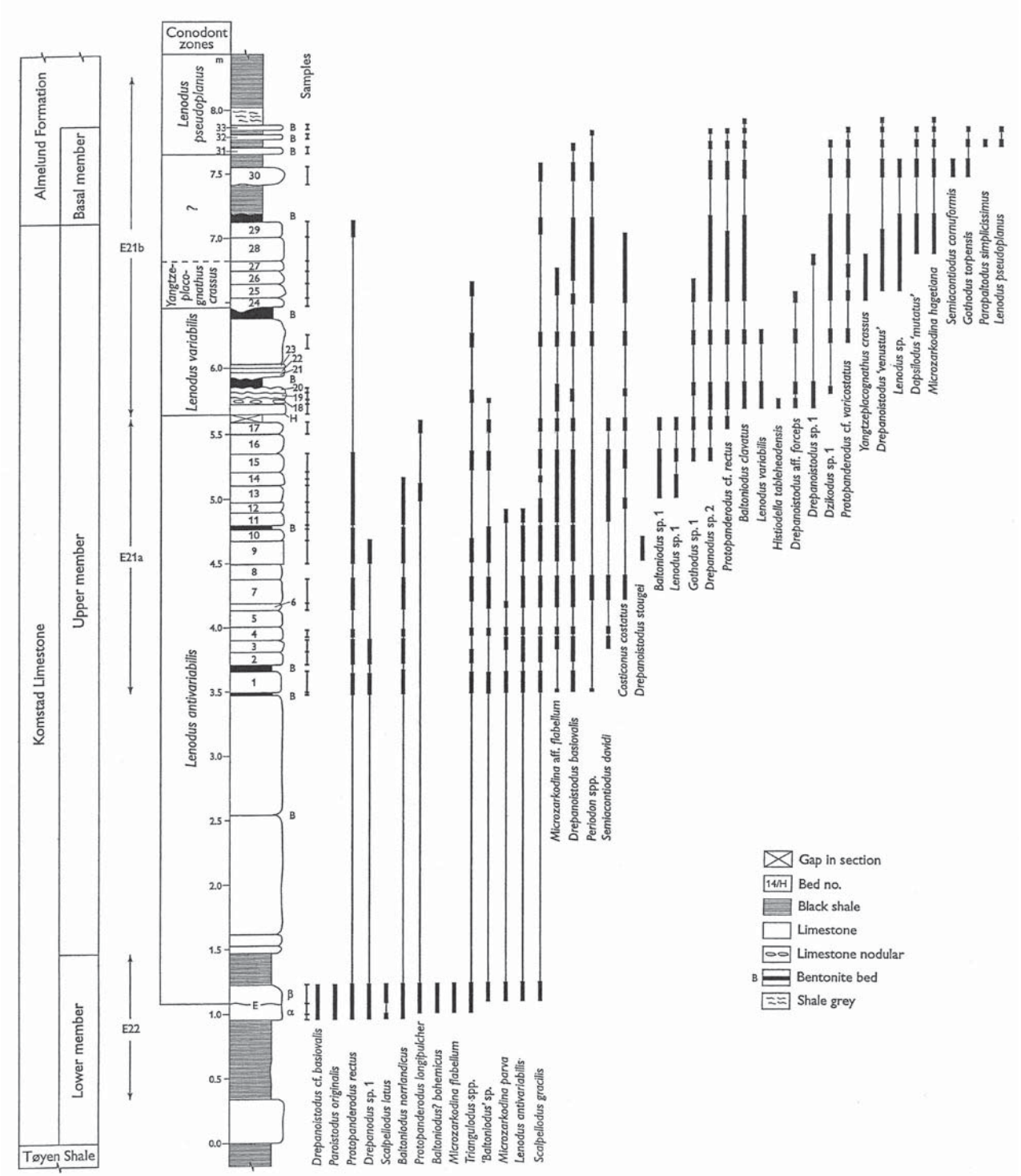

Fig. 4. Stratigraphic column showing lithologic succession and conodont distribution through the early Darriwilian (early Middle Ordovician) Komstad Limestone at Fågelsång. Also shown are the stratigraphic ranges of the E21a, E21b and E22 outcrops. The type stratum of the interesting graptolite *Pseudophyllograptus cor* (Strandmark) is the shale bed just above limestone bed E near the base of the Komstad Limestone. (Figure slightly modified from Stouge and Nielsen, 2003).

by trilobites (more than 20 species), but also includes conodonts (about 40 species), cephalopods, brachiopods, and ostracodes. The trilobites attracted particular attention when the quarries were in operation and the site is the type locality of several species, including some described by Angelin in his classic Palaeontologia Svecica (1851) and Palaeontologia Scandinavica (1854). Stouge and Nielsen (2003) recently summarized the known range of trilobites and conodonts in the Komstad Limestone in these outcrops (Fig. 4). The succession represents the *Megistaspis limbata, Asaphus expansus*, and *Asaphus raniceps* Trilobite Zones, and the *Lenodus antivariabilis, Lenodus variabilis*, and *Yangtzeplacognathus crassus* Conodont Zones. In terms of global series classification, the Komstad Limestone is of early Middle Ordovician (Darriwilian) age. It is also referred to the upper Volkhovian and lower Kundan Stages in the Baltoscandic classification.

Locality E22

On the east side of the Fågelsång (Rögle) Brook about 100 m north of the former railway there is a small outcrop of a 0.24 m thick bed of limestone overlain and underlain by shale. This is apparently the lowermost exposed part of the Komstad Limestone (Fig. 4) or/and the uppermost part of the underlying Tøyen Shale. The shale has yielded graptolites of the *Didymograptus hirundo* Zone. The shale bed just above the limestone bed E is of special interest in that it is the type stratum (Strandmark, 1902) of the morphologically peculiar and geographically widespread graptolite *Pseudophyllograptus cor* (Strandmark) (Fig. 5). The type material of this species was re-described by Cooper and Lindholm (1985).

Locality E23

This outcrop is an approximately 5 m high shale section in the south bank of the Sularp Brook a few tens of m east of the mouth of the Fågelsång (Rögle) Brook (Fig. 3). Although not as well exposed as in the past, this is the best outcrop of the lower part of the Almelund Shale (formerly Upper *Didymograptus* Shale) in the Fågelsång area and it has been studied by several authors since Törnquist (1865), especially by Ekström (1937). The diverse graptolite fauna includes, among others, *Pterograptus elegans, Phyllograptus? glossograptoides,* and *Didymograptus murchisoni* and indicates the *D. murchisoni* Zone, or in another, more recent, zone classification (Maletz, 1998) the *Pt. elegans* Zone (Darriwilian Stage).

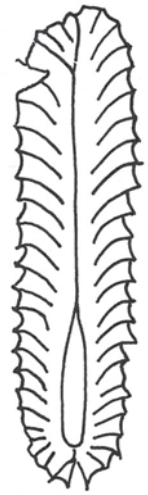

Fig. 5. Outline drawing of the graptolite *Pseudophyllograptus cor.* Redrawn from Cooper and Lindholm (1985, fig. 3:G). Length of specimen 21 mm.

Localities E14a–c and E15

These four outcrops are 4-5 m high natural cliff sections along the south side of the Sularp Brook, 0.4-0.5 km west of the mouth of the Fågelsång (Rögle) Brook (Fig. 3). The most convenient route to these sections is by a footpath that runs westward from near the mouth of the latter brook along the south bank of the Sularp Brook. An alternative route is walking southward from highway 941 across the cultivated field and the meadows in the Sularp Brook Valley just north of the brook but parts of the latter are swampy and carry tall and dense vegetation in the summertime. These sections may also be reached by walking northward across the cultivated fields from the former railroad bank (now bicycle path) near the Fågelsång settlement but this should obviously be avoided during the growing season.
There is little doubt that the E14-E15 outcrops (Fig. 6) are the most well-known, and most intensely studied, sections in the Fågelsång area. The E14b outcrop is the

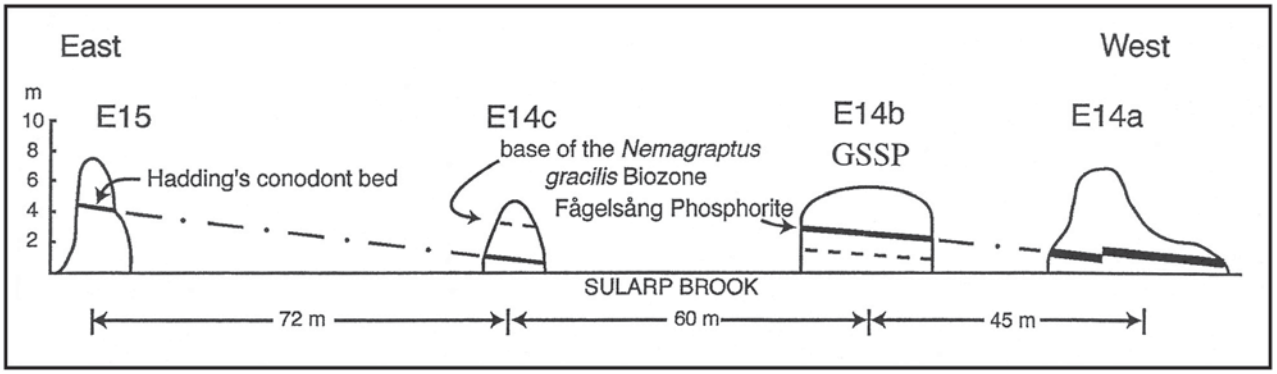

Fig. 6. East-west cross section showing the relations between the E14a-c and E15 outcrops along the Sularp Brook. Note the position of the Fågelsång Phosphorite that marks the boundary between the Sularp Formation and the Almelund Shale. Also note the level of the base of the *Nemagraptus gracilis* Zone that at the E14b GSSP marks the base of the global Upper Ordovician Series.

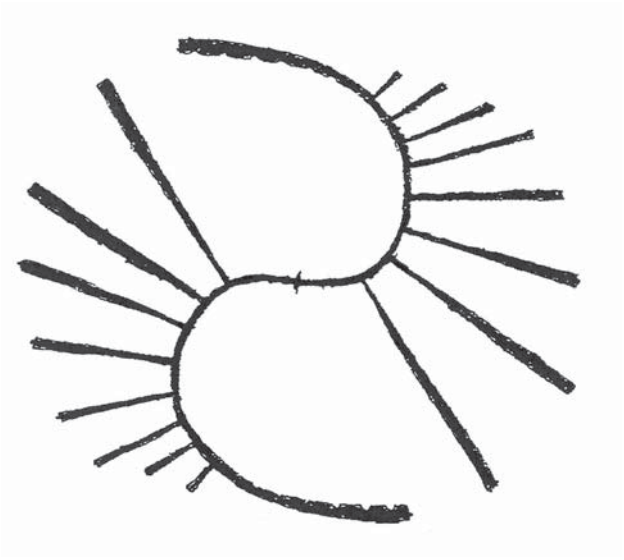

Fig. 7. The graptolite *Nemagraptus gracilis* (Hall), the first appearance of which at the locality E14b marks the base of the global Upper Ordovician Series.

GSSP of the base of the global Upper Ordovician Series, the level of which is now marked by a "golden spike" in the shale wall. The beds dip slightly to the south-west and the sections overlap so a total of about 13 m vertical succession is exposed. The exposed rocks are a lithologically rather monotonous succession of dark-grey to black shale and mudstone with occasional large (up to 1 m in diameter) concretions of impure limestone. There are also a few, with one exception quite thin, beds of phosphorite and several K-bentonite beds (especially at E14a).

These K-bentonites represent the lower part of one of the most extensive complexes of early Paleozoiic K-bentonites known anywhere in the world that in the Koängen drill-core includes more than 150 individual beds (Bergström and Nilsson, 1974). Unfortunately, the E14a K-bentonite beds have not yielded isotopically dateable minerals. The lower portion of the shale succession from the top of the Komstad Limestone up to the prominent phosphorite bed (named the Fågelsång Phosphorite by Bergström et al., 2000), is referred to the Almelund Shale (Bergström et al., 2002). The strata above the phosphorite represent the lowermost part of the Sularp Formation (Fig. 2).

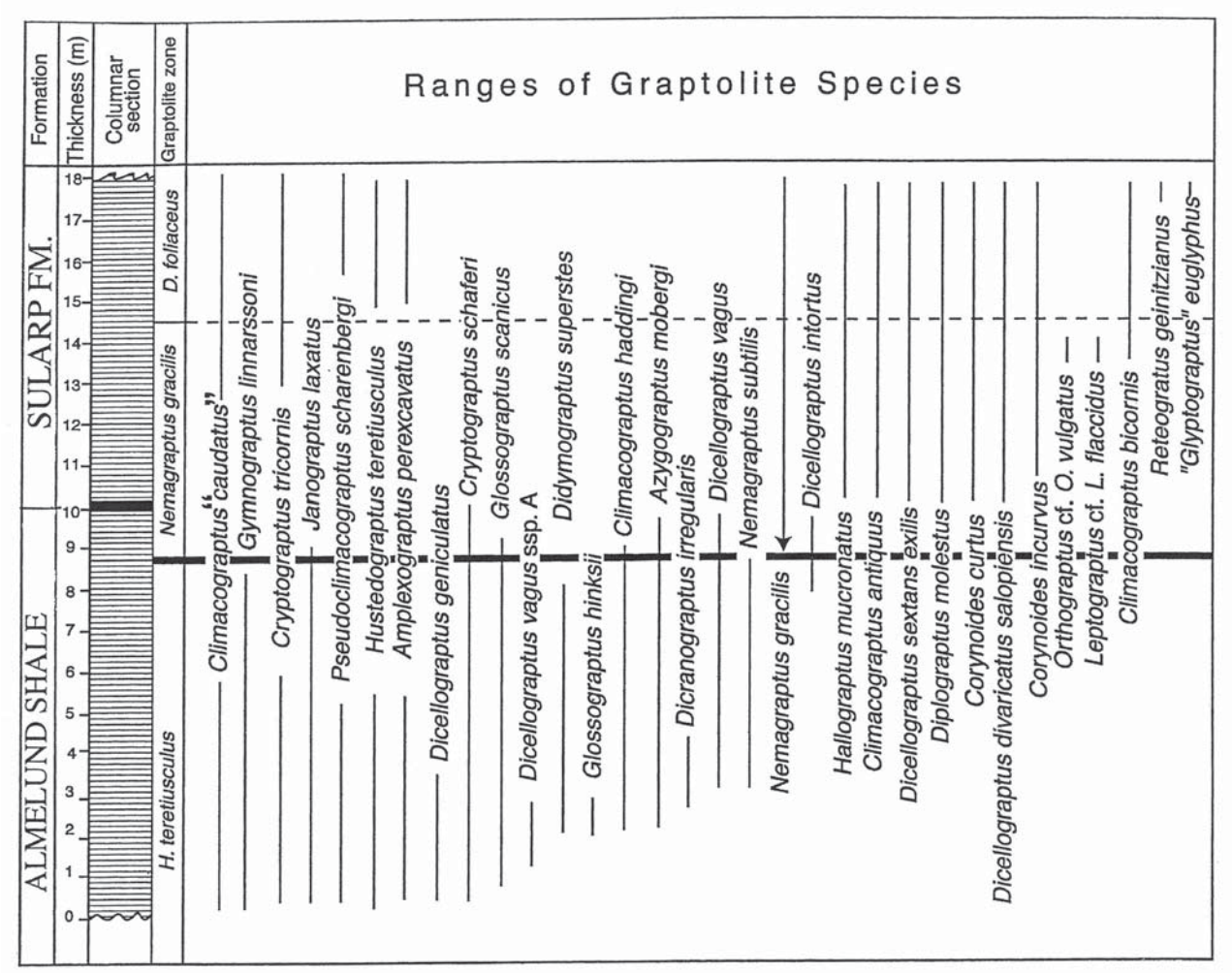

Fig. 8. Known ranges of important graptolites in the upper *Hustedograptus teretiusculus, Nemagraptus gracilis*, and lower *Diplograptus foliaceus* Zones in the Fågelsång area. Based on Hede (1951), Nilsson (1977), and Pålsson (2001). Recent study shows that the Fågelsång graptolite identified as *Climacograptus caudatus* by Hadding (1913) and other workers is an undescribed new species. Note the position of the base of the *Nemagraptus gracilis* Zone about 1.4 m below the Fågelsång Phosphorite (marked by a bold black line). (Slightly modified from Bergström et al., 2000).

Graptolites are moderately abundant in the shales throughout the succession and they are frequently quite well-preserved. These fossils have been collected from these outcrops for more than two centuries, and the type locality of the widespread zone index *Hustedograptus teretiusculus* is at this site. As early as 1865, Törnquist published the first illustrated Baltoscandian record of *Nemagraptus gracilis* based on specimens from these outcrops. This was only the second record from Europe of this species (Fig. 7), which was originally described from New York State by Hall (1847). The classical study of graptolites from these outcrops is that by Hadding (1913), and the graptolites of the corresponding interval in the Fågelsång and Koängen drill-cores have been investigated by Hede (1951) and Nilsson (1977), respectively. However, recent restudies by Pålsson (2001) and S. Finney suggest that some of the previous records are in need of re-assessment. The distribution of selected graptolites, based on both outcrops and drill-cores, is summarized in Fig. 8.

Two graptolite zones are recognized in the succession at the E14–E15 outcrops, the lower one being the *Hustedograptus teretiusculus* Zone and the upper one the *Nemagraptus gracilis* Zone (Fig. 8). Comparison with drill-cores indicates that virtually the entire thickness of these zones is exposed at these localities. Until recent studies, the base of the latter zone was taken to coincide with the Fågelsång Phosphorite, which is an important lithostratigraphic marker bed in this region. However, restudy of core specimens, as well as reinvestigation of the outcrops, show that the first appearance of *N. gracilis*, which defines the base of the *N. gracilis* Zone and the base of the global Upper Ordovician Series, is somewhat lower stratigraphically, namely about 1.4 m below the phosphorite bed. This level is best accessible at E14b and this is the GSSP outcrop with the 'golden spike'. It should be noted that specimens of the index fossil *N. gracilis* are relatively rare below the phosphorite bed but much more common above this bed at the E14a outcrop.

The graptolite fauna of the *Hustedograptus teretiusculus* Zone is quite distinctive and includes, among others, early dicranograptids (*Dicranograptus irregularis*), early dicellograptids (*Dicellograptus geniculatus, D. vagus*), and early nemagraptids (*N. subtilis*) along with *Hustedograptus teretiusculus, Glossograptus scanicus, Gymnograptus linnarssoni*, and *Janograptus laxatus*. The graptolite fauna of the overlying *Nemagraptus gracilis* Zone includes, among others, *N. gracilis* (a probable descendant of *N. subtilis*), *Dicellograptus divaricatus salopiensis, D. sextans exilis, Diplograptus molestus, Corynoides curtus*, and *Hallograptus mucronatus*. Higher parts of the *N. gracilis* Zone have yielded *Climacograptus bicornis* and large biserial taxa, such as *Orthograptus* cf. *vulgatus*. In other parts of the world (China, North America) this interval would be classified as the *C. bicornis* Zone.

A biostratigraphically important component of the fauna is conodonts that occur sparsely on shale surfaces and more commonly in the 2-cm limestone bed just beneath the Fågelsång Phosphorite, and in a thin phosphorite bed (Hadding's conodont bed in Bergström et al., 2000) about 4.25 m above the base of the E15 outcrop. Conodonts were first described from these outcrops by Hadding (1913), and his taxa were later revised by Lindström (1955). Recent work (Bergström et al., 2000) has led to the establishment of a conodont biostratigraphy through the boundary interval. The *Pygodus serra/Pygodus anserinus* Conodont Zone boundary, a key horizon in global correlation, is about 5 m below the Fågelsång Phosporite and 3.6 m below the base

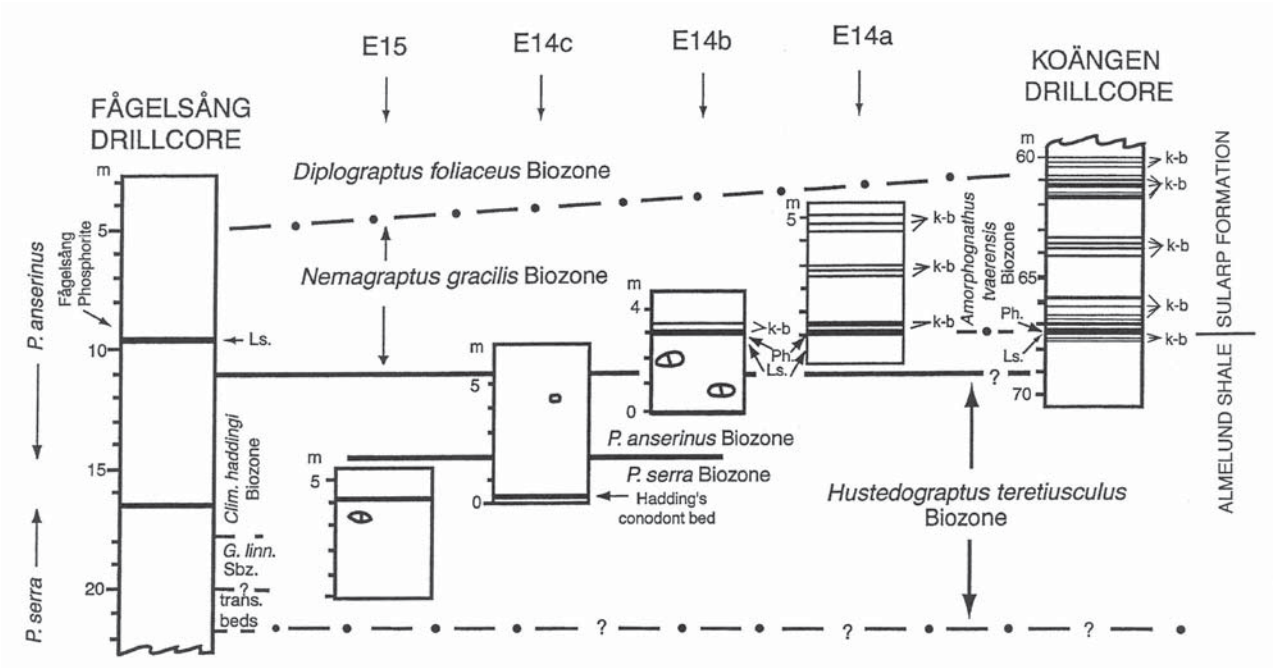

Fig. 9. Diagram showing relations between the successions of graptolite and conodont zones in the upper Almelund Shale and lower Sularp Formation in two drill-cores and the E14a–c and E15 outcrops. K-b refers to K-bentonite beds; Ls., limestone bed; *G. linn*. SbZ., *Gymnograptus linnarssoni* Subzone of Hede (1951). (Modified from Bergström et al., 2000).

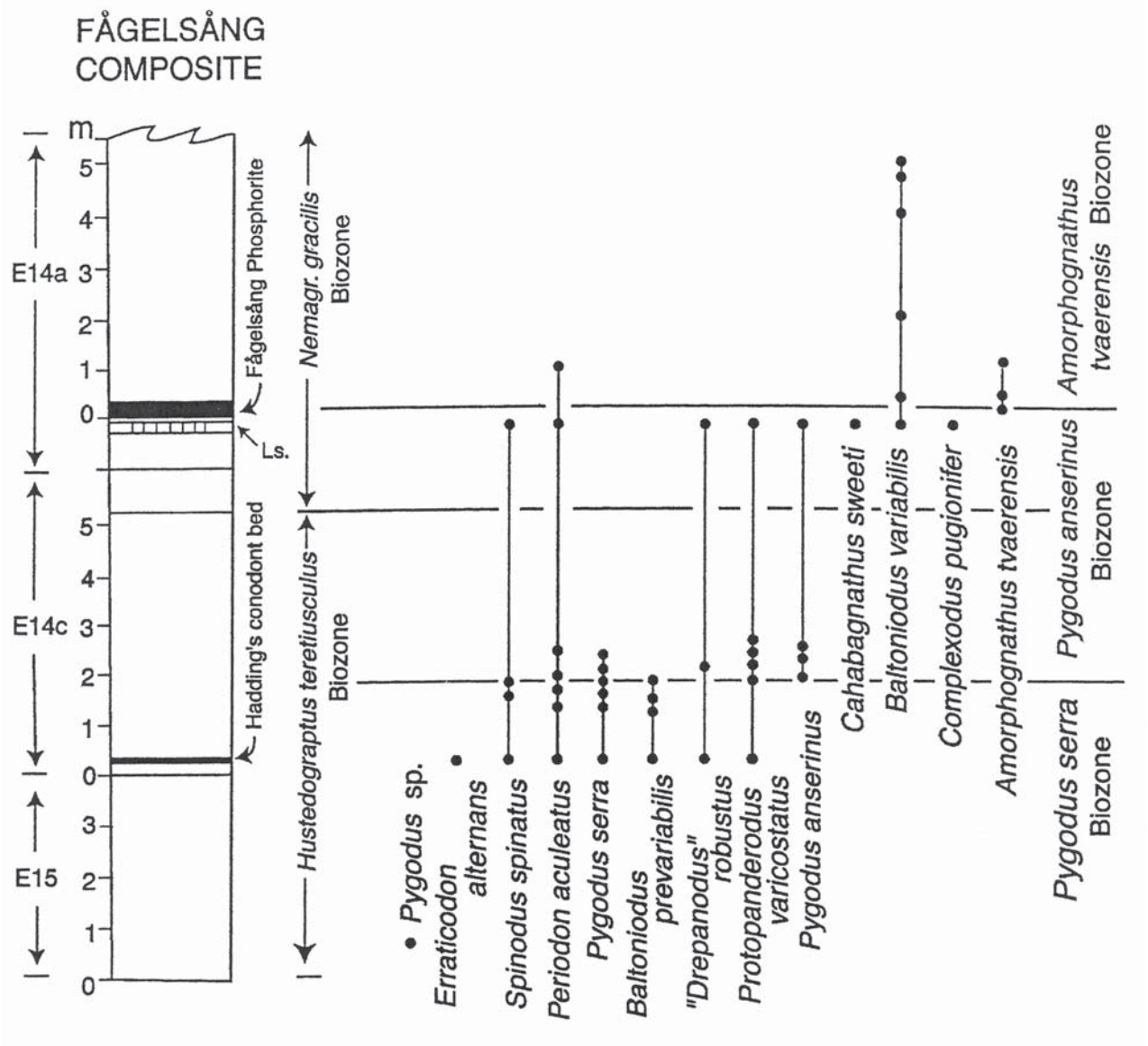

Fig. 10. Known ranges of important conodonts in, and conodont and graptolite zone classification of, the upper Almelund Shale and lower Sularp Formation at the E14a, E14c, and E15 localities. Note the position of the *Pygodus serra/Pygodus anserinus* Zone boundary about 5 m below the Fågelsång Phosphorite, and about 3.6 m below the base of the *Nemagraptus gracilis* Zone. At the E14b GSSP the latter marks the base of the global Upper Ordovician Series. (Modified from Bergström et al., 2000).

of the *N. gracilis* Zone. This level is readily accessible about 2 m above the base the E14c outcrop (Fig. 9). Relatively sparse but biostratigraphically diagnostic conodonts of the *Amorphognathus tvaerensis* Zone, including several specimens of the zone index, have been found on shale bedding-planes just above the Fågelsång Phosphorite. For a summary of the known ranges of important conodont species in these sections, see Fig. 10.

Chitinozoans are common and relatively well preserved in the E14b sequence. A preliminary study (Bergström et al., 2000) indicated that the base of the *N. gracilis* Zone, and the base of the Upper Ordovician, is within the *Laufeldochitina stentor* Chitinozoan Zone. In a more detailed study, as yet only published briefly in an abstract, Vandenbroucke et al. (2003) recognized three chitinozoan zones in the GSSP section. It is expected that also these microfossils will prove very useful for the recognition of the base of the global Upper Ordovician Series.

Description of Cambrian localities

Most of the Cambrian succession is not exposed in the Fågelsång area and is known only from drill-cores, the most informative ones being the Södra Sandby drilling (Westergård, 1942, 1944) and the Almbacken drilling (Axheimer and Ahlberg, 2003). A very comprehensive outcrop of the Lower Cambrian sandstone succession is the Hardeberga Quarry, which is located about 2.5 km south-west of the Fågelsång settlement.

Localities F5 and F6

Upper Cambrian strata are exposed along the north bank of the Sularp Brook at Södra Sandby in the easternmost part of the Fågelsång area (locality F5 of Moberg, 1910, p. 72; locality 5 of Westergård, 1922, fig. 8). The section was described in detail by Moberg and Möller (1898) and consists of about 2 m of alum shales with concretionary limestone (orsten) lenses. The lower part of the exposed section contains the trilobites *Acerocare ecorne* (abundant) and *Parabolina acanthura*, which indicate the uppermost Subzone of the *Acerocare* Zone (uppermost Cambrian). The middle and upper parts of the outcrop are poorly fossiliferous and have yielded only a few indeterminate trilobite fragments. This outcrop is the type locality for both *A. ecorne* and *P. acanthura* that were first described by Angelin (1854).

The lower part of the *Acerocare* Zone (either the *Peltura transiens* Subzone or the *P. costata* Subzone) was previously exposed in a small stream about 50 m southeast of the F5 locality. This outcrop (locality F6 of Moberg, 1910) is now covered or destroyed but has in the past yielded *Acerocarina granulata* and the fairly widespread *Parabolina heres heres*.

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This paper is a contribution to the IGCP project No. 503

ERLANGER
GEOLOGISCHE
ABHANDLUNGEN

Gegründet von Prof. Bruno von Freyberg

Herausgeber:

Institut für Geologie der Universität Erlangen-Nürnberg

Sonderband 5

Schriftleitung

Werner Buggisch

Institut für Geologie der Universität Erlangen-Nürnberg

Schloßgarten 5, D-91054 Erlangen

International Symposium on

Early Palaeozoic Palaeogeography and Palaeoclimate

September 1-3, 2004
Erlangen, Germany

Editors: Axel Munnecke, Thomas Servais, and Christian Schulbert
Layout: Christian Schulbert
Print: City-Druck, Tischner & Hoppe GmbH, Eberhardshofer Straße 17, D-90429 Nürnberg, Germany
ISSN: 0071-1160