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

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The formation name Almelund Shale is proposed for a lithostratigraphically defined unit to replace the outdated chronostratigraphical designations Upper *Didymograptus* Shale and *Dicellograptus* Shale in the Middle and lowermost Upper Ordovician succession in Scania. The Almelund Shale is a lithologically uniform unit of dark-grey to black shales with rare carbonate interbeds between the Komstad Limestone and the Sularp Shale. Apart from a diverse graptolite fauna it yields a few shelly fossils (mostly lingulate brachiopods) and biostratigraphically diagnostic conodonts and chitinozoans. In the type sections of the Almelund Shale along the Sularp Brook in the Fågelsång area, W-central Scania, the top of the unit is taken to be the base of the Fågelsång Phosphorite, and its basal contact is at the top of the underlying Komstad Limestone. Its total thickness in the Fågelsång drill-core is 28.32 m. The unit is widely distributed in the subsurface in a SE-NW belt across Scania.

Key words: Ordovician, graptolite biostratigraphy, lithostratigraphy, Scania, Sweden.

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The relatively condensed but stratigraphically remarkably complete Ordovician succession in Scania (Skåne), southernmost Sweden (Fig. 1) is in several respects unique in Baltoscandia. Lithologically, the 150-200 m thick sequence is dominated by deeper-water dark shales and mudstones with planktic faunas. There are only three thin but significant limestone units, the Lower Ordovician Bjerkåsholmen Formation and the Komstad Limestone, and the Upper Ordovician Skagen Limestone (or Skagen Formation). This sequence is lithologically strikingly different from those in most other outcrop areas in Sweden and the East Baltic where the Lower and Middle Ordovician successions mainly consist of shallower-water epicontinental carbonates with diverse shelly benthic faunas but with few graptolites. This difference reflects the fact that the Scanian succession was deposited on a marginal portion, rather than on the cratonic interior, of the Baltic plate, in an outer shelf-upper slope, or possibly a foreland basin, environment. Based on dominating lithofacies and supplemented by faunal data, Jaanusson (1982, 1995) referred the Ordovician in Scania to the Scanian Lithofacies Belt and stressed its differences to the Central Baltoscandian Confacies Belt with its calcareous sediments. Jaanusson also noted the close lithological and faunal relations of the former belt to the Oslo Lithofacies Belts, especially in the case of the Lower Ordovician.

The Ordovician succession in Scania is also unique in having one of the biostratigraphically most complete graptolite successions in the world, and for more than a century, it has served as a reference standard for the graptolite zone succession in Baltoscandia. The present study is concerned with only a portion of this succession, namely the interval between the Lower Ordovician Komstad Limestone and the Upper Ordovician Sularp Formation, and its lithostratigraphic classification.

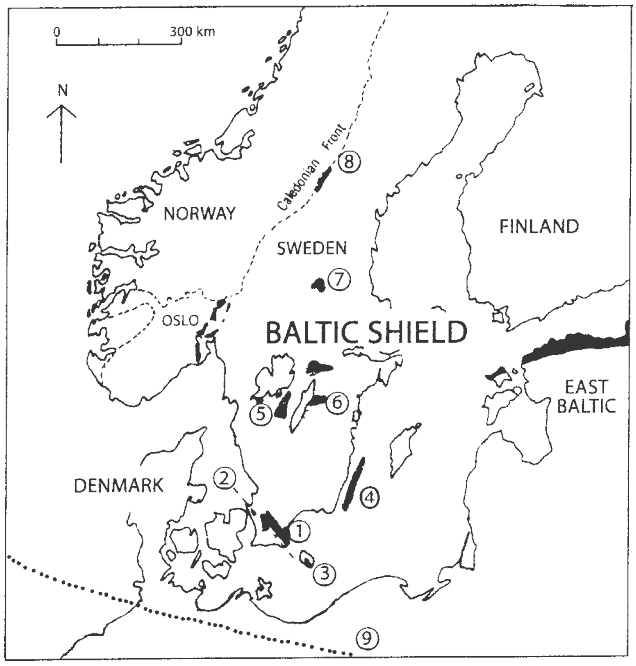

Fig. 1. Sketch-map of Baltoscandia showing location of the study area in southernmost Sweden, major outcrop areas of Lower Palaeozoic rocks (black), and some important geotectonic features. Explanation of numbers: 1. Scania; 2. Romele fault; 3. Bornholm; 4. Öland; 5. Västergötland; 6. Östergötland; 7. Dalarna; 8. Jämtland; 9. Approximate position of the southern margin of the Baltic Shield (dotted line).

In pioneer studies during the 19th century (e.g. Tullberg 1882; Törnquist 1889), a stratigraphical framework of graptolite zones was established in the Middle and Upper Ordovician and used as a basis for recognition of a sequence of larger stratigraphical units which were named for characteristic graptolite genera (Fig. 2). The stratigraphical scopes of these units, the Upper *Didymograptus* Shale, and the Lower, Middle, and Upper *Dicellograptus* Shale, were clearly defined in terms of graptolite zones (cf. Regnéll 1960, table II)

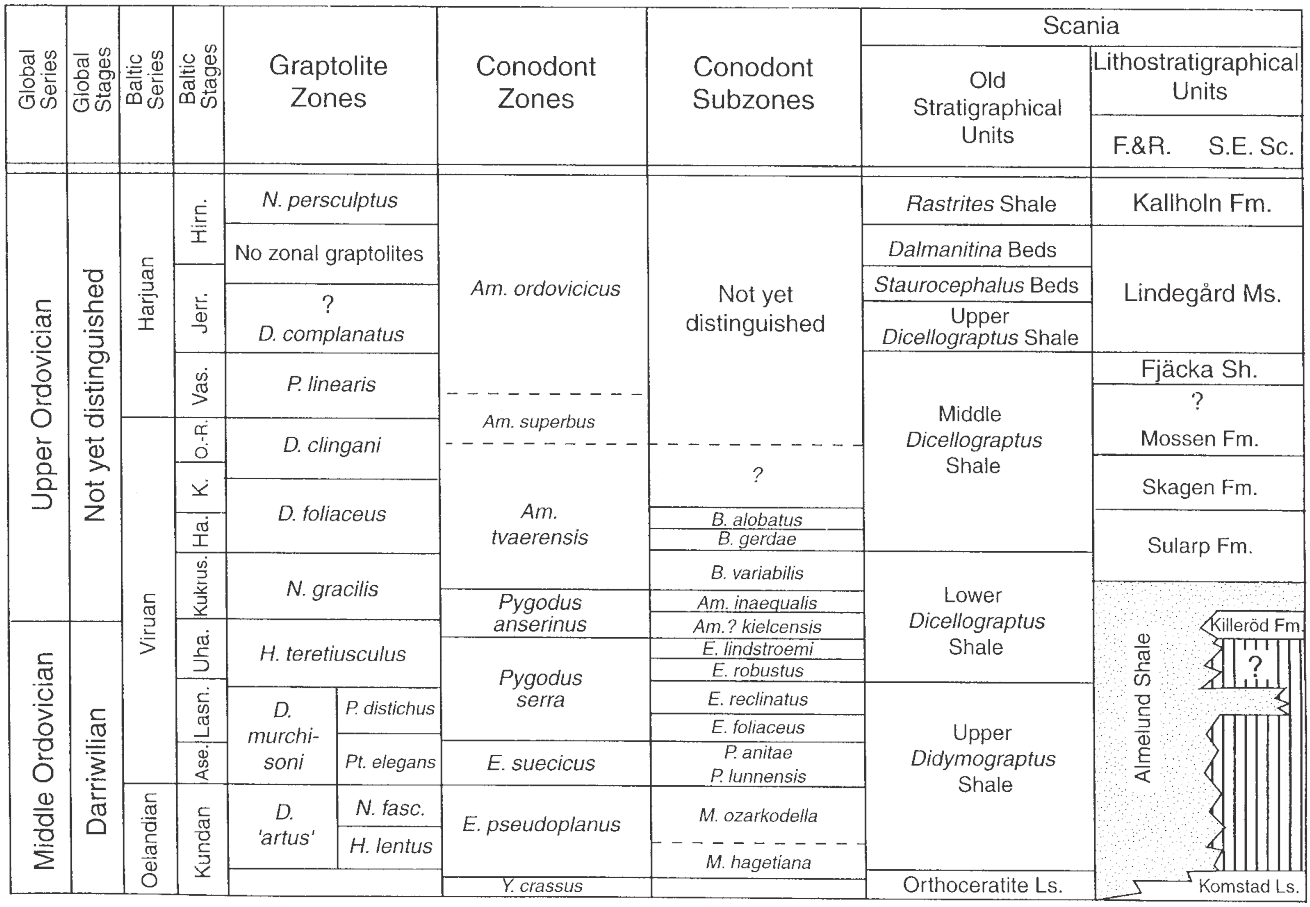

Fig. 2. Chronostratigraphical and lithostratigraphical classification of the Middle and Upper Ordovician of Scania. The base of the Upper Ordovician is taken to be at the base of the *Nemagraptus gracilis* Zone following the recently proposed global classification scheme (Bergström et al. 2000). Not all conodont zones and subzones shown have yet been recorded from Scania but they occur in coeval strata elsewhere in Baltoscandia. Note the stratigraphical scope of the Almelund Shale. Abbreviations: Hirn., Hirnantian; Jerr., Jerrestadian; Vas., Vasagaardian; O.-R., Oanduan-Rakaverian; K, Keilan; Ha., Haljalan; Kukrus., Kukrusean; Uha., Uhakuan; Lasn., Lasnamägian; Ase., Aserian; *fasc.*, *fasciculatus*; F. & R., Fågelsång and Röstånga; S.E. Sc., SE Scania.

rather than on lithology, and in modern chronostratigraphical terminology, they basically correspond to stages although they have never been used in that sense in the past or current literature. For reviews of the gradual development and refinement of this classification, see Moberg (1910a), Hadding (1913), and Ekström (1937).

Modern international stratigraphical guides advocate separation of lithostratigraphical and chronostratigraphical (biostratigraphical) classifications (Hedberg 1972, 1976; Salvador 1994), and such chronostratigraphical terms as the Upper *Didymograptus* Shale and *Dicellograptus* Shale are clearly outdated and inappropriate in a lithostratigraphical classification of the Scanian Ordovician sequence, a fact that has been noted by, e.g., Lindström (2000). Recent studies have led to the recognition of several lithostratigraphical units in this succession (Fig. 2), such as the Kallholn Formation, Lindegård Mudstone, Fjäcka Shale, Skagen Formation, Sularp Formation, Killeröd Formation, Komstad Limestone, and Tøyen Shale (Jaanusson 1960; Bergström 1982; Bergström et al. 1997, 1999) and there is now an adequate lithostratigraphical classification of the entire Ordovician in Scania with one glaring exception. This is the lithologically rather uniform Middle Ordovician interval between the Komstad Limestone and the Sularp Shale that to date lacks a formal lithostratigraphical name. In the absence of a proper such term, the old chronostratigraphical designations Upper *Didymograptus* Shale and *Dicellograptus* Shale have been retained also in recent contributions (Bergström et al. 2000; Lindström 2000; Månsson 2000). The only exception to this is Maletz (1998) who suggested that the Norwegian designation Elnes Formation should be used for this interval in Scania. Although Maletz (1998) showed convincingly that the Norwegian unit is a correlative of the Upper *Didymograptus* Shale and of part of the *Dicellograptus* Shale, the use of the Norwegian name appears inappropriate in view of the marked lithological differences between the Scanian and Norwegian units. That is, whereas the Scanian unit is a sequence of black or dark-grey shales with rare thin carbonate interbeds (cf. Hede 1951, pp. 10–13; Maletz 1998, Fig. 17; Fig. 3),

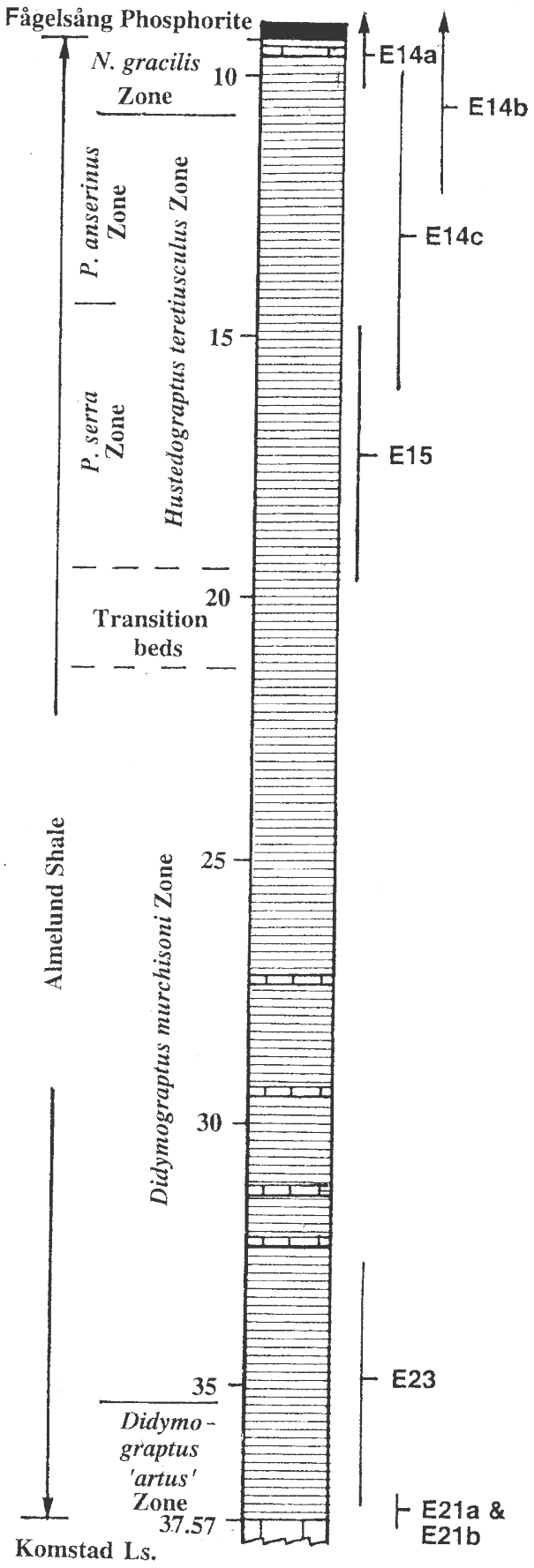

Fig. 3. Stratigraphical column of the Almelund Shale in the Fågelsång area. Lithology and core depth figures based on the Fågelsång core (Hede 1951). Horizontal ruling, shale and mudstone; brick pattern, limestone; black, phosphorite. Graptolite zonation modified after Hede (1951), conodont zones after Bergström et al. (2000). Vertical lines to the right of the stratigraphical column shows the stratigraphical extent of important outcrops with section designations following Moberg (1910b).

much of the typical Elnes Formation is an interbedded grey shale-limestone succession (Owen et al. 1990, Figs 11, 12); in fact, two of the five members (Helskjer and Håkavik members) of the Elnes Formation recognized by Owen et al. (1990) are particularly characterized by the occurrence of very abundant beds and concretions of limestone containing a diverse shelly fauna that has no counterpart in coeval Scanian strata. To obscure these conspicuous lithological differences by using the Norwegian formation name for the Scanian unit seems inappropriate.

The need for a revised stratigraphical classification of this interval has now become particularly urgent because sections in the Fågelsång area, representing part of this interval, have been proposed as Global Stratotype Section and Point (GSSP) for the base of the Upper Ordovician in the new international stage and series classification of the Ordovician System (Bergström et al. 2000). The base of the interval under discussion, that is, the base of the Upper *Didymograptus* Shale, is the top of the Komstad Limestone, which is the most significant carbonate unit in the Ordovician succession in central and southeastern Scania and hence a very distinctive stratigraphical marker. The Upper *Didymograptus* Shale and the overlying *Dicellograptus* Shale are not separable lithologically and form a uniform sequence of dark-grey to black, mostly non-calcareous, shales and mudstones with occasional limestone concretions and rare thin beds of argillaceous limestone and phosphorite (Fig. 3). There are also a few thin K-bentonite beds (Nielsen 1995). This stratigraphical interval, which in the Fågelsång area has a thickness of about 28 m (Hede 1951), is a typical 'graptolitic shale' that apart from a diverse graptolite fauna yields only a few shelly fossils (mostly lingulate brachiopods) and biostratigraphically diagnostic conodonts and chitinozoans (Bergström et al. 2000). This unit is overlain by the Sularp Formation (Lindström 1953; Nilsson 1977), most of which is a strongly silicified dark mudstone containing a very large number of K-bentonite beds (Bergström & Nilsson 1974) and occasional layers of more or less impure limestone. The Sularp Formation is currently best known from the Fågelsång area where it has yielded numerous graptolites (Nilsson 1977), as well as a variety of shelly fossils (Lindström 1953; Nilsson 1977), but it has also been identified at Röstånga (Bergström et al. 1999). The Sularp Formation corresponds to the lower portion of the Middle *Dicellograptus* Shale in the previous classification (Regnéll 1960, Table II).

Almelund Shale

For the lithological unit between the Komstad Limestone and the Sularp Formation we propose the formation designation *Almelund Shale*. The name is taken from the Almelund Farm which is located 0.7 km NNW of the important sections of the formation at the localities E14a-c, E15 and E23 along the Sularp Brook in the Fågelsång area (Fig. 4; also see Moberg 1910b).

The basal contact of the Almelund Shale, which is well marked lithologically but appears conformable, has been recorded from Moberg's (1910b) E21b locality (for descriptions, see Ekström 1937, pp. 15–16 and Nielsen 1995, pp. 21–23) and in the Fågelsång core (Hede 1951). Although the E21b section tends to be covered by loose material and requires excavation for detailed study, it is currently the best exposure of the basal contact of the Almelund Formation in the Fågelsång area, and it is here designated as the stratotype of the base of the unit. The lower, but not basalmost, part of the Almelund Shale is currently best exposed at locality E23, and the upper portion of the unit is readily accessible in the E14a-c and E15 outcrops (Bergström et al. 2000). In the Fågelsång drillcore (Hede 1951), which included a complete section of the Almelund Shale, it has a total thickness of 28.32 m. Its lithology in this core and its stratigraphic extent in some outcrops in the Fågelsång area are illustrated in Figure 3.

The upper part of the Almelund Shale grades into the overlying Sularp Formation without any visible lithological break. This transition takes place within the *Nemagraptus gracilis* Graptolite Zone. The Sularp Shale was introduced by Lindström (1953) as a lithostratigraphical designation for a sequence of silicified shales and mudstones, impure limestones with diverse shelly fossils, and numerous K-bentonite beds exposed in outcrops along the Sularp Brook but no stratotype section was selected. In view of its appreciable content of non-shale materials, Bergström et al. (1997) referred to the unit as the Sularp Formation, and that practice is followed herein. No outcrop exposes more than a few m of the Sularp Formation but the entire unit was cored in the Koängen well, where it has a thickness of about 35 m (Nilsson 1977). In the absence of a sharp lithological change at a particular level it is here proposed that for convenience, the basal contact of the Sularp Formation, and the top of the Almelund Shale, in the Fågelsång area is taken to be the base of the Fågelsång Phosphorite, which is an excellent marker bed (Bergström et al. 2000). This level is well exposed at Moberg's (1910b) localities E14a and E14b along the Sularp Brook, which are separated from each other by only about 20 m (Bergström et al. 2000, Fig. 2D). Together these outcrops are suitable to serve as

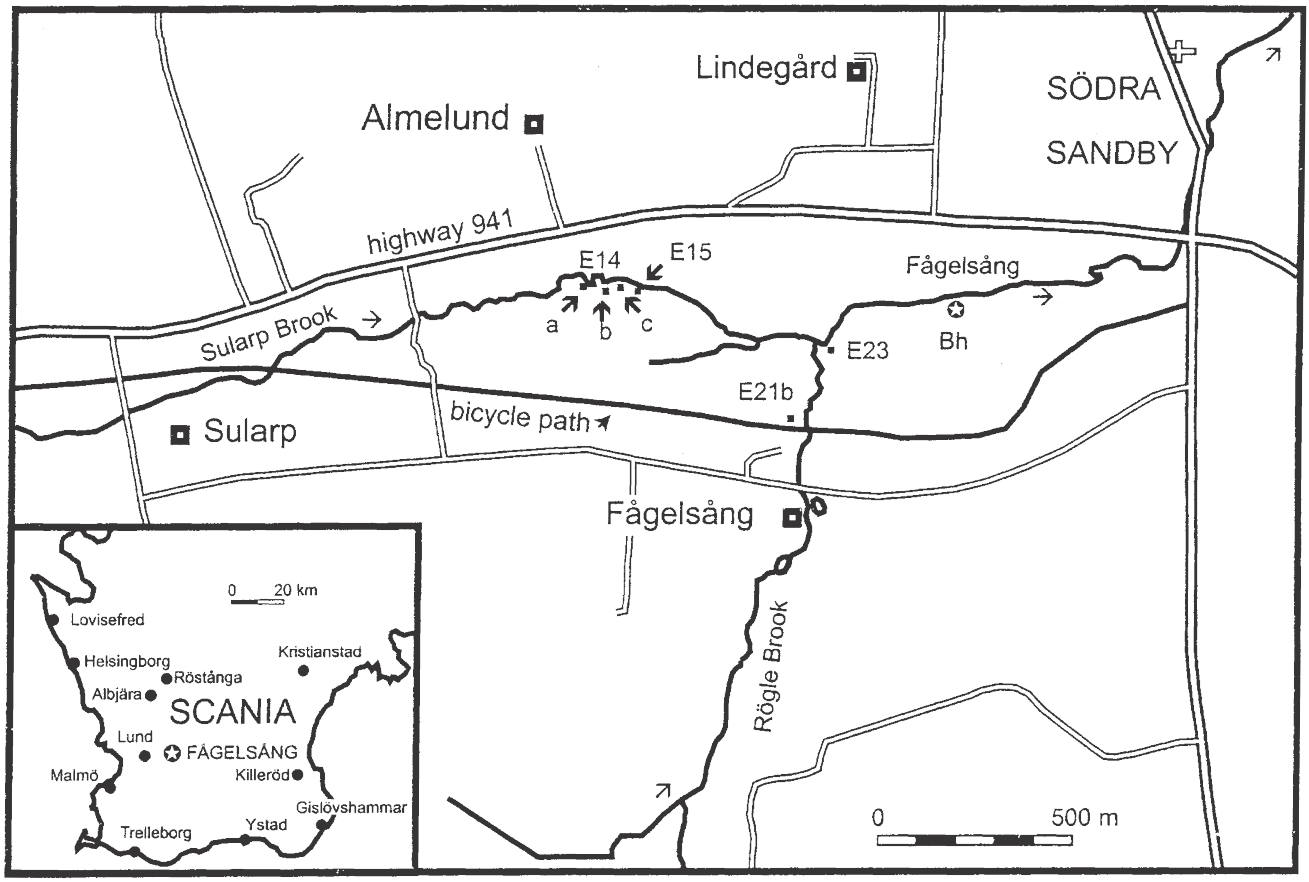

Fig. 4. Sketch-map of the Fågelsång area showing the location of the type sections of the Almelund Shale (the E14a-b, and E21b localities) and the locality E23. Also note the situation of the Fågelsång borehole (Bh) about 0.4 km ENE of locality E23 from which Hede (1951) described a complete sequence through the Almelund Shale.

stratotype of the base of the Sularp Formation. In terms of graptolite zones, the Almelund Shale corresponds to the interval from the *Didymograptus 'artus'* Zone to about 1.4 m above the base of the *Nemagraptus gracilis* Zone as the latter zone is defined by Bergström et al. (2000). The biostratigraphical relations of the Almelund Shale are illustrated in Figure 2.

Regional occurrence

The Almelund Shale is known from several other regions in Scania and it is likely to be present in the subsurface across a substantial portion of the province. In the Röstånga area (Fig. 4), Hadding (1913) and Ekström (1937) exposed much of the unit by trenching along the Church Brook (Kyrkbäcken) but there are currently no exposures of the formation at this locality or elsewhere at Röstånga. However, virtually the entire Almelund Shale, which here has a thickness of about 80 m and consists of dark shale with a few thin limestone beds, was cored in a well drilled in 1989 at Albjära about 15 km SW of Röstånga and 26 km NW of Fågelsång (Fig. 4). The remarkable graptolite succession in this drill-core, apparently the stratigraphically most complete in this interval in northern Europe, has been described by Maletz (1995, 1998), who in the Almelund Shale recognized a detailed zone sequence that includes his *Holmograptus lentus*, *Nicholsonograptus fasciculatus*, *Pterograptus elegans*, *Pseudamplexograptus distichus*, and *Hustedograptus teretiusculus* Zones (Fig. 2). Whether or not this zone succession can be applied also to the Fågelsång sequence is not yet clear from the available published information. The entire Almelund Shale was also cored in the Lovisefred well (Nilsson 1984, and personal communication 1986), where it has a thickness of about 80 m and consists of dark-grey to black shales and mudstones with rare thin beds of impure limestone. This well was drilled by the Geological Survey of Sweden at a site about 1 km S of Lovisefred Farm and 4 km NNE of Höganäs Church in northwesternmost Scania. In southeastern Scania, the thin shale unit above the Komstad Limestone and below the Killeröd Formation at Killeröd (Månsson

1995; Nielsen 1995) clearly represents a tongue of the Almelund Shale. However, locally in southeastern Scania, for instance at Gislövshammar, the Killeröd Formation rests directly on the Komstad Limestone and the Almelund Shale is missing (Nielsen 1995). The siliceous shales with K-bentonite beds that rest directly on the Komstad Limestone on the Island of Bornholm, Denmark, which represent the *Diplograptus foliaceus* (formerly *D. multidens)* Zone (Bergström & Nilsson 1974), are best classified lithostratigraphically as the Sularp Formation.

In the lower Palaeozic outcrop areas in Öland, Västergötland, Östergötland, Dalarna, and Estonia (Fig. 1), the stratigraphical interval of the Almelund Shale is developed mainly in limestone facies (Lindström 2000, Fig. 2.16). However, the Andersö Shale in Jämtland (Karis 1998; Pålsson et al. in press) is an equivalent to a portion of the Almelund Shale but its lithology of interbedded shales and limestones is more similar to that of the Killeröd Formation in Scania than to that of the non-calcareous shale succession of the former unit. Finally, as noted above, the Elnes Formation in the Oslo Region, Norway is clearly a correlative of the Almelund Shale although developed in a far more calcareous facies.

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