THE LØKKEN-HØLONDA-STØREN AREAS

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INTRODUCTION

The region around Løkken, Hølonda and Støren, south and south-west of Trondheim (Fig. 1) is classical ground for the interpretation of the Lower Palaeozoic stratigraphy of western Trøndelag. In fact it is the only area in the entire Caledonian belt in which fossils are present in sufficient number, variety and preservation to allow detailed palaeontological and stratigraphical work. Even so, knowledge of the faunas is still incomplete and fossil localities so far recorded are limited to a narrow east-west belt from Løkken to Hovin, a distance of approximately 30 km. The fossils are Ordovician in age and include graptolites (Blake 1962; Berry 1968; Skevington 1963), brachiopods (Reed *in* Kiær 1932; Neuman & Bruton 1974), trilobites (Strand 1948; Neuman & Bruton 1974), cephalopods (Foerste *in* Kiær 1932), echinoderms (Bockelie 1974) and conodonts (Bergström 1971, 1979). Early Ordovician (Arenig-Llanvirn) shelly faunas are of North American type, while the graptolites show strong Australian affinities and a zonal scheme based on this has been introduced by Skevington (in Ryan *et al.* 1980). These facts led Wilson (1966), Dewey (1969) and Dewey *et al.* (1970) to suggest a two-fold division of the Scandinavian Caledonides into eastern and western parts, each developed independently on opposite sides of a proto-Atlantic (Iapetus) Ocean. The junction between the two is now represented by a major low angled thrust (Nicholson 1971) separating the Gula and Støren nappes (Fig. 1). Evidence for the two-fold division is structural (Nicholson 1971, 1979), faunal (Bruton & Harper 1981) and geo-chemical (Gale & Roberts 1974). Basaltic greenstones in the area of Løkken and Hølonda have been interpreted as representing either a marginal or a major ocean basin (Pearce & Gale 1974; Grenne *et al.* 1980), while a back-arc volcano-sedimentary basinal environment has been inferred for the overlying Lower and Upper Hovin Groups (Bruton & Bockelie 1980). However, there is no

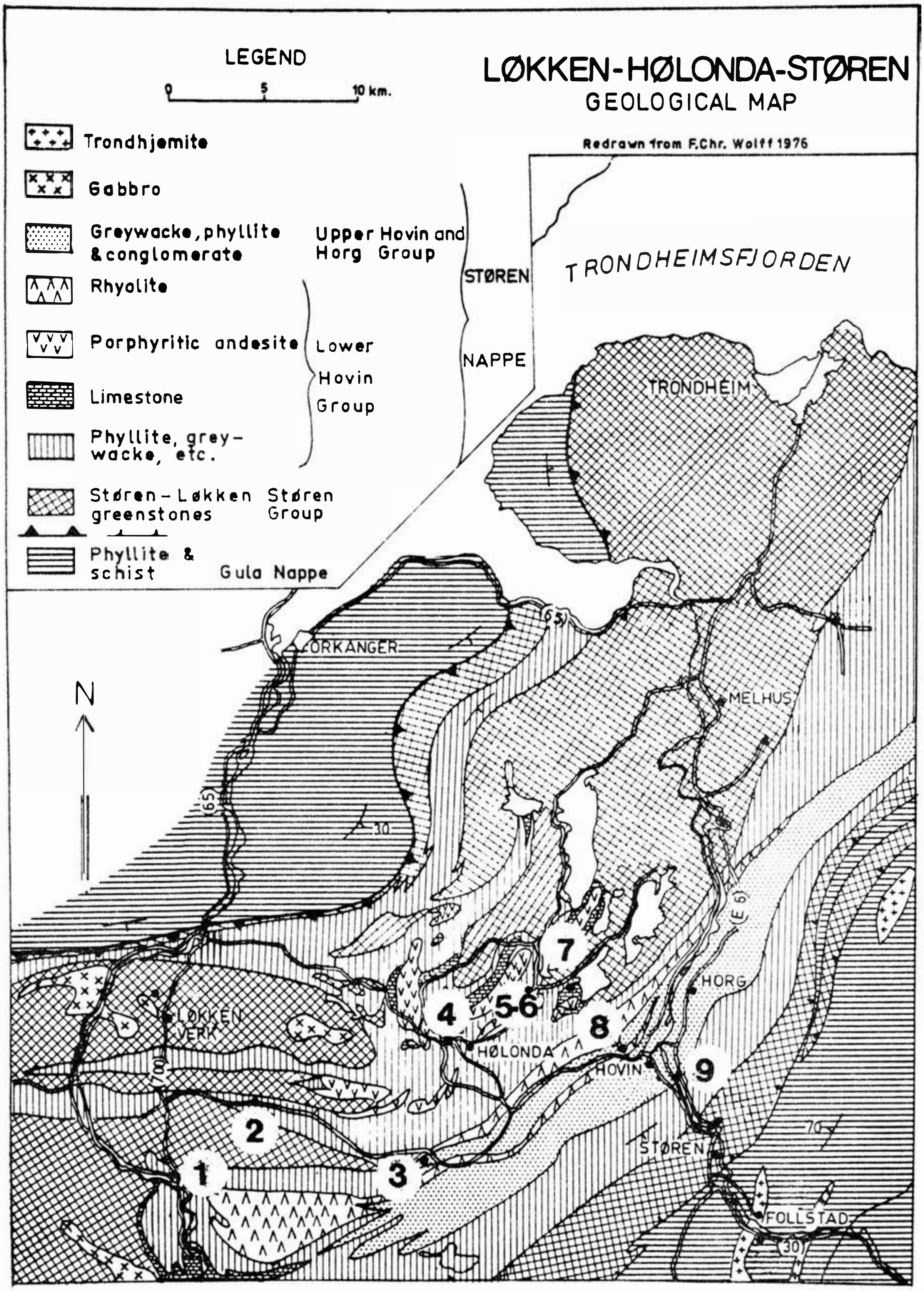

Figure 1. Geological map of the excursion area with marked stops (Modified after Gee & Wolff 1981).

WESTERN TRØNDELAG - STØREN NAPPE	
HORG GROUP	Greywackes and conglomerates (age uncertain)
UPPER HOVIN GROUP	Greywackes and conglomerates. Subord lst and rhyolitic tuffs. (Mid Ordovician and possibly younger)
LOWER HOVIN GROUP	Black phyllites greywackes and conglomerates. Andesites and rhyolites. Limestones. Basal volcaniclastic conglomerates. (Mid Arenig to Upper Caradoc)
STØREN GROUP	Pillow lavas, cherts and very subord. phyllites. Other units of ophiolites (sheeted dykes and layered gabbro) also present locally. (pre-Mid Arenig)
GULA NAPPE COMPLEX	

Figure 2. Stratigraphy of the Støren Nappe (modified after Gee & Wolff 1981).

agreement on the direction of subduction related to the development of the basin. The North American affinity of the fossils suggests westward-dipping subduction, while the reverse has been suggested by Ryan *et al.* (1980) because the Lower Hovin Group sediments are considered to contain continental detritus derived from the margin of Baltoscandia. Recent geochemical studies by Roberts (1980) suggest deposition in a basin marginal to Baltoscandia or to a ? microcontinent with associated back-arc spreading. These apparently conflicting interpretations need further examination.

STRUCTURE

The structure of the area is complex and a variety of interpretations are illustrated in Fig. 3. Recent work shows that the basaltic greenstones in the Løkken area occur in a synformal anticline which can be followed further west (Grenne *et al.* 1980). In the Hølonda area, Vogt (1945) considered the structure to be a simple syncline with the sedimentary rocks capped by the Hølonda porphyrites (andesites). Bockelie & Bruton (1980) have shown all sedimentary units to be diachronous and the andesites to be penecontemporaneous intrusions and extrusions. The rocks strike NE-SW, folds being overturned towards the south-east. A series of low-angled thrusts occur, running parallel or cross-cutting the strike and separating distinct sedimentary units from the north-west to south-east. A major thrust, identified by the authors (t-t, Fig. 4), separates

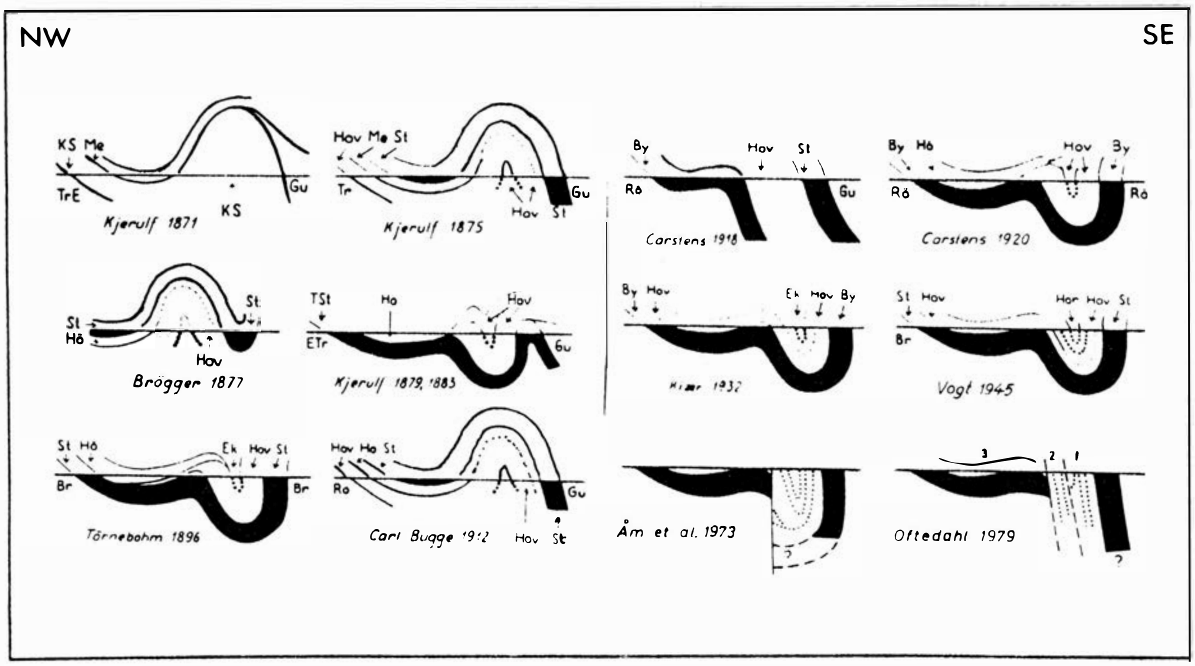

Figure 3. Historical review of structural interpretation in the Hølonda-Horg-Støren region (see Vogt 1945). Gu - Gula Group; St - Støren Group (black); Hov (3,1) - Lower and Upper Hovin Groups; Hor (2) - Horg Group. (After Gee & Wolff 1981)

the succession of Arenig-Caradoc rocks in the north-west form a younger Caradoc-Ashgill succession in the south-east. These two units are recognised by Oftedahl (1980) who agrees that they are separated by a thrust and are not limbs of what was formally known as the Horg Syncline.

STRATIGRAPHY OF THE STØREN NAPPE

Vogt (1945) divided the succession into four series, now known as the Støren, Lower Hovin, Upper Hovin and Horg groups (Figs. 2, 6), separated from each other by conglomerates marking three diastrophic events. He also identified a number of formations which have since been redefined and modified by Chaloupsky (1970). Mapping carried out by the present authors has shown that many of Vogt's formations in the Lower Hovin Group are diachronous (Fig. 5) and that the Upper Hovin Group belongs to a separate thrust unit.

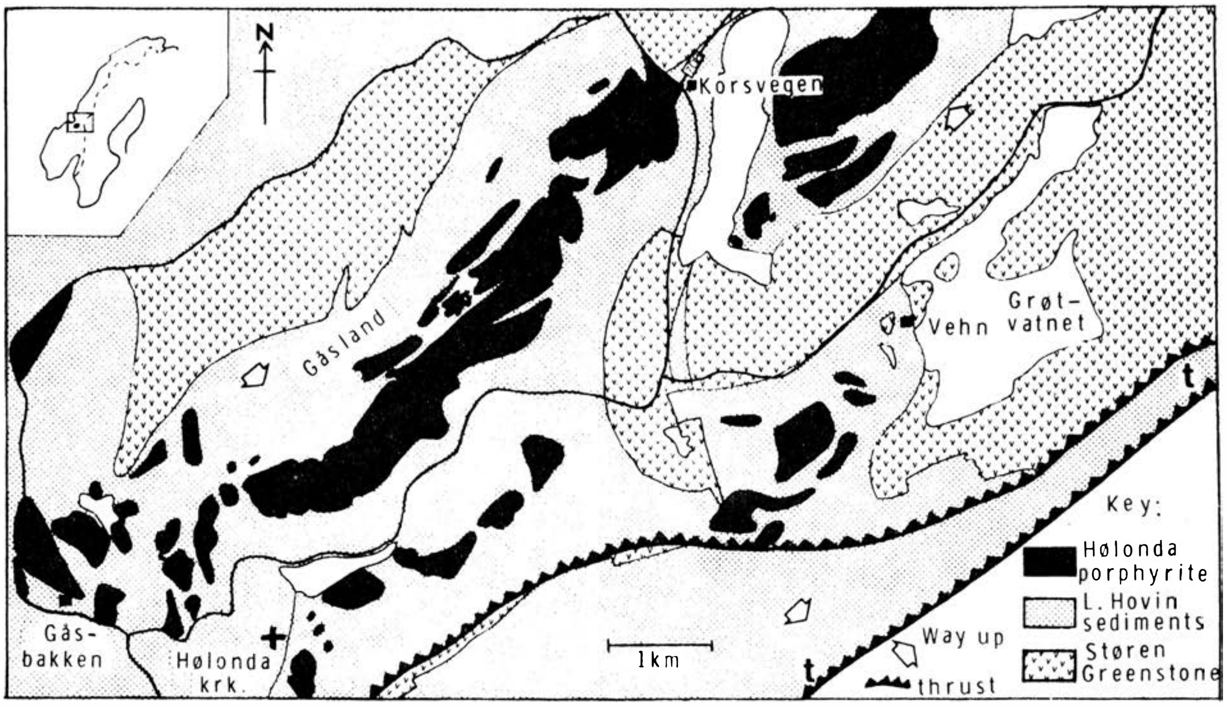

Figure 4. Simplified geological map of the Hølonda area based on the authors' own mapping. Inset map shows position of area in the Trondheim region. Many of the contacts between Støren Greenstone and Lower Hovin sediments are tectonic. Major faults are indicated by dashed lines. Line t-t is a major thrust separating the succession of Arenig-Caradoc rocks in the north-west from a younger Caradoc-Ashgill succession in the south-east. (After Bruton & Bockelie 1980.)

The Støren Group is about 3 km thick and is dominated by basaltic lavas of tholeiitic composition and ocean floor affinities. Pillow basalts are common and the association of cherts, sheeted dykes and layered gabbros allows the recognition of part of an ophiolite suite (Grenne *et al.* 1980). The copper mineralisation of the Løkken Mine is associated with these rocks. Some authors correlate the basalts in the type area of Støren with those at Løkken and regard both to be of pre-middle Arenig age (Furnes *et al.* 1980), while others, including Ryan *et al.* (1980), regard the Løkken unit as middle to late Arenig. This is based on associated graptolite bearing shales in the Meldal area south and west of Løkken (Fig. 6).

In the Hølonda area, Bruton & Bockelie (1980) have shown that folding, accompanied by uplift and erosion of the Støren Group, allowed the formation of locally thick conglomerates prior to deposition of sediments of the Lower Hovin Group. Rapid changes in sediment type and thickness suggests that local faulting produced NE-SW troughs in which the conglomerates were deposited. The conglomerates contain blocks of the immediately underlying greenstones and cherts but towards the top, red conglomeratic sandstones have been interpreted as being of continental origin (Vogt 1945) or near shore shallow marine (Furnes *et al.* 1980).

The Lower Hovin Group Bruton & Bockelie (1980) have shown that erosion of the greenstones in the Hølonda area continued at the same time as black graptolitic shales, including the Bogo Shales, were being deposited 20 km farther west. The top of the Bogo Shale is topmost Arenig (late *Didymograptus hirundo* Zone) and is equivalent in age to part of the Hølonda Limestone dated using trilobite-brachiopod associations (Neuman & Bruton 1974) and conodonts (Bergström 1979).

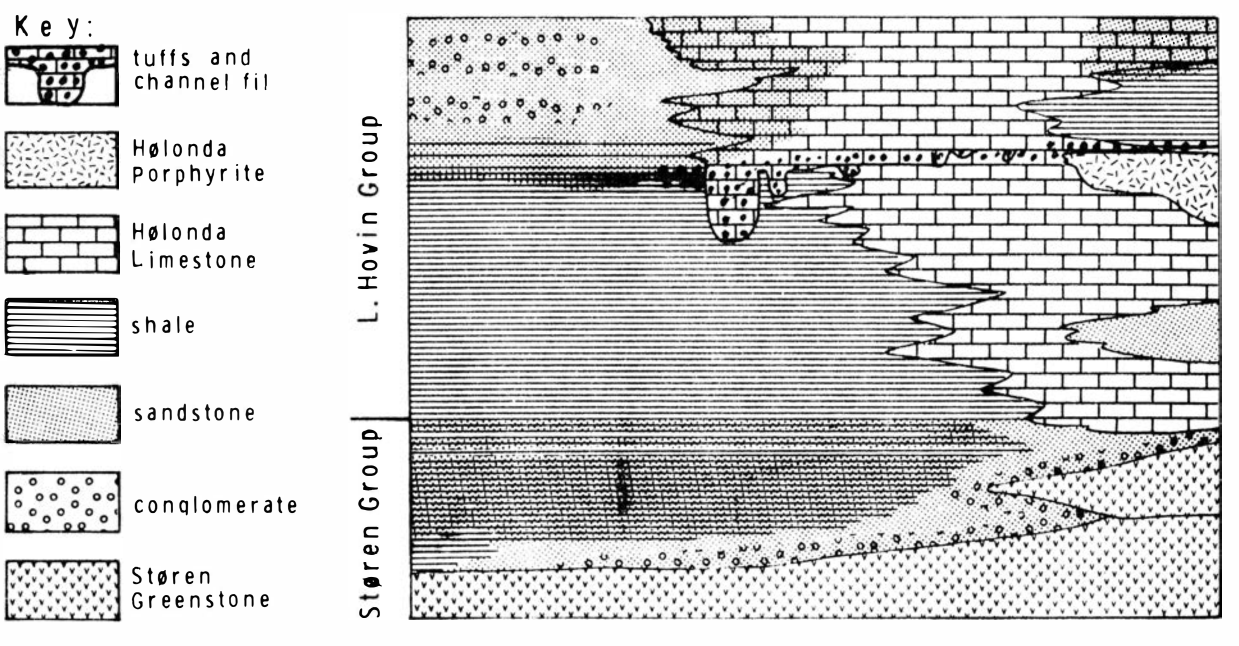

Figure 5. Lithostratigraphic synthesis of Lower Ordovician (Arenig-Llanvirn) rocks in the Hølonda area. Note the complex facies changes in the Lower Hovin Group. Silt influx is shown in shales and limestones where appropriate. (From Bruton & Bockelie 1980.)

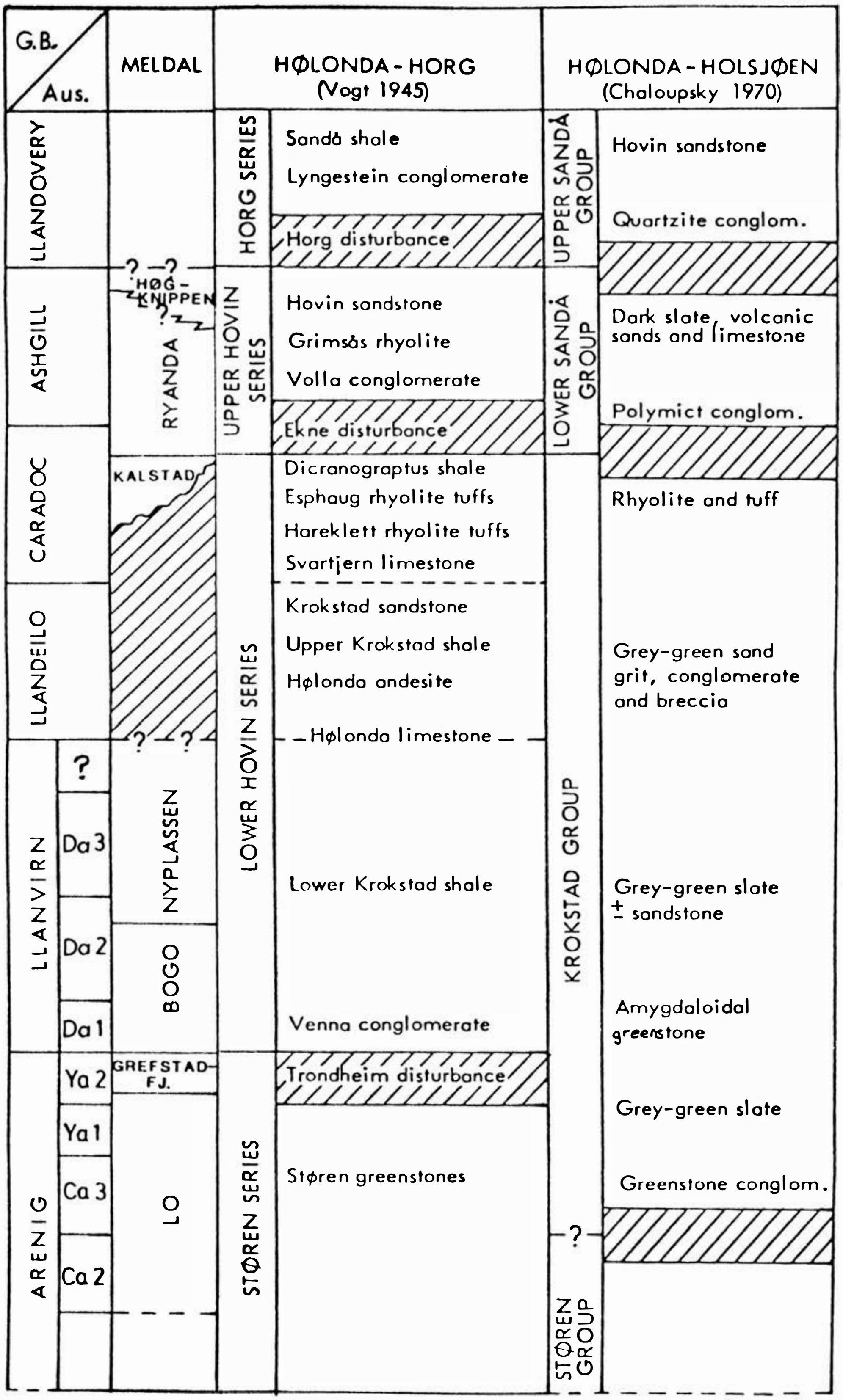

Figure 6. Stratigraphical schemes for the region based on Ryan et al. (1980), Vogt (1945) and Chaloupsky (1970). Modified from Ryan (MS).

A series of limestones, including the Hølonda Limestone, were deposited locally around 'greenstone islands' with a succession of deeper water sediments off-shore. In addition, penecontemporaneous intrusion of the Hølonda andesites caused uplift and island formation in previously deeper areas of the basin. Both limestone breccias and limestone-andesite conglomerates filled channels off these volcanic islands (Fig. 7).

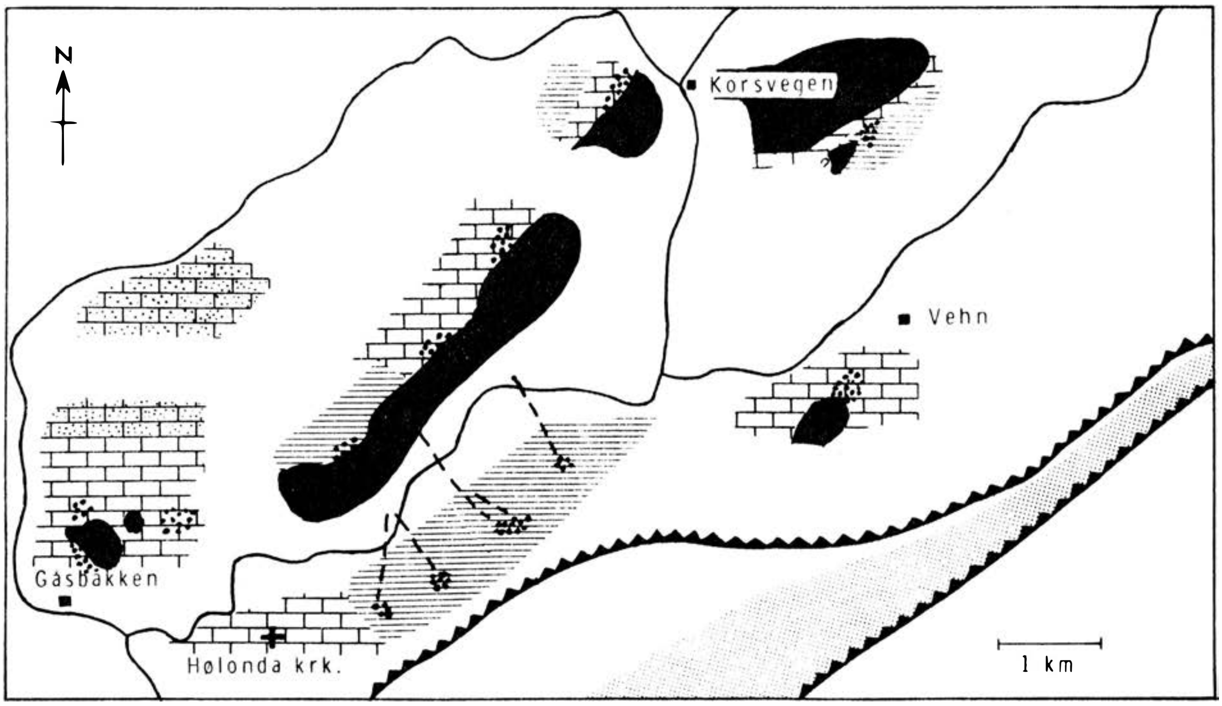

Figure 7. Simplified palaeogeographic map for the early Ordovician (Arenig-Llanvirn) of the Hølonda area after the formation of the Hølonda Porphyrite (black). Those porphyrite bodies shown formed local islands around which the different sediment types were deposited. Erosional channels (direction illustrated by dotted lines), filled with blocks of porphyrite, extend from some of the islands out into the deeper shaly parts of the basin. Note the deposition of clastic sediments on the northwestern and southeastern margins of the basin. Symbols as in Fig. 5. (From Bruton & Bockelie 1980)

Fossils in sediments pre- and post-dating intrusion of the andesites show that the geological evolution of the island arc system (Fig. 8) took place in a relatively short period of time from late Arenig to early Llanvirn (Bruton & Bockelie 1980).

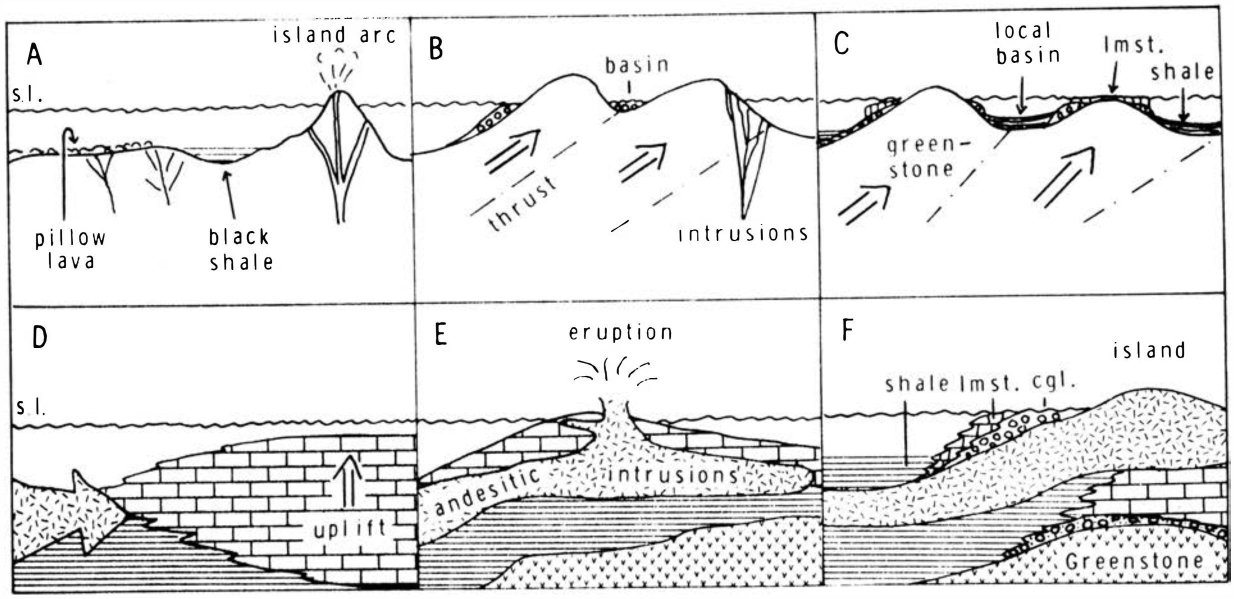

Figure 8. Geological evolution of the Hølonda area during the early Ordovician (Arenig-Llanvirn). A, Pre-Arenig. Ocean floor spreading with the formation of pillow lavas (Støren Greenstones) and an immature island arc. B, Middle Arenig. Uplift associated with thrusting and erosion of the greenstones and arc, and formation of local basins. C-F, Late Arenig - early Llanvirn. C, Development of local basins. D, Injection of some Hølonda porphyrites with formation of explosive breccias, tuffs and islands. Shape of bodies possibly influenced by the underlying sediments, greenstones and reactivated thrusts. F, Erosion of islands and formation of concentric facies belts. (From Bruton & Bockelie 1980)

Younger brachiopod faunas of possible Caradoc age occur between Løkken and Hølonda in successions previously mapped as Lower Hovin Group, although they may belong to the Upper Hovin Group. Graptolites belonging to the Dicranograptus clingani Zone (late Caradoc) have recently been identified from shales below the Volla Conglomerate which defines the base of the Upper Hovin Series at the type locality north of Støren.

The Upper Hovin Group consists of a succession of greywackes, intraformational conglomerates, limestones, light coloured volcaniclastic sandstones, rhyolites and rhyolitic tuffs, which are best seen near Hovin. Some units contain brachiopods suggestive of a Caradoc age, while one might be Ashgill (Neuman, written comm. 1981). All localities yielding Caradoc and younger faunas are on the lower, south-east side of a major thrust (t-t, Fig. 4) separating older rocks to the north-west.

In the Meldal area (Fig. 6) a lime-mud mound, known as the Kalstad Limestone, is in contact with the Løkken greenstones (Ryan *et al*. 1980). Ryan (pers. comm.) regards the contact to be an erosional unconformity, while the present authors believe it to be a fault contact. Brachiopods from bedded sediments associated with the carbonate mound suggest a Caradoc age for these while crinoid ossicles and the corals (Kiær 1932) suggest an Ashgill one.

The Horg Group The status of this group is uncertain (Chaloupsky 1970) and the age is uncertain. The unit consists of greywackes and shales (phyllites) with a monomict quartz conglomerate at the base. No fossils have been recorded from the area and the once supposed Llandovery age (based on correlation with the Slågån Group in Meråker 80 km to the north east) is far from certain.

ROAD LOG

Leader: J. Fredrik Bockelie (assisted by Robert B. Neuman, Bjørn Wandås and Olaf Schmidt)

5:1 MELDAL (1521 III Løkken, 360915). Section on north side of road. 1 km north of Meldal.

This section, described in detail by Kiær (1932, p. 17), is an inverted sequence, dipping north. The bedded limestones and tuffaceous shales, known as the Kalstad Limestone (Ryan *et al*. 1980), are thought to be of Caradoc-Ashgill age. At the south end of the outcrop (top of sequence) dark weathering, tuffaceous shales are underlain by alternating nodular limestones and shales, separated by a minor thrust from the more compact coral, algal bryozoan limestone. Stratigraphically below, a small roadside limestone quarry contains silty beds which have yielded fragments of a trinucleid trilobite. Stratigraphically down section, a thick series of silty shales contain abundant crinoid ossicles of ?Ashgill age (Bockelie in prep).

About 800-1000 m to the north-west, a shale, underlying a massive partly brecciated limestone, contains a brachiopod fauna, including *Dalmanella* sp., *Dinorthis*, *Glyptorthis*, *Rafenesquina* and *Sowerbyella* (Neuman pers. comm. 1981).

5:2 BOGO RIVER (1521 II Hølonda, 396964). East side of bank, Bogo river, 20 m downstream from the waterfall.

This locality, first reported by Blake (1962), has since become widely known because it yields one of the few Pacific Province, Early Ordovician graptolite faunas in Europe (Berry 1968; Ryan *et al*. 1980). The graptolites occur in the black, rusty-weathering Bogo shales. Massive, resistant tuffs form prominent features and thinner, well bedded tuffs, often calcareous, occur within the black shales at this locality and at another about 75 m down stream on the west bank of the river. Cooper (1973) reported the occurrence in the Bogo Shale of Isograptus caduceus australis, a species characteristic of the Australian Yapeenian Stage which is generally correlated with the Didymograptus hirundo Zone. Other graptolites include: Tetragraptus bigsbyi (Hall), Isograptus caduceus spp and Didymograptus similis (Hall).

The section has recently been cleared by dipl. geol. Olaf Schmidt (University of Göttingen) who will be present to explain his work.

5:3 SVARTSÆTRA (1521 II Hølonda, 494922). Section in track leading to Svartsætra.

This section shows at least 140 m of tuffs, interbedded with fossiliferous grey limestone, pale weathering shales and dark banded siltstones. The limestones contain gastropods, a rugose coral and algal structures. The shales contain abundant crinoid ossicles together with brachiopods including Dalmanella sp., Glyptorthis sp., Leptaena sp., P. multicostella sp., Oxoplecia sp., Skenidioides sp. and Sowerbyella sp. (Neuman pers. comm. 1981). This succession occurs on the south-east side of the major thrust which crosses the area. The relationship of the limestone at Svartsætra to the Kalstad Limestone in the west and the Hølonda Limestone in the north is unknown. The fauna suggest a Caradoc age.

5:4 GÅSBAKKEN (1521 II Hølonda 507986). Road section 500 m east of Gåsbakken.

This locality shows well-bedded Hølonda Shales overlying Hølonda Limestone and penecontemporaneous porphyrites. The massive limestone contains blocks of porphyrites near the base, but is intruded by porphyrite near the top. At Trotland, approximately 2 km to the north-west, the limestone contains a rich trilobite, brachiopod and crinoid fauna (Neuman & Bruton 1974) of Arenig-

Llanvirn age. The limestone is diachronous and varies considerably in thickness in the Hølonda area (Bruton & Bockelie 1980).

5:5 ALMÅS (1521 II Hølonda 552012). Road-section 600 m south-west of Stenset cross-roads.

A recent road-cut showing more than 200 m of well-bedded, dark siltstone. The coarse tuffs contain scour markings and graded bedding is common. These beds belong to the Hølonda Shale and are thought to have been deposited in the deeper portion of a small basin. From this locality, observe the distinctive hills of Högåsen and Middagsåsen, formed of porphyrite, with Lower Hovin sediments in the lower ground.

5:6 STENSET (1521 II Hølonda 553013). North-west side of road Hølonda-Kvål, at Stenset cross-roads.

This stop, 600 m north of Stop 5, shows a small outcrop of Gaustadbakk breccia (Vogt 1945), thought by the leaders to be basal sediments, eroded from and deposited on the Støren Greenstone Complex. The beds consist of alternating green and red conglomeratic siltstones containing bands of red jasper and greenstone clasts. The sediments show cross-bedding and grading, indicating way-up to the north. No fossils are known from these beds. The locality is next to a major NW-SE trending fault.

5:7 KATUGLEÅSEN (1521 II Hølonda 566008). South side of hill. Steep climb (15 mins).

This locality was first described by Brøgger (1875) and has since yielded a rich, shelly fauna (Kiær 1932; Strand 1948) consisting of trilobites, brachiopods, gastropods and cephalopods from the Hølonda Limestone which forms the top and steep southern slope. Recently, a new brachiopod assemblage has been identified by R.B. Neuman in cleaved calcareous siltstones near the base of this section. These siltstones form a good marker horizon and can be traced westwards at least 1 km along strike to Damtjernet, 0.6 km south-west of Vehn farm.

The brachiopods (Neuman pers. comm. 1981) include:
Aporthophyla stoermeri Neuman, 1974
"Chonetoidea" triangularis Reed in Kiær, 1932
?Desmorthis sp.
Idiostrophia sp.
Rhysostrophia sp.
?Taffia sp.
Trondorthis strandi Neuman, 1974
Syndielasma sp.
Dr. E.L. Yochelson (pers. comm.) has identified the gastropod Loxoplocus (Lophospira) sp. (see also Yochelson 1977, p. 383).

The locality is one of several in the area from which Bergström (1979) has obtained conodonts. These are moderately well preserved with a colour alteration index (Epstein et al. 1977) of 5, which indicates a heating in excess of 300 °C. Bergström concluded that the conodonts are of Whiterock age and equivalent to part of the Anomalorthis Zone. Trilobites and brachiopods from the Hølonda Limestone at Trotland (Neuman & Bruton 1974) support this.

5:8 SJURSMOEN (M711/1521 I Hølonda 606986). New road-cut ca. 400 m east of Sjursmoen on road from Hølonda to Hovin.

This section shows representative lithologies in the Upper Hovin Group: rhyolites, acidic tuffs, conglomerates containing well-rounded ?ejecta, and interbedded fossiliferous limestones containing brachiopods, gastropods, rugose and tabulate corals, Solenopora algae and crinoid debris. The limestone also contains well-rounded blocks of volcanic material. According to Vogt (1945) these beds may belong to the Espehaug tuffaceous unit of the Lower Hovin Group, but they probably belong to the Upper. The fauna resembles that of the Kalstad Limestone. In the middle of the section a large block of bedded fossiliferous limestone is included within the conglomerate as a giant slump horizon.

5:9 GYLLAN (M711/1621 III Støren 632965). E6 road section ca. 4 km north-west of Haga bridge and Gaula river exposure.

A new road-cut shows a section of dark, pyrite-rich shales with interbedded calcareous beds and tuffaceous siltstones belonging to the so-called Dicranograptus Shales. Beds dip south but are inverted. This locality is one of several in the area from which Getz (1887) collected graptolites later briefly described, but not figured, by Hadding (Kiær 1932). He concluded that although the material was badly deformed, identifications indicated the zones of D. clingani or P. linearis. New collections made by Bruton and Wandås in May 1982 have since been examined by S.H. Williams. The specimens are badly cleaved with little thecal detail, but have been tentatively identified as Dicellograptus forchhammeri (s.l.), Climacograptus spiniferus (? = bicornis of Hadding) and diplograptid spp indet. Both the two named taxa and others listed by Hadding do not occur above the D. clingani Zone as defined by Williams (in press) at Dob's Linn, southern Scotland, and the strata may belong to this zone. The Dicranograptus shales and overlying greywackes contain limestone erratics and grade into the polymict Volla Conglomerate (Vogt 1945) taken as the base of the Upper Hovin Group. The conglomerate is best exposed below the small cabin beside the river 100 m north. Clasts up to 1 m in size include granites, trondhjemites, basalts, quartzites, limestones and greywacke.

From here the bus will stop at the Støren Hotel for refreshment before continuing the long drive to Sundvolden (estimated time of arrival: around midnight).