N. A. Shaikh

SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 717 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 69 NR 9

DAVID G. GEE

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WITH 2 PLATES

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ISBN 91-7158-084-0

VÄXJÖ 1975 C DAVIDSONS BOKTRYCKERI AB

INTERNATIONAL GEODYNAMICS PROJECT

SWEDISH GEODYNAMICS PROJECT —
CALEDONIAN RESEARCH PROJECT

TO THE MEMORY OF KARL-ERIK STRÖMGÅRD

Kalle Strömgård was a student of Professor Hans Ramberg at the Mineralogical and Geological Institute of Uppsala University, where he completed his Fil. lic. degree — an experimental study of boudinage and associated structural phenomena, in 1972. For five summers he worked in the Caledonides with the Swedish Geological Survey and proved himself to be one of Sweden's most promising young geologists. He died suddenly and unexpectedly at the age of twenty-seven, just at a time when his future with the Swedish Geodynamics Project was secured and we were anticipating several years of close collaboration. The project lost greatly by his death. For those of his friends who had watched his rapid growth from inexperienced student to independent research geologist his loss is immeasurable.

CONTENTS

ABSTRACT

The segment through the Scandinavian Caledonides described here is some 200 km wide and extends some 300 km from the Caledonian Front in Sweden to the Norwegian west coast. The Geotraverse rocks are treated in two major rock units referred to as the Eastern and Western Complexes. The Eastern Complex is made up of basement crystalline rocks of Svecofennian to sub-Jotnian age overlain by a late Pre-Cambrian (post c. 950 m.y.) to Silurian sequence of sediments up to about two kilometres thick. The Complex extends from the Caledonian Front to the Norwegian coast. It is overriden by the Western Complex of (late Pre-Cambrian and Cambrian?) Ordovician and early Silurian volcanic and sedimentary rocks, over five kilometres in thickness, transported by Silurian thrusting from west of the Norwegian coast. The Eastern and Western Complexes are overlain by late-orogenic (Silurian-Devonian) sediments.

The Caledonian frontal zone is characterized by décollement tectonics with cover shortening in the Eastern Complex in excess of seventy kilometres. The décollement zone is overthrust by the highest tectonic units of the Eastern Complex, the Offerdal and associated Nappes, an allochthon composed of mylonitized basement and late Pre-Cambrian sandstones, translated over one hundred and twenty kilometres eastwards. The lowest unit of the Western Complex, the Särv Nappe, containing a tholeiitic dolerite dyke swarm (unknown in the underlying Eastern Complex) has been translated at least one hundred and probably two hundred kilometres over the Eastern Complex allochthon. The Seve-Köli Nappe Complex, overriding the Särv Nappe, is composed of a high grade (including eclogites) lower part (Seve) and a lower grade (including Ordovician and Silurian faunas) upper part (Köli). This nappe complex requires at least seventy kilometres of shortening above the Särv Nappe. The uppermost units of the Western Complex are allochthonous on the Köli, at least in part, and contain the Ordovician faunas of American affinites.

Minimum crustal shortening across the Geotraverse is thus in the order of about five hundred kilometres. This vast shortening is explicable in terms of Plate Tectonic theory, it being relatable to a subduction process operating during the Silurian and well into the Devonian, movement occurring at an average rate of a few centimetres per year.

INTRODUCTION

The Geotraverse area outlined in this paper is a segment through the Scandinavian Caledonides some 200 km wide and 300 km long (WNW-ESE). Its relation to the North Atlantic Caledonides is shown in Fig. 1, where it is apparent that the traverse occupies the eastern part of an orogenic belt which, prior to Tertiary sea-floor spreading, with separation of Greenland from Scandinavia, was probably in the order of 1 000 km wide.

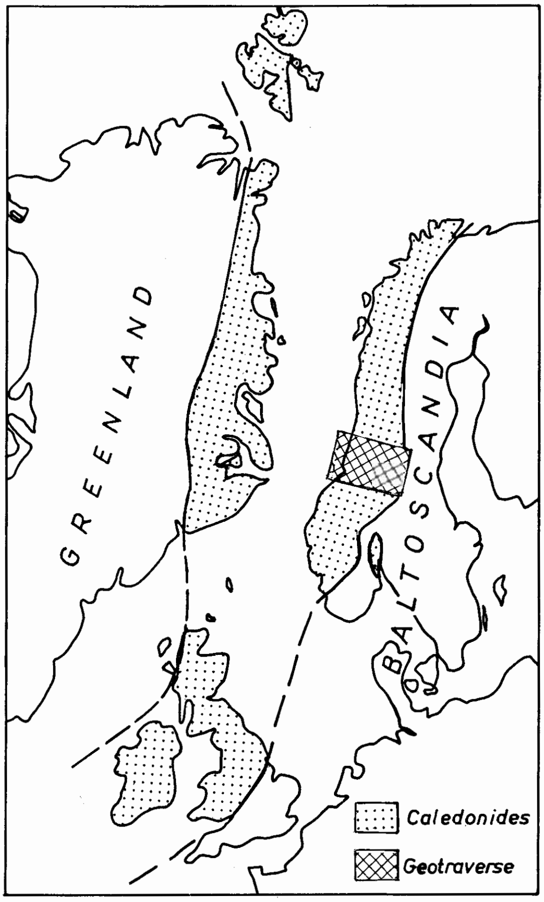

Fig. 1. Location of the Geotraverse in the North Atlantic Caledonides (Continental drift reconstruction based on Bullard et al. 1965).

This area of Scandinavia has been selected for special study in the context of the Inter-Union Commission on Geodynamics (Annersten 1973). It is divided more or less symmetrically by the Norwegian-Swedish border across which fundamental differences of tectonic interpretation have evolved. This paper is not a comprehensive review of the Geotraverse geology; rather, it is an attempt to weld together the main lithological and tectonic units in Norway and Sweden and present a co-ordinated model for this segment of the mountain belt. This model provides the basis for a tectonic synthesis which is presented elsewhere (Gee 1975).

The Geotraverse extends westwards from the eastern Caledonian Front to the Norwegian west coast in a broad strip embracing Östersund in Sweden and Trondheim in Norway. The orogenic belt is deeply eroded and pre-Caledonian basement can be traced through much of the area from the rigid foreland to the mobile interior, underlying a cover of autochthonous and allochthonous units. It was in this area (Törnebohm 1888 and 1896) that the theory of nappe tectonics was first applied to the Scandinavian Caledonides, providing evidence of easterly nappe transport in the order of 100 km and the suggestion of a root-zone in western Norway. It was also in this area that Asklund (1938) rejected the possibility of a root-zone for his "Great Seve Nappe" within the borders of Scandinavia, implying transport distances in excess of 250 km.

The geology of the Geotraverse area is illustrated in Plates I and II. Boundaries to most rock units have been taken from the 1:1 000 000 maps of Norway (Holtedal 1960) and Sweden (Sveriges geologiska undersökning 1958) locally modified in relation to more recent data. The character of some of the boundaries between rock units has been amended in accord with the conclusion that the Norweigan successions overlying the Pre-Cambrian crystalline basement and its veneer of late Pre-Cambrian sediments, are completely allochthonous. In this way the map, Plate I, differs from some previous interpretations of the area (eg. Strand 1961, Roberts et al. 1970).

New geological maps over the Swedish (Jämtland) and Norwegian (Trøndelag) parts of the Geotraverse are in preparation by Doc. A. Strömberg at the Swedish Geological Survey and State geologist F. Wolff at the Norwegian Geological Survey. These maps, at scales of 1:200 000 (Jämtland) and 1:250 000 (Trøndelag), will substantially improve the detail of Plate I.

Early studies of the Scandinavian Caledonides (e.g. Högbom 1909) referred to an "Eastern" and "Western" facies for the two different and tectonically superimposed Lower Palaeozoic successions. An extension of this practice is followed here, the rock units of the Geotraverse being treated below in three categories (Fig. 2, Table 1), the Eastern Complex, the Western Complex and the Late-Orogenic sediments.

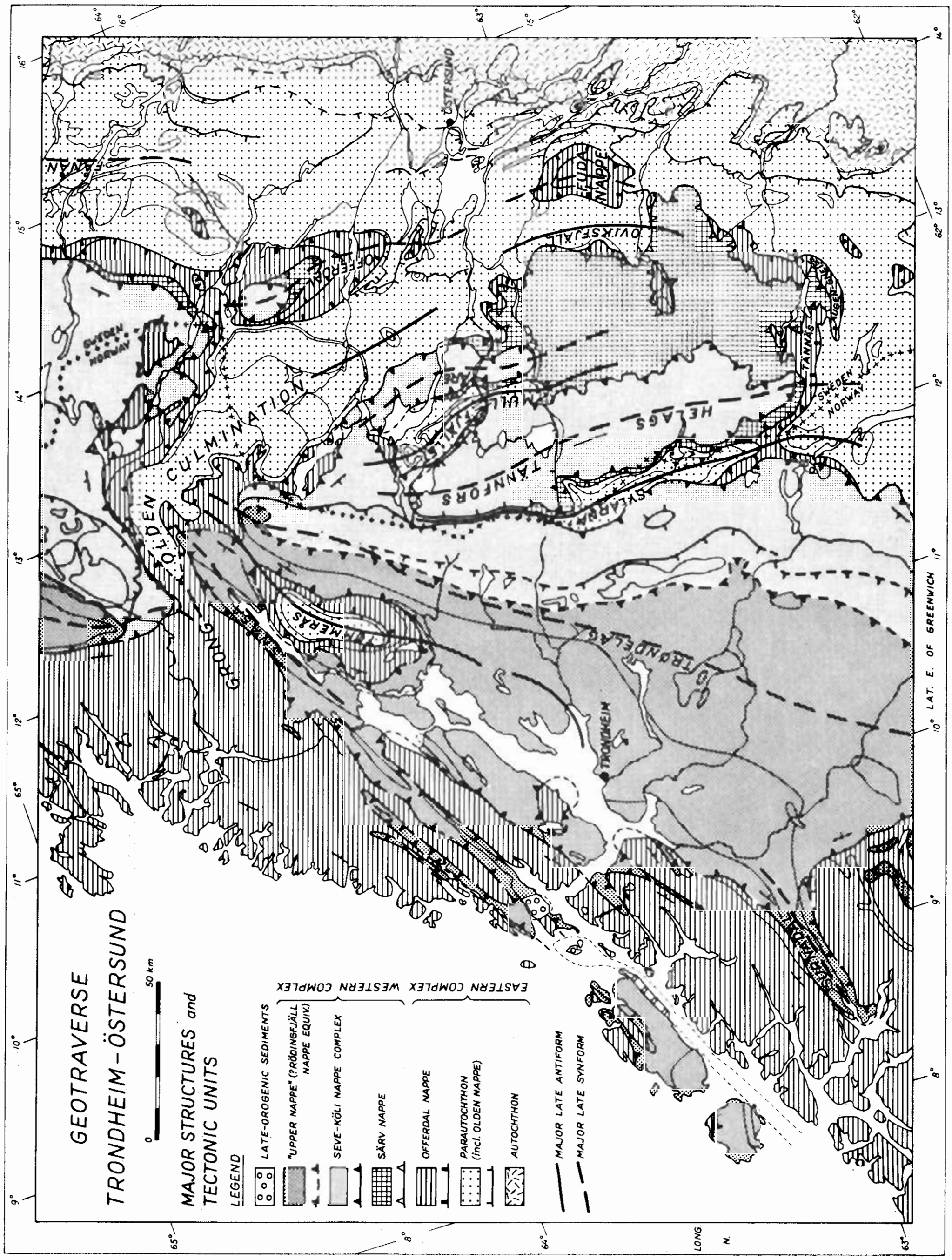
GEOTRAVERSE
TRONDHEIM–ÖSTERSUND
50 km
0
MAJOR STRUCTURES and
TECTONIC UNITS
LEGEND
LATE-OROGENIC SEDIMENTS
"UPPER NAPPE" (?RÖDINGFJÄLL NAPPE EQUIV.)
SEVE-KÖLI NAPPE COMPLEX
SÄRV NAPPE
WESTERN COMPLEX
OFFERDAL NAPPE
PARAUTOCHTHON (incl. OLDEN NAPPE)
AUTOCHTHON
EASTERN COMPLEX
MAJOR LATE ANTIFORM
MAJOR LATE SYNFORM
ÖSTERSUND
TRONDHEIM
OLDEN CULMINATION
TÄNNFORS
HELAGS
SYLARNA
TRONDELAG
GRONG
TÄNNÄS
SWEDEN
NORWAY
OFFERDAL
OVIKSFJÄLL
FUDA NAPPE
LONG.
N.
LAT. E. OF GREENWICH

TABLE 1. Summary of tectonic and stratigraphic units in the Geotraverse

TECTONIC UNITS			STRATIGRAPHY and LITHOLOGIES	
LATE-OROGENIC SEDIMENTS			HITRA FORMATION and overlying Ludlovian (?) to Middle Devonian sediments	
WESTERN COMPLEX	Low meta. grade High meta. grade	"Upper Nappe"	TRONDHEIM SUPERGROUP	Silurian (?), Ordovician, Cambrian (?) and (?) older sediments and volcanic rocks
	Low meta. grade High meta. grade	Seve-Köli Nappe Complex	KÖLI SUPERGROUP SEVE SUPERGROUP	Silurian, Ordovician and (?) older sediments and volcanic rocks
	Low meta. grade	Särv Nappe	SÄRV GROUP (locally on basement)	Late Pre-Cambrian sediments Dolerite dyke-swarm Pre-Cambrian crystalline rocks
EASTERN COMPLEX	Allochthon	Offerdal (Granite-mylonite, Alsen and Fuda) Nappes	CRYSTALLINE BASEMENT and RISBÄCK GROUP	Late Pre-Cambrian sediments and Pre-Cambrian crystalline rocks
	Parautochthon	Lower nappes of Jämtland incl. Olden Nappe	JÄMTLAND SUPERGROUP (locally on basement)	Silurian, Ordovician, Cambrian and late Pre-Cambrian sediments Pre-Cambrian crystalline rocks
	Autochthon	Stable platform	JÄMTLAND SUPERGROUP BASEMENT	Ordovician and Cambrian sediments Pre-Cambrian crystalline rocks

1. EASTERN COMPLEX

This complex is composed of Pre-Cambrian crystalline basement overlain by late Pre-Cambrian and Lower Palaeozoic sediments. The units are autochthonous in the Caledonian Front; parautochthonous and allochthonous further west. They are derived locally from the margin of the Baltoscandian Shield. Thus the nappes of the Eastern Complex differ from those of the Western Complex in that they are all thought to be rooted in the Geotraverse area. They include the Jämtland Nappes, the Vemdal and Ström Quartzite Nappes and Offerdal and Granite-mylonite Nappes of Asklund (1960) and the Lower and lower part of the Middle Thrust Nappes of Kulling *(in* Strand and Kulling 1972).

2. WESTERN COMPLEX

Overriding the Eastern Complex are a series of nappe units, referred to here as the Western Complex, whose root-zones can only be indirectly inferred. The lowermost of these nappes (the Särv Nappe) contains sediments closely comparable with the late Pre-Cambrian feldspathic sandstones of the Eastern Complex and may well have been derived from the Baltoscandian margin. Likewise this is possible for the overlying Seve-Köli Nappe Complex but is improbable for at least the highest tectonic units (the western part of the Trondheim Nappe). The Western Complex is in part composed of fossiliferous Ordovician and Silurian rocks which probably pass down into the Cambrian and late Pre-Cambrian. The name "Western Complex" is used here to emphasize *derivation* of the allochthon (it is clear from the map that the Eastern Complex extends geographically as far west as the Western Complex).

The division into Eastern and Western Complexes in part deviates from the traditional treatment of this part of the Swedish Caledonides (Törnebohm 1896 and Asklund 1938). Asklund's "Great Seve Nappe" included the allochthonous upper part of the Eastern Complex, the base being taken at the base of the Offerdal (Granite-mylonite) and equivalent nappes (see Zachrisson 1973, p. 250). These are thought to be rooted within the Geotraverse area, whereas the root-zone for the overlying units is less well defined. The base of the "Western Complex" is here taken at the base of the Särv Nappe and includes the overlying Seve-Köli Nappe Complex and the Trondheim Nappe.

3. LATE-OROGENIC SEDIMENTS

Sediments, derived from the metamorphosed Western and Eastern Complexes are preserved along the Norwegian west coast and in the area of Røragen (Fig. 3) near the Norwegian-Swedish border. These units are of uppermost Silurian and Devonian age. They lie with marked unconformity on the metamorphosed allochthon and are themselves in part folded and thrust, probably during the later stages of the Caledonian orogeny.

4. GENERAL STRUCTURE

The structure of the Geotraverse area is dominated by nappe tectonics with vast translation of allochthonous units on to the margin of the Baltic Shield. Crustal shortening is estimated to be over 500 km of which c. 30—50 % involves the upper part of the basement. Décollement-style nappes in the eastern front contain small slices of basement and further west mylonitized basement is a conspicuous component of the tectonic units. Within the Western Complex the nappe units and their internal stratigraphy thin and wedge out westwards. The entire Western and much of the Eastern Complex were gently folded about Caledonian axes at a stage when nappe translation had subsided or ceased. The orogenic sequence is of Silurian to early Devonian age with deformation progressing from west to east on to the Baltic Shield. It is consistent with a Plate Tectonic model involving steady (a few centimetres per year) Siluro-Devonian subduction during collision orogeny.

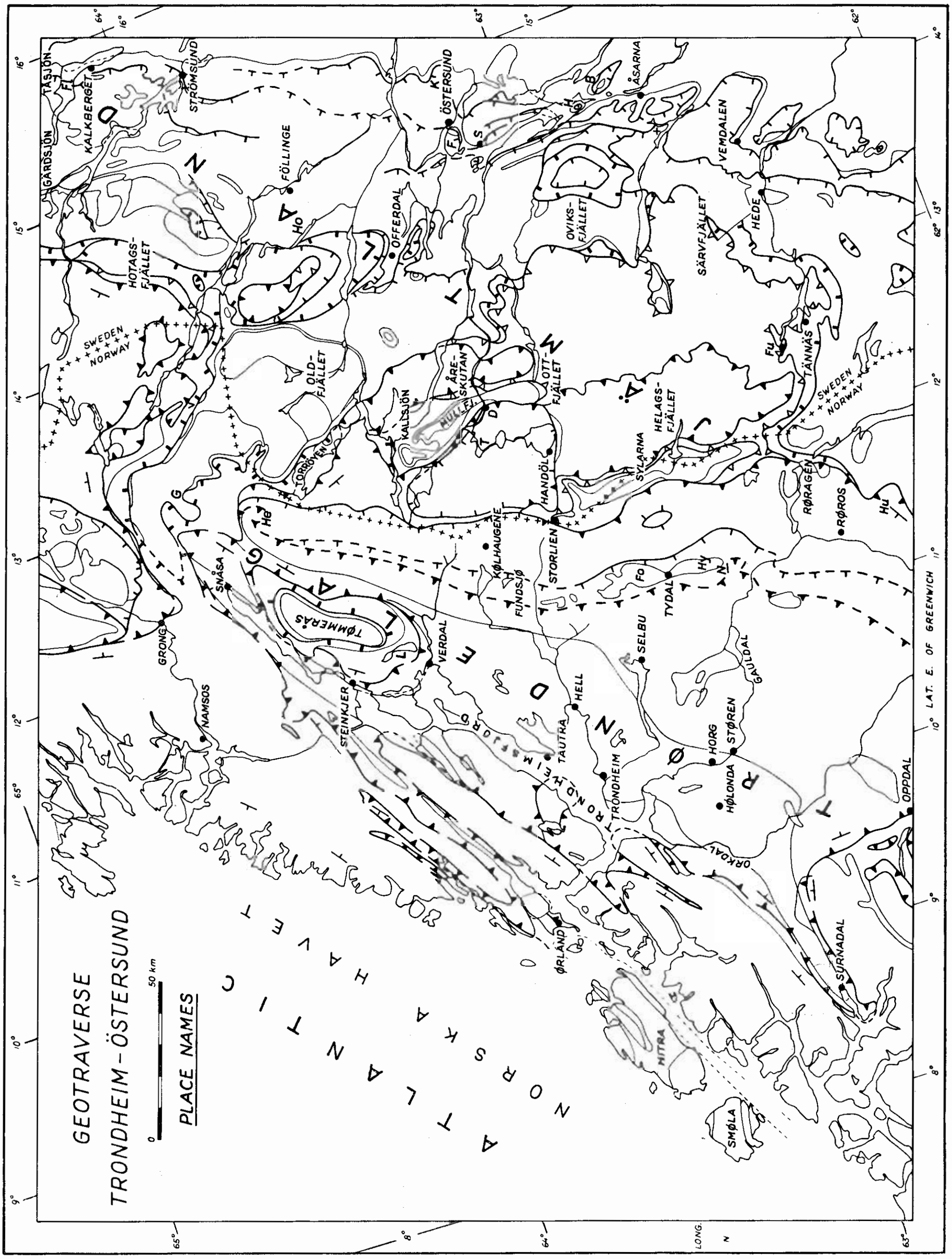

Fig. 3. Place-names referred to in the text. B = Bingsta, D = Duved, F = Frösön, Fl = Flåsjön, Fo = Fongen, Fu = Funäsdal, G = Grong, H = Hoverberget, He = Heggsjøfjell, Ho = Holmsjö, Hu = Hummelfjell, Hy = Hyllingen, K = Kyrkås, L = Leksdalsvatn, N = Nordaunevollen, S = Sunne, T = Tännfors.

EASTERN COMPLEX

The rock units composing this complex of basement crystalline rocks and late Pre-Cambrian to Lower Palaeozoic cover sediments are well preserved in the eastern part of the Geotraverse area where the various type sections have been (are being) described. The complex can be traced westwards to the Norwegian west coast where the basement is partly remobilized and the sedimentary cover is locally preserved flanking and intercalated with this basement. The Eastern Complex is extensively covered by the allochthonous Western Complex.

The Eastern Complex is treated below in four categories:

1. Pre-Cambrian crystalline basement
2. Sedimentary cover (Jämtland Supergroup)
3. Structure
4. Metamorphism

The general stratigraphic relationships between the rock units of the Eastern Complex are summarized in Fig. 4, taken, with modification, from Gee (1972a). The structure is illustrated in Plate II.

Within the Eastern Complex three tectonic divisions are referred to here, the *autochthon* of undeformed basement and Cambro-Ordovician platform sediments, the *parauthochthon* of the décollement-style cover nappes involving the entire late Pre-Cambrian and Lower Palaeozoic succession (with local evidence of basement activity), and the *allochthon* of the major nappe units involving both basement and cover (e.g. the Offerdahl Nappe) and giving evidence of translation in excess of 120 km. The category *parautochthon* here includes all those lower nappe units beneath the Offerdal Nappe (i.e. beneath the base of Asklund's "Great Seve Nappe"), independent of translation distance, the latter in general being controversial. Movement on the décollement in northern Jämtland exceeds seventy kilometres, (SGU unpublished results) and twice this distance is inferred in some of the sections of Plate II, implying that at least part of the parautochthon is transported substantially further than the term would allow in the type-Alpine context.

1. PRE-CAMBRIAN CRYSTALLINE BASEMENT

Crystalline rocks, providing the basement on which the late Pre-Cambrian and Lower Palaeozoic sequences were deposited, occur undeformed beneath the autochthonous sediments of the Caledonian Front, retrogressed and partly mylonitized in the parauthochthon and extensively mylonitized in the Offerdal Nappe (called the Granite-Syenite Nappe on the 1:1 000 000 geological map of Sweden, Sveriges geologiska undersökning 1958). Basement crystalline rocks can be traced in outcrop continuously from the parautochthon of the Olden area,

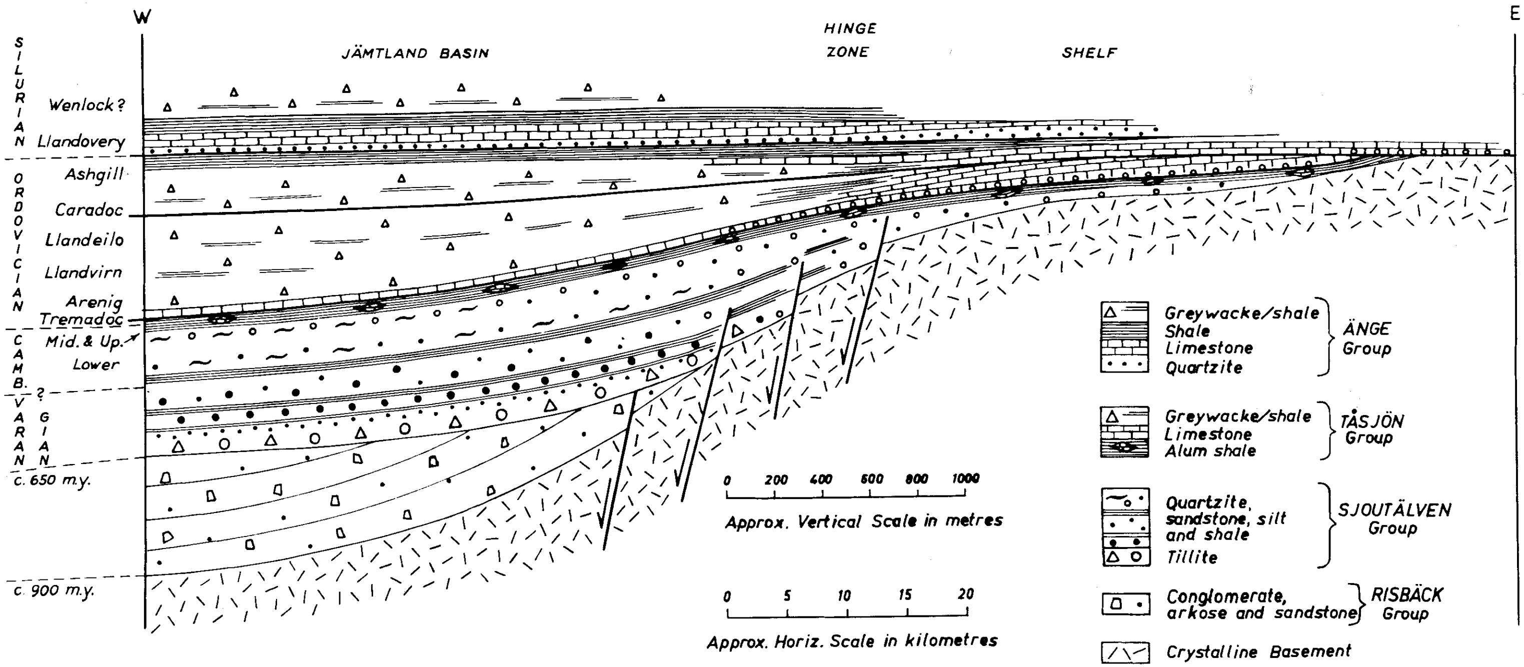

Fig. 4. General facies relationships of the Jämtland Supergroup in the Geotraverse (taken with modification from Gee 1972).

beneath the Western Complex to the Norwegian west coast where they are partly remobilized.

a. AUTOCHTHON

Much of the Caledonian Front in the northern and central parts of the Geotraverse area is underlain by "Revsund granite" a coarsely porphyritic adamellite, the distribution of which is outlined in the 1:1 000 000 geological map of Sweden (1958). This extensive granite has been dated at 1785 ± 40 m.y. (Welin et al. 1971) by the Rb/Sr whole-rock method ($\lambda = 1.39 \times 10^{-11}$ yr $^{-1}$). It is regarded as a late or post-orogenic granite in relation to the Svecofennian (Svecokarelian) orogeny. In the Geotraverse area, it intrudes metasediments which dominate the basement east of Östersund. These schists and gneisses are thought to be of Svecofennian (Welin 1970) age.

The southern part of the Geotraverse area autochthon is dominated by the Rätan granite and rhyolitic sub-Jotnian Dala porphyries (Hjelmqvist 1966). This related igneous activity has been dated by the Rb/Sr whole-rock method ($\lambda = 1.39 \times 10^{-11}$ yr^{-1}) to 1669 ± 38 m.y. (Welin and Lundqvist 1970), or 1570 ± 40 m.y. ($\lambda = 1.47 \times 10^{-11}$ yr^{-1}) (Priem et al. 1970). Priem et al. (1970) also showed that the sub-Jotnian basement was influenced by a Sveconorwegian (Dalslandian) "tectonothermal event" at c. 925 m.y. (Rb/Sr and K/Ar biotite ages).

Various basic rocks intrude the granite and metasediments. They are of post-Jotnian age, and have yielded a K/Ar isochron age of 1245 ± 20 m.y. (Welin and Lundqvist 1975).

b. PARAUTOCHTHON

West of the Caledonian Front and beneath the Offerdal Nappe, crystalline basement occurs in the cores of major antiforms (windows) and as minor slices in the décollement-style lower nappes. In the antiforms, granite dominates in the east and quartz porphyries in the west. In the décollement nappes, porphyry dominates. These acid igneous rocks are comparable with the Revsund and Rätan granites and Dala porphyries of the autochthon and have been related to them. No age-determination data is as yet available on these rocks.

c. ALLOCHTHON

The crystalline rocks of this uppermost unit of the Eastern Complex are very extensively retrogressed granites, syenites and porphyries. In the southern part of the Geotraverse area an augen gneiss dominates (interpretated by Asklund 1961, as mylonitized Pre-Cambrian porphyritic granite), associated locally with a basic complex (the Tännäs Complex) of Pre-Cambrian age and compared by Strömberg (1961) to the Jotun suite of south Norway.

In the north (the Olden area) mylonitized granites and porphyries flank the parautochthonous basement and its veneer of Cambro-Ordovician sediments, overlying the latter and separating them from the Western Complex. They can be mapped westwards into Norway where they have been identified as foliated porphyries and "gneiss-granites". The root-zone for the Offerdal Nappe has been placed north of Snåsavatn on the basis of Foslie's mapping (Oftedahl 1956). This requires that the whole of the Norwegian west coast basement should be treated as allochthonous — the western part of the Offerdahl Nappe. (An alternative solution has been proposed by Gee and Zachrisson 1974, in which the Offerdal Nappe is rootless in the Geotraverse area and the Norwegian west coast basement treated as parautochthonous.)

The basement of this part of western Norway is made up of foliated porphyries, referred to locally as leptites (e.g. in the "Tømmerås Anticline", Springer Peacey 1964) granites and gneiss-granites. These acid igneous rocks are intruded by dolerite dykes which apparently do not penetrate the overlying metasediments (Springer Peacey 1964), and are therefore thought to pre-date Caledonian deformation. The basic rocks are metamorphosed in lower amphibolite facies (Springer Peacey 1964) in the Tømmerås Antiform and upper amphibolite facies further west (Ramberg 1944). Whereas the dykes are never developed as a swarm (cf. the Särv Nappe) they are reported to be numerous in Tømmerås and west of the Snåsa Synform and are apparently absent to the east.

2. SEDIMENTARY COVER (JÄMTLAND SUPERGROUP)

These sediments are treated in four groups referred to here as the Jämtland Supergroup. They range in age from post-Dalslandian (c.900 m.y.) to Llandoverian. The lower two groups are of terrestrial to shallow marine origin and include a tillite. The upper groups are marine, with a general pattern of shallow water facies in the east and deeper in the west.

Type sections in the lower three groups of the Jämtland Supergroup have been described (Gee et al. 1974) from the northernmost parts of Jämtland's parautochthon and this formal nomenclature is applied here generally to the Geotraverse area. The uppermost group has a type area in central Jämtland and has been referred to as the Änge Group by Strömberg (1974). The group relationships are summarized in Table 2.

In Sweden the lowermost group has previously been referred to as "Sparagmites". In Norway this term has included both the lower groups. Because of this ambiguity and for reasons outlined by Bjørlykke et al. (1968) and Gee (1972a), the term sparagmite is not used here.

TABLE 2. Summary of Jämtland Supergroup stratigraphy

GROUP	FORMATION	LITHOLOGY	AGE	
ÄNGE	EKEBERG	Greywacke and shale	Llandoverian	Silurian
	BÅNGÅSEN	Shale		
	BERGE	Limestone		
	EDE	Quartzite		
TÅSJÖN	NORRÅKER	Greywacke and shale	Tremadocian to Ashgillian	Ordovician
	FJÄLLBRÄNNA	Black shale & bituminous limestone	Middle Cambrian to Tremadocian	
SJOUTÄLVEN	GÄRDSJÖN	Quartzite and shale	Varangian to Middle Cambrian	Cambrian
	DABBSJÖN	Tillite and shale with outsized clasts	Varangian	
RISBÄCK	KALVBERGET	Dolomite	pre-Varangian	Pre-Cambrian
	MÅNGMANBERGET	Feldspathic sandstone		
	TVÄRSELET	Siltstone and fine sandstone		
	STORA RAIJAN	Feldspathic sandstone		
CRYSTALLINE BASEMENT			c: 1800-1000 m.y.	

a. RISBÄCK GROUP

Kulling (*in* Strand and Kulling 1972) gave the name Risbäck Group to the sedimentary sequence underlying the tillite formation of northern Jämtland and southern Västerbotten. The type area lies some fifty kilometres north of the Geotraverse. Similar sediments are known from the parautochthon elsewhere in the northern and southern parts of the Geotraverse and are broadly correlatable with the pre-tillitic sequences of the classical Mjøsa "sparagmite" area of southern Norway (Skjeseth 1963, Bjørlykke 1974). Both in the south (Stålhös 1956, Asklund 1960) and north (Asklund and Thorslund 1935, Gee 1972a) of the Geotraverse area, the Risbäck Group has been described as being deposited directly on "horst" basement of the major antiforms. New evidence on the décollement of northern Jämtland has cast doubt on this relationship at least in the north.

In Norway, sediments thought to be correlatable with the Risbäck Group have been referred to by Springer Peacey (1964) as the Leksdalsvann Group in the Tømmerås area and appear in the Tingvoll Group further south (Hernes

1956). The sediments have been described and their correlation discussed by Springer Peacey (1967).

Within the Offerdal Nappe, unfossiliferous feldspathic sandstones occur which show similarities with the Risbäck Group.

(i) Within the parautochthon

Northern part of Geotraverse

The Risbäck Group in the type area (Gee et al. 1974) and to the south in northern Jämtland occurs in four main outcrop areas, two of which are shown on Plate I. Important facies variations exist between these four areas and their correlation is at present under investigation. Whereas in the Risbäck area the sediments are dominated by feldspathic sandstones and reach a thickness of c. 600 m, in the north of the Geotraverse the facies is conglomeratic and arkosic and a smaller thickness is preserved. Previous interpretation of the depositional environment of these sediments as NW—SE orientated basins (Asklund 1960) is in doubt. A progressive change from coarse terrigenous sediments in the south to arkoses, feldspathic sandstones and mixed sandstone-siltstones of possible shallow marine origin in the north may reflect a connected depositional basin, subsequently disrupted by Caledonian faulting (Kumpulainen, pers. comm.).

Southern part of Geotraverse

Sediments correlated with the Risbäck Group extend over large areas of Härjedalen in the southern part of the Geotraverse. Strömberg (1955) and Asklund (1958) presented a general description of the sequence. Stålhös (1956) gave a more detailed account of the type area around Hede and subsequently (1958) compared the clastic sediments with similar lithologies in the Risbäck Group elsewhere.

Stålhös (1956) recorded a succession, some 350 m thick from the Hede area, including a basal shale, greywacke, conglomerate formation (the Hockla formation), a limestone (the Hede limestone formation) and overlying grey and red "sparagmites". The Hede formation locally is also conglomeratic (a "boulder clay" facies) as are the "sparagmites" and these rock units are recorded to rest on the basement. Stålhös postulated a restricted basin in which the lowermost units were overlapped by successively higher units, as illustrated in Asklund (1958). Within this succession feldspathic sandstones, arkoses and conglomerates dominate and it is these, probably fluviatile sediments, that occupy much of the parautochthon of the southern part of the Geotraverse.

(ii) Within the allochthon

The Offerdal Nappe and associated tectonic units, the Granite-mylonite, Alsen and Fuda Nappes, contain cross-bedded feldspathic sandstones and arkoses comparable with the Risbäck Group and thought to represent a western development of these late Pre-Cambrian sediments. Nowhere within the Offerdal and associated nappes have primary relationships been recorded between the sediments and the basement rocks, the contact zones being characterized by development of a very penetrative foliation and feldspar porphyroblastasis. Nevertheless it is probable that these sediments were deposited on the basement, their subsequent translation over 120 km eastwards having obscured the primary relationships.

In Norway, sedimentary sequences (the Leksdalvann Group) overlying the crystalline basement contain "impure feldspathic sandstones and dark sandy siltstones" (Springer Peacey 1964, p. 38) with "abundant depositional features e.g. cross-bedding and grading". These sediments she compared with similar units elsewhere in western Trøndelag (Springer Peacey 1967). In the Oppdal area, comparable "Eocambrian flagstones" rest with a basal conglomerate on the Pre-Cambrian crystalline rocks (Strand, *in* Strand and Kulling 1972). Whereas in the Tømmerås area the Leksdalvann Group is clearly allochthonous, in Oppdal they may be parautochthonous.

b. SJOUTÄLVEN GROUP

Throughout Jämtland, a unit dominated by orthoquartzite rests on the crystalline basement or Risbäck Group sediments. Where these quartzites occur in the Caledonian Front nappes they have been referred to as the Vemdal (in the south) and Ström (in the north) quartzites.

The autochthonous quartzites thin out eastwards, being overlapped by the overlying Tåsjön Group. In northern Jämtland they thicken westwards, are intercalated with shales, siltstones and fine sandstones and are underlain by a diamictite, interpretated as a tillite of Varangian age. The type area for this group of latest Pre-Cambrian and Cambrian shallow water sediments is located about ten kilometres north of the Geotraverse area in the Sjoutälven river-section (Gee et al. 1974). The youngest units of the group in the northern part of the Geotraverse have yielded lower Middle Cambrian trilobites (Thorslund, *in* Asklund and Thorslund 1935).

In the Sjoutälven profile (Asklund and Thorslund 1935, Asklund 1960, Gee 1972a) Risbäck Group arkoses are overlain by diamictites and laminated siltstones with outsize pebbles and boulders referred to as the Dabbsjön Formation (Gee et al. 1974). This unit was previously called the Långmarkberg Series or Group by Kulling (1942, 1960 and *in* Strand and Kulling 1972). They have been interpreted as tillites (Asklund and Thorslund 1935, Kulling 1942) and correlated with the Varangian glaciation (Kulling 1942). They are overlain by quartzite pebble conglomerates passing upwards into quartzites. These form the basal member of the Gärdsjön Formation, a lateral equivalent of the Ström and Vemdal Quartzite Formations, containing prominent white quartzite members and including an important red and green shale member. The uppermost part is generally developed as a phosphorite-bearing conglomerate and green siltstone. Sjoutälven Group sedimentology, stratigraphy and correlation are being investigated by T. Thelander, whose work provided the main basis for description of the new type-section (Gee et al. 1974).

In the central part of the Geotraverse area the Sjoutälven Group is thinner and the Dabbsjön Formation and shale members of the Gärdsjön Formation are thin or absent. In general, the Gärdsjön Formation is a few tens of metres thick resting directly on crystalline basement. In the south, in Härjedalen, the Varangian tillite unit has also been recorded (Strömberg, pers. comm.).

The Sjoutälven Group is restricted to the parautochthon and a very thin development in the autochthon. It can be traced westwards flanking the Grong-Olden basement culmination as far as the eastern limb of the Snåsa Synform underlying the Offerdal Nappe. Recently it has been suggested (Gee 1974) that it also occurs in the core of the Tömmerås Antiforms as part of Springer Peacey's (1964) Bjørntjern Formation. In these Norwegian areas the unit is a rather monotonous quartzite, white or blue-grey in colour (often yellow weathering) with a basal quartzite conglomerate at least locally developed; shale members and a basal tillite formation have not been recorded.

The feldspathic sandstones and arkoses occurring in the overlying Eastern Complex allochthon have been described above (p. 18) along with the Risbäck Group on the basis of lithological similarity. They may represent a lateral equivalent of the Sjoutälven Group, but this interpretation is not favoured here in view of the lateral persistance of the quartzite facies in northern Trøndelag.

c. TÅSJÖN GROUP

The Lower Palaeozoic stratigraphy of Jämtland has been reviewed by Thorslund (1960) and only the main aspects are treated here. A black alum shale facies with fossiliferous stinkstone lenses of Middle and Upper Cambrian and locally of Tremadocian age overlies the Sjoutälven Group throughout the Geotraverse area. It is probably the most widespread lithostratigraphic unit in Scandinavia, being recognizable from Digermulhalvøya in the north (upper part of the Kistedal Formation of Reading 1965) to Skåne and Oslo in the south. It is clearly indicative of a remarkably long period of crustal stability over a vast area of the Baltoscandian Platform. In the northern part of the Geotraverse it is referred to as the Fjällbränna Formation (Gee et al. 1974).

The Fjällbränna Formation, in the order of some fifty metres thick, is developed in both the parautochthon, as in the type section, and the autochthon where it is thinner. The formation is locally overlapped by the Ordovician carbonate facies of the easternmost autochthon in the area east of Östersund. In the western parautochthon of the Olden area, the formation has not yielded fossils and is only a few metres thick. Deformation and recrystallization in this area beneath the Offerdal Nappe makes primary thickness estimates uncertain but the unit has been mapped westwards into Norway and may occur in the Tømmerås Antiform (Gee 1974).

Ordovician stratigraphy above the Cambrian/Tremadocian black shale facies is very variable. In the autochthon, shelf limestones, with subordinate shales, dominate a thickness of c. 150 m. This is also the case over much of the parautochthon, although the thickness is substantially less and recrystallization makes interpretation of the limestone facies difficult.

This basal limestone unit referred to as the Kalkberget Formation (Gee et al. 1974) in northern Jämtland and elsewhere as the "orthoceratite limestone" (e.g. Thorslund 1960) has been traced along the Grong-Olden Culmination to the eastern limb of the Snåsa Synform and is thought to be present in the Tømmerås Antiform. Whereas this limestone facies spans the Lower, Middle and lowermost Upper Ordovician (Thorslund 1960) of the autochthon its uppermost part is older further west and largely confined to the Lower Ordovician. Lateral transition from limestone to shale and greywacke, as illustrated in Fig. 4, dominates the facies pattern.

In the northern part of the Geotraverse in the Tåsjö area, a sandy calcareous phosphoritic, glauconitic facies a few metres thick overlies the Fjällbränna Formation and passes upwards directly into shales and greywackes. Together, these clastic units have been called the Norråker Formation by Gee et al. (1974). In the Tåsjö area they are at least 200 m thick and further south, where they have been described as greywackes of Föllinge-Holmsjö facies (Frödin 1922), the thickness probably reaches c. 500 m. These clastic units were deposited contemporaneously with the autochthonous shelf limestones and the facies juxtaposition implies active basement downwarping during the Ordovician. They are thought to have been derived from westerly land masses (Asklund 1960).

A dark shale facies of Ashgillian and/or Upper Caradocian age at the top of the parautochthonous greywackes (and the autochthonous carbonates) indicates a return to relatively stable conditions prior to deposition of the overlying Änge Group.

d. ÄNGE GROUP

A shallow water sandstone facies overlies the Tåsjön Group. It makes up the basal part of the Änge Group, (name proposed by A. Strömberg 1974) to include the entire sedimentary sequence above the greywacke and shale formation of the parautochthon. The type area, near Offerdal, is in central Jämtland where

Thorslund (1948 and 1960) described four formations, the basal Ede Quartzite Formation, the Berge Limestone Formation, the Bångåsen Shale Formation and the uppermost Ekeberg Greywacke Formation.

The thin (a few metres) lowermost formation is unfossiliferous and rests with sharp contact on the underlying upper Ordovician shales. It passes transitionally upwards into the Llandoverian Berge limestone (some c. 75 m thick) which is likewise transitional into the Bångåsen shales (c. 20 m) and thence into the Ekeberg greywackes (a few tens of metres thick), all of Llandoverian age. A Wenlockian age for the upper part of the Ekeberg Formation is possible (Thorslund 1960).

The Ange Group has not been recognized west of the Mullfjället Antiform. Towards the east in the Östersund area a sandstone and mudstone unit, the Kyrkås quartzite of Thorslund (1943), spans the Ordovician-Silurian boundary (Thorslund 1960) and, locally, passes upwards into the highest stratigraphical units in the eastern parautochthon — the Berge reef limestone of Llandoverian age.

3. STRUCTURE

The structure of the Eastern Complex is dominated by major thrusting, followed by large scale open folding. The allochthon of crystalline basement and late Pre-Cambrian sediments, translated eastwards a minimum of 120 kilometres from at least as far west as the Snåsa Synform, overrides a series of subordinate thrusts grouped here within the parautochthon. These subordinate nappes have a general geometry (Plate II) comparable with the classical décollement terrains of the Jura, the Appalachians and the Rockies. However, they apparently differ from these classical examples by containing isolated slices of crystalline basement.

Caledonian Front structure is best known from work by the Boliden Company and the Swedish Geological Survey (SGU) some twenty kilometres north of the Geotraverse area (Du Rietz 1960, Gee 1972a). In this area, mapping and drilling for lead (by Boliden AB) and uranium (SGU) in the parautochthon has yielded evidence of autochthonous stratigraphy thirty kilometres west of the outcropping sequences in the Caledonian Front and proved a passive basement and a décollement-style for at least forty kilometres west of the front. This is illustrated in profile A-B of Plate II. Cover shortening amounts to over 70 kilometres.

This evidence of nappe geometry differs fundamentally from that of Asklund (1938 and 1960) as shown on the 1:1 000 000 geological map of Sweden, where all the major areas of Ström and Vemdal quartzite in the Caledonian Front are presented as klippes. It likewise rejects a rooting of the lower nappes as proposed by Gee (1972a). And it is in agreement with Asklund's opinion that the nappe tectonics essentially pre-dates the development of the major antiforms (Asklund's "horsts") and synforms (e.g. the Offerdal Synform).

The presence of thin "slices" of basement in the base of these décollement-style nappes is known from Tåsjöberget and a variety of localities in the Geotraverse area including Flåsjön, Frösön, Sunne, Hoverberget and Bingsta. Granite or porhyry units some tens of metres thick and hundreds of metres to a few kilometres in other dimensions underlie the basal quartzites of the nappes. In some localities, as at Tåsjöberget, it can be shown that the fragment of crystalline basement "floats" above the décollement, completely detached from the underlying passive basement. An apparently similar basement "slice" occurs in Laisvall, further north (Lilljeqvist 1973). Other examples in the Geotraverse area are less obviously unrooted and those in the Östersund area (e.g. as recorded by Thorslund 1943) are interpreted here in accord with the Tåsjö data. The root-zone for the décollement remains conjectural; it may be cut out beneath the overlying allochthon as suggested in section A-B or root in basement beneath the latter. Asklund (1961) claimed the Olden massif to be thrust (the Olden Nappe), a concept receiving some support from the penetrative deformation of parts of this basement and the considerable elongation of agglomerate fragments in the Pre-Cambrian volcanic rocks. This hypothesis of the Olden Nappe would require the basal thrust to pass eastwards into the décollement of the eastern front, a solution shown in sections C-D and E-F of Plate II.

In the southernmost part of the Geotraverse, the pre-Varangian sediments are described (Stålhös 1956) as resting undisturbed on the granitic basement. East of this basement high the Vemdal quartzites of the lower nappe were thought by Asklund to occur as klippes, thrust over the basement or Risbäck Group sediments. Other authors (Strömberg 1955 and Stålhös 1956) have preferred to root the frontal nappes below this basement high as shown in Section I-J. Asklund's interpretation required a translation distance of over eighty kilometres for these lower nappes.

In the section (G-H) the evidence from the 1:1 000 000 geological map of Sweden (1958) that the Risbäck Group sediments are at least partly thrust has been taken to allow the alternative hypothesis to that shown in section I-J, i.e. the thrust below the lower nappes is drawn to ride over the basement antiform and its veneer of Sjoutälven Group sediments.

In the eastern part of the parautochthon, well below the Offerdal and associated nappes, movement is taken up on the different shale horizons, particularly the graphitic alum shales of the Nybränna Formation and the sediments are in general not extensively recrystallized, containing well-preserved faunas. Crushing and mylonitization beneath the more important thrust slices are usually conspicuous in the basal few metres of the quartzites or basement of the lower nappes but are otherwise very subordinate. Cleavage is developed in incompetent units of the central parautochthon, axial-planar to parasitic folds related to the major folds accompanying the décollement translation and also, at least locally, to the folding of this décollement. In the vicinity of the Offerdal Nappe, the underlying units contain a well-developed fine-grained schistosity and evidence of repeated folding and flattening. In general, the penetrative secondary foliation in the parautochthon parallels the foliation in the overlying nappe. Where juxtaposition of competent units occurs e.g. along the eastern front of the Offerdal Nappe where it rides over Llandoverian limestones, mylonitization is extensive over several metres. In contacts further west between e.g. greywacke-shales and the fine feldspathic sandstones of the allochthon, the contact, superfically at least, may appear transitional, with development of phyllonites.

The penetrative secondary foliation in the Offerdal and associated nappes and immediately underlying sediments is increasingly well developed towards the west. Foliation in the igneous basement rocks parallels that in the sediments and has lead some authors (e.g. Oftedahl 1964, Springer Peacey 1964) to treat the foliation as a primary pre-Caledonian phenomenon. Mapping of this structure from Sweden into Norway suggests that it is an essentially Caledonian phenomenon related to the nappe translation.

As mentioned earlier (p. 15), the intensively foliated Offerdal Nappe can be traced on the basis of Foslie's mapping (Oftedahl 1956) along both the north and south sides of the Grong-Olden Culmination as far as the Snåsa Synform. In this area it is either rooted as suggested by Oftedahl (1956, 1966) or wedges out against the overlying allochthon (Gee and Zachrisson 1974). The former alternative is accepted in this presentation but the problem needs reinvestigation.

West of the Tømmerås Antiform the basement is folded in major more or less upright antiforms and synforms of tighter style than to the east. These major folds have been shown (Ramberg 1973) to fold earlier, isoclinal repetitions of metasediment and granite. The major antiforms and synforms are generally cylindrical, varying a little in the amount and direction of plunge. They represent the northern continuation of the main basement domes of the Norwegian coast south of Trondheimsfjorden.

4. METAMORPHISM

In the autochthon, the units appear to be little metamorphosed. In the eastern parautochthon, recrystallization is apparently in sub-greenschist facies. Within the fine-grained schistosity of the parautochthon directly beneath the allochthon and within the latter, muscovite and chlorite crystallize. In the same lithologies and structural positions further west (in the border-zone between Norway and Sweden) fine-grained biotite is present and in the eastern limb of the Snåsa Synform very small, spessartine-rich garnets (Gee 1974) appear in these low-grade phyllites. In the Swedish parautochthon it is very probable that the thermal energy required for this metamorphism was obtained from the overriding Western Complex. Inverted isograds have not as yet been described but it is improbable that the basement beneath the décollement was the heat source for this metamorphism. Investigation of lower greenschist facies and sub-greenschist facies metamorphism of the parautochthon is in progress.

In western Norway the relationships are less clear. The metamorphism of the parautochthonous phyllites mentioned above may very well still be related to the overlying Western Complex. Springer Peacey (1964) suggested that the metamorphism in the vicinity of the Tømmerås Antiform increased downwards into the core of the structure but she emphasized the lack of a rigorous investigation, and this view is doubted (Gee 1974).

Areas west of the Snåsa Synform exhibit greater mobility (Ramberg 1944) and it has been concluded from the metamorphism of basic rocks that Caledonian metamorphism of the Eastern Complex reached (upper) amphibolite facies with partial remobilization of the acid igneous rocks. Ramberg inferred that metamorphic zoning is normal in the extreme west. Thus in these areas relationships prior to this metamorphism are obscured by regional recrystallization.

WESTERN COMPLEX

The Western Complex, overlying the Eastern Complex allochthon and parautochthon, is a composite nappe unit, metamorphosed in greenschist to upper amphibolite (with eclogite) facies. It is rootless in the Geotraverse area and composed of at least three major tectonic units, the Särv Nappe (Strömberg 1955), the Seve-Köli Nappe Complex (Zachrisson 1969) and an "Upper Nappe" (Gee and Zachrisson 1974). The "Upper Nappe" was previously regarded as forming a part of the Trondheim Nappe (Kulling 1961, Wolff 1967), the latter being considered an essential part of the Seve-Köli Nappe Complex (Roberts et al. 1970). The "Upper Nappe" is regarded as a possible equivalent of the Rödingsfjäll Nappe (Kulling, *in* Gavelin and Kulling 1955), occurring above the Seve-Köli Nappe Complex in areas north of the Geotraverse.

Whereas the allochthonous nature of the Särv and Seve-Köli Nappe Complex in relation to the Eastern Complex is unambiguous in Sweden and in the northern part of eastern Trøndelag, in western Trøndelag, Seve units have been claimed (Springer Peacey 1964, Roberts et al. 1970) to be autochthonous on a thrust basement of the Offerdal Nappe. This relationship is rejected here for the reasons discussed on page 36.

The Western Complex is treated below in three parts:

1. Särv Nappe
2. Seve-Köli Nappe Complex in Sweden
3. Seve-Köli Nappe Complex and higher tectonic units in Norway

1. SÄRV NAPPE

The Särv Nappe (Strömberg 1955, 1961) is a wedge-shaped tectonic unit, confined almost entirely to Swedish territory and most extensively developed in the southern and central part of the Geotraverse area. It has been correlated (Asklund 1961, Strömberg 1961) with the Kvitvola Nappe (Törnebohm 1896) further south in Norway. It rests on a variety of Eastern Complex units with marked discontinuity and a well-developed mylonite zone. The nappe is essentially composed of a sequence of non-fossiliferous arkoses and feldspathic quartzites intruded by an olivine-bearing tholeiitic dyke swarm (Strömberg 1969). Comparable basic dyke rocks have not been reported from the underlying Eastern Complex east of the Tømmerås Antiform and even west of this antiform they are not developed as a swarm.

The majority of the sediments of the Särv Nappe, referred to as the Särv Group (Strömberg 1969), are typical of the late Pre-Cambrian pre-Varangian units of the Eastern Complex. Nevertheless the possibility of an older (Asklund 1961) or younger age cannot be rejected. Strömberg (1961) defined a lower "quartzite series" composed dominantly of quartzites, arkoses and local conglomerates overlain by a "greywacke series" of impure sandstones, greywackes and siltstones. Locally a "quartzite series" was recorded overlying the greywackes but tectonic superposition was inferred. Dolomites and limestones appear near the base of the Särv Nappe particularly in the southern part of its outcrop. The thickness of the nappe is conjectural. Strömberg (1961) described a section through the (lower) quartzite series of c. 300 m but mentioned no thickness of the greywacke series. His sections allow a total thickness in the order of 500 m.

It is possible that the crystalline basement of the Särv sequence is exposed in the vicinity of Tännäs. Here, a breccia passing upwards into arkoses and quartzites has been described overlying an amphibolitic/anorthositic unit, the Tännäs Complex at the base of the Särv Nappe (Strömberg 1961). Strömberg drew attention to a possible comparison between these crystalline rocks and the Jotun basement of southern Norway (Gjelsvik 1947, Strand 1951).

The olivine dolerite dykes (Fig. 5) are developed throughout most of the nappe and vary in thickness up to c. 100 m. They are referred to as the Ottfjället dolerites. In areas of good exposure it has been possible to estimate the proportion of dyke-rock to sediment and in some areas the intrusive units clearly predominate. Strömberg (1969) estimated the regional extension implicit in the presence of the intrusions to be at least 30 km. Where least deformed, the dykes are orientated perpendicular to bedding in the arkoses. The latter are in part very well preserved with an abundance of way-up structures, mainly cross-bedding, and little evidence of pre-dyke deformation. Strömberg (1961, p. 86) claimed some pre-dyke folding but the evidence is ambiguous; he concluded that intrusion clearly preceded thrusting.

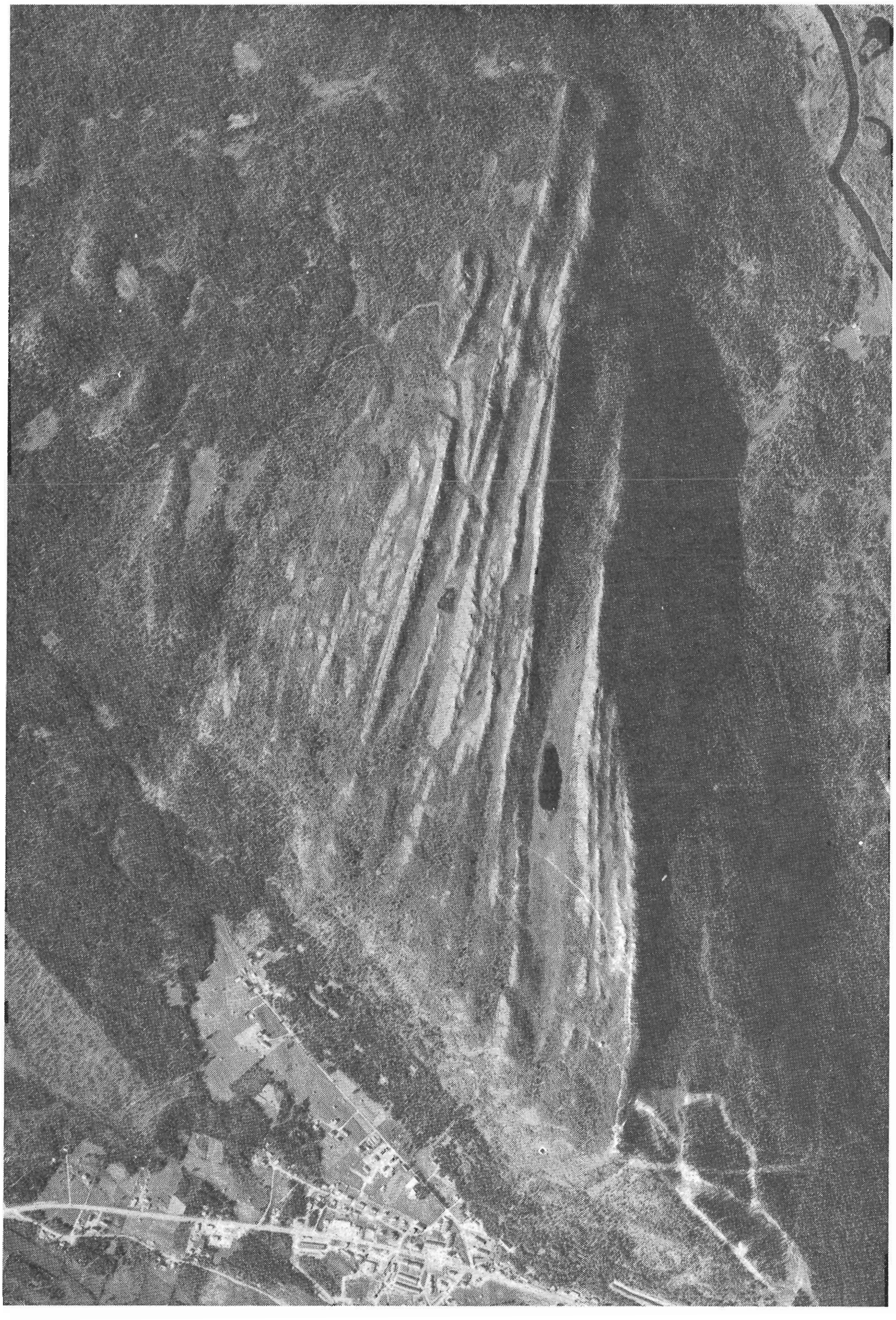

Fig. 5. Funäsdalsberget. Vertical air-photograph of the Ottfjället dyke swarm of the Särv Nappe. (Published by permission of Rikets Allmänna Kartverk 1974-01-17.)

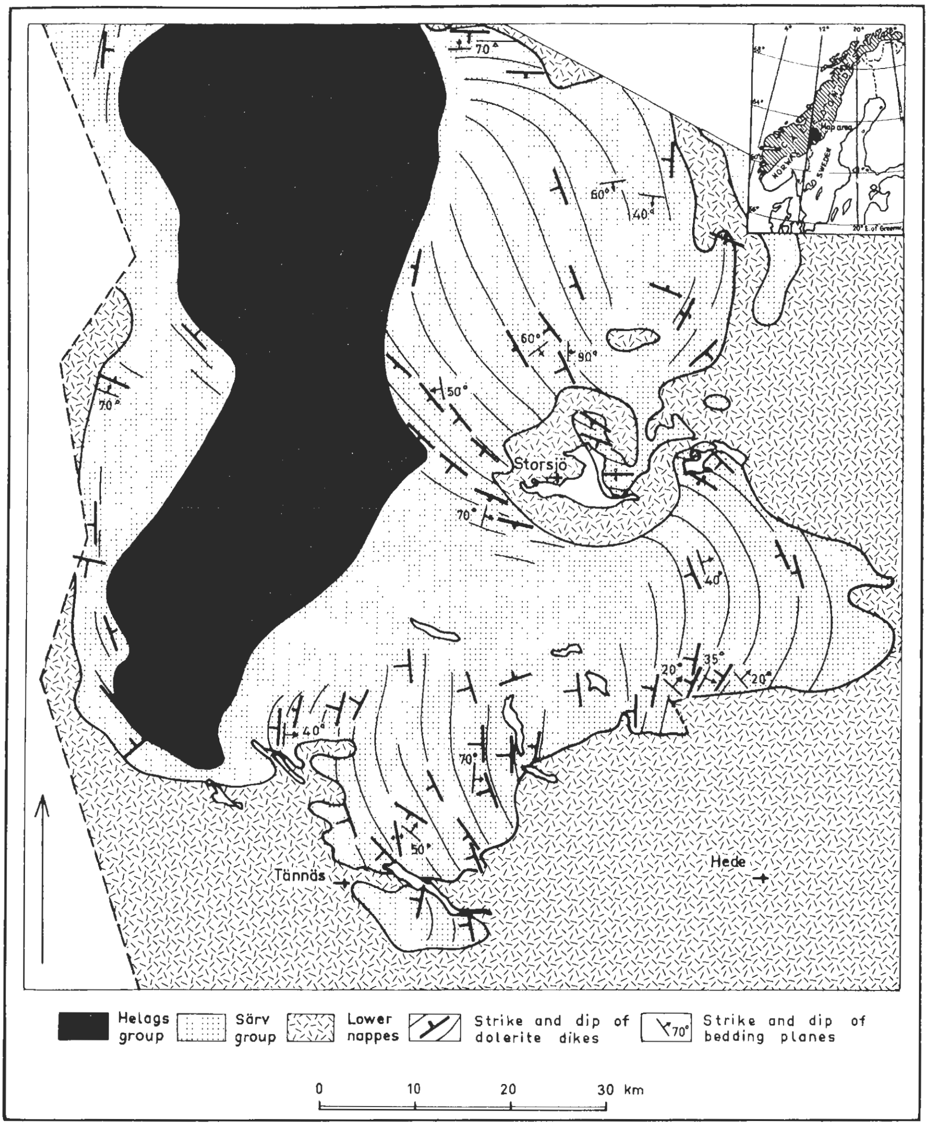

Fig. 6. Orientation of the Ottfjället dolerite dyke swarm in the Särv Nappe of southern Jämtland (taken, with minor modification, from Strömberg 1961).

The general orientation of the dyke swarm is seen in Fig. 6 (from Strömberg 1961). The intrusions generally dip westwards or south-westwards. At the base of the nappe, sills have been described (Strömberg 1961, 1969). Deformation within the nappe is usually manifest as zones of intense foliation with obliteration of sedimentary structures and retrogression of the dolerites to fine-grained foliated amphibolites and chloritic phyllonites. The latter are particularly conspicuous at the base of the nappe where WNW to NW-lineated mylonites and blastomylonites separate it from the underlying Eastern Complex. It is clear that the translation of the Särv Nappe occurred at least in part under greenschist to lower amphibolite facies conditions. In view of the underlying Eastern Complex décollement and the high metamorphic grade of the overlying Seve of the Seve-Köli Nappe Complex, it is probable that the heat source for this metamorphism was located above the nappe. No data is as yet available on variation of metamorphic grade within the Särv Nappe.

2. SEVE-KÖLI NAPPE COMPLEX IN SWEDEN

The Seve-Köli Nappe Complex is composed of two major lithological units, the Seve and the Köli, treated here as supergroups. These terms were introduced by Törnebohm (1872) to refer to rock units separable on the basis of both lithology and metamorphism. Current usage has tended to emphasize the latter; in general the Köli are low-grade (up to lower amphibolite facies) rocks whilst the Seve are of higher grade (lower and upper amphibolite, locally with eclogite, facies). The terms are retained here on a general lithostratigraphic basis, pending description of local stratigraphic sequences and their correlation. The Köli Supergroup is at least partly of Lower Palaeozoic age containing Ordovician and Silurian fossils. The unfossiliferous Seve may be of the same age but is probably older.

The Seve Supergroup occupies the lower part of the nappe complex, resting on the Särv and other allochthonous and parautochthonous units and separated from them by an extensive zone of mylonitization. Like the Särv nappe, the Seve (Zachrisson 1973) and possibly the Köli, wedges out westwards, the Seve being largely confined to Swedish territory. Within the nappe complex, metamorphic grade increases upwards from a basal zone of extensive retrogression, through amphibolites, to a central part of pyroxene amphibolites and, locally, eclogites. Above this zone there is a general decrease in grade into the Köli greenschist facies units. Although this decrease is apparently gradational in extensive areas north of the Geotraverse area (Stephens, in press), in others (Trouw 1973) and in the Geotraverse area itself the fall in metamorphic grade upwards is interrupted, isograds are cut out and marked tectonic discontinuities occur. The regional significance of this discontinuity between the Köli and Seve is conjectural. It is clear however, that the Köli and the Seve were metamorphosed together prior to dislocation of the sequence.

The thrusting of the Seve-Köli Nappe Complex is largely a post-metamorphic phenomenon, rock units and isograds being truncated. The complex was metamorphosed prior to translation. Nevertheless the nappe complex was probably a heat-source even after the main translation was accomplished, the underlying nappes being in greenschist facies and showing probable isograd inversion

(p. 23). Trouw (1973), on the basis of the presence of blastomylonite zones stable to hornblende within the Seve, has argued for translation of the complex during the waning stages of metamorphism.

a. SEVE SUPERGROUP

The Seve is a complex rock unit. Variation in metamorphic grade from lower amphibolite facies to upper amphibolite, pyroxene amphibolite and locally eclogite facies, taken along with the presence of extensive internal blastomylonite zones, have prevented the establishment of a coherent stratigraphy. The wedging-out of the unit westwards further complicates the picture, the westerly Seve being extensively retrogressed.

Åreskutan, in the centre of the Geotraverse, has traditionally been the type locality for the Seve (Törnebohm 1872, 1888 and 1896, Högbom 1894). The area has been described by Helfrich (1967) and S. Yngström (unpublished Fil. lic. 1969, Stockholm Univ.). Helfrich recognized three separate tectonic units above the Särv Nappe — the "Amphibolite schist nappe", the "Fröå-Bjelke nappe" and the "Åre nappe", the latter being the highest unit. The Åre nappe contains kyanite-bearing aluminous metasediments, potash feldspar gneisses and pyroxene-garnet amphibolites; it is in part migmatitic. The underlying Fröå-Bjelke nappe, itself considered to be a composite tectonic unit with a repeated stratigraphy of quartzite-gneiss, marbles and serpentinitized peridotite, is also kyanite-bearing. The Amphibolite schist nappe contains garnet, mica and quartz schists and amphibolites. Metamorphic grade decreases downwards through these Seve nappes in Åreskutan; the basal part is extremely retrogessed but apparently crystallized in lower amphibolite facies prior to this retrogression.

At Åreskutan, the Seve is c. 1 500 m thick. It thins in the western limb of the Mullfjället Antiform and some fifty kilometres to the west (Storlien) the unit is reduced to a few tens of metres of mylonitized amphibolites. In the southern part of the Geotraverse, in the Helags area, the thickness probably exceeds that in Åreskutan. Minor basic intrusions have been recorded in the lower part of the Seve in this area (referred to as the Helags Nappe) and banded amphibolites and quartzo-feldspathic sediments are present.

A thick mylonite and phyllonite zone generally separates the Seve of the Helags Nappe from the underlying Särv nappe. Similarity exists between some of the metasedimentary units in the Särv Nappe and lower part of the Helags Nappe. Occasional discordant basic rocks occur in the latter along with concordant amphibolites of intrusive or extrusive origin. Similarity in the geochemistry of the Ottfjället dolorites (Särv Nappe) and the amphibolites of the Seve (Helags area) led Strömberg (1969) to suggest that the superposition of the Seve on the Särv is a primary relationship, partly disturbed by later thrusting but essentially giving evidence of a pre-orogenic relationship.

The tectonic style of the Seve-Köli Nappe Complex (p. 34), the tectonic contact between Seve and Särv and the evidence of increase in metamorphic grade upwards from the base of the Seve, denies this possibility of primary superimposition of the rock units as they are now. The Seve is clearly thrust over the Särv a distance of at least c. 70 km. Nevertheless, this does not deny the hypothesis that basic intrusions of Ottfjället dolerite type were the sub-volcanic feeders for the Seve extrusions.

The highest unit in the Seve of Åreskutan is overlain elsewhere by amphibolite and schists of lower metamorphic grade and these pass up into the Köli. The Seve-Köli contact has been recorded as transitional over large areas north of the Geotraverse in northern Västerbotten and Norrbotten. Further south (Zachrisson 1969, Trouw 1973) and in the Geotraverse area it is at least in part tectonic, the presence of mylonites and the interruption of metamorphic isograds, testifying to substantial displacement. This is the case along the western side of the Mullfjället and Sylarna windows and it has been inferred elsewhere in Plate I.

b. KÖLI SUPERGROUP

The Köli Supergroup overlies the Seve. In Sweden, within the Geotraverse it is largely confined to the Tännfors area, where the internal stratigraphy has not been established in detail but various rock units characteristic of the type Köli of Västerbotten are represented.

Fig. 7 illustrates the general lithologies of the Köli, their age and relationship to the Eastern Complex lithologies. Thickness estimates for the Köli Supergroup are very uncertain (Zachrisson, 1964, suggested about five kilometres) but there seems little doubt that the succession is substantially greater than the corresponding one in the Eastern Complex. The type area for Köli stratigraphy is located north of the Geotraverse in central-west Västerbotten where Kulling (1933) established the fossiliferous succession overlying the Seve. This stratigraphy is shown in the left column of Table 3, where it is seen that a substantial sequence of conglomerates, phyllites, volcanic rocks, serpentinites and serpentinite conglomerates separate the only fossiliferous (Ashgillian and Llandoverian) units from the underlying Seve. In the northernmost part of Kulling's type-area (Björkvattnet-Virisen), Stephens (in press) has described a transitional sequence downwards into the Seve schists and amphibolites and has documented an accompanying gradational increase in metamorphic grade.

The succession (Table 3) described by Zachrisson (1964 and 1969) relates to areas southwest of Björkvattnet-Virisen where a sequence comparable to Kulling's but in slightly higher metamorphic grade (lower amphibolite facies) rests directly on basement of the Børgefjell and Fjällfjäll windows, or on a thin sliver of Seve, the main part of the latter having wedged out westwards.

The Köli succession was apparently deposited in relatively deep water environ-

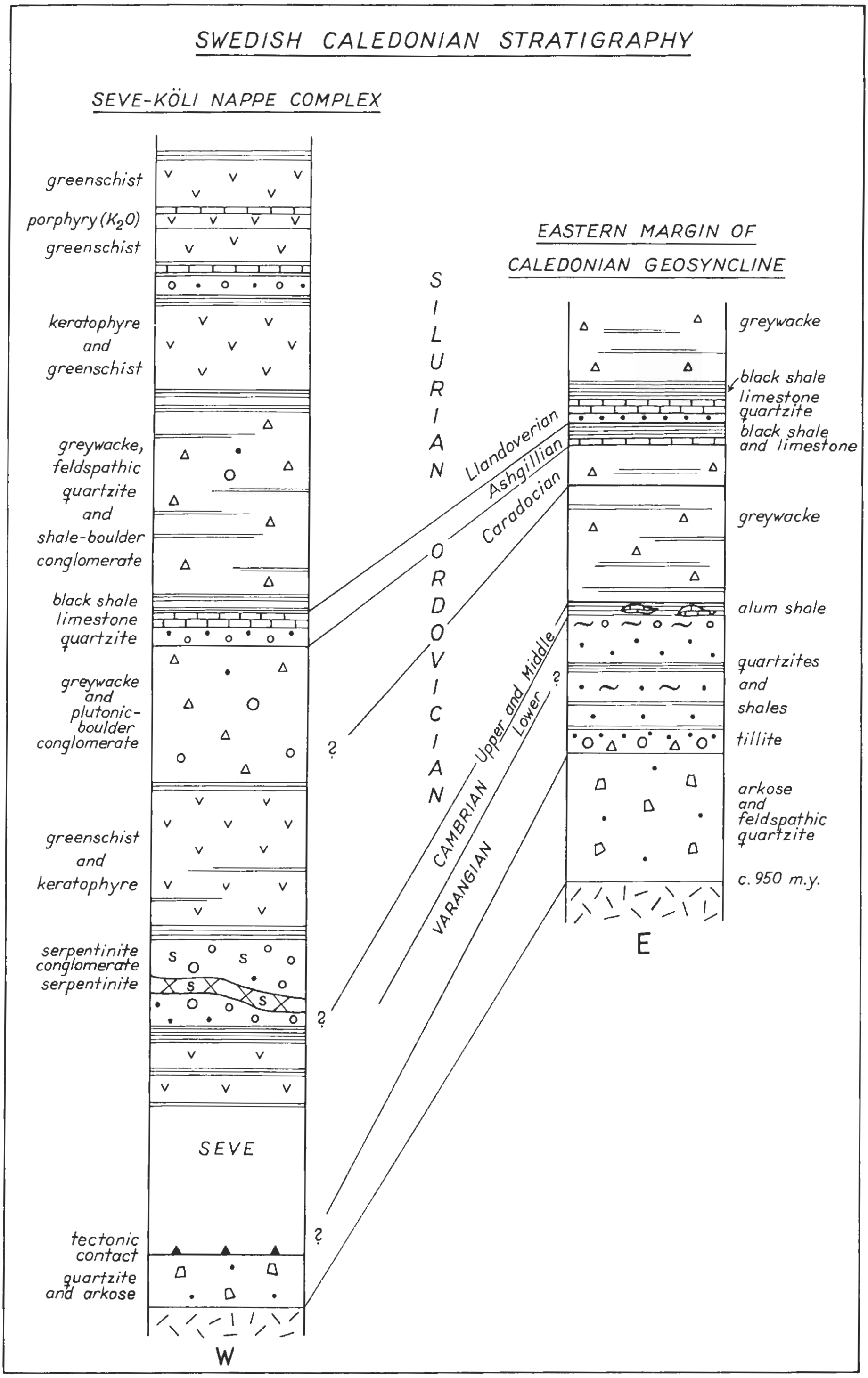

Fig. 7. General Köli Supergroup stratigraphy compared with the Jämtland Supergroup (taken, with minor modification, from Gee 1972 a).

TABLE 3. Comparison of Western Complex stratigraphy (taken from Gee and Zachrisson 1974)

	CENTRAL VÄSTERBOTTEN Björkvattnet - Virisen (Kulling 1933,1955,1958)	CENTRAL-SOUTHERN VÄSTER-BOTTEN & N. JÄMTLAND (Zachrisson 1964,1969,1971)		EASTERN TRONDHEIM REGION (This paper)		EASTERN TRONDHEIM REGION (Chaloupsky,Fediuk,Siedlecka, Wolff 1967)	WESTERN TRONDHEIM REGION Hølonda - Horg (Chaloupsky 1970)		(Vogt 1945)		
SILURIAN		Frems Phyllite Remdalen Greenschist with quartz-porphyry and limestone Graphitic and calcareous phyllite Remdalen-Portfjäll quartzite cgl	REMDALEN GROUP	Hegsjöfjell conglomerate							
		Stekenjokk and Lasterfjäll qz-keratophyre and greensch.	LASTERFJÄLL GROUP	Metabasite and qz-keratophyre	FUNDSJÖ GROUP						? (Wenlockian) ?
		Grey and graphitic phyllite, Lasterfjäll Greenschist		Grey and black phyllite, calc. metasst., metabasite	SULÅMO GROUP						
	Viris Quartzite Lövfjäll Phyllite	Lasterfjäll and Blåsjö Calcareous Phyllite (meta-gabbro in upper part)		Grey and calc. phyllite and metagraywacke with cgl (meta-gabbro in upper part)	KJØLHAUGEN GROUP						
	Broken black phyllite and sst Ⓕ			Black phyllite Ⓕ and metasst.	SLÅGÅN GROUP	SLÅGÅN GROUP Ⓕ	Hovin sst and shale Quartzite cgl	UPPER SANDÅ GROUP	Sandå shale and sst Lyngestein cgl	HORG SERIES	Llandoverian
ORDOVICIAN	Slätdal Limestone Ⓕ Vojtja Conglomerate	Bellovare Formation	LASTERFJÄLL GROUP			KJØLHAUGEN GROUP	Dark slate volc. sst and limestone Polymict cgl	LOWER SANDÅ GROUP	Hovin sst Grimsås rhyolite Volla cgl	UPPER HOVIN SERIES	Ashgillian
	Gilliks Series	Dark phyllite Greywacke Polymict cgl Limestone	TJOPASI GROUP			SULÅMO GROUP	Rhyolite & tuff		Tømme beds Ⓕ Espehaug and Hareklett rhyolite tuff	LOWER HOVIN SERIES	Caradocian
	Seima Series	Greenschist and quartz-keratophyre					Grey-green sst, grit, cgl, breccia. Grey-green slate. Amygdaloidal greenstone. Grey-green and dark slate. Greenstone cgl	KROKSTAD GROUP	Svarttjern lst Krokstad sst Upper Krokstad shale, Hølonda andesite		Llandeilian
	Ro Series	Dark phyllite Serpentinite cgl Quartzite cgl Peridotite							Hølonda lst Ⓕ		Llanvirnian
(CAMBRIAN) ?		Varied sedimentary, tuffitic and volcanic rocks							Lower Krokstad shale & breccia Ⓕ Venna cgl		Arenigian
		Lower contact tectonic				FUNDSJÖ GROUP SONVATN GROUP Ⓕ (GULA GROUP)	Støren greenstones	STØREN GROUP	Støren greenstones	STØREN GROUP	Tremadocian

ments both before and after the Ashgillian. Cross-bedded sandstones and conglomerates of the Vojtja Formation passing transitionally upwards into coral limestones of the Slätdal Formation interrupt an earlier Ordovician and a later Silurian greywacke and volcanic rock association of deeper water origin.

The overlying succession of Llandoverian black shales (Broken Formation) giving way transitionally to shales and greywackes (Lövfjäll Formation) and feldspathic quartzites (Viris Formation) passes up in westerly areas into volcanic rocks of Zachrisson's Lasterfjäll Group. These are overlain by more conglomerates, limestones and volcanic rocks of the Remdalen Group.

Below the Ashgillian quartzites, a greywacke shale and conglomerate unit (Gilliks) contains pebbles and boulders of igneous rocks including potash granites, greenstones, keratophyres and serpentinites. Further north Kulling (*in* Strand and Kulling 1972) has reported a Caradocian coral in a clast in this unit. The formation was apparently derived both from the underlying volcanic complex and a neighbouring area of basement rocks. These volcanic units (Seima) have been described to contain pillow structures and may also be of deep marine origin. In some areas, serpentinites are directly associated with these, mainly basic, Seima volcanic rocks (south of Björkvattnet). In others, they occupy a distinctive unit below them usually associated with graphitic phyllites, and are developed both as massive serpentinite and serpentinite conglomerates. The sedimentary origin of this unit is beyond reasonable doubt, sedimentary structures such as grading and cross-bedding being documented and a transitional relationship to an underlying quartzite conglomerate occurring locally. The serpentinite conglomerate is developed over a very wide area at about the same level in the lithostratigraphy and has been correlated (Kautsky 1949, Kulling, *in* Gavelin and Kulling 1955) with the (Kunda stage) Otta conglomerates of southern Norway (Hedström 1930, Janusson 1973). If this correlation is correct, serpentinite was emplaced during the latest Lower Ordovician and was subject directly to erosion.

Various phyllites and subordinate volcanic rocks underlie the serpentinite conglomerates in the transitional zone down into the Seve.

Within the Swedish part of the Geotraverse, in the Tännfors area, graphitic phyllites, greywackes and plutonic boulder conglomerates of Gilliks type occur south of Duved. Higher in the succession, calcareous phyllites of Lasterfjäll type occur, locally with metagabbro intrusions. Across the border in Norway, the stratigraphy of Eastern Trøndelag bears many similarities with the Köli succession described above and a correlation has been suggested (Gee and Zachrisson 1974).

c. SEVE-KÖLI STRUCTURE AND METAMORPHISM

No detailed analysis exists of the internal structure of the Seve-Köli Nappe Complex in the Geotraverse area and much of the present activity is concerned with this problem. The general major structure and metamorphic relationships have been mentioned above, the overall style being dominated by a wedging-out of rock units westwards and disruption of the original pattern of metamorphic isograds by thrusting. Existing studies of the complex in the Geotraverse area suggest an overall similarity to relationships known from the areas of Västerbotten north of the Geotraverse and these are outlined here.

Zachrisson (1969) summarized the regional structure of the Seve-Köli Nappe Complex in an area in Sweden stretching from the northern boundary of the Geotraverse over a hundred kilometres northwards into central Västerbotten. The study included the classical area for Köli stratigraphy, Björkvattnet-Virisen (Kulling 1933) and summarized general Swedish Geological Survey results from several years mapping, mainly of the Köli (Nilsson 1964, Zachrisson 1964). Zachrisson demonstrated that the essential major structural relationships between the Seve and the Köli (the westerly thinning of the units and the truncation of the metamorphic isograds) occurred prior to the folding of the sequence into the major open north-south trending antiforms and synforms (comparable in style and sequence with the late folds such as the Sylarna Antiform, Tännfors Synform, Mullfjället Antiform, etc. in the Geotraverse profile). A regional penetrative schistosity and associated linear structures, usually of transverse orientation, were likewise folded by the late open folds and their associated parasitic minor structures. The regional schistosity was shown to be associated with isoclinal folding. It was also possible to identify folds formed prior to this regional schistosity and related folding.

Subsequent work by the Geological Survey, and by Trouw (1973) has clarified the geometry of some of the early structures and their relationships to the regional pattern of metamorphism. Within the lowest grade part of the Köli, early major, recumbent isoclinal folds (for example, the Vesken fold) with N—S fold axes, (Zachrisson 1969, p. 27) existed in the Köli prior to the main episode of regional porphyroblastasis (greenschist to lower amphibolite facies in the Köli and transitionally upwards into upper amphibolite and locally eclogite facies in the Seve). After the main phase of porphyroblastasis in the Köli, but in part accompanying it in the underlying Seve, the whole sequence was refolded isoclinally. The regional penetrative schistosity was established during this phase (or phases) of isoclinal folding which accompanied the main translation of the Seve-Köli Nappe from its root-zone and place of metamorphism to its present location. That the Complex retained much of its heat during this emplacement is witnessed by its influence on the underlying rocks as described earlier.

Within the Geotraverse area, the Seve-Köli Nappe Complex shows local deformation and metamorphic patterns that compare well with descriptions from areas further north (Fig. 8). However, we have no studies of comparable detail available, and no evidence of internal Köli major structure. Correlation with areas to the north suggests the existence of a similar fold sequence and relationship to thrusting as described above.

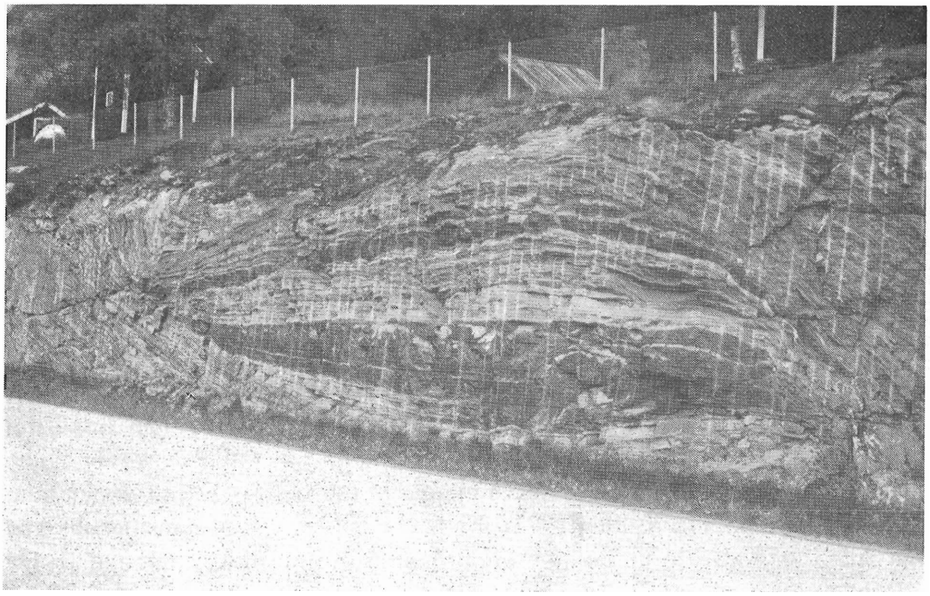

Fig. 8. Amphibolite boudins in the Seve Supergroup of Åre.

3. SEVE-KÖLI NAPPE COMPLEX AND HIGHER TECTONIC UNITS IN NORWAY

a. RELATIONSHIP BETWEEN THE EASTERN AND WESTERN COMPLEXES IN NORWAY

Areas of Trøndelag forming a part of the Geotraverse from the Swedish border to the Norwegian west coast, have been referred to in the literature as the Trondheim region. The rock units are metamorphosed and allochthonous, the nature of the latter being highly disputed. In 1961, Strand commented (p. 169) "Little is known of the Trondheim region, and future research may well show that more than one tectonic unit is present in that large area". Some years later he added (*in* Strand and Kulling 1972, p. 66) "It would be premature in the present state of knowledge to attempt any synthesis of the tectonics of the Trondheim region". On the basis of published information this remain the case. There exists no map over the Norwegian part of the Geotraverse which allows subdivision and correlation of the rock units over the whole area and the western part of Plate I remains an unhappy compromise. Nevertheless the regional tectonics of the eastern part of the Geotraverse have a vital bearing on Trøndelag tectonics; it is these aspects that are emphasized here.

Whereas it has long been accepted that the Trøndelag cover and uppermost basement are allochthonous, translated eastwards on the base of the Offerdal

Nappe (the base of Asklund's "Great Seve Nappe"), opinions have been divided over the relationship between this thrust basement and the overlying Eocambrian (here referred to as Risbäck Group equivalents) and Cambro-Silurian sequences. Kulling (1961) regarded the general cover sequence as part of the Seve-Köli Nappe Complex and referred to it as the Trondheim Nappe implying an allochthonous relationship to this thrust basement. However, the relationships between the units of the Offerdal Nappe and the overlying unit are usually concordant and "transitional" and have lead the majority of authors to doubt the tectonic character of this boundary. In some localities (e.g. Tømmerås, Springer Peacey 1964) a primary sedimentary relationship has been claimed between the crystalline basement and the overlying cover.

That the Trøndelag units described here in the Western Complex are at least partly allochthonous on the thrust basement (Offerdal Nappe) is apparent from Wolff's (1964) and Springer Peacey's (1964) mapping of the eastern side of the Tømmerås Antiform and the southern margin of the Grong-Olden Culmination. Strand (*in* Strand and Kulling 1972) shows the basement/cover relationships in the Snåsa area also to be notably discordant. Springer Peacey referred to the allochthonous units east of Tømmerås as the "Upper Nappe" and in 1967, Wolff included this in his Trondheim Nappe. He and other authors (Roberts et al. 1970) accepted the evidence from western Tømmerås that the Trondheim Nappe was rooted west of this antiform and thus formed a part of the Seve Nappe. Thus Roberts et al.'s Trondheim Nappe was regarded as an essential part of the Seve-Köli Nappe Complex.

The base of the Trondheim Nappe can be traced from eastern Tømmerås, along the south side of the Grong-Olden Culmination and thence southwards along the border between Norway and Sweden. Here the nappe rests on mylonitized Seve rocks of the western limb of the Sylarna Antiform. Thus Wolff's Trondheim Nappe rests on the western, tapering edge of the Seve Supergroup. Köli units overlying the Seve on the east side of the Sylarna Antiform occupy the same structural position as the lowermost units of the Trondheim Nappe on the west side. Some of the lower units of the Trondheim Nappe are notably comparable with the Köli units in Sweden (Siedlecka 1967, Gee and Zachrisson 1974) supporting the conclusion that at least part of the Trondheim Nappe is an essential upper component of the Seve-Köli Nappe Complex.

The hypothesis that the units of the Seve-Köli Nappe Complex (including the Trondheim Nappe) were originally deposited on the crystalline basement and arkosic cover composing the Offerdal Nappe is contested on the following basis:

(i) Crustal shortening required by the Särv and Seve-Köli Nappe Complex

The base of the Offerdal Nappe can be traced into northern Trøndelag as has been shown by Foslie (*in* Oftedahl 1956) and occurs also in Tømmerås (Gee

1974). Overlying this allochthon in the east (and underlying the Trondheim Nappe) are major, metamorphosed nappe units ranging in grade from greenschist to eclogite facies and separated from each other by conspicuous mylonite zones. The cover-shortening implied by these (the Särv and the Seve nappes) denies the possibility of rooting the overlying Trondheim Nappe in the Snåsavatn area.

(ii) Disharmony of major structures in basement and cover

The Trøndelag structure is dominated by a shallow basement synform flanked to east and west by the Sylarna and Tømmerås Antiforms respectively. These structures fold the nappe units and the dominant penetrative foliation in both the cover and the upper part of the basement (including the Offerdal Nappe). The major structures in the cover that are related to this penetrative deformation are disharmonic to the basement, implying that "transition" zones between basement and cover are of tectonic origin.

(iii) Absence of Ottfjället dyke swarm in the Eastern Complex

The wedge-shaped Särv Nappe with the Ottfjället dolerite dyke swarm occupies an area with an east—west dimension of over eighty kilometres. This unit must have been rooted west of the Sylarna Antiform. Lack of comparable dyke rocks in the basement east of Tømmerås suggests that the root-zone lies at least as far as the Norwegian west coast. But even a root-zone for this unit in central Trøndelag would require the Trondheim Nappe to be entirely allochthonous within the Geotraverse area, (see (i) above).

(iv) Metamorphic grade of the Seve

The Seve wedge of the Seve-Köli Nappe Complex can only be rooted in an area west of the Särv root-zone. Nowhere east of Snåsa does the basement reach upper amphibolite facies. However the Seve contains assemblages indicative of even higher grade (probably substantially higher pressures than are recorded anywhere for Caledonian parageneses along the Trøndelag west coast).

(v) Comparison of Ordovician depositional environments for the Köli and Jämtland Supergroups

Jämtland Supergroup units of Ordovician age are notable for their lack of evidence of contemporaneous volcanicity (occasional bentonites excepted). These sediments can be traced westwards to the Norwegian-Swedish border, flanking the Grong-Olden Culmination. Rooting of the Seve-Köli Nappe Complex and higher units along the Norwegian west coast would imply that during Ordovician times the Köli volcanic island environment with its detrital serpentinites existed within not more than fifty kilometres of the non-volcanic Jämtland depositional basin (considerably less if the Jämtland Supergroup rocks of Grasåmoen and Tømmerås are of Ordovician age as is possible on the basis of the lithostratigraphic correlation, Gee 1974). Such proximity of these highly contrasted sequences is denied by any comparison with modern environments.

(vi) Faunal province evidence

It has been argued elsewhere (Gee and Zachrisson 1974) that the stratigraphy of eastern Trøndelag is typical Köli and shows marked dissimilarities from the successions of similar age in the area of Trondheim (sensu stricto). These differences are accentuated by the palaeontological evidence that faunal assemblages of western Trøndelag are of American affinities whereas those of eastern Trøndelag have dominantly Baltic character (Jaanusson 1973). These contrasted Lower-Middle Ordovician faunas must have existed within one hundred kilometres of each other (substantially less if one assumed extensive stretching of the nappes) if the Trondheim area successions are regarded as autochthonous on the thrust basement of the Eastern Complex.

These independent lines of evidence all favour derivation of the Western Complex from west of the Norwegian coast and Plates I and II have been constructed accordingly, all boundaries between basement (with its Risbäck Group clastic cover) and overlying units being marked as tectonic. Where the literature reports that the contact relationships between basement (with its veneer of Risbäck Group sediments) and the cover are transitional (e.g. in the Surnadal Synform, Hernes 1956), it is suggested here that the conformity and transitional character are entirely the product of translatory movements occurring prior to or during regional recrystallization.

b. WESTERN COMPLEX STRATIGRAPHY IN TRØNDELAG

The central part of Trøndelag is occupied by a zone of generally high grade schists and gneisses, locally migmatized. These are included in the Gula Group (Roberts et al. 1970) and have also been called the Røros Group (Carstens 1960, Strand, *in* Kulling and Strand 1972). These high grade rocks are flanked by lower grade units which in general dip east in the west and west in the east beneath the Gula Group. The major structure has been variously interpreted (see Fig. 9) but most authors have accepted that the Gula Group occupies the lower (pre-Ordovician) part of the succession. This relationship has been questioned by Olesen et al. (1973).

The sequences east and west of the Gula Group have been correlated by various authors (e.g. Wolff 1967). Uncertainty over these correlations (Gee and Zachrisson 1974) has resulted in a separate treatment here.

(i) Western Trøndelag stratigraphy

East and south-east of Trondheimsfjorden

West of the E-dipping Gula Group of central Trøndelag there occurs a sequence of volcanic rocks and sediments metamorphosed in greenschist facies. These units, in the Hølonda-Horg area south-west of Trondheim (Vogt 1945) have yielded Ordovician fossils and abundant way-up evidence providing the basis for western Trøndelag stratigraphy. The latter is summarized in column 6 of Table 3. In column 5 of Table 3 an alternative interpretation of the type stratigraphy (Chaloupsky 1970) is presented. The succession west of the Gula Group is dominated by basaltic volcanic rocks in the lower part (the Støren Group) and sediments with subordinate acid volcanic rocks higher up (the Lower and Upper Hovin Group and Horg Group). The total thickness is probably in the order of four to five kilometres. Taken along with the Gula Group this supergroup — referred to here as the Trondheim Supergroup (Roberts, pers.comm.) — is probably in the order of at least six kilometres thick.

Støren Group. The Støren Group is made up of basaltic lavas and pyroclastic units c. 2 500 m thick. Oftedahl (1959) has drawn attention to the variability in development of the group and inferred the presence of various volcanic centres. Whereas some areas of development usually with thicker successions are dominated by pillow lavas others are predominantly composed of pyroclastic rocks. Minor intercalations of acid volcanites (quartz keratophyres) are locally present, particularly in the upper parts of the group. Gabbroic and trondhjemitic intrusions occur within the pile and serpentinites have also been reported at a few localities. Cherts are conspicuous locally and limestones have been reported. Other sediments may be entirely absent and are always subordinate.

The age of the Støren Group is inferred from relationships to the adjacent Lower Hovin Group. Various formations of this group overlie the Støren volcanites. The oldest unit (the Bogo shale) recorded to contain well preserved fossils was described by Blake (1962) to be of middle Arenigian age. This was subsequently revised by Skevington (1963) and Berry (1968). The latter drew attention to the American affinities of this graptolite fauna and correlation elsewhere suggests a latest Arenigian or lowermost Llanvirnian age (Dewey et al. 1970). Recently Neuman and Bruton, (1974) have described Whiterock (Llanvirnian) faunas from the Hølonda limestones near the base of the Lower Hovin Group. Thus the Støren Group is of Arenigian or pre-Arenigian age.

Previous authors have accepted correlation of the Støren volcanites with the volcanic rocks (Fundsjø Group) occurring east of the Gula Group in eastern Trøndelag. Between the Gula Group and the Fundsjø Group at one locality

(Nordaunevollen, Vogt J.H.L. 1889, Vogt T. 1941, Størmer 1941) a dark shale which may be a member of the Gula Group or the Fundsjø Group has yielded Dictyonema flabelliforme. On the assumption that the Gula Group is older than the Fundsjø Group and that the latter is directly correlatable with the Støren Group it has been accepted that the Støren volcanic rocks are younger than this Tremadocian fossil. These assumptions are now in doubt (Olesen et al. 1973, Gee and Zachrisson 1974) and the lower age for the Støren Group is not established.

Lower Hovin Group. Volcanogenic conglomerates generally overlie the Støren Group, and have been given various local names e.g. the Stokvola and Venna conglomerates. Boulders of greenstones dominate; trondhjemite, chert and other Støren Group lithologies are conspicuous. Clasts are often very angular implying local erosion and short transport. Boulder conglomerates pass upwards into pebbly horizons interspersed with finer volcanogenic sediments and these give way to parallel bedded volcaniclastic turbidites of Krokstad type. The latter are extensive in some areas (e.g. Horg) and in the order of 500—600 m thick. In other areas they are absent or subordinate, intercalated with shales, e.g. the fossiliferous Bogo shale (Blake 1962), and Hølonda limestones (Strand 1948, Neuman and Bruton 1974).

Higher in the Lower Hovin succession there occur porphyrites, limestones, dark shales, rhyolitic tuffs and conglomerates. Various units have yielded fossils and the Lower Hovin Group is known to contain faunas at least as young as Ashgillian (the Kalstad Limestone).

Much of the controversy over the details of Lower Hovin Group stratigraphy arises from rapid changes in facies within the group. Deposition occurred in an environment of very varying stability, apparently mostly in deeper water. Volcanogenic material dominates in the clastic rocks and can be matched in the underlying units.

Upper Hovin Group. A polymict conglomerate overlies the Lower Hovin Group. Referred to as the Volla conglomerate it contains boulders derived both from the underlying volcanogenic sequences and from an area of potash granites and gneisses — probably Pre-Cambrian basement. This unit, locally overlain by volcanites (the Grimsås rhyolites) generally passes upwards into thick (c. 500 m) greywackes of turbidite origin, the Hovin sandstones. No fossils have been recorded from the Upper Hovin Group and its late Caradocian or younger age is inferred from units at the top of the underlying group. Correlation of the Volla conglomerates with the Caradocian, Gilliks conglomerates of the Köli (p. 33) and comparison of Hovin sandstones with greywackes thought to be of pre-Llandovery age in eastern Trøndelag have lead previous authors to place the Upper Hovin Group in the Upper Ordovician. It may equally well be Lower Silurian (Chaloupsky 1970).

Horg Group. Quartzite-bearing conglomerates (the Lyngestein conglomerates), nearly monomict but containing occasional limestone and other clasts are described separating the Upper Hovin Group from the Horg Group. These conglomerates pass upwards into greywacke sandstones referred to as the Sandå formation. Chaloupsky (1970) has claimed that the Hovin and Sandå sandstones are one and the same unit and this controversy has cast doubt on this the uppermost part of Vogt's stratigraphy of the Trondheim Region.

West and north-west of Trondheimsfjorden

The Støren Group volcanic rocks have been mapped northwards into the Snåsa synform (Carstens 1960) where they are thinner than in the type area and overlain by the polymict volcanogenic Steinkjer conglomerate (locally up to 2 000 m thick). These conglomerates have been correlated with the Stokvola conglomerate to the south-east and accepted as the basal formation of the Lower Hovin Group. In some areas, limestone directly overlies these conglomerates. In others (e.g. Steinkjer), greenschists and keratophyres separate the Steinkjer conglomerates from this Snåsa limestone. The latter locally attains a thickness of c. 200 m and has yielded poorly preserved fossils of probable Middle Ordovician age (Strand, *in* Strand and Kulling 1972). Acid volcanic rocks are reported above this limestone and together these units are correlated with the Lower Hovin Group (Carstens 1960).

A polymict conglomerate overlies the Lower Hovin Group units containing clasts dominated by quartzite but including potash granites. This, the Hopla conglomerate (correlated with the Volla conglomerate), passes upwards into greywacke sandstones with intraformational slide conglomerates correlated with the Upper Hovin Group sandstones of the area south of Trondheim.

From west of Trondheimsfjorden on the island of Smøla, Holtedal (1915) collected Ordovician fossils from a limestone unit thought to be correlatable with the Snåsa limestone. Strand (1932) described a fauna of mainly American affinities which apparently is not older than Middle Ordovician (Yochelson, *in* Strand and Kulling 1972). Similar limestones with less well preserved fossils are also reported from the island of Tautra.

(ii) Eastern Trøndelag stratigraphy

Northern and central parts

Below the W-dipping Gula Group of eastern Trøndelag there occurs a sequence of volcanic rocks and metasediments (Fig. 10, columns 3 and 4) containing two fossiliferous horizons, the one (referred to on p. 40) of Tremadocian age and the other of Llandoverian age. It has been maintained (Chaloupsky and Fediuk 1967, Siedlecka 1967, Wolff 1967) that the evidence of sedimentary structures requires that the W-dipping succession is inverted. A description of the major rock units from west to east is followed here by discussion of the stratigraphic succession.

Fundsjø Group. From the southern side of the Grong-Olden Culmination southwards to the Røros area in the south of the Geotraverse a suite of metavolcanic rocks flanks the Gula schists. These greenschists and keratophyres, in places several hundred metres thick, contain pillow lavas, amygdaloidal greenstones and a variety of acid and basic pyroclastic units (Chaloupsky and Fediuk 1967, Olesen et al. 1973). Acid and basic hypabyssal intrusions occur related to this volcanicity.

Sulåmo Group. Structurally underlying the Fundsjø Group there occurs a metasedimentary sequence dominated by dark phyllites and greywacke sandstones with a greenstone unit at the base. Limestones and conglomerates (Brenna conglomerate) are locally present (Chaloupsky and Fediuk 1967). Conglomerates (the Lille Fundsjø Conglomerate) containing clasts of the Fundsjø Group rocks have been described to separate the Sulåmo and Fundsjø Groups.

Kjølhaugen Group. This unit occurring structurally below the Sulåmo Group has been described in some detail by Siedlecka (1967). Within the W-dipping sequence it occurs both above and below the Slågån Group and rests in the east with tectonic contact on the mylonitized Seve units of the Sylarna Antiform. Greywacke sandstones and phyllites of turbidite origin and with intercalations of slide conglomerates make up a lithostratigraphic unit several hundred metres thick. Concordant metagabbros intrude the upper part of the group.

Slågån Group. Siedlecka (1967) described the Kjølhaugen Group to pass transitionally into the black phyllites of the Slågån Group. On the eastern side of Kjølhaugen, Getz (1890) recorded the presence of Silurian graptolites (now known to be of Llandoverian age) in these graphitic metasediments. The Slågån Group has been interpreted as occupying the hinge of a syncline, representing the highest rock units in the succession of Eastern Trøndelag and Siedlecka (1967) has reported way-up evidence in support of this interpretation. The way-up evidence is not entirely convincing and this conclusion has been questioned by Gee and Zachrisson (1974).

Discussion. The Llandoverian Slågån Group black phyllites are directly comparable in lithofacies and age with the Broken Formation of the Köli. The Kjølhaugen Group and structurally overlying units compare lithologically with the Llandoverian (and/or younger) succession stratigraphically overlying the Broken Formation in central Västerbotten (Table 3, col. 3), correlation of the Blåsjö and Lasterfjäll calcareous phyllites with the Kjølhaugen Group being particularly striking (Siedlecka 1967). Gee and Zachrisson (1974) favoured correlation of the highest unit, the Fundsjø Group, with the Stekenjokk volcanites and thus entertained the possibility of a Silurian age for the former. However, the composition of the clasts in the Lille Fundsjø Conglomerate suggest that at least the lower part of the Sulåmo Group is younger than the Fundsjø Group, supporting the concept of a regional inversion and an Ordovician age for the latter. Thus an interpretation (Plates I and II) is preferred here, requiring a tectonic discontinuity below the inverted Lille Fundsjø Conglomerate and above the Kjølhaugen Group, a relationship that has so far only been reported from the central part of the Geotraverse.

Southern part

The Røros area in the southern part of the Geotraverse has been described recently by Rui (1972). The rock sequence dips westwards below the Gula Group and is thought to be inverted.

Volcanic rocks of the Fundsjø Group, extending southwards into this area, have been referred to as the Hersjø Formation. These volcanites pass eastwards into the Sulåmo Group equivalents — dark phyllites of the Kjurudal Formation and Sætersjø Formation sandstones and conglomerates. Below the Sætersjø Formation (but thought to be stratigraphically above) are a thick sequence of Røros calcareous schists regarded as equivalent to the Kjølhaugen Group of Upper Ordovician (Siedlecka 1967) or Silurian (Gee and Zachrisson 1974) age.

In this southern part of the Geotraverse in Trøndelag a substantial succession structurally underlies the Røros Schists. These underlying units include the Hummelfjell Formation of feldspathic sandstones and minor quartzites; then some mica schists and greenschists. Rui (1972, p. 6) pointed out that a transition zone between the Røros Schists and the Hummelfjell Formation in the Tynset area (just south of the Geotraverse) includes "polygenic conglomerate, quartzite conglomerate, marble, serpentinite bodies and alternating graphitic and psammitic schists. In places pure serpentinite or talc conglomerates occur next to the serpentinite bodies". These stratabound serpentinite conglomerates (typical of the classical Köli stratigraphy) can be traced southwards into the Gudbrandsdalen valley where at Otta (Hedström 1930) they are known to be of Lower to Middle Ordovician age. Thus, as Rui pointed out, the Røros area stratigraphy contains important incompatibilities, units structurally underlying the Røros Group and thought to be younger, containing formations of probable Lower to Middle Ordovician age.

(iii) Central Trøndelag — the Gula Group

The Gula Group (Kjerulf 1871), occupying the central zone in Trøndelag southwards from the Grong-Olden Culmination, is a major rock unit of very variable character, in part highly metamorphosed. It lies structurally above the adjacent Støren (in the west) and Fundsjø (in the east) Groups. Most authors have treated the interrelationship between the volcanites and the Gula schists as one of primary superposition and the presence of the Dictyonema fossils in the contact between the volcanites and the sediments (see Rui 1972, p. 10) suggests that one or the other or both groups are of Ordovician age. Olesen et al. (1973), from the Tydal area, have drawn attention to the character of the conglomerates in the Gula-Fundsjø contact zone and along with local way-up evidence in the sediments, have suggested that the Gula Group is younger than the Fundsjø Group. Rui (1973), further south, has described way-up evidence to the contrary. Other authors have generally accepted the Gula Group to be older (Cambrian?) than the volcanites, apparently due to the higher metamorphic grade of the former (Wolff 1967, p. 129). In the Røros area there is little difference in metamorphic grade between the Røros and Gula Schists and some previous authors have correlated them.

The Gula Group thus remains a highly controversial stratigraphic unit. Knowledge of internal stratigraphy is rudimentary. Calcareous, graphitic, psammitic and pelitic schists are recorded and metagreywackes and conglomerates have been identified. Thin bedded greenschists and amphibolites occur locally and marbles are also reported near the contact with the Fundsjø volcanites. A volcanogenic conglomerate has been reported from some areas in the vicinity of this contact. High grade metamorphism and local migmatization has, up till now, prevented establishment of an internal succession. Thickness is likewise uncertain — the unit could be as much as five kilometres thick judging by some published profiles (e.g. Olesen et al. 1973) but these figures are very uncertain.

(iv) Area north of the Grong-Olden Culmination

The rock units of the Geotraverse north of the Grong-Olden Culmination and overlying the Offerdal Nappe are composed of Seve rocks in the east, wedging-out beneath Köli and higher units in the west. These higher units are known from Foslie and Strand (1956), Oftedahl (1956) and Strand (1963) to be included in at least two tectonic units, the Gjersvik and (in the west) the Rödingsfjäll nappe. The latter is composed of high grade schists and gneisses, injected with granite. The Gjersvik Nappe is composed essentially of a volcanic, greenstone dominated, unit intruded by gabbros and trondhjemites. Below the Gjersvik Nappe and above the Seve, a Köli sequence (Nilsson 1964) is repeated in at least three separate tectonic units (Zachrisson 1969). The lower part is made up of a normal Köli succession superimposed by the Gellvernokko and Leipik Nappes. The uppermost unit has been described by Strand to contain conglomerates (the Liming Group) comparable with the Volla conglomerates and resting with regional discontinuity on the underlying mixed metasedimentary and volcanic rocks (the Rørvik Group). Fossils are lacking and the lithostratigraphic correlation is uncertain.

(v) Correlation of stratigraphy in Trøndelag

The Western Complex of Trøndelag contains rock units at least of Ordovician and Silurian age and were thus deposited contemporaneously with part of the

Köli. Unfortunately, dependable biostratigraphy is only locally established, mainly in Western Trøndelag, and facies variation in this "eugeosynclinal" environment appears to be rapid (witness the variations across the Horg syncline, Strand, *in* Kulling and Strand 1972). Correlation has largely been based on general lithological similarities and comparison of conglomerates (Wolff 1964, 1967), the latter, as Siedlecka has pointed out (1967, p. 47), being a somewhat hazardous practice.

In Western Trøndelag, the general sequence (excepting the uncertainty of the Gula Group) of the Trondheim Supergroup appears well established. A major volcanic unit, the Støren Group (of Arenigian or pre-Arenigian age) is overlain by a mixed sedimentary sequence, initiated by volcanogenic conglomerates and terminated by black shales (Caradocian) — the Lower Hovin Group. Influx of basement material as well as a volcanic element in coarse basal conglomerates marks the initiation of a new sedimentary sequence of Caradocian or younger age, the Upper Hovin Group, in which the overlying turbidite sandstones and slide conglomerates are regarded as characteristic and mappable over very extensive areas.

Correlation of the Trondheim Supergroup with the successions of eastern Trøndelag has been attempted by various authors (Table 3). Gee and Zachrisson (1974) maintained that the lithostratigraphical similarities between the eastern Trøndelag successions and the classical Köli Supergroup stratigraphy were clearer than those suggested to exist with the western succession. The limited faunal evidence likewise supported the Köli correlation. Their discussion applied primarily to the evidence in the Meråker profile and related to the upper part of the Köli stratigraphy. Further south in the Røros area the similarities between the lower parts of the Köli stratigraphy and the sequence below the Røros schists are also striking and various authors have commented on the probable correlation of some of the rock units (Kautsky 1949, Kulling, *in* Gavelin and Kulling 1955, Strand, *in* Strand and Kulling 1972). On the basis of this general lithostratigraphic comparability, Gee and Zachrisson (1974) included the eastern Trøndelag sequence in the Köli. Taking into account the palaeontological evidence of Lower Ordovician faunal affinities discussed below, they claimed a major tectonic contact between the western and eastern Trøndelag successions (discussed on p. 49).

(vi) Comparison of Köli and Trondheim Supergroup stratigraphy

Biostratigraphy affords the essential basis for comparing the rock successions. Lack of post-Ashgillian fossils in the Trondheim Supergroup and pre-Caradocian fossils in the Köli renders this correlation uncertain. Perhaps the most notable similarity is the appearance in the middle of both successions of polymict, conglomerates (the Volla conglomerates in the west and the Gilliks in the east) derived from at least two sources, the one volcanic and the other granitic basement. This occurred in the Caradocian in the Köli and at the same time or later in the Trondheim Supergroup. After this, in the Köli, a shallowing of the sea (Vojtja quartzite conglomerates and Slätdal coral limestones) and relative stability marks the end of the Ordovician prior to deepening and then turbidite deposition in the Llandoverian. In the Trondheim successions thick turbidite sandstones follow the polymict conglomerates directly and pass up into conglomerates (Lyngestein) with dominantly quartzite clasts. No fossil evidence exists above the Volla conglomerate in the type area and the interpretation of the Hovin greywacke sandstones as upper Ordovician is based on comparison of the Vojtja and Lyngestein conglomerates — hardly a dependable basis for correlation.

Below the polymict conglomerates of Caradocian (and possibly younger age in the Trondheim area) the successions are even more difficult to compare. Whereas in the Trondheim Supergroup the fossil evidence is sufficient to control an Ordovician succession above the major volcanic unit (the Støren Group), in the Köli the only biostratigraphic evidence is indirect, being based on a lithostratigraphic correlation of the fossiliferous Otta serpentinite conglomerates with those of Rotiken (Kulling, *in* Gavelin and Kulling 1955). Accepting this correlation, the lower part of the Köli that was deposited more or less contemporaneously with the Lower Hovin Group and perhaps the Støren Group of the Trondheim Supergroup differs from the latter in containing thick Middle Ordovician greenschists and keratophyres and extensive intrusion/extrusion of serpentinite along with deposition of serpentinite conglomerates. Volcanites in the Köli below the serpentinite conglomerate may be contemporaneous with the Støren Group but this cannot be assumed. Thus it would seem probable that the similarities between the Köli and Trondheim Supergroup stratigraphy are greater after the Middle Ordovician than before, a conclusion of significance for reconstruction of the geosyncline and discussed elsewhere (Gee 1975).

The faunal affinities of the Ordovician fossil assemblages in the two supergroups is of relevance to this general stratigraphic discussion and perhaps to the regional tectonics. Various authors (Strand 1932, Spjeldnæs 1961) have drawn attention to the American affinities of various elements of the Trondheim faunas. Assemblages of trilobites (Strand 1948, Bruton, *in* Neuman and Bruton 1974), brachiopods (Neuman, *in* Neuman and Bruton 1974), graptolites (Berry 1968) and conodonts (Bergström 1971) in the Lower and lower Middle Ordovician sequences, all differ markedly from contemporaneous assemblages in the Jämtland Supergroup and its Baltic equivalents. At genera (and in some cases, species) level they compare well with faunas from Nevada, Newfoundland and East Greenland.

Köli Supergroup faunas in the type area are not older than Ashgillian and have mixed faunal assemblages. However, the Otta serpentinite conglomerates have yielded well preserved brachiopods, gastropods and trilobites of unambiguous

Baltoscandian affinities (Kunda stage, Jaanusson 1973). This difference between the Köli and Trondheim Supergroups adds to the conclusion drawn above that at least the pre-Caradocian successions differ substantially, perhaps implying greater physical separation than during the later Ordovician.

c. WESTERN COMPLEX STRUCTURES IN TRØNDELAG

Central Trøndelag is dominated by a "shallow trough" (Roberts et al. 1970, p. 133) referred to here as the Trøndelag Synform. This structure folds the Eastern Complex and the Western Complex Nappes. It is flanked to the east by the Sylarna Antiform and to the west by the Tømmerås Antiform. West of the Tømmerås Antiform is the Snåsavatn Synform which divides further south into the Trondheimsfjord Synform (to the east) and the Fosen Synform (to the west). All these structures are late stage folds influencing both the Eastern and Western Complexes together.

The internal Western Complex structure of Trøndelag has been disputed by many authors. Roberts (1967, p. 92) summarized the background to much of the controversy and illustrated the different models proposed. He concluded that "the essential structure of the region (central Trøndelag) is an anticline flanked by recumbent fold nappes (F 1) which spill outwards on either side of a NE-trending spine". This "anticline" was truncated against basement (the Offerdal Nappe) along the south side of the Grong-Olden Culmination but further southwest such discordance was not inferred. Indeed it was thought possible that the basement might be involved in the mushroom. This interpretation is illustrated in Fig. 9 A.

Wegmann (1925) regarded the Gula Group as allochthonous on the volcanic rocks of the Støren and Fundsjø Groups and Fig. 9 B attempts to project this solution into the same Meråker profile. Rui *(in* Røhr-Torp 1972) entertained the possibility that the entire Trøndelag succession was inverted in an early recumbent fold and then refolded (Fig. 9 C). Gee and Zachrisson (1974) favoured a solution, in keeping with the nappe geometry further east in the Geotraverse (Fig. 9 D).

Interpretation A (Fig. 9) requires (Roberts et al. 1970) that the cover is autochthonous on basement west of the mushroom; this interpretation is rejected on the basis of discussion on p. 36. Alternatively, if the mushroom exists, it would be entirely allochthonous requiring the coincidence of a mushroom axis more or less superimposed on the Trøndelag Synform axis. The interpretation B suggested by Wegmann (1925) is compatible with the regional tectonic style but fails to explain the differences in Trondheim and Köli Supergroup stratigraphy and the evidence of different faunal provinces in the west and east limbs of the Trøndelag Synform. Likewise profile C faces the same criticism.

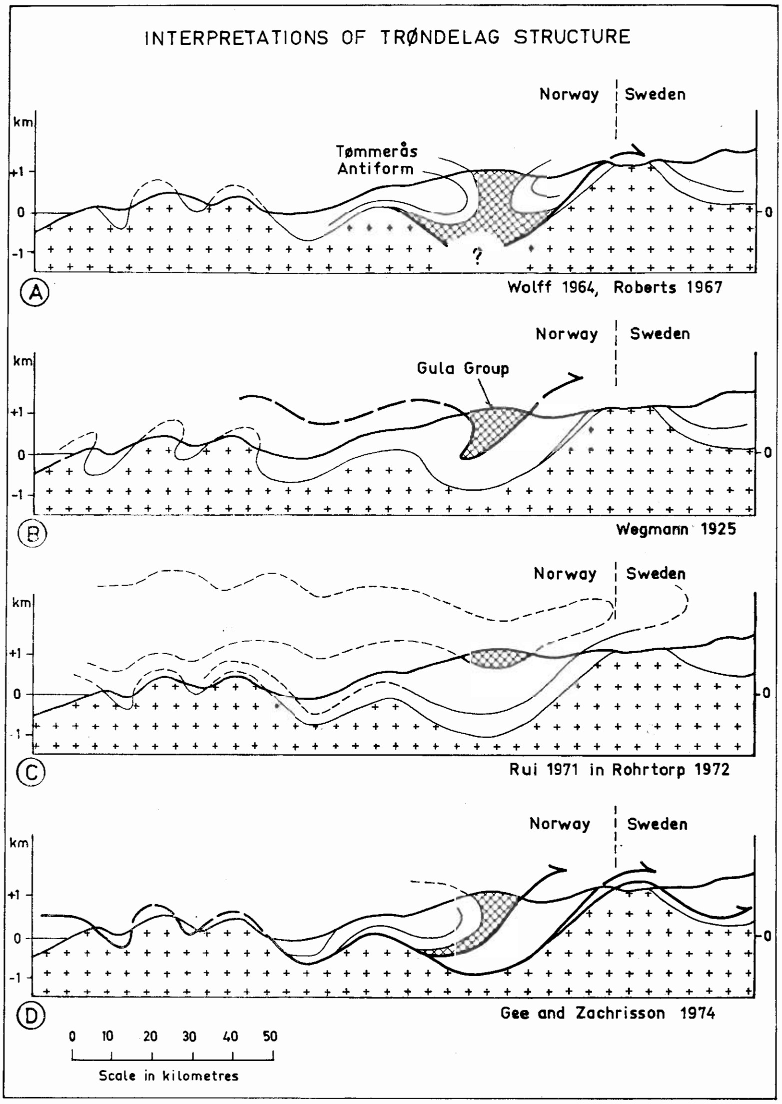

Fig. 9. Sketch reconstructions of alternative interpretations of the Trøndelag structure, all projected into the same central profile through the Geotraverse from the Norwegian west coast to the border with Sweden.

Fig. 9 D was proposed by Gee and Zachrisson (1974) to explain their reinterpretation of the eastern Trøndelag stratigraphy. They treated the entire section in the Meråker profile below the Gula Group as Silurian and therefore placed an important tectonic contact separating the Gula and Fundsjø Groups. They proposed that the geometry of this dislocation should be comparable with tectonic contacts between major rock units further east and that the units referred to the Trondheim Supergroup here were contained in a separate major nappe possibly equivalent to the Rödingsfjäll Nappe.

Profile D satisfies the restrictions on interpretation imposed by the structural, stratigraphic and metamorphic patterns further east. Undeniably, it raises major problems of local interpretation in Trøndelag. It interprets a contact mapped as of primary pre-tectonic origin to be of major tectonic importance (the contact between the Gula and Fundsjø Groups). Stratigraphical considerations led Gee and Zachrisson (1974) to allow this tectonic contact to cut through the Fundsjø Group south of Meråker to join a mylonite zone east of the Hyllingen Gabbro. An alternative solution is shown in Plate I, where the major tectonic discontinuity is placed within the Gula Group, above the Gudå conglomerates and close to the Fundsjø Group contact. This solution accepts the Tremadocian (at least in part) age of the Fundsjø Group and requires that the tectonic superposition of the latter on the Sulåmo Group east of Tydal (Olesen et al. 1973) is a regional relationship applicable both north and south of the area in which the discontinuity has at present been recognized (cf. Rui 1972).

The evidence for the general allochthonous character of the Western Complex in Trøndelag (p. 38) requires a new assessment of the cover structures. Distinction is needed between structures related to the Western Complex nappes and their transport, and structures that deform the Eastern and Western Complexes together after nappe transport. As discussed earlier (Fig. 9) some authors have regarded the major structure in the Western Complex of Trøndelag as synclinal; others consider it anticlinal. The interpretation shown in Plates I and II avoids this controversy by following a modification of Gee and Zachrisson (1974). A regional tectonic discontinuity is inferred to separate the Trondheim and Köli Supergroups. The importance of this discontinuity is dependent on assessment of the extent to which Trondheim and Köli Supergroup successions can be correlated and the importance given to Lower-Middle Ordovician faunal affinities. Present evidence suggests fundamental differences between the Trondheim and Köli Supergroups and the two rock units are treated in separate major nappe complexes. No estimate of the amount of movement on this discontinuity is possible. It is argued elsewhere (Gee 1975) that the increasing similarity of stratigraphy and fauna in the upper parts of the two supergroups reduces the need for major translation.

Some of the major folds in the Western Complex of Trøndelag may also influence the underlying Eastern Complex (e.g. the Hegre Antiform of Roberts et al. 1970) Others such as the Heggsjøfjell fold (Springer Peacey 1964, p. 81), the geometry of which remains controversial (Roberts 1967), are clearly confined to the Western Complex and truncated at the basal thrust. The incompatibility of internal Western Complex structure and Eastern Complex structure has apparently inhibited most previous authors from drawing sections across Trøndelag.

Appreciation that the Western and Eastern Complexes are independent major tectonic units should lead to a clearer assessment of Western Complex internal major structure.

Assessments of the sequential development of the minor structures and their relationship to major structure within Trøndelag are to be found in most recent studies. Roberts (1967) described four fold phases in the Meråker profile, the first two being related to major folds. Early isoclines (F 1) were related to the Stjørdal Anticline and these were regarded as refolded by F 2 structures, the Teveldal Synform being treated as such. Thrusting was thought to occur at a late stage of F 2. Subsequently, Olesen et al. (1973) showed that Robert's F 1 Stjørdal Anticline passed south into the late-phase Selbu Antiform. General correlation of fold phases in Eastern Trøndelag apparently is not yet possible.

d. INTRUSION AND METAMORPHISM

Some of the intrusions into the Western Complex are spacially related to the volcanites, have suffered the effects of all recognizable tectonic episodes and in all probability were subvolcanic hypabyssal rocks directly connected with the volcanism. These apart, there occur a large number of major intrusive masses that are clearly discordant to early structures but are involved in the nappe translation. Along the Norwegian west coast, acid intrusions occur that are probably later than the nappe movement, (Ramberg 1944). The pre-orogenic intrusions have been mentioned earlier; the syn-orogenic intrusions are considered below after an outline of the metamorphism.

Goldschmidt (1916) presented a general map over the southern part of the Trondheim region showing the distribution of index minerals chlorite, biotite and garnet, the areas of sub-greenschist facies and the central area of high grade gneisses (in the Gula Group). In addition he presented the evidence for local contact metamorphism around some of the major intrusive masses. Similar data is not available for the northern part of the Geotraverse. Metamorphic grade in general increases downwards through the stratigraphy of the Trondheim Supergroup but this generalization is not entirely secure due to the uncertain status of the Gula Group. The latter, in central Trøndelag, attains the highest grades recorded in the area, with a normal Barrovian sequence through biotite, garnet, staurolite and kyanite to sillimanite (Olesen et al. 1973).

In the Swedish-Norwegian border zone along the Sylarna Antiform the metamorphic grade of the Western Complex clearly exceeds that of the window rocks. Along the Norwegian west coast (Ramberg 1944 and 1973) metamorphic grade apparently increases downwards gradationally from the Western to the Eastern Complex. The relationships between metamorphism of the Western Complex cover and the Eastern Complex elsewhere in Trøndelag is not clear from the literature. As far west as the Tømmerås Antiform it is claimed that the Western Complex cover rocks are of higher metamorphic grade than the basement (Gee 1974).

Discussion of the relationship of metamorphism to folding is complicated by the lack of agreement over the correlation of the fold phases in Trøndelag, as mentioned above. Suffice it to say that most authors (Roberts et al. 1970, Birkeland and Nilsen 1972, Olesen et al. 1973) are agreed that the early folding of the Western Complex rocks occurred prior to the climax of regional metamorphism and that important refolding, partly accompanying this metamorphism and partly later, was related to nappe translation

The major intrusive masses in the Western Complex are dominated by two types, gabbros and trondhjemites. Some of the gabbro masses of eastern Trøndelag (Kisch 1962, Nilsen 1973, Olesen et al. 1973) show rhythmic and cryptic layering and are well documented as major layered intrusions. A thickness of five kilometres has been specified for the Fongen massif (Olesen et al. 1973). These huge basic intrusions show minor intermediate and acid differentiates (Nilsen 1973). In some cases they are spacially related to the major trondhjemite masses. The relationship between intrusion of the major gabbros and the folding and metamorphism has been described recently by Birkeland and Nilsen (1972) and by Olesen et al. (1973). Contact aureoles containing cordierite, andalusite and sillimanite have been described and the relationship of these to the regional metamorphic pattern has allowed the conclusion that intrusion preceeded the climax of regional metamorphism. Olesen et al. (1973) maintained that the earliest folding occurred prior to the intrusion, whereas Birkeland and Nilsen (1973) allow the possibility of pre-tectonic intrusion.

Detailed, local studies of metamorphic parageneses in the Western Complex have lead to differing interpretations of the temperature and pressure of regional metamorphism and the relationship of the latter both to basic intrusion and migmatization. Thus Dudek et al. (1973, p. 10), from a study of the Færen area north of Meråker, refer to a "Barrovian-type facies series of low to intermediate pressure". They described migmatization to be later than the growth of regional staurolite and some garnet but did not comment on the relationships to kyanite, which occurs sporadically in the migmatites. Further south demonstration by Olesen et al. (1973) of a normal Barrovian sequence appears to be representative of central Trøndelag in general. Thus the Western Complex in Trøndelag yields evidence of early folding and intrusion, depression and Barrovian-type regional metamorphism, and then upthrusting on to the Eastern Complex. Along the Norwegian west coast the Eastern and Western Complexes were metamorphosed together after translation of the Western Complex. The metamorphism of the Trondheim Supergroup contrasts notably with that of the Seve-Köli Nappe Complex further east where the presence in the Seve of pyroxene amphibolites and eclogites (locally) implies crystallization under higher pressures.

e. TIMING OF WESTERN COMPLEX DEFORMATION

There has been a tendency in the literature on the Scandinavian Caledonides to import the names of orogenic episodes from elsewhere in the Caledonian-Appalachian orogen (e.g. Taconic, Acadian, Grampian, Svalbardian etc.) and apply them to "disturbances" as indicated by the presence of conglomerates in the Western Complex successions, or to "orogenic events" as testified by isotopic age-determinations (Sørøy). This practice is apparently based on the assumption that pulses of deformation should be synchronous throughout an orogenic belt. Yet the diachronous nature of some of these imported orogenic events is established even within their type areas (e.g. in the case of the Taconic, Rodgers 1971). Biostratigraphic evidence in Scandinavia is, in general, inadequate to make these correlations. Modern tectonic theory, with the evidence of irregular plate margins and a continuous process of production and destruction of crustal material, hardly supports the probability of synchroneity of deformation.

Orogenic deformation of the Western Complex with folding metamorphism and thrusting on to the Eastern Complex commenced and ended in the Silurian (Gee and Wilson 1974) as witnessed in the biostratigraphic record of the complex itself and the overlying late-orogenic sediments. Translation of Eastern Complex units continued into the Devonian. This orogeny occurred over a timespan apparently unrelated to the major orogenic (Grampian) events in the Western Caledonides. Whether or not these western phenomena influenced the Baltoscandian margin (or the rocks of the "Upper Nappe" derived from west of this margin) needs investigation.

LATE-OROGENIC SEDIMENTS

Late-orogenic sediments occur within the Geotraverse in two areas, the one along the Norwegian coast in the vicinity of the island of Hitra and the other near the Norwegian-Swedish border at Røragen. In both areas, coarse, fluviatile sandstones and conglomerates contain abundant clasts of the adjacent and underlying metamorphosed rocks. Deposition occurred in intramontane basins after extensive erosion of the Western and Eastern Complexes and removal of at least some ten kilometres of overburden.

a. HITRA AND NEIGHBOURING AREAS

Early mapping of this part of the Geotraverse by Reusch (1914) established the presence of a post-metamorphic sandstone and conglomerate sequence containing fossils of Devonian age. Subsequent investigations established a narrow belt of continental sediments occupying a trough somewhat over a hundred kilometres long and stretching from Smøla in the south to Ørlandet in the north.

These rocks were shown to contain fossils ranging from probable Downtonian age (Størmer 1935) on Hitra to Early and Middle Devonian (Vogt 1929, Høeg 1945) on the neighbouring islands.

Siedlecka and Siedlecki (1972) described the Hitra sequence of conglomerates, sandstones and mudstones some 1 300 m thick. A basal breccia and conglomerate passes up through feldspathic sandstones into a thick arkose, overlain by an arkose and dark mudstone unit. It was in these dark mudstones that the Dictyocaris specimens were collected and dated as of probable Downtonian age. Channel conglomerates are present in these fine sediments and the latter are overlain by coarse conglomerates.

In other parts of this trough of continental late-orogenic sediments, conglomerates dominate and appear to be younger than the sediments of Hitra. On the island of Smøla, Peacock (*in* Allen et al. 1967) described c. 3 700 m of conglomerates of Early and Middle Devonian age. North of Hitra, a Middle Devonian flora has been described (Høeg 1945) in similar but apparently thinner sections.

b. RØRAGEN

A small outcrop area (some ten square kilometres) of post-metamorphic conglomerates and sandstones occurs near the lake Røragen in the vicinity of the Norwegian-Swedish border in the southern part of the Geotraverse. Goldschmidt (1913) collected plant fossils which were identified as Devonian, and later (Halle 1916, Høeg 1936) established them to be of Lower Devonian age. The sequence, nearly a kilometre thick, contains a basal conglomerate passing up into sandstones and subordinate shales and then into a thick breccia and conglomerate. Holmsen (1963) mentioned low grade metamorphism of the Røragen sediments, suggesting the existence of a substantial Devonian pile prior to later erosion.

c. DISCUSSION

The post-metamorphic sediments described here were clearly deposited after very substantial erosion of the orogenic belt at a time when the orogen was still being uplifted. Intramontane deposition contrasted with the extramontane environments of similar "Old Red Sandstones" further south in the mountain belt (Nilsen 1973). Whereas the intramontane units are post-orogenic in the sense that they were deposited on, and contain clasts of the high grade metamorphic rocks of the orogen, the extramontane units were involved in the main phase of the Caledonian deformation as it occurred in the Caledonian Front. There is some uncertainty over the precise age of the oldest (Hitra) intramontane sediments (Heintz 1969, Gee and Wilson 1974) but it is very probable that they are at least in part contemporaneous with the pre-orogenic estuarine and fluviatile sediments (Ludlovian and Downtonian) of the Oslo area (Ringerike sandstones).

Deposition in the intramontane basins apparently occurred during the advancements of the nappes, at least during the movement on the Eastern Complex décollement. Advancement of the nappes thickened the pile, established substantial topographic relief, leading to erosion and providing a source for material deposited both westwards into the intramontane basins and eastwards into the pre-tectonic extramontane basins.

The trough of sandstones and conglomerates along the Norwegian coast is extensively faulted. Røragen conglomerates are folded and thrust south-westwards along their eastern margin (Holmsen 1963). Elsewhere, in the south-west Scandinavian Caledonides the Old Red Sandstones are extensively thrust (Nilsen 1968), the distances of translation being uncertain. These sediments are thus of late-orogenic, not post-orogenic character. All this evidence favours the pattern suggested above of continued easterly translation during the Devonian. The movements have been referred to as Svalbardian (Vogt 1928). The suggestion that this deformation has any relationship in character or timing with the Svalbardian movements (Gee 1972b) in the type area on Spitsbergen is insecure.

DEEP STRUCTURE

Our general knowledge of the deep structure of the Geotraverse is based on interpretation of the regional gravity anomalies, aeromagnetic anomalies and deep seismic refraction data.

A Bouguer anomaly compilation over the Geotraverse is shown in Fig. 10 based on anomaly maps presented in Wideland (1951), Grønlie and Ramberg (1970) and Kanestrøm and Haugland (1971). Large amplitude (up to c. —100 mgals) negative anomalies in general coincide with the topographic highs in the vicinity of the Norwegian-Swedish border, decreasing to zero along the Norwegian coast and c. —20 to —40 mgals in the Caledonian Front. They indicate a general isostatic balance across the mountain belt.

The magnetic data is based on flight measurements made during a regional magnetic survey of Scandinavia ("Aeromagnetic Survey of Denmark, Finland, Norway and Sweden") in 1965. The area was covered with a line spacing of 35 km and a flight altitude of c. 3 km a.s.l. A very marked total intensity and vertical Z-component positive anomaly was located over the Geotraverse (Fig. 11) trending from the Grong-Olden Culmination southwards into the area of sub-Jotnian igneous activity south of the Geotraverse.

In 1969 as part of a regional investigation of deep structure in Scandinavia (Dahlman 1971), seismic refraction studies were carried out in profiles, one of which crossed the Geotraverse approximately from Trondheim to Östersund (profile marked in Fig. 10). Vogel and Lund (1971) have presented a preliminary

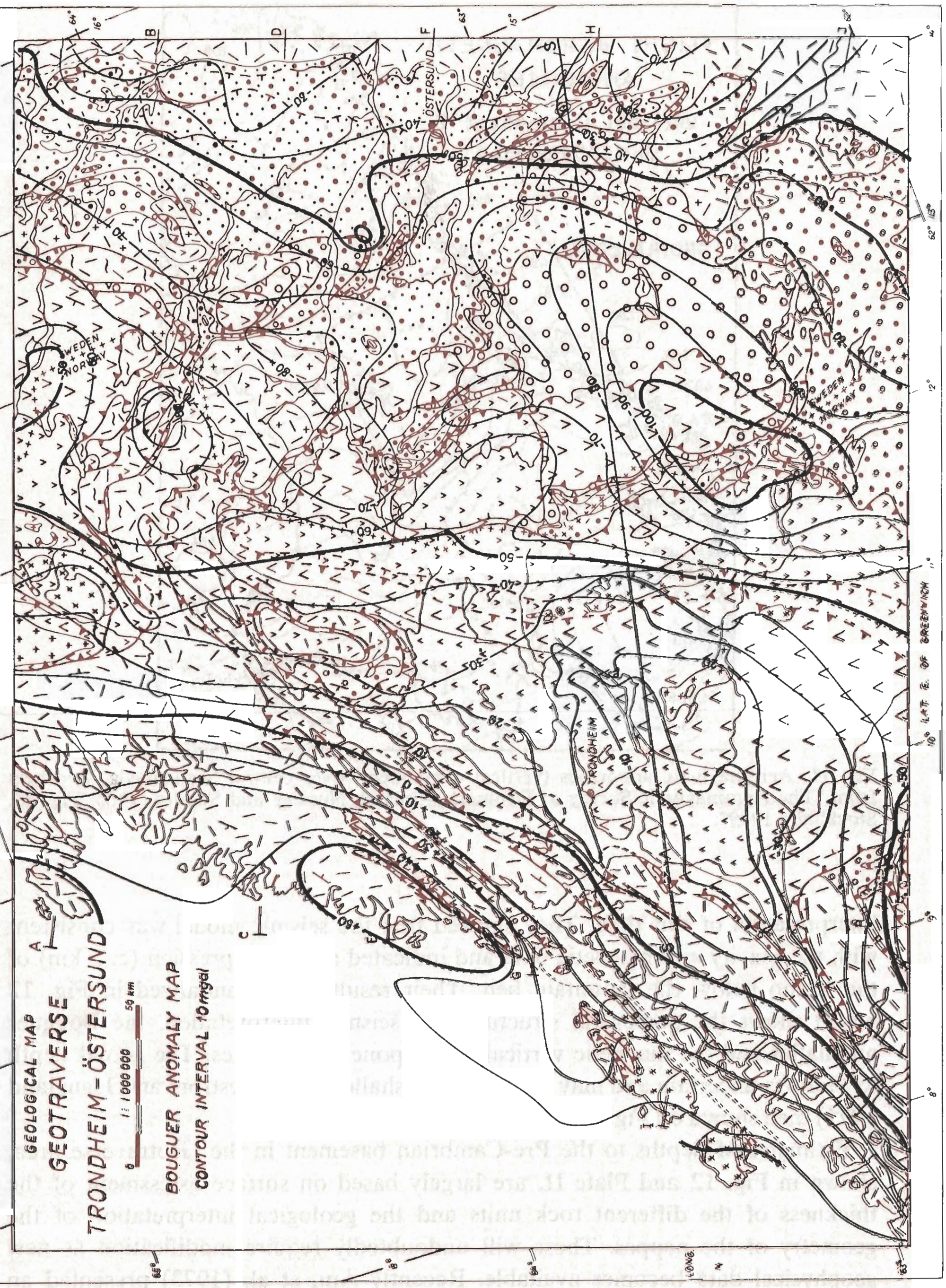

Fig. 10. Bouguer Anomalies over the Geotraverse area. Compilation based on Wideland (1951), Grønlie and Ramberg (1970) and Kanestrøm and Haugland (1971). The line S-S marks the location of the deep seismic profile (Vogel and Lund 1972).

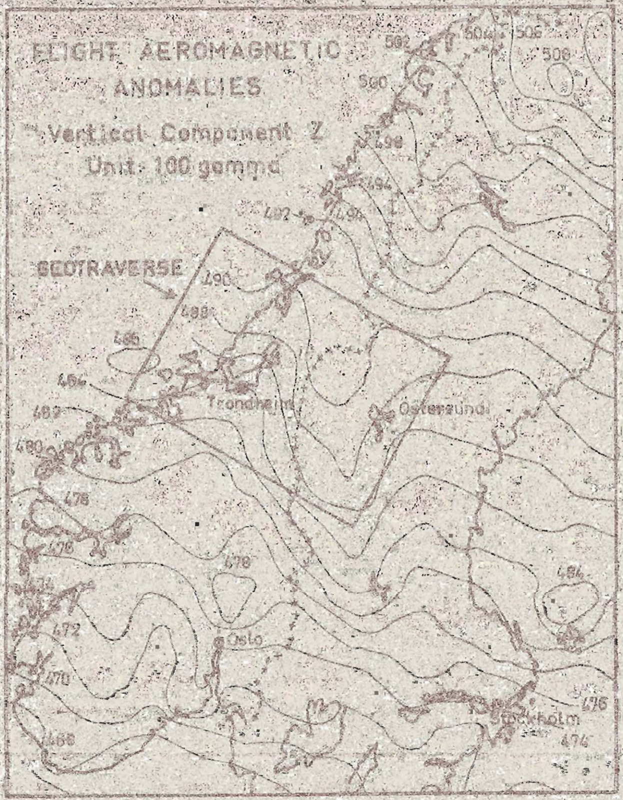

Fig. 11. Aeromagnetic anomalies (vertical component) over central Scandinavia. Redrawn from "The Aeromagnetic Survey of Denmark, Finland, Norway and Sweden, 1965, Fig. 23, Stockholm 1969".

interpretation of this data. They showed that the seismic model was consistent with the gravity and magnetic data and indicated a clear depression (c. 5 km) of the Moho below the mountain belt. Their results are summarized in Fig. 12 which shows the geological structure, the seismic interpretation, the Bouguer anomalies and the magnetic vertical Z-component anomalies. The actual depth to Moho is uncertain and may be 5—10 km shallower (Kanestrom and Haugland 1971) than shown on Fig. 12.

Estimates of depths to the Pre-Cambrian basement in the Geotraverse area, shown in Fig. 12 and Plate II, are largely based on surface assessment of the thickness of the different rock units and the geological interpretation of the geometry of the nappes. These will undoubtedly require modification as new geophysical data becomes available. Recently Am, et al. (1973) presented an interpretation of gravity data from the Horg area, near Trondheim, indicating that the Horg Syncline extends to a depth of at least ten kilometres i.e. over twice

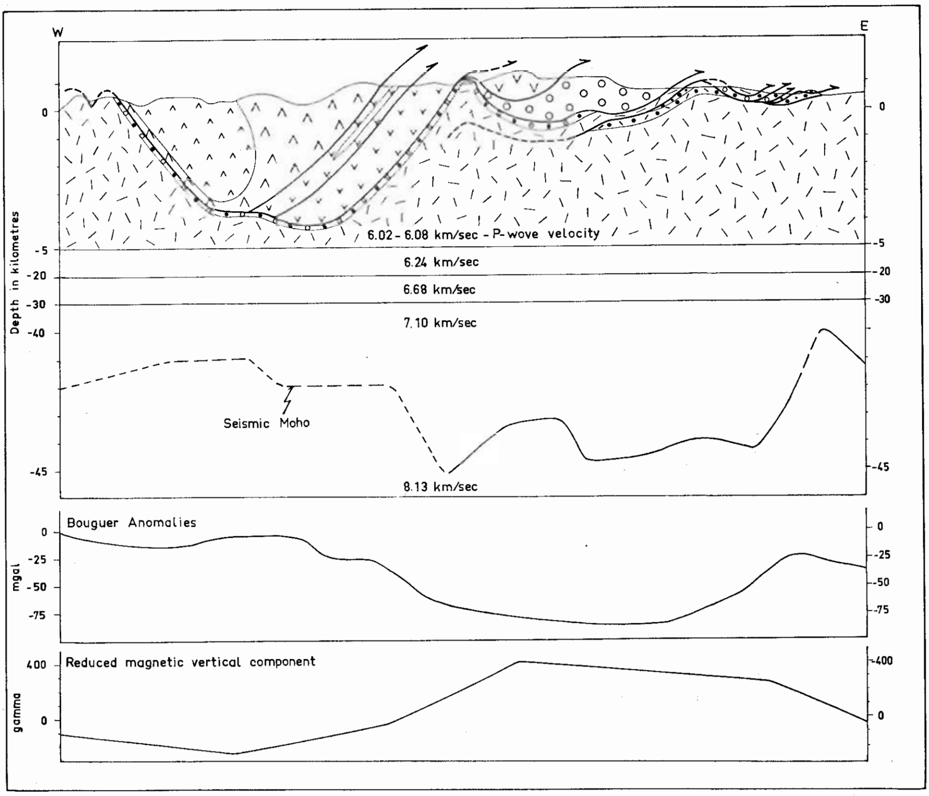

Fig. 12. Comparison of the geological profile S-S with the geophysical data (Vogel and Lund 1971). Symbols as on Plate I.

the depth shown on Fig. 12. It is also clear from the Bouguer anomalies over the central part of Trøndelag that the relative high, relatable at least in part to the thick development of basic volcanic rocks may require a greater depression of the Trøndelag Synform than shown on Fig. 12.

It is of interest to assess the character of the Caledonian rocks west of the Geotraverse area, particularly in view of a conclusion that the Western Complex has been derived from west of the Norwegian coast. Magnetic measurements over the shelf and Vøring Plateau were interpreted by Åm (1970) and gravity data by Grønlie and Ramberg (1970). Talwani and Eldholm (1972) summarized the general geophysical data, gravity, magnetic and seismic, obtained along the Norwegian continental margin. Basement, either Pre-Cambrian crystalline rocks or Lower Palaeozoic metamorphic rocks underlie a large area offshore from Trøndelag, extending westwards some 500 km to the Vøring Plateau escarpment. This basement is overlain by a variable, few kilometres of Tertiary, Mesozoic and possibly older sediments. Magnetic strip anomalies indicative of oceanic crust, appear along the western margin of the Vøring Plateau.

Talwani and Eldholm (1972 p. 3575) drew attention to "A nearly continuous belt of positive gravity and magnetic anomalies that exists just landward of the edge of the shelf attributed primarily to intrabasement density contrasts in rocks that are probably Precambrian in age. It extends from Scotland to the Lofoten-Vesterålen islands". These anomalies in the vicinity of Northern Scotland can be related to the character of the Lewisian basement. Thus the present geophysical evidence suggests that part of the Vøring Plateau may be underlain by non-Svecofennian crystalline basement related to the western (Greenlandian) front of the Caledonides. This evidence is consistent with the conclusion that the uppermost part of the Western Complex (including the Trondheim Supergroup) was derived from a position (in the Ordovician) closer to the Greenlandian continent than to the Baltoscandian.

CONCLUDING REMARKS

The geological evidence outlined above allows an attempt (Fig. 13) to restore the rock units to their pre-orogenic positions. This restoration is fundamental to an interpretation of the mechanism of orogenic deformation (Ramberg 1966) in this part of the Caledonides and it can be hoped that during the coming years of concentrated research within the Geotraverse a more precise restoration can be achieved. Restoration of the nappes is also a prerequisite for assessment of the pre-orogenic history and the construction of a model for the evolution of the Geotraverse Caledonides (Gee 1975).

Fig. 13 presents a section through the Geotraverse and a restoration of the nappe units. The restoration accepts that the nappe geometry is sufficiently well established to allow confident estimates of minimum shortening. One of the most critical factors influencing this restoration is the assessment of a root-zone for the lowest unit of the Western Complex — the Särv Nappe. In the restoration it is placed just west of the Eastern Complex units now located along the Norwegian west coast, on the basis that basic dyke rocks in this underlying Complex along the Atlantic coast, although apparently increasing in number westwards are not developed as a swarm. This choice of a Särv root-zone places important constraints on the pre-tectonic location of the overlying Seve-Köli Nappe Complex and the "Upper Nappe". Translation of the former on to the Särv Nappe exceeds c. 70 m. The actual displacement is probably substantially greater in view of the contrasted metamorphic condition of the Särv and Seve.

Within the Seve-Köli Nappe Complex there is evidence of tectonic repetition, implying considerable shortening and abundant evidence of extension in a direc-

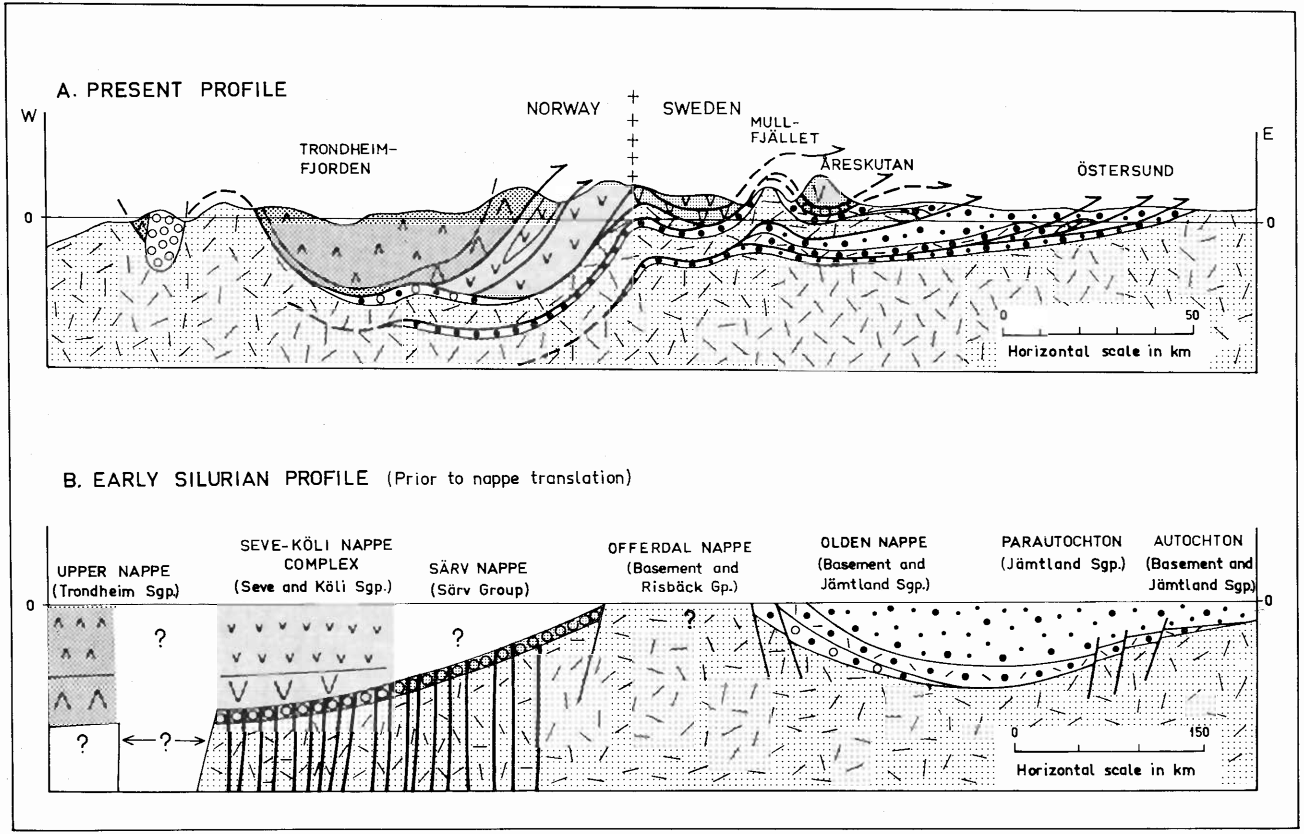

Fig. 13. Comparison of the present Geotraverse profile and the pre-orogenic (early Silurian) profile. Symbols as on Plate I.

tion more or less parallel to the nappe translation. We have as yet no adequate assessment of the extent to which the shortening within the nappe may be compensated by the stretching.

The Upper Nappe requires restoration to some location west of the Seve and Köli Supergroups. Speculation as to the root-zone for this nappe depends very much on the importance attributed to the faunal evidence (p. 38), assessment of the environment of deposition of the succession, character of the volcanic rocks etc. — lines of evidence which are at present under investigation.

Evidence of shortening within the Eastern Complex also significantly influences the pre-tectonic model. Translation of the Offerdal Nappe at least 120 km eastwards, added to the evidence of translation of the Olden Nappe and Jämtland décollement requires at least 200 km of crustal shortening. The most probable interpretation of the relationship between the Olden Nappe and the Jämtland décollement shown in Plate II and Fig. 13 requires that Eastern Complex shortening should exceed 300 km. Thus the total shortening across the Geotraverse must be in the order of 500 km and may very well be substantially in excess of this figure.

Replacement of these nappe units westwards requires their extension far on to the Vøring Plateau west of Trøndelag. If the conclusion is correct that the western part of Vøring Plateau is underlain by the eastern edge of the old Greenlandian craton contacting the Baltoscandian craton some 50—100 km offshore then either the units of the Seve-Köli Nappe Complex were deposited on Greenlandian basement or there has been substantial (at least of few hundred kilometres of closure between the two cratons after deposition of the Köli, with thrusting of the latter from a position between the presently existing cratons. Whereas the faunal evidence from the Trondheim Supergroup suggests a location on or marginal to the Greenlandian craton in the Early Ordovician, the Köli evidence, though limited, requires a Baltoscandian proximity. Thus the second alternative is preferred and it is inferred that the crustal shortening can be accepted as favouring greater physical separation of the Greenlandian and Baltoscandian cratons prior to orogeny. The implication of this conclusion is that the closure of these cratons was related to the orogenic process. These lines of evidence need critical reinvestigation. Should they be substantiated they provide important, independent support for the hypothesis that Caledonian orogenesis was the result of continental collision; support for the application of plate tectonic theory to the early Phanerozoic (Dewey 1969).

The Late Silurian and Devonian successions of the intra- and extramontane basins provide the critical evidence for the progressive translation of the nappes south-eastwards on to the Baltoscandian platform. This translation started after the Llandoverian in the case of the Seve-Köli Nappe Complex but may have been somewhat earlier (but still probably Silurian) for the Upper Nappe. Accepting a Ludlovian age for the Hitra late-orogenic conglomerates and sandstones it can be concluded that translation of the Western Complex had ceased prior to the end of the Wenlockian and that most of the Western Complex translation must have been achieved during the Wenlockian. South of the Geotraverse in the Mjøsa area, a sandstone facies follows the Wenlockian limestones, appearing slightly earlier than in the Oslo area (Ludlovian) and apparently derived from a north-westerly source (Whitaker 1965). This source area coincides with the area of advancing nappes and suggests that the translation of the Eastern Complex nappes was accompanied by a marked increase in topographic relief, a delta fan spreading south-eastwards in front of the nappes. Not until after the Downtonian did the frontal décollement reach the Oslo area, with the accompanying folding of the extramontane basin.

Approximate estimates can be made of the average rate of translation of the nappes, accepting translation distances of c. 500 km and a period for translation from the early Silurian to the early Devonian. Such estimates, say 1—3 cm/year, are of an order of magnitude comparable with present rates of plate construction and destruction, lending further support to the proposal that plate tectonic theory can be usefully applied to the Caledonian cycle.

ACKNOWLEDGEMENTS

The Swedish Geodynamics Project is supported by annual grants from the Swedish Natural Science Research Council. Although this paper is essentially based on material available prior to the start of the project, the geological synthesis has been influenced by my own field studies during the first year of the project; financing of this work is gladly acknowledged.

I am indebted to my colleagues, particularly those directly involved in the Caledonian Research Project whose interest and discussion have influenced this presentation. An early draft of the manuscript was reviewed by Doc. A. Strömberg and Dr. E. Zachrisson and the final draft has benefited from many of their suggestions. The paper has also benefited from general discussion with Dr. G. Kautsky and Prof. H. Ramberg. Mrs. S. Järnefors redrew the diagrams and Plates. All have my sincere thanks for their contribution.

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GFF = Geologiska Föreningens i Stockholm Förhandlingar
NGT = Norsk Geologisk Tidsskrift
NGU = Norges geologiske undersøkelse
SGU = Sveriges geologiska undersökning

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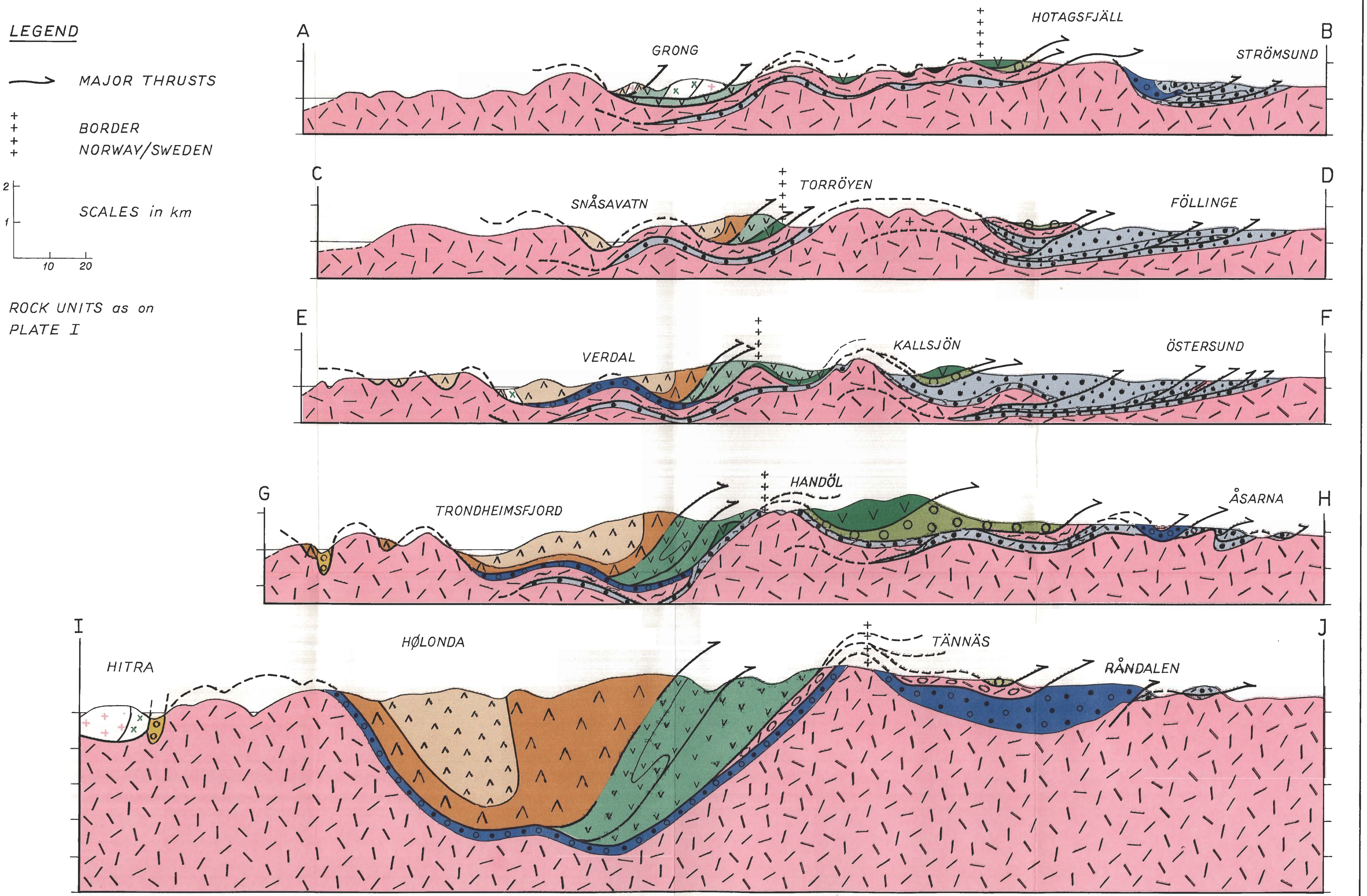
PLATE II

SKETCH SECTIONS WNW–ESE THROUGH THE GEOTRAVERSE AREA



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