SVERIGES GEOLOGISKA UNDERSÖKNING

SERIE C NR 774 AVHANDLINGAR OCH UPPSATSER ÅRSBOK 74 NR 2

DAVID G. GEE AND RISTO KUMPULAINEN

AN EXCURSION THROUGH THE CALEDONIAN MOUNTAIN CHAIN IN CENTRAL SWEDEN FROM ÖSTERSUND TO STORLIEN

WITH 1 PLATE

GUIDE TO EXCURSION NO 003A OF THE
26TH INTERNATIONAL GEOLOGICAL CONGRESS
PARIS 1980

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INTERNATIONAL GEODYNAMICS PROJECT

SWEDISH GEODYNAMICS PROJECT –
CALEDONIAN RESEARCH PROJECT

PREFACE

During the last decade, the Caledonian Research Project of the Swedish Geodynamics Project has organized a number of excursions through the central part of the Scandinavian Caledonides from Östersund to Trondheim. Unpublished excursion guides have been compiled to which a variety of authors have contributed; in this context, in the Swedish part of the profile, we have particularly benefited from the experience of A. Strömberg, P. Thorslund and E. Zachrisson. This excursion guide has grown out of the earlier editions and incorporates a range of more recent data including specific ''stop descriptions'' by J.-O. Arnbom, M. Beckholmen, S. Claesson, L. Karis, K. Larsson, H. Sjöström and S. Tirén. We are greatly indebted to them for their contributions which are identified specifically in the text. Future reference to particular stops in the guide should be accredited to the specified authors.

The Caledonian Research Project was financed by the Swedish Natural Science Council. The project was also promoted by the Geological Survey of Sweden. We are glad to have the opportunity to acknowledge this support.

This guide has been produced for Excursion No 003 A of the 26th International Geological Congress in Paris 1980 at the request of the organizers.

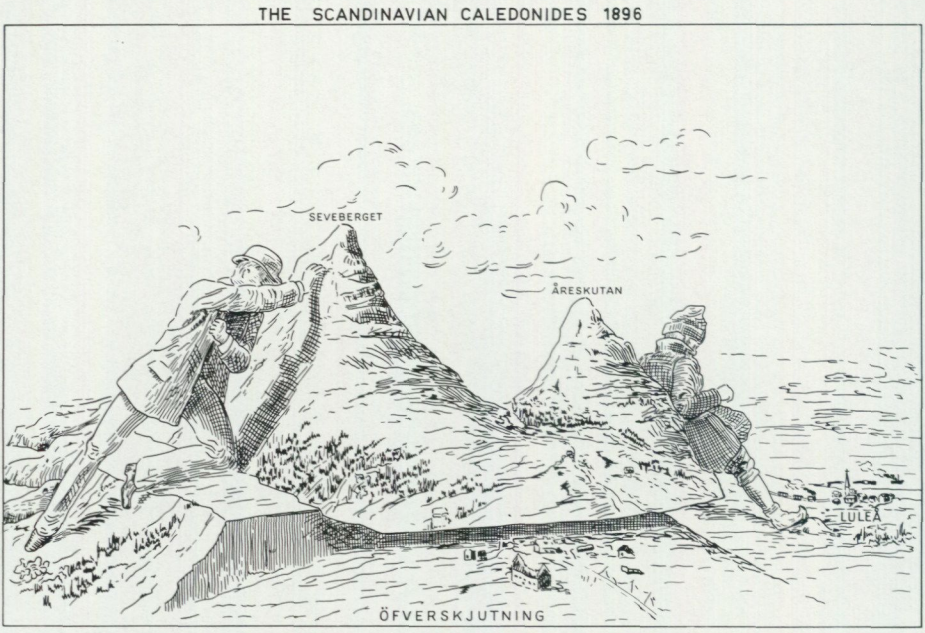

Fig. 1. The Caledonian controversy towards the end of the last century, personified in Törnebohm to the left and Svenonius to the right. This cartoon has been redrawn by S. Järnefors from the original by E. Erdmann (alias En Elak), drafted by P. Röding and circulated at the dinner celebrating the 25th anniversary of the Geological Society of Stockholm in 1896.

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ABSTRACT

The central part of the Scandes, from Östersund in Sweden to Trondheim in Norway, is the classical area for the application of nappe theory in the Scandinavian Caledonides. It was in areas of Sweden, in the western part of central Jämtland County, that Törnebohm, towards the end of the last century, first recognized important thrusting and provided the evidence for the vast displacement of the higher tectonic units of the Scandian allochthon. The nappe pile is composed of a variety of relatively thin, thrust sheets, derived from miogeoclinal and eugeoclinal environments and transported eastwards on to the Baltoscandian Platform; these nappes can be subdivided into three categories, referred to as the Lower, Middle and Upper Allochthon. The underlying autochthonous Precambrian crystalline basement and Cambro-Ordovician sedimentary cover of the thrust front dips very gently westwards beneath the allochthon. Further west this basement, together with the allochthon, is folded by late-orogenic, major, open, N-trending antiforms and synforms; within some of the antiforms, sections are exposed from the parautochthonous basement core, through the nappe pile, to the Upper Allochthon.

The excursion starts in the eastern front of the orogen in the Autochthon and traverses westwards, examining the various nappe units. Attention is concentrated to the regional tectono-stratigraphy and the criteria for recognizing the considerable nappe displacements. The eastern sedimentary successions of Cambro-Silurian age in the lower tectonic units are the focus of the first two days of the traverse. Thereafter, the excursion largely concerns the Middle and Upper Allochthon, examining the extensive mylonites of the Offerdal and associated nappes, the remarkable dyke-swarm of the Särv Nappes, the granulite and amphibolite facies schists, gneisses, metabasites and migmatites of the overlying Seve Nappes, and the highest allochthon (Köli) of greenschist facies metasediments. The excursion is planned to last for four and a half days and takes the geotraverser from Östersund as far as Storlien on the border with Norway; a continuation of the traverse westwards to the Atlantic Coast is published elsewhere.

GENERAL INTRODUCTION

The mountains of western Scandinavia provide a variety of particularly instructive sections through an orogen; an orogen dominated by nappe tectonics. Tertiary uplift and erosion of the Scandes has exposed relationships between the Precambrian crystalline basement and the overlying Caledonian cover from the autochthon of the eastern front, westwards, via the numerous windows, to the Norwegian west coast, a distance of up to three hundred kilometres (Fig. 2). This deep level of erosion allows control of nappe geometry and tectono-stratigraphic correlation through the orogen. The conditions are thus unusually favourable for assessing the extent and timing of nappe translation, these being prerequisites for understanding the dynamics of Caledonian orogenesis.

This excursion concerns the central Scandes (lat. 63–64°N), the classical area for the development and application of nappe theory in Scandinavia. The area has provided a

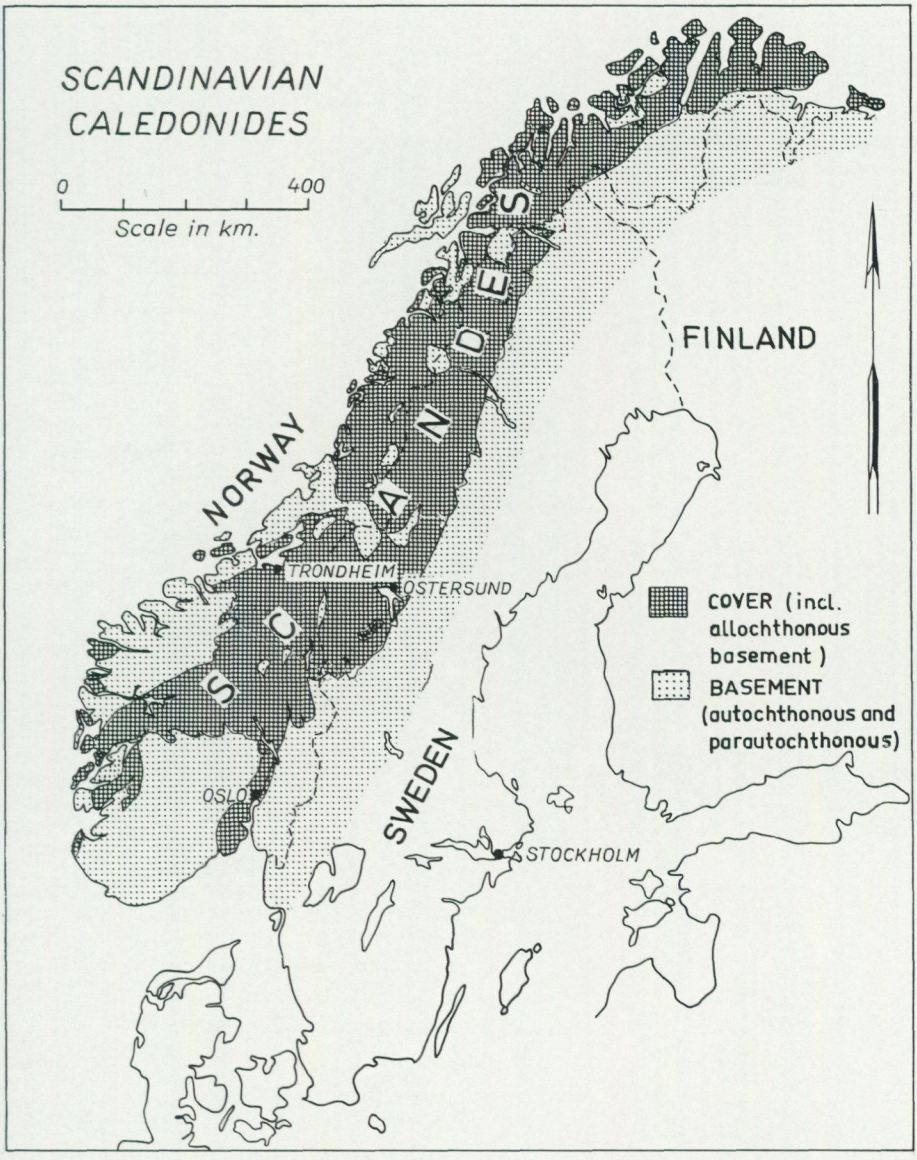

Fig. 2. Relationships between the Precambrian crystalline basement (autochthonous and parautochthonous) and its Caledonian cover (largely allochthonous).

focus for geological research during the last hundred and twenty years and has naturally been frequented by numerous excursions, most notably in the contexts of the 11th (Stockholm 1910) and 21st (Copenhagen 1960) International Geological Congresses. This guide describes the eastern part of a traverse through the orogen from

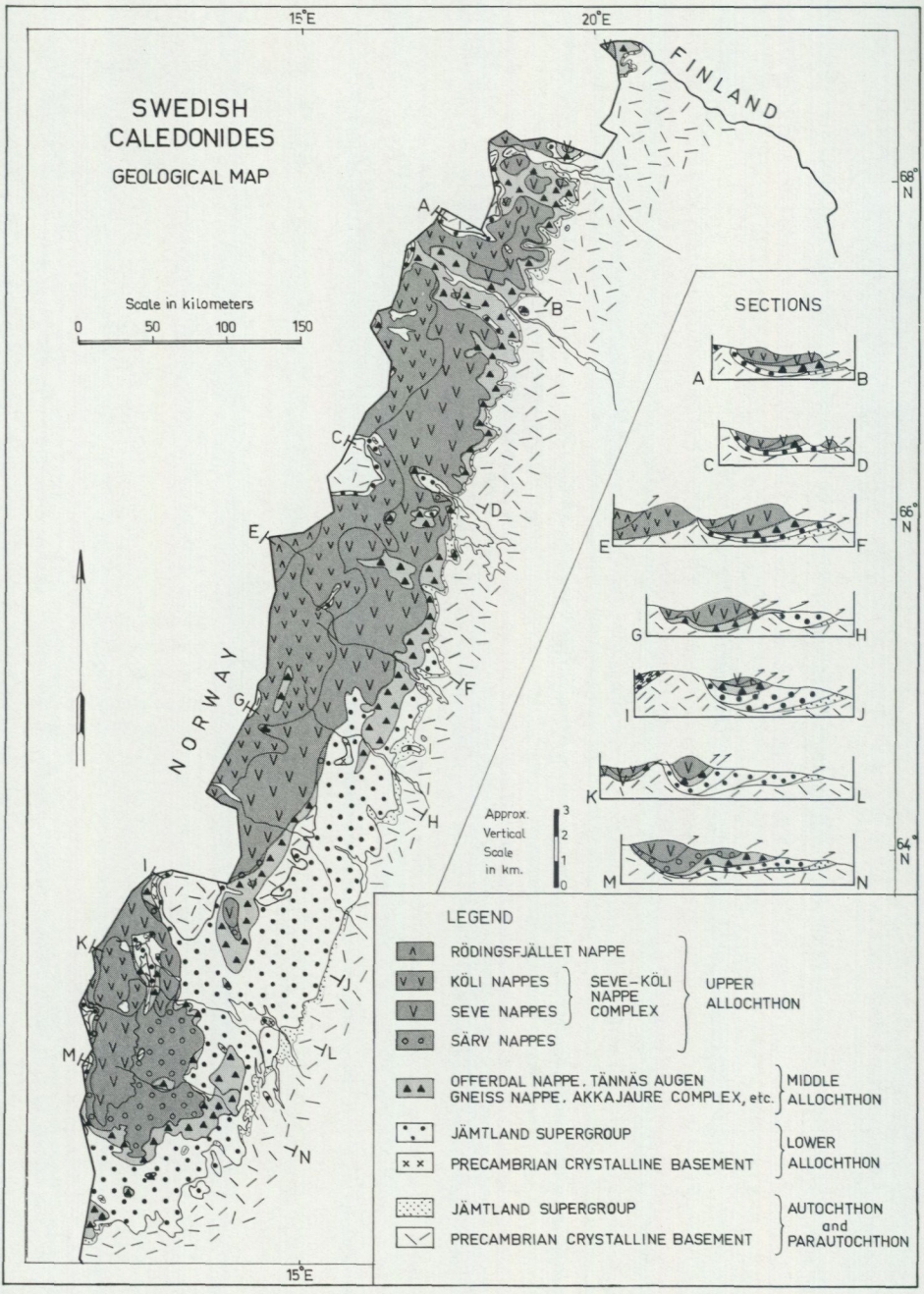

Fig. 3. Geological map of the Caledonides in Sweden (based on Gee and Zachrisson 1979 with minor revision).

Östersund via Storlien to Trondheim and the Norwegian west coast, a distance of about 250 km. The western, Norwegian part of the section is treated separately (Wolff in press).

A general review of the Caledonides in Sweden has been provided recently by Gee and Zachrisson (1979); the reader is referred to that source for a more comprehensive summary of regional structure and references to previous literature. As is apparent from the map and sections (Fig. 3), the Swedish Caledonides contain a variety of nappes (treated in three categories, the Lower, Middle and Upper Allochthon), thrust eastwards over the Precambrian crystalline basement with its very thin veneer of latest Precambrian and Early Palaeozoic cover sediments. The nappes thin westwards and the majority, the Upper, Middle and even parts of the Lower Allochthon, are derived from west of the international border with Norway. The Lower Allochthon is composed of late Precambrian and Cambro-Silurian sediments. The Middle Allochthon is dominated by Precambrian crystalline rocks, generally cataclastically deformed and extensively mylonitized, along with sandstones probably of late Precambrian age. The Upper Allochthon differs from the underlying units in containing widespread evidence of Caledonian (sensu lato) igneous activity; it is composed of a variety of nappes derived from the Precambrian crystalline basement, the miogeoclinal cover and, in the highest tectonic units, volcano-sedimentary associations of eugeoclinal aspect.

Geological reconnaissance of the central Scandes in the middle of the last century established the approximate distribution of the various lithologies, recognizing the presence of fossiliferous Cambro-Silurian successions in the east and more highly deformed and metamorphosed rock units in the west. In the late eighteen-sixties (Törnebohm 1884) a variety of localities were discovered where massive quartzites and mica schists were found to overlie fossiliferous sediments. These remarkable relationships led Törnebohm to concentrate his attention to the vicinity of Åreskutan, one of the highest mountains in western Jämtland (Fig. 4), where he was quickly able to demonstrate (Törnebohm 1872) that the structure was essentially synformal and that the schists, gneisses and migmatites on the mountain top overlay fossiliferous shales and limestones in the valley. Subsequent mapping demonstrated the regional extent of this superposition (Törnebohm 1896) of metamorphosed rocks over fossiliferous sediments; yet the very scale of the phenomenon inhibited an interpretation that for us today is readily applicable in most orogens.

Other authors with experience of northernmost Jämtland (e.g. Svenonius 1881) questioned the regional development of this superposition of high grade metamorphic rocks on the fossiliferous strata (hence Fig. 1). Indeed it was not until the late eighteen eighties that Törnebohm (1888) ''was bold enough to draw the necessary conclusions'' and present the ''overthrust theory'' (Högbom 1909, p. 291). Subsequent publication of the geological map of Jämtland (Högbom 1894) and of the central Scandinavian Caledonides in general (Törnebohm 1896) established the colossal dimensions of the so-called Great Seve Thrust. Movements of in the order of a hundred kilometres were irrefutable and Törnebohm regarded the allochthon to be derived from western

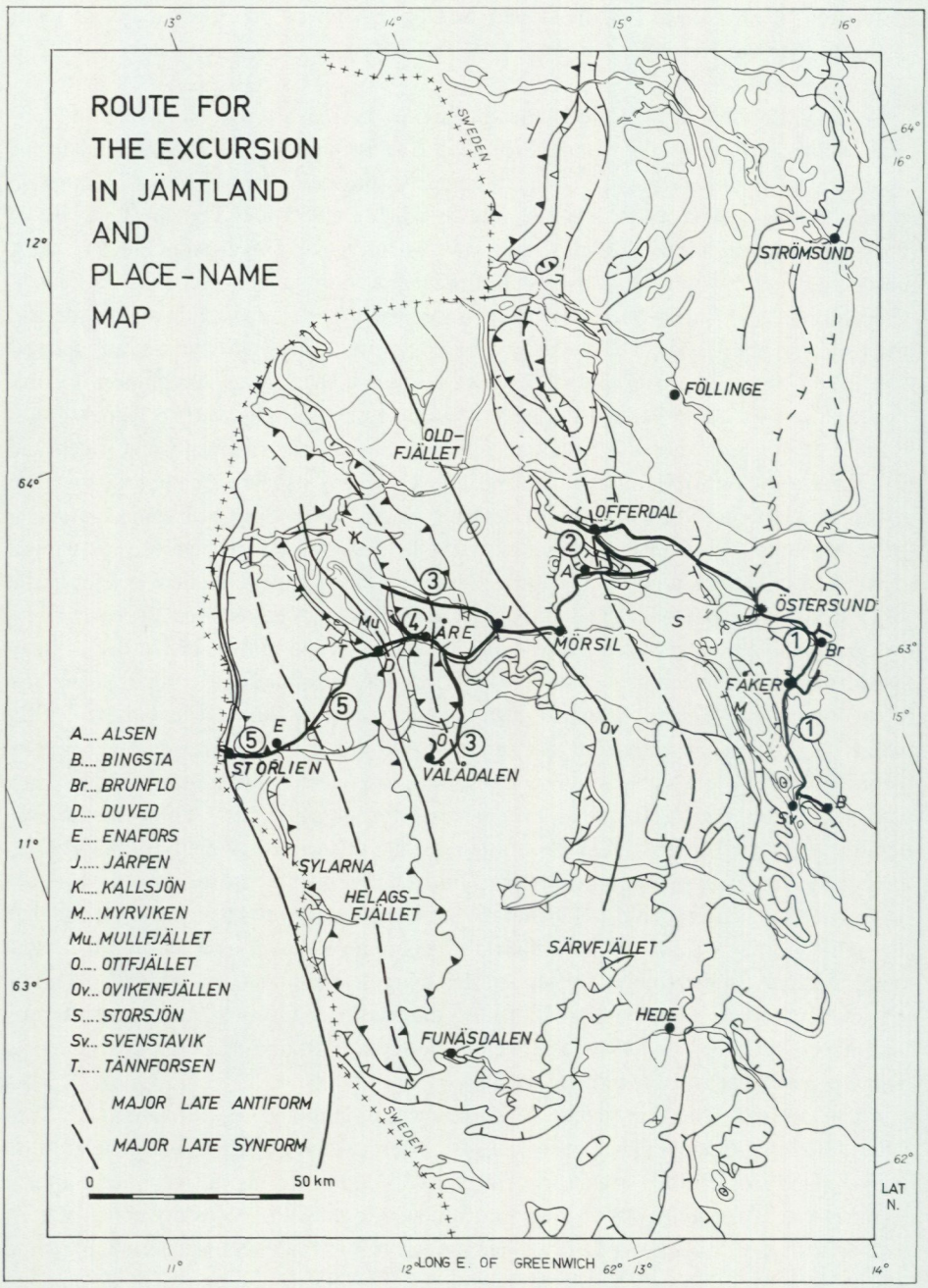

Fig. 4. Place-name map and excursion route through the Caledonides of Jämtland County. Days are marked with rings.

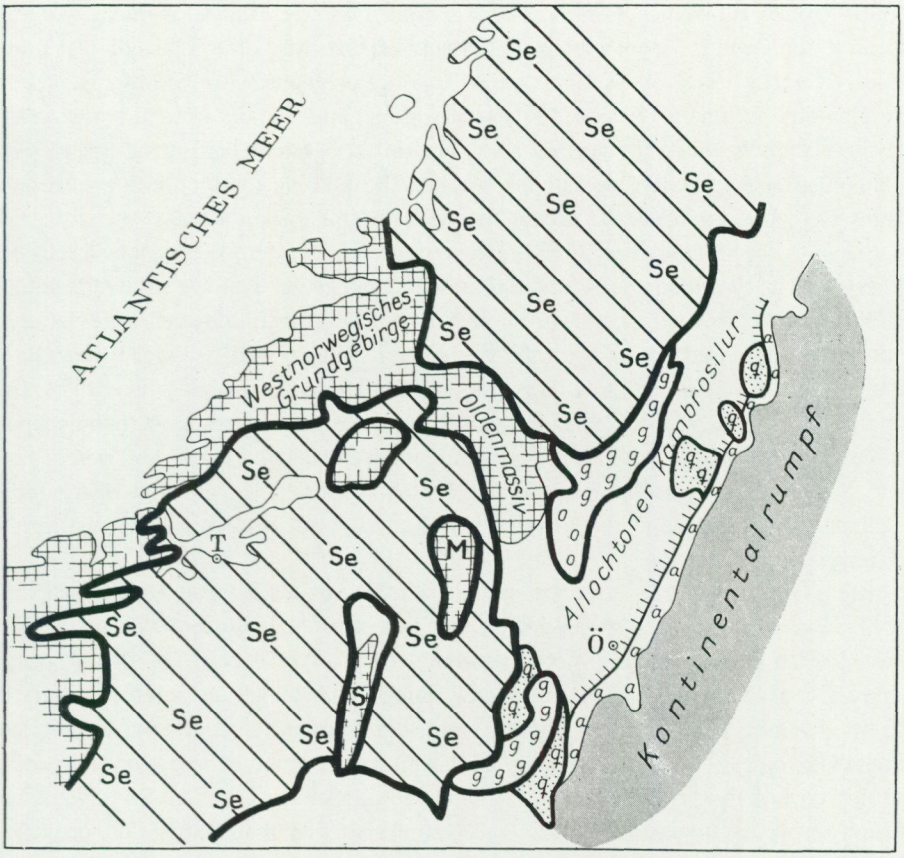

Fig. 5. Asklund's (1938 Fig. 51) interpretation of the main allochthon in the central Scandes. Symbols (our translation) – Se=Great Seve Nappe; g=Granite Mylonite Nappe; o=Offerdal Nappe; q=Quartzite Nappe; a=Autochthonous Cambro-Silurian rocks; M=Mullfjället Basement Window; S=Sylarna Basement Window; T=Trondheim; Ö=Östersund.

Trøndelag. Högbom (1909) entertained the possibility of even greater translation distances.

A number of dissident voices were to be heard during the nineteen-twenties from those who either could not grasp the dimensions of the allochthon or accept the mechanical implications. Nevertheless, work in the thirties by various authors and particularly by Asklund and Thorslund in Jämtland and Kulling further north in the mountain belt not only reaffirmed the nappe hypothesis but provided a variety of new data on the complexity of the various allochthon. In 1938, Asklund provided new evidence supporting Högbom's (1909) suggestion that the major allochthon was not derived from Trøndelag, but from west of the Norwegian coast (Fig. 5). Although Törnebohm's nappe interpretation was by then universally accepted, the new hypo-

thesis proved too radical for most of his contemporaries and subsequent workers. Despite supporting evidence from further south (Holtedahl 1936, Oftedahl 1943) and north (Kautsky 1946, 1953, Gustavsson 1966), allochthoneity in the order of at least two hundred kilometres has been regarded with general scepticism until recent years. Relationships between the various rock units in the western part of the Scandes are concordant and mylonites are inconspicuous. Those doing research in these western areas have been reluctant to accept the evidence for discontinuities; that this concordance is the result of very high ductile strains. The western successions have been interpreted as essentially autochthonous and the conclusion naturally drawn (Ramberg 1966) that the thrusting in the eastern part of the orogen was achieved in response to vertical collapse and stretching of the westerly successions. Only in recent years has a closer analysis of the tectono-stratigraphy in Jämtland and Trøndelag (Gee 1974, Gee and Zachrisson 1974) established the vast transport of the allochthon. It found support in new chemical data from the Upper Allochthon in western Trøndelag, where Gale and Roberts (1974) recognized, in the Støren basalts, trace element distributions characteristic of oceanic tholeiites. Ophiolites have subsequently been recognized (Grenne et al. in press).

The nineteen-seventies have witnessed intensified research in the central Scandes. A broad geotraverse (Gee 1975 a and b) from Östersund to Trondheim was selected by the Swedish Geodynamics Project (Annersten 1974, Bylund et al. 1976) for special study and has resulted in a variety of new information which are referred to further below. More recently, Norwegian and Swedish activity in the context of the International Geological Correlation Programme has further contributed to our understanding of this part of the fold belt. A new geological map of the Caledonides in Jämtland County is being prepared by Karis and Strömberg (in Lundegårdh et al. in prep.); Wolff (1976, revised 1977) has provided a new map of central Trøndelag. A description of a profile through the orogen from Svenstavik to Smøla has been prepared by Dyrelius et al. (in press). Thus, whilst this excursion (Fig. 4) returns to a variety of the old, classical localities, several of which are referred to in the 1960 congress guides (Asklund 1960; Thorslund, in Thorslund and Jaanusson 1960), it includes a large number of new stops identified during the recent research.

A general geological map of the eastern (Swedish) part of the geotraverse is presented in Plate I; along with some sections illustrating the regional structure. As is apparent from the map and sections, the structure is dominated by a variety of thrust nappes. Décollement characterizes the tectonic style in the Caledonian Front (Lower Allochthon). It gives way westwards into basement imbrication. The overlying Middle Allochthon is in many areas dominated by basement crystalline rocks. The Upper Allochthon, composed of the Särv Nappes and Seve-Köli Nappe Complex, contains both Precambrian basement and Caledonian cover units. These allochthonous units, along with the underlying parautochthon, are arched by major antiforms and synforms that trend northwards, parallel to the general axis of the orogen. From east to west these are referred to (Gee 1975 b) as the Offerdal-Fuda Synform, the Olden-Oviksfjäl-

TABLE 1. Summary of tectonic and stratigraphic units in the Jämtland Caledonides.

TECTONIC UNITS			LITHOSTRATIGRAPHY		LITHOLOGIES	AGE
UPPER ALLOCHTHON	SEVE KÖLI NAPPE COMPLEX	TRONDHEIM NAPPE	KJØLHAUGENE GROUP		GREYWACKES & CONGLOMERATES	LLANDOVERY (OR YOUNGER SILURIAN)
		KÖLI NAPPES IN SWEDEN			CALCAREOUS PHYLLITES, GREYWACKES, CONGLOMERATES WITH SUBORDINATE LIMESTONES & QUARTZITES; GABBROS & U-MAFITES	PROBABLE ORDOVICIAN AND/OR SILURIAN
		SEVE NAPPES			GNEISSES & AMPHIBOLITES	
					GRANULITE FACIES GNEISSES & MIGMATITES	
					AMPHIBOLITE FACIES SCHISTS, MARBLES, AMPHIBOLITES & ULTRAMAFITES	
	SÄRV NAPPES		TOSSÅSFJÄLLET GROUP		FELDSPATHIC SANDSTONES WITH MINOR CONGLOMERATES, DOLOMITES & TILLITES	LATE PRECAMBRIAN (INCL. VENDIAN)
MIDDLE ALLOCHTHON	OFFERDAL NAPPE				FLAGGY, FELDSPATHIC SANDSTONES	PROBABLY LATE PRECAMBRIAN
					MYLONITIZED CRYSTALLINE ROCKS	PRECAMBRIAN
	TÄNNÄS AUGEN GNEISS NAPPE				COARSE AUGEN GNEISSES & GRANODIORITES (EXTENSIVELY MYLONITIC)	PRECAMBRIAN, C. 1680 MA
	VEMAN NAPPE				GRANODIORITES (EXTENSIVELY CATACLASTIC)	PRECAMBRIAN, C. 1680 MA
LOWER ALLOCHTHON	JÄMTLANDIAN NAPPES		JÄMTLAND SUPERGROUP	ÄNGE GROUP	SANDSTONES, LIMESTONES, BLACK SHALES & GREYWACKES	LLANDOVERY (& YOUNGER)
				TÅSJÖN GROUP	SHALES, GREYWACKES & LIMESTONES	CAMBRIAN & ORDOVICIAN
				SJOUTÄLVEN GROUP	QUARTZITES, SHALES & TILLITE	VENDIAN TO (?) EARLY CAMBRIAN
				RISBÄCK GROUP	FELDSPATHIC SANDSTONES, SHALES & CONGLOMERATES	LATE PRECAMBRIAN
			BASEMENT		MINOR SLICES OF PORPHYRITIC RHYOLITES & GRANITES	PRECAMBRIAN, PROBABLY C. 1600 MA
PARAUTOCHTHON	"AUTOCHTHON" OF THE WINDOWS AND MINOR DISTURBED UNITS IN THE CALEDONIAN FRONT		JÄMTL S-GROUP	TÅSJÖN GROUP	SHALES, GREYWACKES & LIMESTONES	CAMBRIAN TO ORDOVICIAN
				SJOUTÄLVEN GROUP	QUARTZITES (LOCALLY TILLITES IN WINDOWS)	VENDIAN TO EARLY CAMBRIAN
			BASEMENT		PORHYRITIC RHYOLITES & GRANITES	PRECAMBRIAN, C. 1500+MA
AUTOCHTHON	STABLE PLATFORM		JÄMTL S-GROUP	TÅSJÖN GROUP	SHALES & LIMESTONES	CAMBRIAN TO ORDOVICIAN
			BASEMENT		DOLERITES	PRECAMBRIAN, C. 1250 MA
					GRANITES & GNEISSES	PRECAMBRIAN, C. 1800-1650 MA

len Antiform, the Åre Synform, the Mullfjället Antiform, the Helags-Tännforsen Synform and the Sylarna Antiform (Fig. 4).

This introductory outline is followed by a description of the excursion route and localities. The general tectono-stratigraphy is summarized in Table 1, and described briefly below.

OUTLINE OF THE JÄMTLAND CALEDONIDES

AUTOCHTHON

The autochthon of Jämtland County is composed of Precambrian crystalline rocks (Lundqvist 1979) overlain by thin Cambrian shales and Ordovician limestones. In areas south of Svenstavik, granites (Rätan type) and quartz porphyries dominate the bedrock; these post-Svecokarelian rocks have been dated to c. 1 600–1 700 Ma. North of Svenstavik, gneisses and granites (Revsund type) compose part of the Svecokarelian Complex (c. 1 800–2 000 Ma). A variety of younger (c. 1 200–1 250 Ma) alkaline-olivine dolerites occur in these older complexes.

Deep erosion and planation of the crystalline basement occurred in the late Precambrian, providing a fairly regular surface on which the Cambrian shales were deposited. In general, the basement dips 1–2° W and is overlain by c. 20 m of Middle and Upper Cambrian shales. Locally, a sandy, phosphatic and glauconitic facies occurs at the base. These so-called Alum Shales (referred to as the Fjällbränna Formation in northern Jämtland) are divisable into a lower grey and grey-green unit and a thin upper unit of black, highly organic, uraniferous shales with bituminous limestone lenses.

The Cambrian shales are overlain by Ordovician limestones. In the area of Lockne, east of Storsjön, these limestones rest directly on a basement high which rises up to c. 70 m above the floor of the surrounding peneplain. This evidence (Thorslund 1940) has been interpreted to imply the existence of an irregular basement topography in the area, existing from the Mid-Cambrian into the Mid-Ordovician.

Biostratigraphy of the autochthon of central Jämtland has been treated by Thorslund (1940 and in Magnusson et al. 1960); new data on the Cambrian has been presented by Bergström (1980 and in prep.) and on the Ordovician by Larsson (1973).

PARAUTOCHTHON

The term parautochthon is used here first and foremost for the various units of autochthonous aspect that occur in the windows west of the Caledonian Front. It is also applied in the thrust front to disturbed units that are intimately related to the autochthon. Some of the overlying nappes have been previously treated as parautochthonous;

this practice is avoided here for reasons presented elsewhere (see Gee and Zachrisson 1979, p. 13).

The windows of western Jämtland are cored by Precambrian porphyries and granites (minimum age c. 1 500 Ma) overlain by thin quartzites, radioactive black shales and, locally, limestones. The black shales can be correlated with the Cambrian shales of the autochthon on the basis of their remarkable trace element geochemistry. Both in the Olden Window (Walser 1980, Troeng pers. comm.) and Mullfjället Window (Tirén in prep.) these thin successions are overthrust by sediments of the Lower Allochthon. Similar relationships may also exist in the Sylarna Window (Sjöström, pers. comm.). The basement rocks in the cores of the windows generally contain a semi-penetrative foliation and mylonite zones occur, dipping at moderate angles westwards. The extent to which these ''autochthonous'' units have been displaced laterally remains an open question as is indicated by the question marks on the sections. They are therefore treated here as parautochthonous.

LOWER ALLOCHTHON

Throughout much of the Caledonian Front in Scandinavia, the Cambrian black shales provide a detachment surface close above the Precambrian crystalline basement over which the overlying sedimentary pile has been transported eastwards. In northern Jämtland the tectonic style (Fig. 6) has been demonstrated by drilling through the sole thrust (Gee et al. 1978); interpretation of magnetic (Hesselbom in press) and seismic (Lund in press) data have supported and extended this evidence for décollement. In the area south of Storsjön, a similar sole thrust has been identified by drilling through the allochthon but the relationship between this thrust and the Lockne ''high'' referred to above remains unclear. In this area Thorslund (1940) identified three subordinate thrust units, the Skute, Bjärme and Sunne Nappes and, further west, the Föllinge and Olden Nappes have been inferred by Asklund (1938); the geometry of the latter two allochthon have been disputed by various authors. The general geometry and regional significance of these tectonic units, together referred to as the Jämtlandian Nappes are

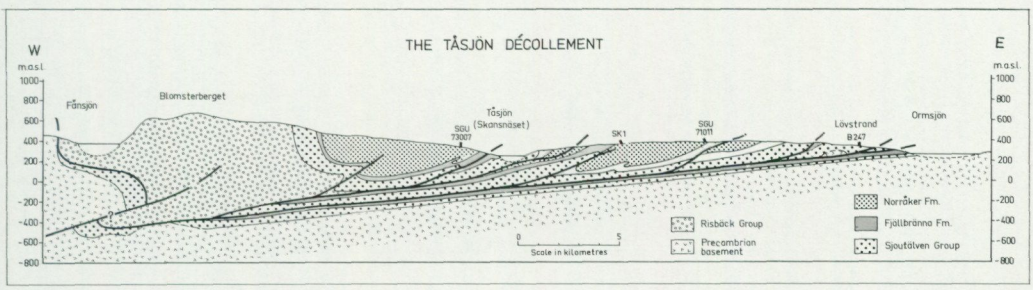

Fig. 6. Section through the Caledonian Front from Fånsjön to Ormsjön, northernmost Jämtland (taken from Gee et al 1978).

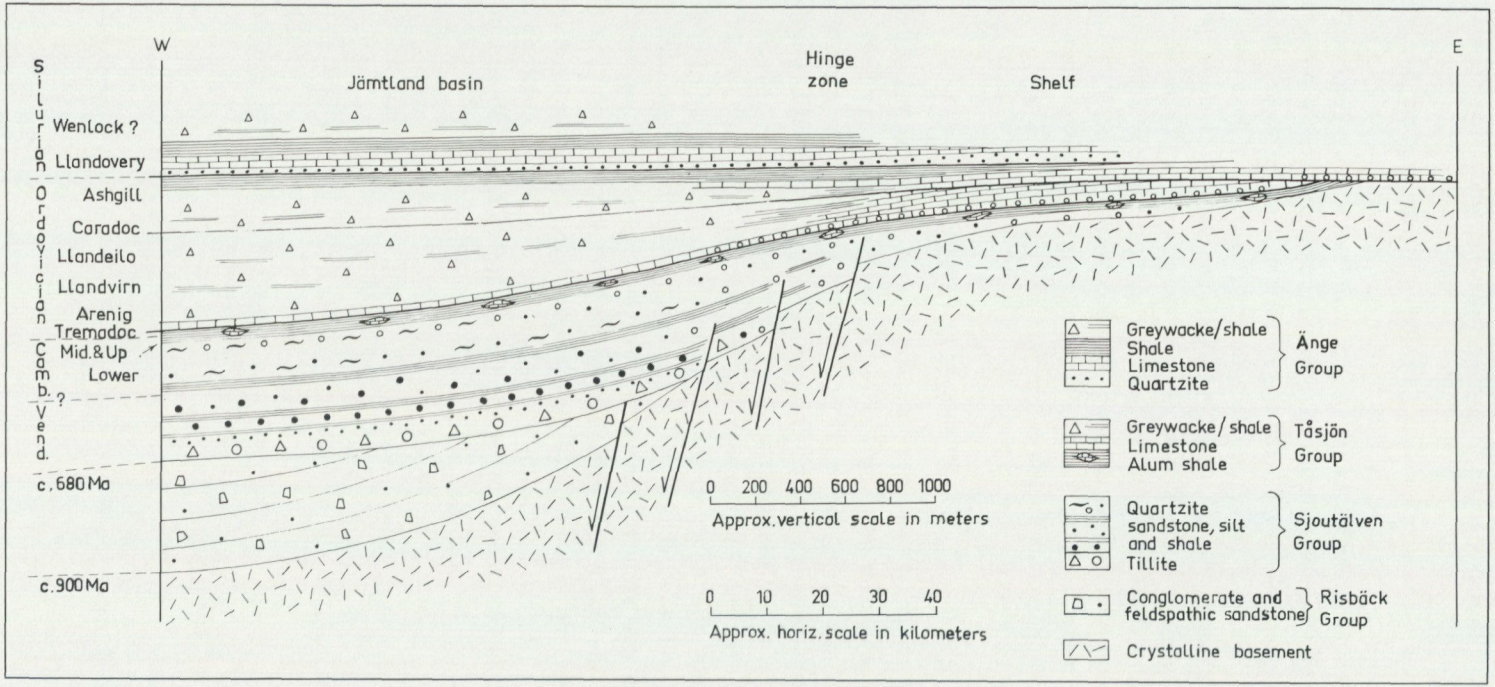

Fig. 7. Lateral variation in the Jämtland Supergroup stratigraphy – a pre-orogenic reconstruction (based on Gee 1972).

being investigated; their relationships both to the Caledonian Front sole thrust and to the new evidence for décollement in the windows of western Jämtland, referred to above, remains one of the most important problems of Caledonian Front tectonics in central Scandinavia.

Whereas in the Caledonian Front the amount of crystalline basement involved in the Lower Allochthon is thought to be very small and restricted to isolated slices (e.g. on Frösön, near Östersund) at the base of some of the nappes, in western Jämtland the evidence from both in the Olden Window and the Sylarna Window indicates that basement involvement increases and the sole thrusts pass westwards beneath a thick allochthon of foliated porphyries and granites derived from west of the border with Norway. Similar relationships are reported by Kumpulainen and Thelander (in prep.) from northern Jämtland. It can be concluded that whilst cover shortening over a passive basement characterizes Caledonian Front structure, basement shortening accompanies cover shortening in areas west of the international border. Basement shortening may be present beneath the windows of western Jämtland (Strömberg 1974), as indicated in the profiles (Plate 1).

The Caledonian sedimentary succession in Jämtland is referred to as the Jämtland Supergroup (Gee 1975 b). It is divisable into four groups and can be illustrated diagrammatically as shown in Fig. 7 – an attempt to reconstruct relationships prior to the nappe displacement. Of the four groups only three are represented in the Lower Allochthon of central Jämtland. The lowest unit of feldspathic sandstones, referred to as the Risbäck Group (the Långå Group in southern Jämtland) are absent in the excursion area as are the tillites at the base of the overlying Sjoutälven Group. The latter is dominated by quartzites of Vendian or Lower Cambrian age and are overlain by Cambrian black shales composing the basal formation of the Tåsjön Group. These shales, which are the most persistant formation in the whole of Scandinavia, extended far westwards beneath the Caledonian nappes being recognized in the parautochthon as far west as Tømmerås in Norway. They are overlain in the lowermost Jämtlandian Nappes of the Storsjön area by Ordovician limestones and shales which pass laterally westwards into shales and greywackes. The Tåsjön Group is overlain by the Ånge Group composed of a basal quartzite formation overlain by limestones and black shales of Llandovery age and greywackes which may be as young as Ludlow.

General biostratigraphy of the Lower Palaeozoic succession of the Jämtland Supergroup was treated by Thorslund in 1960. A diagrammatic summary of the Ordovician and Silurian has been compiled by L. Karis (Fig. 8) for this excursion.

MIDDLE ALLOCHTHON

The Middle Allochthon is composed of schistose quartzo-feldspathic sediments and cataclastically deformed Precambrian crystalline rocks. Mylonites and phyllonites are extensively developed. Whether they are derived from the sediments or the basement rocks is not always apparent; those (e.g. Asklund 1938) favouring a dominantly

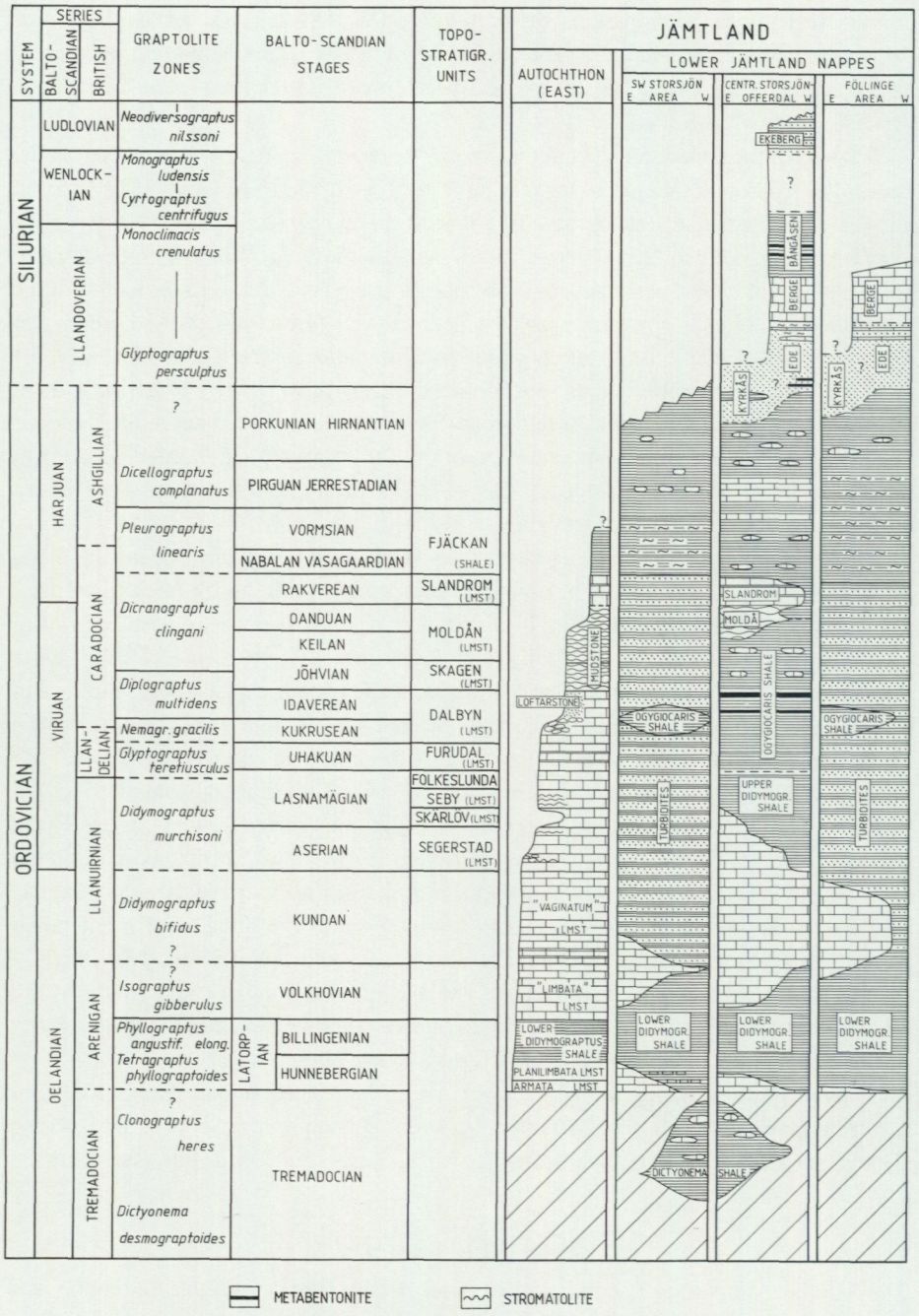

Fig. 8. Ordovician and Silurian stratigraphy of the Autochthon and Lower Allochthon in the Jämtland Caledonides (by L. Karis).

basement origin have preferred to refer to the allochthon as the Granite (or Syenite) Mylonite Nappe (cf. 1:1 000 000 geological map of Sweden in Sveriges geologiska undersökning 1958).

In central and northern Jämtland, sediments dominate and the term Offerdal Nappe is generally applied. In the vicinity of Offerdal itself a conglomerate, probably of fluvial origin, and containing a variety of basement clasts, occurs beneath the Offerdal sandstones. The criteria for including this, the so-called Offerdal Conglomerate, in the Middle Allochthon or referring it to the Lower Allochthon have yet to be agreed. Some forty kilometres west of Offerdal, similar conglomerates occur in the Mullfjället Antiform at the same tectonic level, where they have been shown (Strömberg 1975) to be overlain by quartzites and black phyllites. The latter are radioactive and therefore probably of Cambrian age, implying a late Precambrian age for the Offerdal conglomerates.

In the southern part of Jämtland County, the Middle Allochthon is very largely dominated by Precambrian crystalline rocks, developed as augen gneisses with subordinate granodiorites and granites and occasional basic rocks. This basement allochthon can be divided into an upper augen gneiss unit, the Tännäs Augen Gneiss Nappe, and a lower wedge composed largely of foliated granodiorites, the Veman Nappe (Röshoff 1978). The acid igneous rocks have yielded a Rb/Sr errorchron and U/Pb zircon age of 1 685 Ma (Claesson in press). Intense development of the gneissosity in the Tännäs Augen Gneiss Nappe induces some scatter from the 1 685 Ma age but complete Caledonian resetting occurs only in the mylonites separating the Tännäs Augen Gneiss Nappe from the overlying Särv Nappe of the Upper Allochthon.

Deformation of the Middle Allochthon occurred along with the greenschist facies metamorphism. A regionally developed generally flat-lying penetrative schistosity developed, related to isoclinal folding, accompanied by recrystallization of muscovite and chlorite. Occasional biotite occurs and garnet has been reported locally in the basal phyllonites.

UPPER ALLOCHTHON

The Upper Allochthon is composed of three major units, the Särv, Seve and Köli Nappes, the latter two referred to together as the Seve-Köli Nappe Complex. The presence of Caledonian igneous rocks characterizes the Upper Allochthon.

SÄRV NAPPES

At least three related tectonic units (Strömberg 1961) are included in the Särv Nappes, all intruded by tholeiitic dolerites. The upper and middle nappes are composed of sediments and the lower of basement crystalline rocks.

The upper tectonic unit dominates the Särv allochthon. The dykes, referred to as the Ottfjället Dolerites, are developed as a swarm; they are conspicuous throughout the

nappe and locally compose over 50 % of the bedrock. The intrusions occur in a thick (up to 6 km) sedimentary sequence, the Tossåsfjället Group, of probable late Precambrian age (Kumpulainen in press). Five formations have been recognized in the Tossåsfjället Group (Fig. 9), which is dominated by alluvial sandstones and contains dolomite and tillite formations.

Throughout much of the outcrop area of the upper unit of the Särv Nappe, the dolerites dip at moderate angels westwards and the sediments at low to moderate angles eastwards. Sedimentary structures and igneous textures and mineralogy are usually well preserved. Rotation of some parts of the nappe occurred during emplacement, as for example on Ottfjället where the dykes trend east–west and dip south. Local zones of high strain occur, obliterating the primary features and inducing complete concordance of the quartzo-feldspathic and basic rocks along with development of greenschist facies metamorphic parageneses. In the eastern parts of the nappe, east dipping successions pass through the vertical to dip westwards (Kumpulainen op. cit.). This overturning is apparently related to inverted successions recorded at the base of the nappe in the Storsjö kapell Window and to the underlying Särv unit.

The upper major unit in the Särv Nappes overrides two subordinate units occurring along its base in southern Jämtland. The lower of these is composed of Precambrian igneous rocks and gneisses intruded by occasional dolerites of Ottfjället type. These crystalline rocks occur as lenticular sheets in the order of up to c. 200 m thick and are referred to as the Svansjön Complex (Röshoff 1978). They are generally separated from the main tectonic unit by a mixed sedimentary unit up to c. 100 m thick of sandstones and dolomites in which diamictites have been recorded locally. These sediments compare most closely with the upper part of the Tossåsfjället Group; they were referred to by Strömberg (1961) as the Ulvberg Complex. Dyke frequency is apparently lower in the Svansjön Complex than in the overlying allochthon of the Särv Nappes.

Analyses of the Ottfjället dolerites for major, minor and trace elements (Solyom et al. 1979) has demonstrated that the basic rocks are completely dominated by tholeiites with trace element distributions typical of ocean floor associations. Potash values are slightly high and probably related to contamination during intrusion through continental crust into the sediments.

Intrusion of the dolerites apparently occurred in the late Precambrian, prior to Caledonian deformation. The stratigraphy of the Tossåsfjället Group, and particularly the occurrence of glacial sediments overlying dolomites, favours intrusion in the latest Precambrian or Early Palaeozoic. Claesson (1976) provided a Rb/Sr isochron of 720±260 Ma (^{87}Rb $\lambda = 1.42 \times 10^{-11} a^{-1}$) for the dolerites. K/Ar ages range from c. 600–2 400 Ma; the wide range of older ages presumably reflects varying increments of excess argon.

A Rb/Sr study (Claesson in press) of the mylonites separating the Särv Nappes from the Tännäs Augen Gneiss Nappe yielded an age of 485±50 Ma implying that the Särv Nappe may have been emplaced on to the Middle Allochthon in the Ordovician prior to

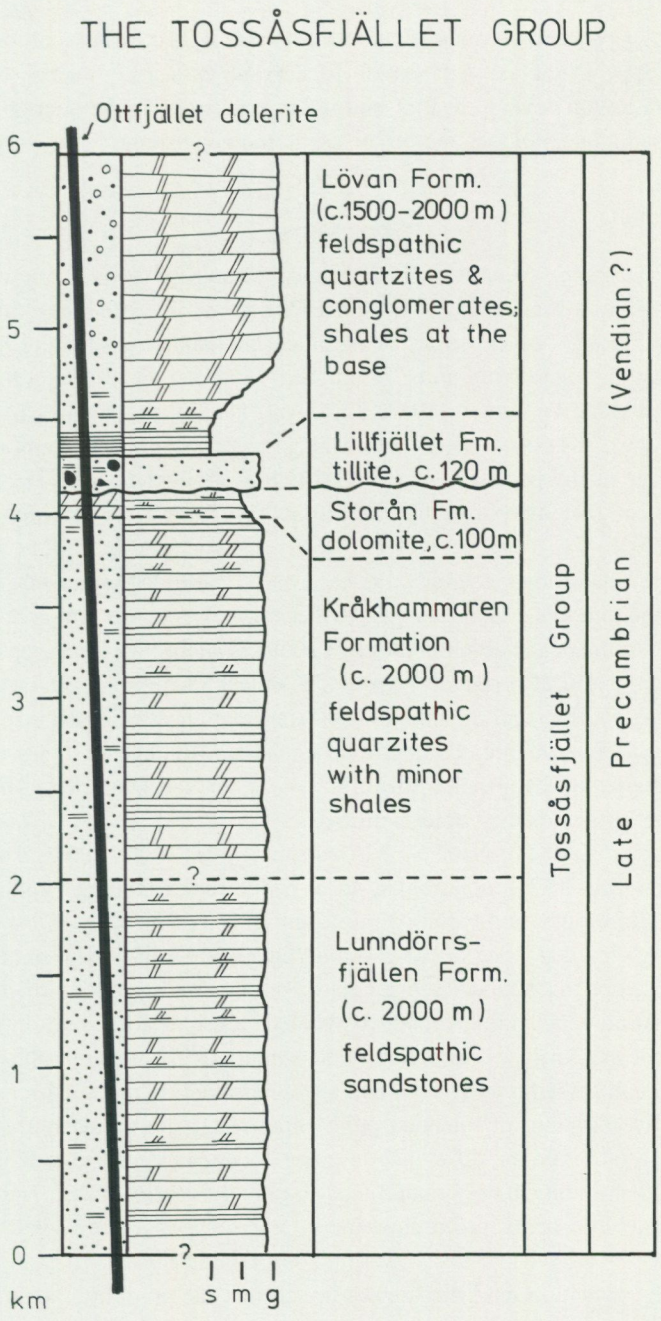

Fig. 9. Stratigraphy of the Tossåsfjället Group of the Särv Nappe, southwest Jämtland (from Kumpulainen in press).

Late Silurian to Early Devonian transport of the nappe pile on to the Jämtland Supergroup.

The Särv Nappes thin westwards and northwards and are locally cut out below the Seve-Köli Nappe Complex. Attenuation of Särv units is accompanied by thorough recrystallization with development of biotite and muscovite in the quartzo-feldspathic rocks and hornblende, epidote and oligoclase in the greenstones.

SEVE NAPPES

The relative structural simplicity of the Särv Nappes gives way upwards into a complex allochthon, the Seve (Zachrisson 1973), composed of at least three separate nappes, all subject to polyphase deformation and metamorphosed under higher grade conditions than the underlying units. In northern Jämtland and Västerbotten the Seve has been subdivided by Trouw (1973) and Zwart (1974) into a lower psammite and amphibolite unit, a central gneiss unit and an upper schist and amphibolite unit. Eclogites occur in the gneisses. The central unit is thought to have been subject to Sveconorwegian metamorphism on the basis of a Rb/Sr age-determination study (Reymer 1979).

In central Jämtland, two tectonic units have been identified that may be correlatable with the central and lower Seve Nappes further north. The lower unit is dominated by feldspathic psammites and amphibolites and contains subordinate marbles and schists; ultramafite lenses are also present. The upper unit is of higher grade, composed of granulite facies gneisses and migmatites. On Åreskutan these units occur in a synform overlying fossiliferous Jämtland Supergroup sequences. Further west they thin and are locally cut out over the Mullfjället Antiform, only to thicken again in the Helags-Tännforsen Synform, towards the border with Norway.

Descriptions of the Seve Nappes on Åreskutan by Helfrich (1967) and Yngström (unpublished thesis 1971) contributed to a better understanding of the structural development, lithologies and variation in metamorphism. The name Åreskutan Nappe (Yngström op. cit.) is applied to the granulite facies upper unit. The underlying unit and its relationships to attenuated representatives of the Särv Nappes remains ambigiuous and formal nomenclature is therefore avoided. More recent studies of the Seve in the Åre area include analyses of folding (Ghosh et al. 1979), metamorphism (Arnbom and Troeng, unpublished report 1979) and age-determination investigations (Claesson in prep.). Investigation of metamorphic parageneses (particularly biotite-garnet studies) have established the difference in grade between the granulite facies Åreskutan Nappe and the immediately underlying amphibolite facies units. The latter give way downwards into upper greenschist facies assemblages in the lowest part of the Seve.

The age-determination work has demonstrated that the granulite facies migmatites and associated granites have been subject to high grade Caledonian metamorphism; initial strontium ratios suggest that the rocks may have originated from the pre-Caledo-

nian basement. Late pegmatites, yielding a Caledonian age, cut gneissosities in the upper unit; they are themselves deformed in the mylonite zone separating the Åreskutan Nappe from underlying units.

Within the Helags-Tännforsen Synform, amphibolites, several hundred metres thick, occur in the lower Seve unit, referred to there as the Helags Nappe (Strömberg 1961). These amphibolite and uppermost greenschist facies basic rocks are generally of tholeiitic composition (Strömberg 1969). A recent study (Solyom et al. 1979) of the major, minor and trace elements in one of the basic units, the Sylarna amphibolite, has confirmed compositional affinity with the underlying Ottfjället Dolerites. The thick Sylarna massif has been shown to pass laterally into interbanded greenstones and metasediments (Zachrisson pers. comm.). The evidence is thus compatible with Strömberg's (1969) suggestion that the Ottfjället intrusions were related to volcanicity represented in the Helags Nappe. Nevertheless substantial lateral displacement of the Seve on to the Särv Nappes is required by the metamorphic inversion.

In summary, it can be concluded that the Seve Nappes contain both Caledonian basement and cover elements, the latter potentially related to late Precambrian deposition and volcanicity. High grade Caledonian metamorphism influenced both basement and cover and was followed by thrust emplacement of the granulite facies above the amphibolite facies units during nappe transport onto the Baltoscandian Platform.

KÖLI NAPPES

The classical Köli terrains are located in Västerbotten, c. 300 km north of the excursion area. Volcano-sedimentary successions overlying the Seve Nappes were established there to be at least of Ordovician and Silurian age (Kulling 1933). In central Jämtland, the greenschist facies Köli metasediments have been reported to contain crinoids (Beckholmen 1980), but comparison with the Västerbotten succession can be based only on lithological correlation (Table 2).

The Köli rocks occur in the Tännforsfältet area of western Jämtland, within the Helags-Tännforsen Synform. They overlie Seve amphibolites, schists and gneisses; locally in the eastern limb of the synform where the latter are cut out, the Köli metasediments rest directly on underlying units of the Middle and Lower Allochthon and Parautochthon.

Much of Tännforsfältet is poorly exposed. Early work established that calcareous phyllites dominate the lithologies and that conglomerates are present near the base in the east limb of the synform. The presence of hornblende-garnet-biotite bearing assemblages (Garbenschiefer) in the upper part of the synform overlying biotite-muscovite and chlorite-muscovite assemblages implies inversion or nappe repetition within the Köli of Tännforsfältet. Recent work by Beckholmen (1980) in the eastern limb of the synform has established a succession (Table 2) in the lower unit, with conglomerates at or near the base, overlain by quartz phyllites, quartzites and limestones and then by grey phyllites and calcareous phyllites. Thin phyllites and

TABLE 2. Comparison of Köli successions in the Tännforsen (Jämtland County) and Björkvattnet–Virisen (Västerbotten County) areas.

KÖLI SUCCESSIONS			
VÄSTERBOTTEN EASTERN SYNFORM (Kulling 1933, Strand & Kulling 1972)		TÄNNFORSEN AREA (Beckholmen 1980)	
Viris Formation	Feldspathic quartzite		
Vesken Formation	Greywacke and conglomerate		
Lövfjäll Formation	Calcareous phyllite	Gevsjön Formation	Calcareous phyllite
Broken Formation	Black shale (incl. greenstone locally)	Långmyren Formation	Grey phyllite
Slätdal Formation	Limestone	Ravaänge Formation	Quartzite, quartz phyllite and limestone
Vojtja Formation	Quartzite and quartzite conglomerate		
Gilliks Formation	Greywacke, phyllite and conglomerate (incl. detrital serpentinite)	Forsaberget and Årsberget Formations	Greywacke and conglomerate in the former; polymict conglomerate with limestone in the latter, both intruded by metagabbro
Seima Formation	Basic volcanic rocks	Storlidtjärnen and Buttulsbäcken Formations	Greenschist and quartz keratophyre (?) in the former: garnetiferous phyllite in the latter
SEVE NAPPES			

possible metavolcanic rocks occur locally between the conglomerates and the underlying tectonic units. Ultramafites are also known at this level in the succession.

In the eastern limb of the synform in the vicinity of Nordhallen, the conglomerates (Årsberget Formation) contain quartzite pebbles in their upper parts; lower down in the formation amphibolites and metagabbros appear in the clasts and, in the basal beds, the basic rocks dominate the clast compositions. On the basis of this evidence Högbom (1909, p. 17) inferred unconformity between the Seve rocks and these Köli conglomerates. He sought support for the hypothesis in the discontinuity between the Seve and the overlying Köli rocks along their eastern and southern contacts.

The new work (Beckholmen op. cit.) has demonstrated the structural complexity of the Köli and of the relationships between the Seve and the Köli. In general the contact between these two major rock units can be demonstrated to be a zone of high strain; locally the Seve is cut out completely and mylonites are prominent. Nevertheless the possibility remains that the Seve greenstones were metamorphosed to amphibolites prior to erosion and Köli deposition and that the unconformity, favoured by Högbom, has been obscured by the subsequent deformation.

The Köli Nappes of Tännforsfältet thin westwards and are cut out in the vicinity of the Sylarna Anitform, being overlain in the western limb of this structure by conglomerates and phyllites of eastern Trøndelag (Norway). These greenschist facies sediments compose the basal units in the Trondheim Nappe, a tectonic unit that is treated further in the Norwegian excursion guide (Wolff in press).

LATE-OROGENIC SEDIMENTS

Sediments younger than the emplacement of the nappes are not preserved in Sweden but occur near the international border with Norway at Röragen c. 40 km west of Funäsdalen. Fluvial sandstones and conglomerates of Lower Devonian age were deposited in an intramontane basin eroded into the nappe pile. Thus, nappe emplacement into Sweden occurred after the Early (and possibly Mid) Silurian and prior to the Early Devonian. Movement on the frontal décollement probably continued into the Devonian.

DERIVATION OF THE ALLOCHTHON

Any assessment of the displacement distances of the various Swedish nappes and the relationship of the different rock units prior to thrusting requires an analysis of the western, Norwegian part of the central Scandes. The reader is referred to the Norwegian excursion guide (Wolff in press) covering the area from Storlien via Trondheim to the west coast and to syntheses and discussion of data provided by Gale and Roberts (1974) and Gee (1975 a and 1978). Evidence from the windows, that the Jämtland Supergroup sediments were deposited directly on the basement as far west as the Snåsa Synform requires over a hundred kilometres of transport for the higher nappes in the Lower Allochthon. That this basement and cover is not penetrated by Ottfjället Dolerites implies that the Särv Nappes were derived from even further west; they must have been separated from the derivation area of the Lower Allochthon by a bedrock composed of basement and cover sandstones (Middle Allochthon) that also lacked the dolerites. High grade Caledonian metamorphism of the Seve-Köli Nappe Complex occurred substantially further west of the Särv derivation area.

Clearly the higher allochthonous units in Norway, including the ophiolites, were transported from even further west (Fig. 10). As has been emphasized elsewhere (Gee 1976, 1978), this evidence requires the build up of a nappe pile composed of various

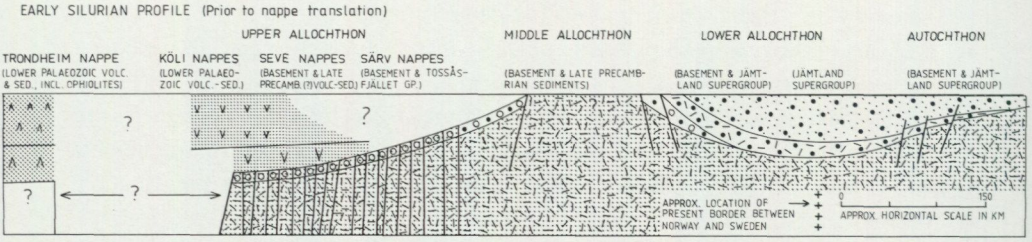

Fig. 10. Pre-orogenic reconstruction of the central part of the Swedish Caledonides, from Gee 1978. (cf. Plate 1 for symbols).

basement and cover elements charaterized by a higher density than the underlying parautochthonous basement. Emplacement of this composite allochthon resulted in depression of the Baltoscandian margin and folding together of the entire tectono-stratigraphy. Högbom's suggestion (1909, p. 52) to the participants of the 11th International Geological Congress Excursion that "the strong folding of the Norwegian part of the highland range may be younger than the great thrust, and that the root therefore may really be situated yet still further to the west "appears today as a well-established hypothesis, supported by evidence from a wide range of geological disciplines.

EXCURSION ROUTE AND ROAD-LOG

Those interested in geotraversing through an orogen are well advised to start in the mountain front in the relative simplicity of the autochthon before progressing into the complex interior. This advice is particularly applicable to the Caledonides in Scandinavia where excursions do well to start in the east and migrate westwards. The criteria for recognition of the various tectono-stratigraphic units must be identified where they are characteristic and well preserved before attempt is made to follow them into the interior where attenuation is general and the critical evidence if often fragmentary. This fragmentary evidence in the interior has proved, in the Scandes, to be well preserved locally in the cores of mega-boudins.

This excursion starts in the vicinity of Östersund in central Jämtland and, with various diversions to the north and south (Fig. 4), follows the European Highway E 75 westwards via Åre and Storlien to Trondheim.

We head upstream from the Storsjön area, and follow the river Indalsälven towards the watershed at Storlien, before making the descent into Norway and to the Atlantic coast.

In this, the central part of the Scandes, the mountain front has retreated westwards to Åreskutan, where the Seve Nappes override the Jämtland Supergroup of the Lower Allochthon. The terrain east of Åreskutan to Storsjön and the environs of Östersund is gently undulating and not particularly well exposed. Evidence of the Quaternary history (Lundqvist 1969, Agrell 1979) is ubiquitous, from the glacially carved relief of

the higher peaks to the various terraces of the ice-dammed lakes and the thick moraines and eskers of the lowlands. The best farming land occurs around Storsjön, where Cambrian alum shales and Ordovician limestones and shales provide a soil that is comparable with the best in the country. Only the short growing season with melting of the winter snows in May and the early frosts in September, inhibits the selection of

TABLE 3. Summary of programme for the excursion from Östersund to Storlien.

DAY	AREA	GEOLOGY
1	STORSJÖN	*Caledonian Front–Autochthon and Lower Allochthon* Lower Palaeozoic successions; stratigraphy and structure
2	ALSEN–OFFERDAL	*Offerdal Synform–Lower, Middle and base of Upper Allochthon* Upper Ordovician and Silurian successions of the Jämtland Supergroup overlain by phyllonites of the Offerdal Nappe and (uppermost) dolerites and sandstones of the Särv Nappe
3	OTTFJÄLLET–JÄRPEN-KALLSJÖN	*Åre Synform–Upper, Middle and Lower Allochthon* In Ottfjället area, Särv Nappe (sandstones and dolerites) overlying mylonitized basement of Middle Allochthon. At Kallsjön, attenuated Särv and Offerdal Nappes overlie Ordovician and Silurian successions of Jämtland Supergroup
4	MULLFJÄLLET–ÅRESKUTAN	*Åre Synform and Mullfjället Antiform–Parautochthon, Lower and Upper Allochthon* Basement porphyries of Mullfjället Window; Silurian crinoidal limestones: amphibolite facies schists and greenstones and overlying granulite facies gneisses and migmatites of Seve Nappes.
5	DUVED–ENAFORS STORLIEN	*Tännforsen Synform and Sylarna Antiform–Upper and Lower Allochthon* Köli metasediments of Tännforsfältet, attenuated Seve amphibolites and lower units in Sylarna Antiform; basal mylonites of Trondheim Nappe

crops that can be harvested before the long winter months take over. The summers, though short, are usually sunny and hot, at least in areas east of the watershed, and midges thrive. Excursioners should be prepared for the usual eccentricities of mountain weather and be armed with thick jerseys, waterproof clothes and boots.

The excursion from the Caledonian Front to the Atlantic coast lasts nine days, of which the first four and a half cover the profile from the Storsjön area westwards to Storlien. The areas to be visited during the days in Sweden along with brief comments on the geology are to be found in Table 3.

The various excursion localities are located by reference to a 1:50 000 map-sheet and coordinates in the National Grid System (Rikets nät).

DAY 1. THE STORSJÖN AREA

Caledonian Front–Autochthon and Lower Allochthon

INTRODUCTION

The area around lake Storsjön is composed of Lower Palaeozoic sediments, overlying a Precambrian crystalline basement of Svecokarelian granites and gneisses (Fig. 11). Most of the sediments are folded and thrust eastwards; only along their eastern margin are autochthonous units preserved. In southern and northeastern parts of Fig. 11, the Precambrian basement surface is regular and dips 1–2°W, overlain generally by c. 20 m of Middle Cambrian grey shales, locally with a few decimetres of uppermost Lower Cambrian glauconitic, phosphatic sandstones at the base. These shales contain thin limestone bands and lenses and are overlain by a few metres of bituminous limestones and black shales of Upper Cambrian age. Ordovician limestones, a few metres to tens of metres thick, may also be present in the autochthon, beneath the sole thrust of the Lower Allochthon. In the vicinity of Lockne, east of Storsjön, the Ordovician limestones overlap onto the basement and strata as young as earliest Late Ordovician locally rest on the Precambrian granites. This basement high rises up to c. 70 m above the surrounding peneplain of the sub-Cambrian unconformity.

In the Hackås-Myrviken area of southern Storsjön, drilling (SGU unpublished results) to basement has demonstrated that the autochthonous Cambrian shales, locally with Lower Ordovician limestones, are preserved below the sole thrust for a distance of at least 20 km from the thrust front. The succession above the sole thrust contains quartzites of pre-Mid Cambrian age at their base, overlain by Cambrian shales comparable with, but thicker than in the autochthon. Ordovician limestones and shales occur in the eastern part of the Lower Allochthon; they give way laterally westwards in central Storsjön into shales and greywackes. Overlying thin quartzites passing up into Llandovery limestones, compose the youngest units in most of the Storsjön area; however, north of Östersund a mudstone and quartzitic sandstone unit, the so-called Kyrkås Group has been recognized (Thorslund 1948) to span the Ordovician-Silurian boundary.

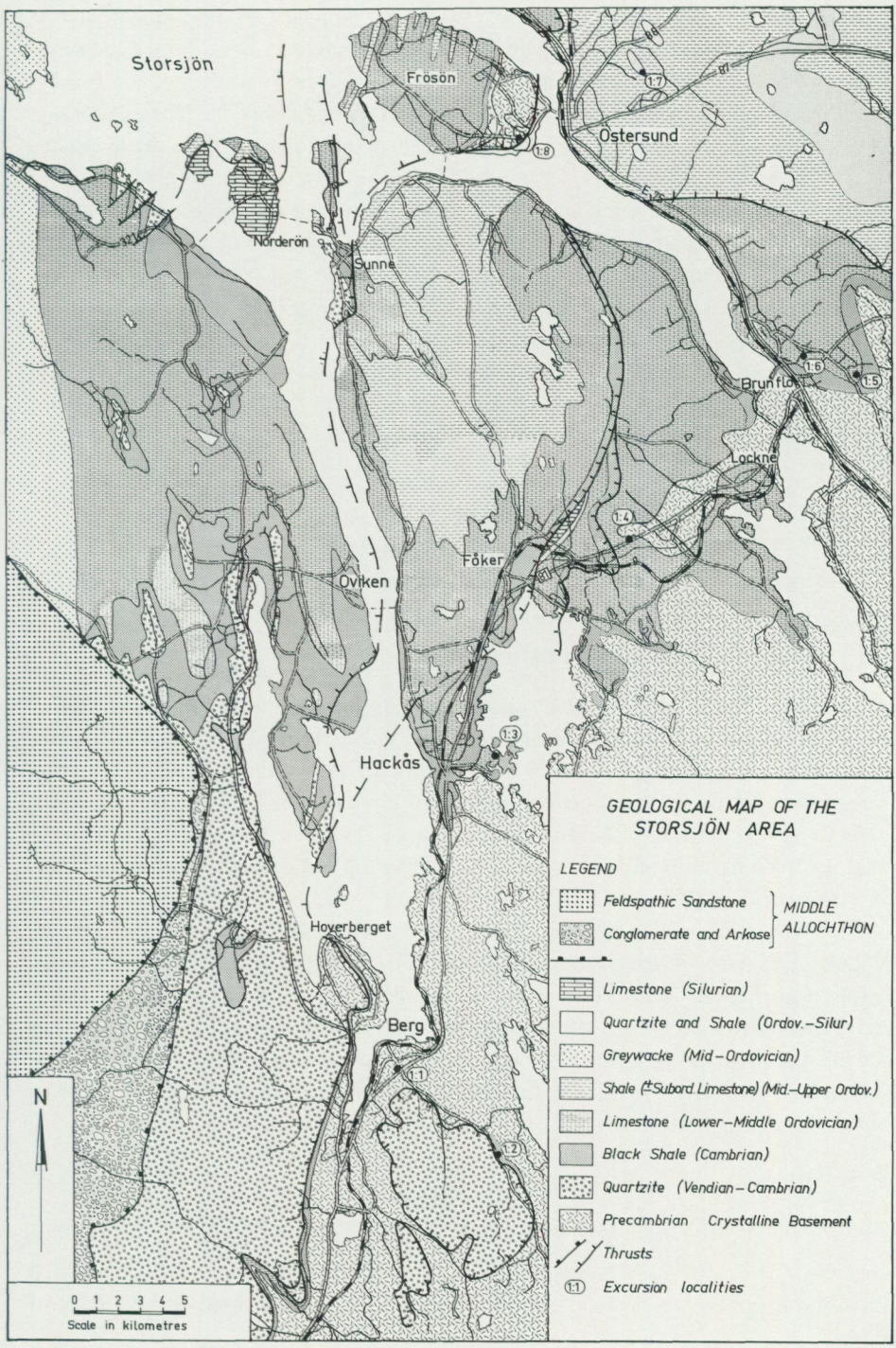

Fig. 11. Geological map of the area south and east of Storsjön.

As in northern Jämtland (Gee et al. 1978), the structure in the Storsjön area is dominated by a décollement style with most of the sedimentary cover folded and thrust over a passive crystalline basement. Only locally (e. g. on Hoverberget and Frösön) are slices of basement preserved at the base of the Lower Allochthon. The relationship between the sole thrust of the Lower Allochthon and the basement high of the Lockne area is being investigated.

The excursion starts in the southern part of the area on the sub-Cambrian unconformity and examines the relationships of the Cambrian shales to the quartzites of the overlying allochthon. It then moves northwards to the Lockne ''high'' where the Ordovician limestones with basal conglomerates and sandstones rest on the Precambrian granites. Thereafter, it examines the Ordovician limestone succession and its deformation in the Brunflo area, before journeying westwards to the Kyrkås Group, north of Östersund. The final stop of the day is made on the Precambrian porphyries and quartzites of the Frösön Allochthon, a couple of kilometres west of Östersund.

ROAD-LOG

Stop 1:1 **Nytorp**

Autochthon: Precambrian crystalline basement and sub-Cambrian unconformity

Location: (18E, Hackås SO, 69655/14325). On main road (81) c. 3.5 km northeast of Svenstavik at road junction to Skanderåsen.

Description: Precambrian basement lithologies are dominated by foliated (c. N 70° E/vert.) feldspar porphyritic greenstones cut by aplite sheets (N–S/vert.). The basement units are well exposed c. 50 m southeast of the road junction. The present ice-striated surface of these outcrops approximately coincides with the surface of the basal Cambrian unconformity. This contact has been exposed on the eastern side of the road, overlain by c. 30 cm of dark shales yielding a Middle Cambrian *Eccaparadoxides oelandicus* stage fauna (L. Karis, pers comm).

From the road junction there is a good view to the northwest of the Hoverberget Klippe. This unit of the Lower Allochthon is largely composed of Precambrian porphyritic rhyolites and Vendian and/or Cambrian quartzites, thrust over a thin autochthonous sedimentary sequence. The latter has been reported (Thorslund 1960) to contain the uppermost Lower Cambrian fossil *Torellella laevigata* in the basal few decimetres, overlain by Middle Cambrian greenish and dark shales of the *Eccaparadoxides oelandicus* stage.

D. G. Gee

Stop 1:2 **Bingsta**

Autochthon: Middle Cambrian shales underlying quartzites of the Lower Allochthon

Location: (18E, Hackås SO, 69627/14356). Quarry on south side of road from Stop 1:1 towards Gillhov, c. 5.5 km east of Svenstavik, 1 km northwest of the village of Bingsta.

Description: Vendian and/or Lower Cambrian quartzites (Lower Allochthon) of Bingstaknäpp, outcropping in the quarry, are thrust over Middle Cambrian grey-green and dark shales with limestone lenses. These autochthonous sediments are exposed beside the approach road up to the quarry. The lighter shales and the limestones in the dark shales contain an abundant fauna dominated by trilobites with some brachiopods typical of the *Eccaparadoxides oelandicus* and, at the top, *Paradoxides paradoxissimus* stages of the Middle Cambrian.

During construction of the road to Bingsta, near the quarry, local basal Cambrian arkosic sediments (a few decimetres thick) were temporarily exposed and were reported to be of Early Cambrian age (Asklund 1938, p. 27). It should be noted that in other corresponding contacts in the vicinity, the dark shales directly overlie the basement. The total thickness of the Cambrian sediments below the Lower Allochthon is in the order of 20 m.

The relatively well preserved autochthonous shales are intensely cleaved and small folded near the contact with the overlying allochthonous quartzites. This irregular surface is well exposed near the entrance to the quarry.

L. Karis

Stop 1:3 **Målingen**

Autochthon: Irregular surface of Precambrian basement, influencing Cambrian and Ordovician sedimentation

Location: (18E, Hackås NO, 697970/143675). Outcrops along minor road c. 1 km east-southeast of the Näcksta farms, c. 2.5 km east of Hackås.

Description: At locality (a) on Fig. 1. (redrawn with minor modification from Thorslund 1940, p. 63, Fig. 37), on the north side of the road, grey-green and dark Middle Cambrian shales with occasional limestone lenses are overlain by a concentration of bituminous limestones and black shales with an upper Middle Cambrian (*Paradoxides forchhammeri* stage) and Upper Cambrian (*Agnostus pisiformis*, *Olenus* and *Parabolina spinulosa* zones) fauna. The black shales are markedly higher in uranium content (c. 50–100 ppm) than the underlying units. Lower Ordovician limestones overlie the *P. spinulosa* zone stinkstones. Following the section c. 20 m to the southeast along the road, these limestones are downfolded into the Middle Cambrian shales. The hinge of the syncline in the limestones is well exposed with a fold axis c. N 20° E, a steep west limb, a flat east limb and development of a prominent cleavage.

About 50 m further along the road to the southeast, the *P. spinulosa* zone is overlain by Lower Ordovician bedded limestones and Middle Ordovician limestone-pebble conglomerates. At locality (b), the irregular surface of the granitic Precambrian basement is exposed. The palaeorelief appears to have been in the order of c. 15–20 m in the Målingen area, with Cambrian shales filling the deeper pockets in the basement

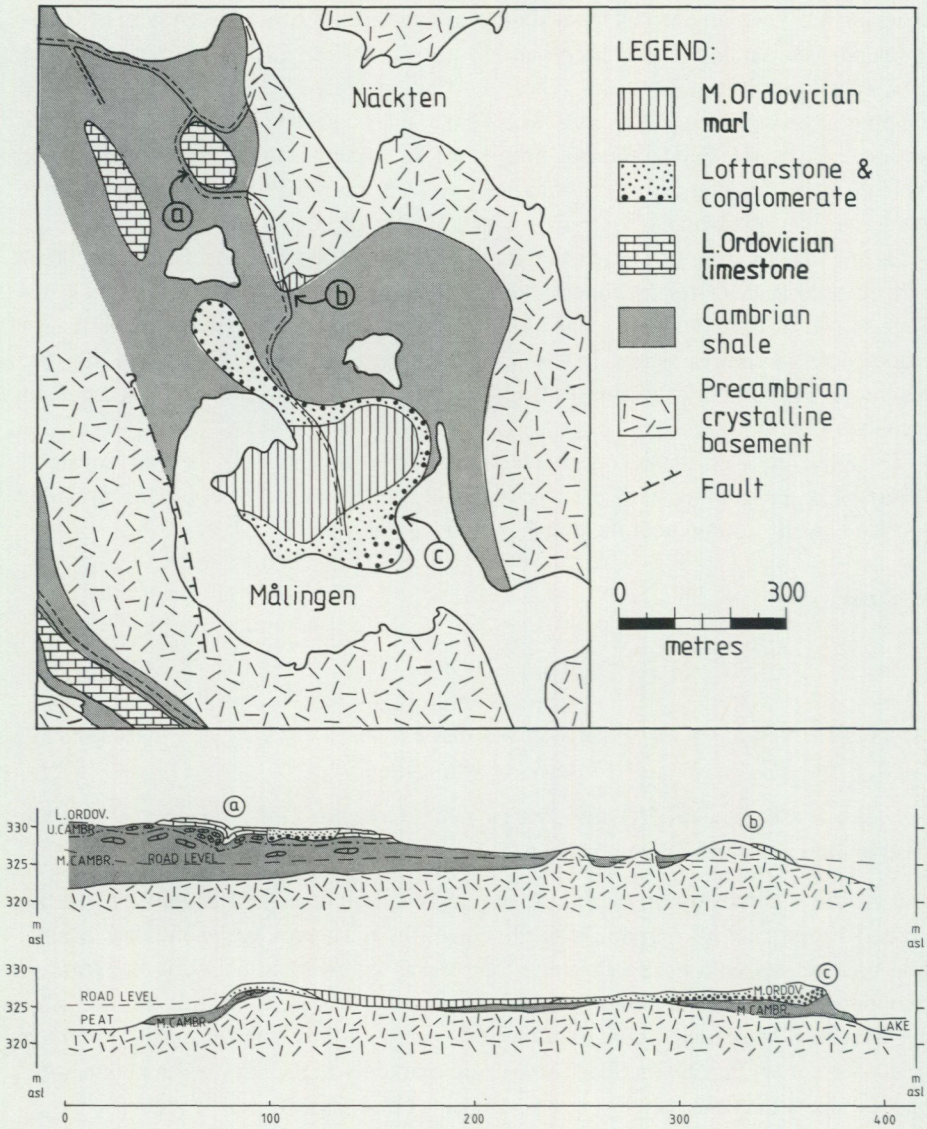

Fig. 12. Geology of the area around Målingen (Stop 1:3).

and Ordovician limestones, conglomerates and mudstones being deposited on the higher parts. Locally, on the east side of the road (east of Högtjärn), marly shales and limestones probably of Late Ordovician age were deposited directly on the weathered granitic basement. These relationships are interpreted to require the existence of an archipelago in the Målingen area which existed from the Middle Cambrian into the Late Ordovician and involved extensive deposition and reworking of the Ordovician

strata. On the road to locality (c) there occur a variety of small exposures of Cambrian shales and stinkstones ranging in age into the *P. spinulosa* zone.

At locality (c) along the north shore of Målingen, dark Cambrian shales are overlain by Ordovician conglomerates. Clasts in the latter are usually composed of Lower Ordovician limestones; they decrease in size upwards and pass into the so-called ''Loftarstone'' (Thorslund 1940), a fine to medium-grained sandstone derived from the Lower Ordovician limestones and underlying granitic basement.

L. Karis

Stop 1:4 **Tand**

Parautochthon on basement high; Middle Ordovician limestones and conglomerates thrust on brecciated granite

Location: (18 E, Hackås NO, 698910/144355). Road-cut west side of main road (81), c. 11 km south of Brunflo.

Description: The Precambrian basement surface in the Lockne area is up to c. 70 m higher than the peneplain to the southwest and northeast. Various Ordovician sediments were deposited on this basement high and the conglomeratic facies contains clasts of most of the underlying units, including basement lithologies, Cambrian shales and stinkstones, and both Lower and Middle Ordovician limestones.

Thorslund (in Thorslund & Jaanusson 1960, p. 45–47) described a number of localities where the sediments, deposited on the Lockne ''high'', can be observed. During reconstruction of road 81, a new section was exposed which is illustrated in Larsson (1973, p. 32).

In the northeastern part of this road section brecciated granite occurs, overthrust by early Mid Ordovician Skärlöv and Seby Limestones and Dalby Conglomerates; the strata dip at high angles to the west, being slightly overturned. The Seby Limestone shows dessication surfaces and algal stromatolites. The polymict Dalby Conglomerate contains pebbles of Lower and Middle Ordovician Limestones and basement granites, the latter being more common in the upper part of the unit.

The steeply-dipping Skärlöv Limestone is apparently underlain by another conglomerate containing boulders of granite, diabase, Cambrian black shale and Ordovician limestone. This conglomerate has an erosive base to underlying limestones of probable Early Ordovician age.

K. Larsson

Stop 1:5 **Lunne**

Parautochthon: Lower and Middle Ordovician limestones

Location: (18F, Bräcke NV, 699700/145320). Quarry on hill-top Lunneberget, c. 2 km northeast of Brunflo church.

Description: This abandoned quarry in the flat-lying Ordovician strata exposes a section (Larsson 1973, p. 12) from the uppermost Lower Ordovician, Kunda Limestone into the Middle Ordovician, Segerstad, Seby and Folkeslunda Limestones. Most of the Folkeslunda Limestone and overlying polymict Dalby Conglomerate are exposed in a narrow trench above the quarry. Immediately above, on the top of the hill, some exposures of ''Loftarstone'' sandstone occur.

The top of the Segerstad and the Seby Limestones have unambiguous shallow-water characteristics with numerous dessication surfaces and algal stromatolites. Small stromatolites also occur close above the base of the Segerstad Limestone, immediately above a distinct, uneven, erosion surface. Large bedding surfaces near the top of the quarry expose drifted cephalopods, partly trapped along mudcracks. The Dalby Conglomerate contains pebbles and boulders of Lower and lower Middle Ordovician Limestones and Precambrian granite, the size of the clasts increasing upwards.

The beds in the quarry undulate slightly with a maximum dip of c. 15° NW. Gentle folding occurs on N 50° E plunging axes. A subordinate fold axis also occurs perpendicular to this main orientation. Two vertical joint systems, N 75° W and 10° E, intersect the quarry. Small thrusts, with displacements of a few decimetres, are visible in the middle of the quarry, the fault-surfaces dipping 25–40° NW.

From the top of Lunneberget there is a good view of the Caledonian Front around Storsjön, this gentle landscape contrasting with the hills to the southwest, forming a part of the Fuda Klippe (Offerdal Nappe, Middle Allochthon), the Lower Allochthonous quartzites of Oviksfjällen, and in the far west, the Upper Allochthon of the Särv Nappes and Seve-Köli Nappe Complex.

K. Larsson

Stop 1:6 **Gusta**

Parautochthon: Thrusting in Lower Ordovician limestones

Location: (18F Bräcke NV, 69978/14530). Quarry c. 3 km east of Brunflo church.

Description: The gently W-dipping limestones of the Caledonian Front Parautochthon contain a variety of low-angle dislocations, occurring most frequently along bedding surfaces. These thrusts can locally be seen to ramp up section into a higher level in the succession. This structural style is thought to dominate the Caledonian Front in areas where basement irregularity is insignificant. The east end of a partly overgrown quarry at Gusta excellently illustrates the tectonic style (Thorslund 1940, p. 97–98). Lower Ordovician Kunda limestones dip a few degrees to the northeast. Small bedding-plane thrusts occur with WNW-trending slickenside lineations. Some of these thrusts can be seen to climb at an angle of c. 30° through a few metres of limestone into a higher bedding surface. The amount of cover-shortening expressed in this type of deformation remains unassessed but may well be measurable in kilometres.

D. G. Gee

Stop 1:7 **Rannåsen**

Lower Allochthon: Type section for the Kyrkås Group of Late Ordovician and possibly Early Silurian age.

Location: (19E, Östersund NO, 701020/144425). Quarry c. 3.5 km northeast of Östersund, c. 1 km east of main road (88) to Strömsund.

Description: This operational quarry (providing road-aggregate etc.) is cut in a folded and faulted sequence, predominantly composed of quartzites, dark shales and mudstones. The entire sequence is at least 35 m thick. It includes two prominent dark mudstone units (c. 1.30 m and 3.30 m) separated by two beds (0.75 m and 0.17 m) of a lighter calcareous siltstone. (These units have recently been well exposed in the northwestern part of the quarry but the face is continually changing.) The lower mudstone units has yielded Ashgillian fossils e. g. *Dalmanitina mucronata, Brongiatella platynota* and various brachiopods, lamellibranchs, cephalopods etc. The upper mudstone has yielded climacograptids, that were thought to be of Early Silurian age (Thorslund 1948). The sediments dip at low agles westwards and are repeated by low angle thrusts. Associated concentric folds with N20°E axes and steep east limbs vary greatly in plunge, both northwards and southwards.

The Kyrkås Group shows a variety of sedimentary structures characteristic of shallow water environments. The lower mudstone contains bedding surfaces with mudcracks, ripple marks and load casts. A thin conglomerate occurs within this mudstone with pebbles of quartz and granite (recently exposed on the eastern face of the quarry). The quartzites are commonly cross-bedded. Sedimentary structures are particularly well preserved on the southeast side of the quarry.

K. Larsson

Stop 1:8 **Frösön**

Lower Allochthon: Precambrian porphyritic rhyolites

Location: (19E, Östersund SO, 700735/143935). Road-cut on the island of Frösön, 2 km west of Östersund.

Description: Within the Lower Allochthon, minor slices of the Precambrian basement occur locally (cf. Hoverberget, stop 1:1) at the base of thrust-sheets, usually in association with Vendian and/or Lower Cambrian quartzites.

At this locality the rhyolitic porphyries occurring on both sides of the road-cut can be seen at the southeastern end of the outcrop to be thrust over quartzites and black radioactive shales (Cambrian). Further west (not exposed at this locality), the rhyolites are overlain by the quartzites, Cambrian black shales and Ordovician limestones and shales. All these units occur within the Frösön Nappe which overrides the Kyrkås Group along the eastern and southern side of the island.

D. G. Gee

DAY 2. THE ALSEN – OFFERDAL AREA

Offerdal Synform–Lower, Middle and base of Upper Allochthon

INTRODUCTION

In the area northwest of Storsjön, from Alsensjön to the environs of Näldsjön and Hällsjön (Fig. 13), the Lower Palaeozoic successions of the Lower Allochthon are overthrust by the Middle Allochthon. Ordovician and Silurian strata dominate the former, composing the cultivated low ground around Alsensjön and from Näldsjön to Hällsjön, whilst the hills between and north of these lakes are largely made up of phyllitic and partly phyllonitic, feldspathic sandstones (flagstones) of the Offerdal Nappe. The latter occur in the Alsen and Ansätten Klippes. The lower part of the Särv Nappes is preserved as the highest unit in the Alsen Klippe.

In the Lower Allochthon, Ordovician greywackes give way upwards into shales, overlain by thin quartzites of the Ede Formation (Thorslund 1948). The latter passes transitionally upwards into Llandovery limestones (Berge Formation) and black shales (Bångåsen Formation) and then greywackes (Ekeberg Formation) which probably reach into the Wenlock but may even be of Ludlow age.

Conglomerates, (the so-called Offerdal Conglomerate), probably of alluvial origin and Precambrian age (p. 19), are thrust over these Lower Palaeozoic sediments, locally separating the latter from the overlying Offerdal Nappe flagstones.

The sediments of the Lower Allochthon are folded on N–S axes with W-dipping axial surfaces and associated cleavage. Apparantly these structures formed in front of the advancing Middle Allochthon, being truncated by the extensive basal mylonites of the latter. The general fine-grained schistosity in the Middle Allochthon, related to isoclinal folding, is regionally flat-lying and approximately parallel to the basal mylonites and phyllonites. It is folded gently in the Offerdal Synform.

The excursion starts in the northern part of the area on the Offerdal Conglomerate and views the regional relationships between the Lower Palaeozoic strata in the lowlands and the overriding Middle and Upper Allochthon of the klippes. It then examines the Silurian stratigraphy before ascending the Alsen Klippe from the basal mylonites of the Offerdal Nappe to the Särv Nappe dolerites and sandstones.

ROAD-LOG

Stop 2:1 **Kläppe**

Middle Allochthon: Offerdal Conglomerate

Location: (19E Östersund NV, 70410/141455). Top of hill, Högkläppberget c. 4 km E of Offerdal church.

Description: Several localities occur at the base of the Middle Allochthon in central Jämtland where the lowest tectonic units are composed of coarse conglomerates

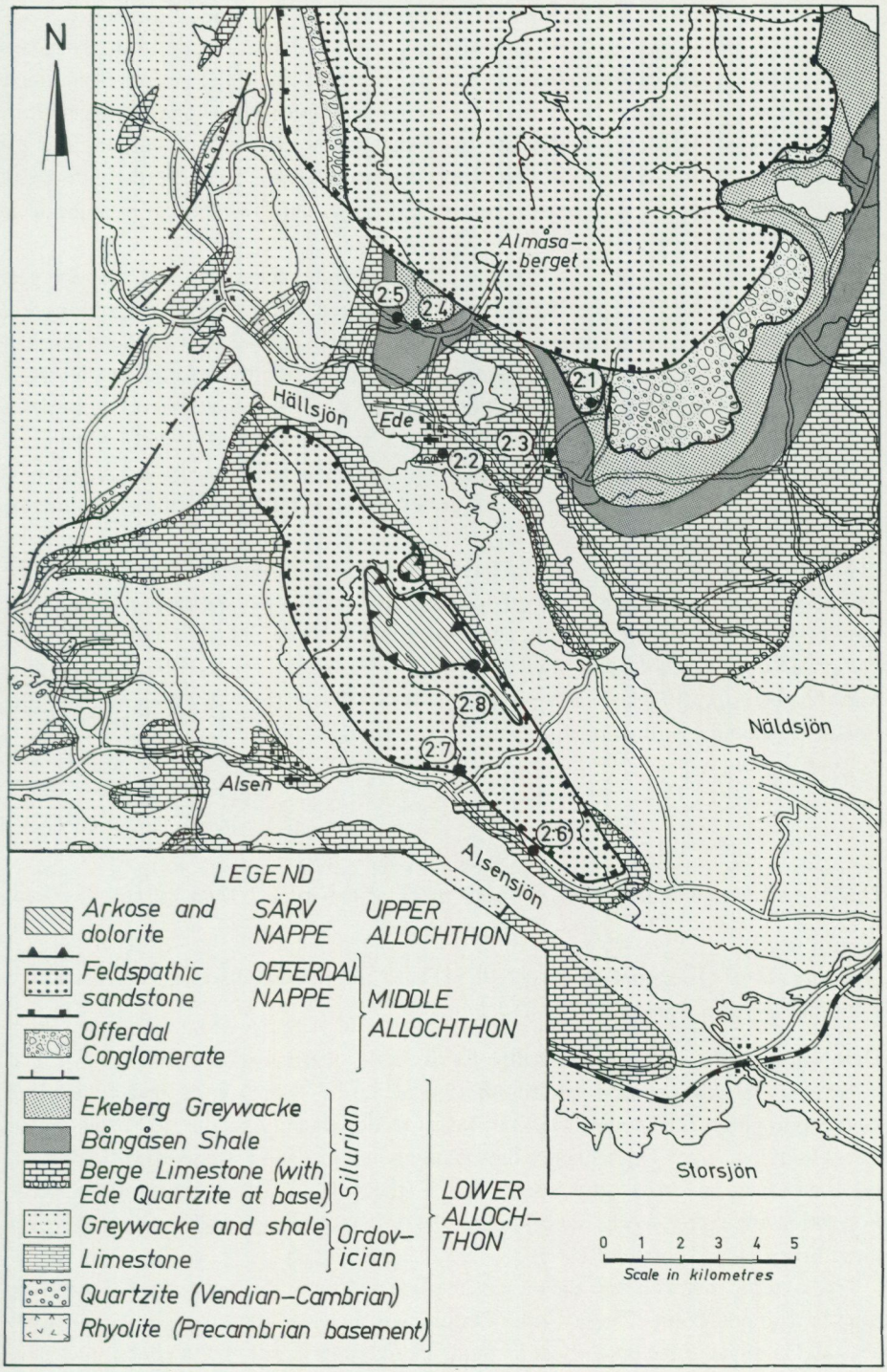

Fig. 13. Geological map of the area from Alsensjön to Almåsaberget.

usually overlying Silurian greywackes, shales or limestones. One of the better exposures occurs in the area north of Offerdal below the Offerdal Nappe in the Ansätten Klippe. The age and tectonic position of these Offerdal Conglomerates has been much discussed in the literature, being regarded by some authors (e.g. Törnebohm 1896) to be Precambrian, occurring within the basal part of the Middle Allochthon, and by others (e.g. Asklund 1960) as of Late Silurian or even Devonian age and a part of the Lower Allochthon. As mentioned elsewhere (p. 19), the Precambrian hypothesis is favoured here.

At the Kläppe locality, the Offerdal Conglomerate occurs on Högkläppberget. Below Högkläppberget, by a farm and in the woods above the farm, greywackes occur, of probable Silurian age. From this farm, follow a small path up the southeastern side of Högkläppberget. The contact to the overlying highly deformed conglomerates is not exposed in this section. Note that the preservation of the conglomerate improves upwards and a variety of pebbles can be distinguished (largely porphyritic rhyolite with subordinate feldspathic quartzites, granites and occasional greenstones) in a feldspathic sandstone matrix. There are several good outcrops of the conglomerate on the top of Högkläppberget.

From the top of Högkläppberget there is an excellent view southwards over the undulating countryside composed of Silurian and Ordovician sediments towards the hills of the Alsen Klippe (Middle and Upper Allochthon). This allochthon, largely composed of Offerdal Nappe phyllonites and "flagstones", capped by a slice of the Särv Nappe (stop 2:8) and occupying a gentle synform, rides discordantly over the Lower Palaeozoic sediments of the Lower Allochthon.

D. G. Gee

Stop 2:2 **Ede**

Lower Allochthon: Ede Formation Quartzites of the Ånge Group overlie Tretaspis shales

Location: (19E Östersund NV, 704020/141115). In woods on southeastern side of a small hill c. 1 km southeast of Offerdal church.

Description: This is the type-locality for the Ede quartzite (Thorslund 1948). The quartzites are well exposed towards the top of the hill which is capped by Silurian Berge Formation limestones. Dark Tretaspis shales underlying the quartzites are of Late Ordovician age. The sequence dips gently northwest and is folded and cleaved. In the road along and below the eastern side of the hill, coral limestones of the Berge Formation are exposed. The succession in the type-section is thought to be thrust over these limestones (Thorslund 1960).

Two to three metres below the base of the Ede quartzites there occurs a *Dalmanitina* zone brachiopod fauna. These Upper Ordovician shales contain thin (c. 1 cm) sandy beds and laminae in the uppermost part and are overlain sharply by the basal quartzites

of the Ede Formation. The quartzite formation is composed of 2–3 m of bluish-grey and white quartzites which pass upwards into calcareous sandstones with thin shales. The latter in turn pass gradationally into the Berge Limestones which contain a Lower Llandovery fauna. The cross-bedded and ripple-bedded Ede quartzites contain corals and brachiopods in their calcareous upper part but have not as yet yielded a diagnostic fauna. Transitional relationships to the Berge limestones suggest an early Llandovery age.

K. Larsson

Stop 2:3 **Ånge**

Lower Allochthon: Uppermost Berge limestone and lower part of Bångåsen shale

Locality: (19E Östersund NV, 704015/141370). Northeastern corner of the football field in Ånge.

Description: At the northern end of the outcrop, light grey Berge limestones dip gently eastwards overlain by dark shales of the Bångåsen Formation. Although the contact is disturbed and there is much slickensiding on bedding and other surfaces, the basal Bångåsen lithologies of shales with occasional limestone lenses is typical of the lower part of the formation elsewhere. Several bentonite horizons occur in the Bångåsen shales, the thickest of these being c. 10 cm. From this shale sequence prolific graptolite faunas show the presence of at least the four upper Llandovery graptolite zones of *Monograptus turriculatus, M. crispus, M. quiestoniensis and M. crenulatus.*

K. Larsson

Stop 2:4 **Bångåsen**

Lower Allochthon: Upper Llandovery Bångåsen shales

Location: (19E Östersund NV, 704330/141050). Roadside exposure c. 1 km east of Bångåsen farms.

Description: The section, located on the north side of the road, is the locality from which the formation received its name (Thorslund 1948). Dark graptolitic shales with subordinate thin limestone bands and lenses dip gently eastwards. A prominent cleavage dips at moderate angles westwards. In the hillside to the north, Ekeberg greywackes occur, overlying the Bångåsen shales.

D. G. Gee

Stop 2:5 **Ekeberg**

Lower Allochthon: Ekeberg greywackes of Late Silurian (?) age

Location: (19E Östersund NV, 704335/141115). Roadside exposure c. 0.5 km south-west of the Ekeberg farms.

Description: The Ekeberg greywackes at this locality are massive fine-grained grey sandstones and interbanded shales. Grading is conspicuous in some units and the

sequence is clearly the right way up. A conglomeratic horizon yielded a clast containing a *Favosites* coral (Thorslund 1948). This has been recently identified as *Favosites cf. subantlanticus*, Sokolov, by Klaaman (written comm.) a fossil that in the Baltic and Eastern European areas is not known from beds older than those corresponding to the zone of *M. neodiversograptus*. It thus appears that sedimentation in the Jämtland Basin may have continued into the Late Silurian prior to nappe emplacement.

L. Karis

Stop 2:6 **Rödeberget**

Middle and Lower Allochthon: Basal phyllonites of the Middle Allochthon overlie Rödeberget sandstones of Lower Allochthon

Location: (19E Östersund NV, 702865/141415). Road cutting on north side of Alsensjön, south side of the hill Rödeberget, c. 8 km east of the village of Alsen.

Description: Approaching this locality from the east, occasional roadside outcrops expose the Ede quartzites dipping gently westwards beneath the Berge limestones. About 1/2 km east of the Rödeberget section grey shales and fine-grained sandstones comparable with the Ekeberg greywackes outcrop on the north side of the road also dipping westwards. These units pass rapidly upwards through an incompletely exposed contact into quartzitic sandstones, with thin shales. Below Rödeberget the sandstones dominate the formation; these sediments have not yielded fossils and their age remains uncertain. A section upwards from the road on the southern wooded slope of Rödeberget provides evidence of increasing penetrative deformation in the sandstones, with development of a phyllonitic texture. On the top of the hill, phyllonites occur, probably derived from the ''flagstones'' of the overlying Offerdal Nappe (Middle Allochthon).

D. G. Gee

Stop 2:7 **Glösa**

Middle and Lower Allochthon: Mylonites separate phyllonites of the Middle Allochthon from underlying greywackes of the Lower Allochthon

Location: (19E Östersund NV, 703165/141070). Section in the Glösa stream c. 0.5 km north of the northern shore of Alsensjön.

Description: Please note the *restricted use of hammers* at this locality which is notable for both geological and archaeological interest. The latter consists of rock carvings dating back to stoneage Sweden (c. 3 000 BC). The figures, largely of animals, are impressed on the phyllonites of the lowest part of the Offerdal Nappe (Middle Allochthon). They occur above a small waterfall (c. 4 m) where flinty mylonites overlie greywackes of the Lower Allochthon. The phyllonites show coarse crystallization of muscovite, chlorite and epidote and occasional garnet porphyroblasts.

D. G. Gee

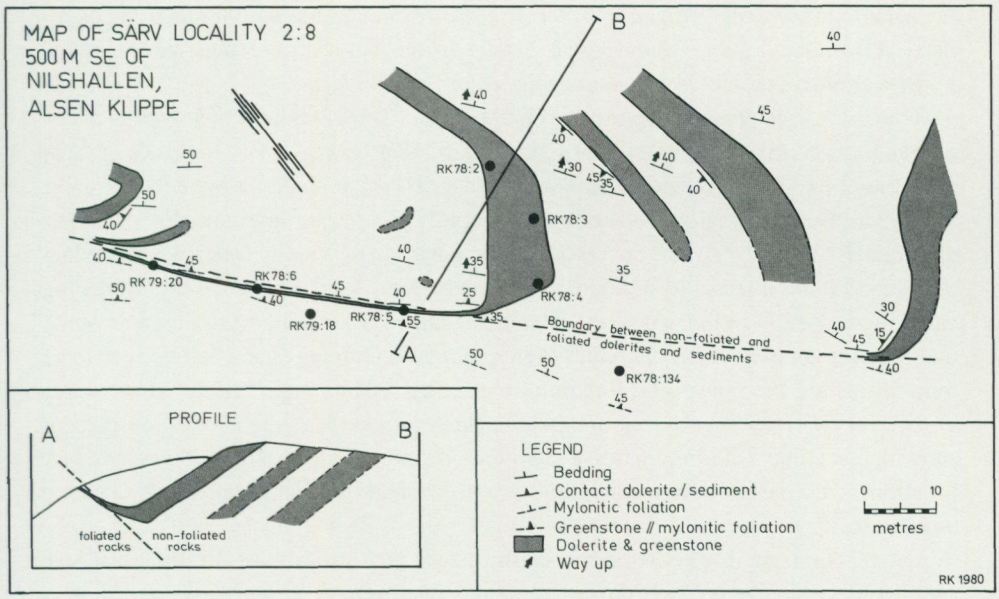

Fig. 14. Interrelationship of dolerites and sandstones in the basal part of Särv allochthon on Hällberget (Stop 2:8).

Stop 2:8 **Hällberget**

Upper and Middle (?) Allochthon of Alsen Klippe: Särv Nappe sandstones and dolerites (Upper Allochthon) thrust over Offerdal Nappe (?) flagstones

Location: (19E Östersund NV, 703450/141110). On top of Hällberget ridge, c. 500 m west of summer farm, c. 10 km north of Alsen. Follow tractor track westwards for c. 2.5 km (20–25 minutes walk) before cutting up on to the ridge via some fields and a deserted farm.

Description: On the top of the ridge, (Fig. 14) alluvial sandstones of the basal part of the Särv Nappes contain well preserved sedimentary structures such as cross-bedding, channel-filling and convolute bedding. Minor hematite bands and laminae occur. These sandstones dip at low angles northeastwards and are cut at high angles (up to 90°) by dolerite dykes related chemically and petrographically to the Ottfjället Dolerites (Solyom, pers. comm.)

The least deformed dolerites preserve a porphyritic texture with relic phenocrysts of epidotized plagioclase and saussuritized clinopyroxene. The matrix is composed of fine-grained blue-green hornblende, epidote and oligoclase. With increased deformation, thinning and development of a secondary foliation, the hornblende megacrysts, formed by replacement of pyroxene, recrystallize to a fine-grained aggregate. With further deformation the megacrysts both of amphibole and plagioclase are drawn into

the foliation. Some chloritization of the amphibole occurs, but the typical basic bands derived from the dolerites and occurring in the lower part of the section are dominated by fine-grained epidote-biotite-albite-oligoclase assemblages.

Trace the well preserved primary relationships southwards and downwards a few metres into the mylonites at the base of the Särv Nappe (Fig. 14). One dyke (c. 4 m thick) can be followed down towards the contact. The high angle between the intrusive sheet and the bedding in the sediments rapidly decreases and the dolerite thins dramatically to c. 0.5 m and curves back into parallelism with an intensive secondary foliation that dominates the structure in the sandstones. Very attenuated cross-bedding can be seen locally in the sediments. The dyke can be followed northwestwards along the ridge for about 50 m. It continues to thin to a few centimetres and can be seen to be repeated within the transposed foliation by isoclinal folding and faulting. Downwards in the section a few metres, the rocks are schistose and thin greenstones are present showing isoclinal folding, extreme attenuation and excision within the secondary foliation. This passes down into a fine-grained banded mylonite apparantly lacking basic rocks.

A magnetometer profile extended southwestwards from this locality identified an anomalous body c. 100 m from this mylonite zone further down the ridge. This is probably due to the presence of a greenstone implying the possibility that a lower Särv unit and not the Offerdal Nappe is represented below the mylonites.

R. Kumpulainen

DAY 3. THE OTTFJÄLLET – JÄRPEN – KALLSJÖN AREA

Åre Synform – Upper, Middle and Lower Allochthon

INTRODUCTION

The Middle and Upper Allochthon of the Offerdal Synform can be followed over the Olden – Oviksfjällen Antiform into the Åre Synform where the Upper Allochthon is particularly extensively developed. The Day 3 excursion concentrates on units of the Särv Nappes and underlying allochthon in the Åre Synform, leaving the Seve (in the Åre type area) for Day 4.

In the southern extension of the Åre Synform (Fig. 15), the upper unit of the Särv Nappes is well preserved on Ottfjället. The top of this mountain provides good exposures of both the main components of this tectonic unit, the sandstones and the dolerite dyke-swarm.

Ottfjället composes the northern part of the main development of the Särv Nappes. This composite unit is relatively thick (varying up to probably in the order of 2 km) and the primary relationships in the sediments and the dykes are well preserved. On Ottfjället only the upper of the Särv Nappes has been recorded. Northwards from

Ottfjället, the Särv allochthon thins dramatically in both limbs of the Åre Synform and is at least locally cut out. The attenuation of the nappes is associated with the development of an intense penetrative schistosity, rotation of the dykes and the bedding into parallelism with this new secondary structure, boudinage and isoclinal folding of the new banding. A greenschist facies mineralogy develops with crystallization of hornblende, epidote, albite-oligoclase and biotite.

The Middle Allochthon in the southern extension of the Åre Synform is largely composed of basement lithologies dominated by granodiorites and augen gneisses with subordinate amphibolitized gabbros. These units are generally cataclastically deformed; locally they are extensively mylonitized. Further north in the synform, in the vicinity of Kallsjön, Offerdal ''flagstones'' dominate the Middle Allochthon.

The excursion starts on the top of Ottfjället, examining the dykes and sandstones where they are well preserved. It then descends into the basement units of the underlying Middle Allochthon. Thereafter, we drive northwards in the west limb of the Åre Synform to examine the Ordovician greywackes of the Lower Allochthon at Järpen before crossing the Åre Synform, north of Åreskutan to a profile in the west limb of the synform as it is exposed on the south side of Kallsjön. Here both the Offerdal and Särv Nappes are attenuated and thrust over the Silurian sediments of the Lower Allochthon.

ROAD-LOG

Stop 3:1 **Ottfjället, Kläppen**

Upper Allochthon: Dolerite-intruded sandstones of the Särv Nappes

Locality: (19D, Åre SV, 701020/135565). At Kläppen, on the southern slope of Ottfjället. (The road up to Ottfjället from Vålådalen is usually kept closed.)

Description: Ottfjället (Fig. 15) is the type area (Holmquist 1894) for the tholeiitic dolerites of the Särv Nappes. This mountain is an excellent locality for observing the character of the dyke-swarm and the style of deformation within the better preserved parts of the nappes. On Ottfjället, the dykes trend E–W and dip at low to moderate angles south. This orientation is at c. 90° to the regional orientation further south; the Ottfjället part is interpreted to have rotated in relation to adjacent units during the nappe emplacement, a hypothesis that has received support from recent palaeomagnetic investigations (Bylund and Zellman, in press).

At this locality the dolerites dip c. 40°S, at high angles to the sediments which dip gently northwestwards (N 30° E/35° NW). The latter are composed of reddish-grey, fluvial, feldspathic sandstones and shales. They display several fining-upwards units varying in thickness from 1 to 5 m. The base of these units is an erosional, scoured surface overlain by a lag conglomerate or coarse-grained sand. The latter may be massive or trough cross-stratified. Ripple cross-stratification and horizontal lamination

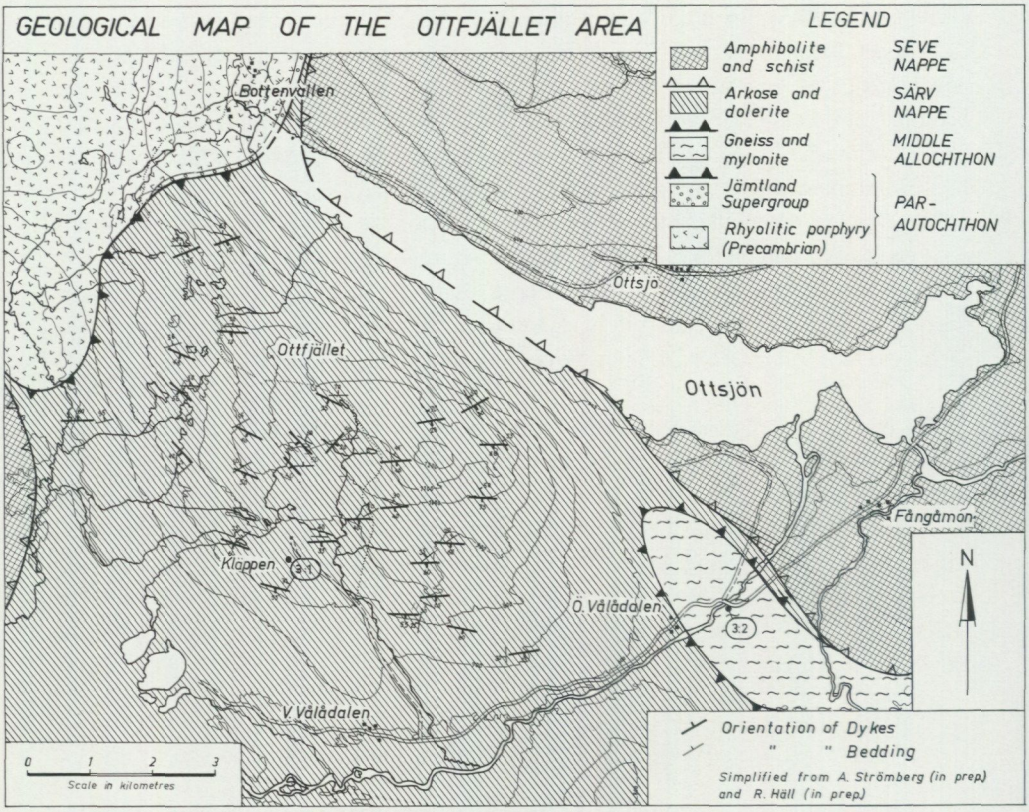

Fig. 15. Geological map of the Ottfjället area, showing the interrelationships between the Ottfjället dolerite dykes and the Lunndörrsfjällen sandstones.

are frequently observed in the fine-grained sandstones and siltstones higher up in the cycle. Some of the coarse-grained, sandy beds exhibit soft-sediment deformation; these structures are probably due to local liquefaction of the sediment.

The characteristics described above taken along with the large grain-size variations and moderate maturity suggest that these sediments were deposited in a distal part of an alluvial fan.

Note that in the immediate contact with the dolerites, the angle between bedding and the chilled dyke contact increases to nearly 90°. This is typical of the well preserved parts of the nappe and implies that the sediments were more or less flat-lying prior to dyke-intrusion.

Weather permitting, the excursion will spend c. 2 hours traversing northwards on to the top of Ottfjället (Fig. 16) to examine further the dyke-swarm, the sandstones and their inter-relationships.

R. Kumpulainen

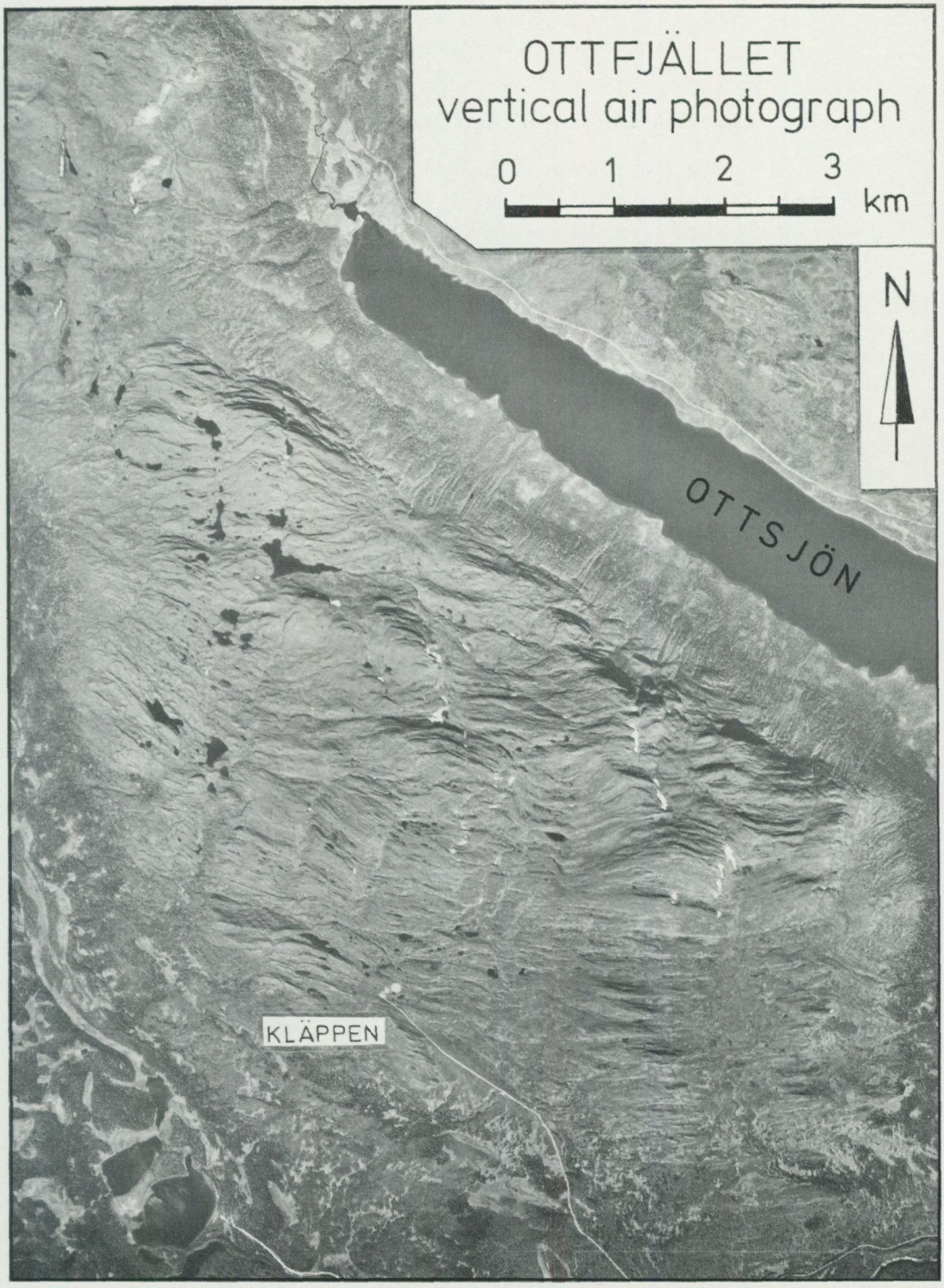

Fig. 16. Vertical air photograph of Ottfjället showing the prominent E–W dyke-swarm. (Published by permission of statens lantmäteriverk 80-03-17.)

Stop 3:2 **Vålån**

Middle Allochthon: Gneisses and mylonites

Locality: (19D Åre SV, 700945/136245). On the road from Undersåker to Vålådalen below the bridge over the stream Vålån and downstream therefrom.

Description: In the northern part of Jämtland County, the Middle Allochthon is dominated by finely schistose ''flagstones'' of the Offerdal Nappe largely derived from feldspathic sandstones. Further south these also occur in the Fuda Klippe. The Middle Allochthon of southern Jämtland is dominated by augen gneisses, generally referred to as the Tännäs Augen Gneiss Nappe. In areas north of Hede these have yielded a U/Pb age of c. 1 700 Ma (Claesson in press). Mylonites separating the overlying Särv Nappes from the Tännäs Augen Gneiss Nappe yielded an age of c. 485 Ma.

In the Vålån section, beneath the bridge, granodiorites and greenstones are relatively well preserved. They contain a high angle foliation that is cut by aplites. Plagioclase is epidotized and sericitized and hornblende partly altered to biotite. Thin NW-dipping mylonite zones are conspicuous, with relic plagioclase and microcline augen and subordinate hornblende and early biotite megacrysts swathed in a gneissosity composed of finer grained muscovite, epidote, biotite, quartz, albite and microcline.

Downstream from the bridge, relics of the basement lithologies are still recognizable, but the mylonitization dominates, dipping at low angles northwestwards.

D. G. Gee

Stop 3:3 **Järpen**

Lower Allochthon: Ordovician shales and greywackes

Location: (19D Åre NO, 702930/138195). Old quarry on east side of road northwards from Järpen to Kall, c. 1 km north of road E 75.

Description: The relatively well preserved graded greywackes and shales at this locality have yielded Middle Ordovician graptolites including *Glyptograptus cf. teretiusculus* (R. Skoglund, pers. comm.).

D. G. Gee

Stop 3:4 **Kallsjön (Sikås)**

Lower, Middle and Upper Allochthon: Ordovician and Silurian sediments overlain by Gråsjön (Offerdal), Särv and Lower Seve Nappes

Location: (19D Åre NV, 704845/136260). Profile (c. 4 km N of Huså) along the southern shore of Kallsjön from the Sikås landing-stage towards the southeast (c. 1 km).

Description: This profile is located in the eastern limb of the Mullfjället Antiform (Fig. 17). The deepest levels of exposure in this major antiform are composed of parautochthonous basement units dominated by porphyritic trachytes and rhyolites (in part ignimbritic) with minor tuffites and occasional gabbros. The volcanic rocks are probably of late Svecokarelian age. They are overlain by a thin sedimentary cover of blue-grey quartzites (< 10 m), black phyllites, limestones and quartz phyllites having a thickness of up to c. 200 m. Usually only the lower part of this sedimentary sequence is present (c. 20–30 m). These parautochthonous units are referred to as the Äggsjön Complex. They are overlain tectonically by a sedimentary allochthon, the Kallsjön Nappe (Lower Allochthon) in which units of the Jämtland Supergroup are represented, from the Vendian-Cambrian quartzites to the Silurian greywackes (up to c. 1 000 m).

Higher units of the Lower Allochthon include the Bottenviken Nappe (alluvial conglomerates and sandstones, siltstones, dolomites, mixtites, blue-grey quartzites and black phyllites) and the overlying Haranäset Nappe (basement lithologies including granites, syenites, porphyritic rhyolites, gabbros, dolerites and anorthosites, overlain by sediments including mixtites, quartzites, greenish grey phyllites, black phyllites and quartz phyllites). Neither of these nappes are exposed in the Sikås profile. The overlying Gråsjön Nappe of the Middle Allochthon is comparable with the Offerdal Nappe being composed of plane-foliated flaggy feldspathic sandstones (c. 50 m); it locally contains large clasts of basement granodiorites. It is overlain by units of the Särv Nappes and Seve-Köli Nappe Complex of the Upper Allochthon. The former (<20 m) comprises generally concordant and highly attenuated porphyritic greenstones (metadolerites) and quartzo-feldspathic schists (metasediments). The overlying Seve Nappes of the Seve-Köli Nappe Complex are divisible into an underlying lower unit of retrogressed amphibolite, schist and marble and an overlying higher grade gneiss, amphibolite, granulite association.

Within the Sikås profile (Fig. 18) on the south side of Kallsjön, the Ordovician and Silurian sediments in the uppermost part of the Lower Allochthon occur in a tight syncline (F1) with SE-dipping axial-surface. The fold axis is thought to trend northeast and the structure may be antiformal or synformal. It is coaxially refolded by a generation of minor asymmetric folds (F2), overturned to the southeast with a N-dipping axial surface cleavage (S2). This foliation is developed regionally, constituting the main cleavage in the Kallsjön Nappe. In the profile, the S2 cleavage is deformed (Fig. 18) and the intensity of deformation increases when approaching the contact to the overlying Gråsjön Nappe. The Gråsjön Nappe (c. 50 m) and overlying Särv Nappe (c. 15 m) are both very much thinner here than in the areas to the east and south of Kallsjön.

Start the profile at the northwestern end, on the shore of Kallsjön.

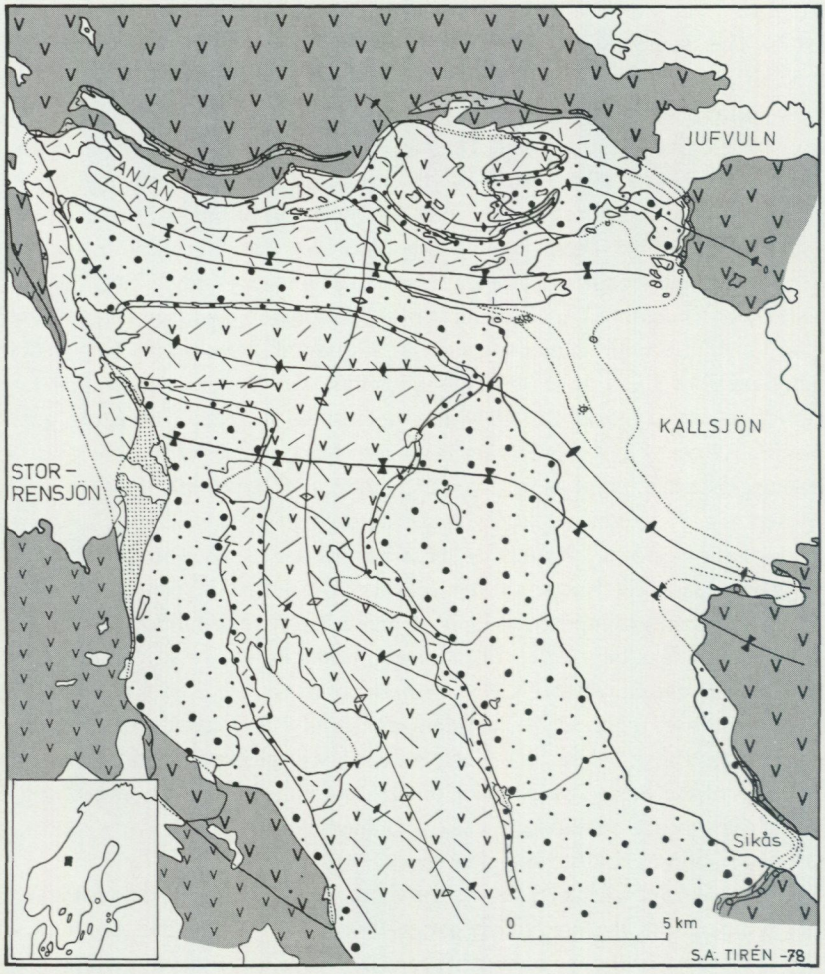

Fig. 17. Geology of the area from Kallsjön to Storrensjön in the northern part of the Mullfjället Window.

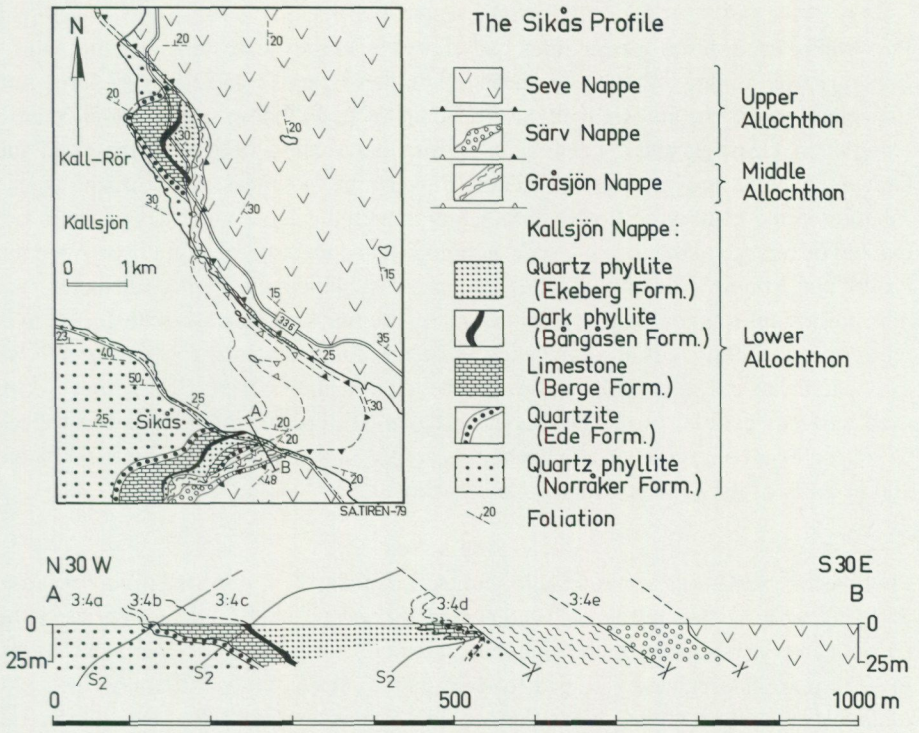

Fig. 18. Geology in the vicinity of the Sikås profile in the eastern limb of the Mullfjället Antiform.

Stop 3:4 a

Psammitic and pelitic phyllites (with white mica, chlorite and subordinate biotite) and thin calcareous quartz-rich layers constitute the upper part of a succession, which, further to the northwest in this area, contains greywackes typical of the Mid Ordovician successions (Norråker Formation) elsewhere in central Jämtland.

Stop 3:4 b

A thin (1–2 m) quartzite (Ede Formation) overlies the phyllites. The quartzite contains thin bands of grey phyllite and is calcareous in its upper part. The immediately overlying lithologies (Berge Formation) are not exposed.

Stop 3:4 c

Blue-grey limestone with crinoid stems and highly deformed corals are comparable with those at Kall-Rör on the east side of Kallsjön and those in Ullån, west of Åre. Thorslund (1948) describes the unit as a typical Silurian limestone and correlated it with the Berge Formation. It contains intercalations of grey phyllites in its upper part and is overlain by thin dark graphitic phyllites (Bångåsen Formation) and then by quartz phyllites correlatable with the greywackes of the Ekeberg Formation.

Stop 3:4 d

Pass southeast from quartz phyllites back into bluish grey limestone and then into a thin quartzite in the inverted southeastern limb of the F1 syncline. Deformation increases towards the contact with the Gråsjön Nappe, with development of an intense crenulation cleavage and by the tight to isoclinal folding of the quartzite. In the Gråsjön Nappe, the mylonitic foliation dips gently southeast, discordant to the foliation in the underlying Lower Allochthon, which dips gently northeast. There is a marked difference in the tectonic style, lithologies and metamorphic grade between the Lower and Middle Allochthon. The latter has a synkinematic garnet (diameter $<$ 1 mm, maximum rotation c. 90°) – white mica – biotite – epidote assemblage which is retrogressed (chloritized) at a late stage of deformation. Isoclinal folds, with WNW-axes parallel to the mineral lineation, can be seen in the Gråsjön ''flagstones'' with axial surfaces parallel to the general penetrative SE-dipping foliation in the nappe. Clasts (cobbles) of granodiorite have been recorded in the Gråsjön ''flagstones'' some 200 m south of the contact with the Lower Allochthon.

Stop 3:4 e

Phyllonites, containing synkinematic garnets (diameter $<$ 1 mm, maximum rotation 360°) as well as late retrogressive deformation, occur in the contact between the Gråsjön and Särv Nappes. In the latter concordant greenstones of varying thickness (up to c. 2 m) are interbanded with quartzo-feldspathic schists. Only extremely low-angle relationships between the orientation of the greenstones and the banding in the quartzo-feldspathic schists have been recorded at this locality. The inference that these porphyritic basic rocks originated from the Ottfjället dolerites is based on comparison with relationships at other localities. The greenstone mineralogy is dominated by albite-oligoclase, epidote and a pale green to blue green amphibole and with plagioclase phenocrysts altered to aggregates of clinozoisite. The contact to the overlying Seve is defined by a narrow zone (c. 5 m) of intense phyllonitization. Marbles, psammites and amphibolites compose the base of the Seve.

S. A. Tirén

Stop 3:5 **Brattland**

Upper Allochthon: Seve amphibolites and schists

Locality: (19D Åre NV, 70275/13704) on north side of road E 75 c. 1 km southeast of the village of Brattland, c. 10 km southeast of Åre.

Description: Quartzo-feldspathic and calcareous schists and amphibolites of the Lower Seve Nappe sheet-dip at low angles westwards, being gently folded by folds with NE-plunging axes. Small isoclinal folds are present with WNW-axes parallel to the dominating transverse lineation. Thin early pegmatites cut the schists and amphibolites and are folded by both fold generations.

D. G. Gee

DAY 4. THE MULLFJÄLLET–ÅRESKUTAN AREA

Åre Synform and Mullfjället Antiform – Parautochthon, Lower and Upper Allochthon

INTRODUCTION

The mountain Åreskutan is the classical area for the early descriptions of the high-grade Seve rocks (Törnebohm 1872) and the first application of the nappe hypothesis (Törnebohm 1888) in the Scandinavian Caledonides. Within the Åre Synform, in the Åre area (Fig. 19), there is a general decrease in metamorphic grade downwards, from granulite facies on the mountain top to lower greenschist facies in the fossiliferous sediments of the Lower Allochthon in the valley. This decrease in grade is interrupted by a number of important tectonic contacts.

The Seve Nappes on Åreskutan are composed of at least two tectonic units separated by a zone of blastomylonites. The upper unit (the Åreskutan Nappe) is composed of migmatites and the lower unit is dominated by feldspathic psammites and amphibolites with subordinate marbles. Ultramafites and gabbros occur in the lower unit. Pegmatites cut both units and are deformed in the mylonite zone separating the two nappes. Within the Lower Seve Nappe, the metamorphic grade decreases downwards to upper greenschist facies in the base, where a thick zone of phyllonites occurs. Concordant greenstones and quartzo-feldspathic schists at this level may be related to the base of the Seve or to the Särv Nappes; at least in this area there appears to be very little difference in metamorphic grade between the lower part of the Seve Nappes and the metamorphism of the Särv units elsewhere in Jämtland.

The Middle Allochthon in this part of the Åre Synform is very thin or absent. A prominent mylonite zone separates the lower greenschist facies sediments of the Lower Allochthon from overlying units of the Särv or Seve Nappes.

The Seve Nappes have a thickness of c. 2 km in the eastern limb of the Åre Synform. This thickness is considerably reduced in the western limb and further west, over the Mullfjället Antiform, the nappes are locally cut out completely, only to reappear again in the Tännforsen Synform.

The excursion starts by briefly visiting the parautochthonous porphyritic rhyolites in the Mullfjället Window and the crinoidal limestones of the Lower Allochthon. We then take the cable-car to the top of Åreskutan to examine the granulite facies migmatites and discuss their mineralogy (Arnbom in prep.) and age (Claesson in prep.) The excursion descends westwards from the Åreskutan Nappe through mylonites into the Lower Seve Nappe, and thereafter via extensive phyllonites and mylonites back into the Lower Allochthon.

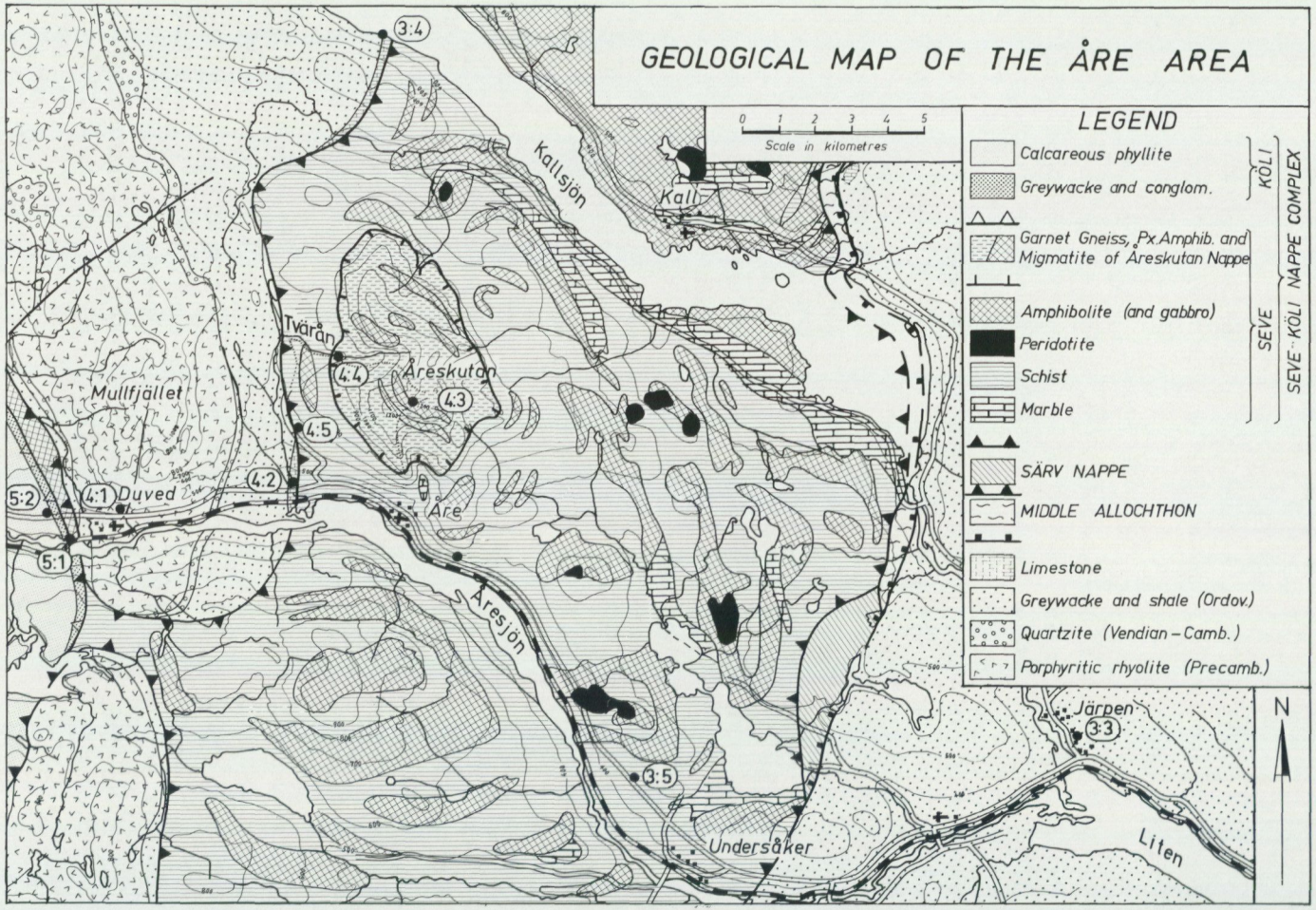

Fig. 19. Geological map of the area around Åreskutan.

ROAD-LOG

Stop 4:1 **Duved,** E 75

Parautochthon: Porphyritic rhyolites of the Mullfjället Window

Locality: (19D Åre NV, 703515/135585). Road-cut on north side of road E 75 northwest of Duved's church, beneath the Mullfjället ski lift.

Description: Massive grey-green and pinkish porphyritic rhyolites of the parautochthonous basement are influenced by a semi-penetrative Caledonian foliation dipping at low to moderate angles westwards.

A variety of primary structures have been reported from the Mullfjället and Olden volcanic rocks including ignimbritic banding, and agglomerates occur locally. In the Olden Window the rhyolites pass transitionally into granites. A Rb/Sr study of the latter has yielded a minimum age of c. 1 500 Ma (I. Klingspor pers. comm.)

D. G. Gee

Stop 4:2 **Ullån**

Lower Allochthon: Crinoidal limestones of (probable) Lower Silurian age

Location: (19D Åre NV, 70359/13610). Beneath a bridge where road E 75 passes over Ullån, c. 3 km west of Åre.

Description: The penetrative foliation in these limestones dips gently southeastwards (N 40° E/20° SE) in the western limb of the Åre Synform. A strong NW-trending linear structure is present and the bedding is largely obscured by the deformation and recrystallization. Crinoid ossicles and deformed corals (Törnebohm 1872) have been

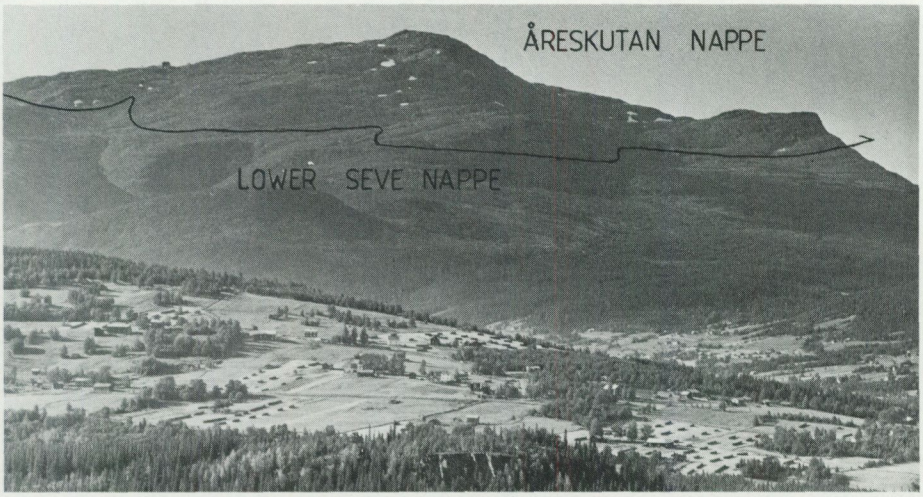

Fig. 20. View of Åreskutan from the southeast. The upper cable-car terminal (Stop 4:3a) can be seen on the sky-line to the left. (Photo B. Weilert, Fotografen, Östersund).

recorded at this locality. The limestone is underlain by a thin quartzite. Correlation with the Lower Silurian limestones of the Berge Formation is favoured. White mica and chlorite recrystallize in these lowermost greenschist facies metasediments.

D. G. Gee

Stop 4:3 **Åreskutan**

Upper Allochthon: Upper (Åreskutan) and Lower Seve Nappes

The excursion takes the cable-car up to the upper terminal (Fig. 20). En route up the mountain, note the conspicuous thin (1–2 m) pegmatites that cut the flat-lying foliation in the gneisses in the upper part of the Seve (Åreskutan Nappe). The pegmatites are intruded at high angles and generally strike NE.

Stop 4:3 a

Åreskutan Nappe: Pyroxene granulites and migmatites

Location: (19E Åre NV, 70383/13639). In vicinity of upper cable-car terminal, c. 1 km southwest of the top of Åreskutan.

Description: Banded basic rocks (hypersthene, diopside, andesine, hornblende) occur as paleosome in a granodioritic–adamellitic (quartz, potash feldspar, andesine, garnet, biotite, sillimanite ± kyanite) neosome. The basic rocks were clearly foliated and probably isoclinally folded prior to mobilization and incorporation in the neosome. Several garnet-biotite pairs from the neosome have been analysed by microprobe and have yielded a mean distribution coefficient K_D Mg/Fe of 0.33, corresponding to granulite facies metamorphism.

J.-O. Arnbom

Stop 4:3 b

Åreskutan Nappe: Foliated granite

Location: (19D Åre NV 70384/13644). 500 m northeast of upper cable-car terminal.

Description: This intrusive body of granitic composition (quartz, oligoclase, orthoclase, biotite, muscovite, garnet, kyanite) contains xenoliths of the basic, two pyroxene gneisses and pelitic gneisses. The granitic body is penetratively foliated and subject to pinch-and-swell deformation, the xenoliths being partly drawn out in this foliation.

J.-O. Arnbom

This granitic body has been the subject of a Rb/Sr isotope age-determination study. A whole-rock isochron was not obtained but a high $^{87}Sr/^{86}Sr$ ratio indicates that the rocks have had a prolonged pre-Caledonian history. Separated minerals (biotite,

K-feldspar, garnet) yielded an age of c. 400 Ma. Thus the intense penetrative foliation is interpreted to be of probable Caledonian origin. Earlier foliations (e.g. in the xenoliths) may be pre-Caledonian.

Traverse northeast along the granitic body observing the sampling (blasted) sites and contact relationships to adjacent rocks. The upper contact is well exposed towards the northeast end of the outcrop.

S. Claesson

Stop 4:3 c

Åreskutan Nappe: Pelitic gneisses and dating of paleosome and neosome of migmatites

Locality: (19D Åre NV, 70382/13639). Beneath the first pylons south of the upper cable-car terminal.

Description: The two pyroxene basic gneisses contain a subordinate neosome (pink andesine/labradorite, quartz, biotite and clinopyroxene) Samples of the basic rocks were collected for a standard Rb/Sr whole-rock study; they failed to give an isochron. A small-scale (sample c. 2 kg) whole rock Rb/Sr investigation of the neosome gave a Caledonian isochron (416 ± 10 Ma).

S. Claesson

Between this locality and the cable-car terminal is a flat-lying zone of intense penetrative foliation, developed in dominantly pelitic gneisses. The parageneses in the gneisses (quartz, andesine, K-feldspar, garnet, biotite, sillimanite) have yielded a garnet-biotite distribution coefficient K_D Mg /Fe of 0.33.

Descend from this locality along the tourist path, observing a variety of well exposed banded, two pyroxene basic rocks, locally with neosome development (including hypersthene-bearing neosome).

J.-O. Arnbom

Stop 4:3 d

Åreskutan Nappe: Late pegmatites and shear zones

Location: (19D Åre NV, 70377/13636). Near and west of ''Raststugan'' c. 500 m south-southwest of the upper cable-car terminal.

Description: Close to the ''Raststugan'' are well exposed two pyroxene-bearing basic gneisses with subordinate neosome. Boudinage is conspicuous within the flat-lying foliation.

About 200 m WNW of ''Raststugan'', a coarse pegmatite dyke cuts the gneissosity in the country rocks at a high angle. These late pegmatites (quartz, oligoclase,

K-feldspar, biotite, muscovite, garnet) are orientated NW/Vert. The basic gneisses within 1 cm of the contact are altered (pyroxenes are chloritized and feldspar sericitized). The pegmatite can be followed a few tens of metres to the northwest from this (blasted) site, into a shear-zone, orientated NE/Vert, where it is displaced c. 6 m. In this fault, blastomylonite is developed (quartz, plagioclase, biotite garnet but *not* chlorite or epidote). Garnet and plagioclase occur as porphyroblasts and biotite is largely recrystallized. A microprobe study has shown that the garnet chemistry is not influenced by the deformation, whilst the recrystallized biotites contain a higher Mg/Fe ratio than in the surrounding gneisses.

J.-O. Arnbom

The pegmatite was sampled for a whole-rock/mineral Rb/Sr age-determination study. This yielded an isochron of 395 ± 15 Ma.

S. Claesson

From this position traverse c. 1.5 km northwest, maintaining about the same height (1 100 m), to the stream Tvärån that flows westwards off Åreskutan. The bedrock is largely composed of granodioritic–adamellitic migmatites, in places with only very subordinate paleosome. A flat-lying penetrative foliation is developed at various levels in the migmatite, becoming more conspicuous downwards.

Stop 4:4 **Tvärån**

Upper Allochthon: From base of Åreskutan Nappe through the Lower Seve Nappe into basal mylonites above Lower Allochthon

Stop 4:4a

Åreskutan Nappe: Lower part

Location: (19D Åre NV, 70394/13632). In stream Tvärån, c. 100 m east of base hut for small Tvärån ski lift.

Description: Near the base of the Åreskutan Nappe the pegmatites are nearly concordant within the foliation in the gneisses. The latter are migmatitic and the paleosome is orientated in the flat-lying foliation. Paleosome composition is dominated by calc-silicates and psammites, in contrast to the basic gneisses higher in the nappe. The pegmatites are intensely foliated with local development of blastomylonite. Blastomylonites in the gneisses (quartz, K-feldspar, andesine/oligoclase, biotite, kyanite, garnet) contain two generations of garnet, an early disrupted larger variety (not retrogressed) and a younger finer grained idioblastic type. Both these generations of garnet have the same composition. Garnet-biotite pairs have been analysed from four different localities in the blastomylonites near the base of the Åreskutan Nappe.

They all yielded Mg/Fe distribution coefficients of c. 0.31 similar to those obtained in the undeformed migmatites.

Immediately below a large (2–3 m thick) pegmatite, there occur marbles and calc-silicate rocks very similar to those in the underlying Lower Seve Nappe. These occur in a small antiform and further downstream the gneissose migmatites are exposed, cut by a strongly foliated pegmatite.

J.-A. Arnbom

Stop 4:4 b

Contact zone between Upper (Åreskutan) and Lower Seve Nappes

Location: (19D Åre NV, 70394/13628). Tvärånfallet; two small (3–4 m) waterfalls c. 200 m from the base hut for the Tvärån ski lift.

Description: In the upper waterfall the migmatitic gneisses are intensely and regularly foliated. In this flat-lying foliation, concordant, attenuated pegmatites occur and development of blastomylonite. Beneath these lithologies there occur banded marbles, calc-silicate rocks, psammites and amphibolites characteristic of the Lower Seve Nappe. These are isoclinally folded and refolded disharmonically.

Below the second waterfall, foliated pegmatites (quartz, oligoclase, K-feldspar, biotite, muscovite, epidote) are locally blastomylonitic; they occur concordantly and are folded together with the meta-sedimentary rocks.

J.-O. Arnbom

Stop 4:4 c

Lower Seve Nappe porphyritic amphibolites

Locality: (19D Åre NV, 70394/13626). In Tvärån.

Description: Traversing downstream, there occur a few scattered outcrops mostly of amphibolite. Anthophyllite has been recorded locally. Thick plagioclase porphyritic amphibolites (green hornblende, oligoclase, epidote/clinozoisite, calcite, sphene) are exposed at locality 4:4c. Continue downstream through the amphibolites.

J.-O. Arnbom

Stop 4:4 d

Phyllonitic zone near base of Seve Nappes

Locality: (19D Åre NV 70396/13618). In Tvärån c. 0.6 km east of Tvärstugan.

Description: Psammites with porphyritic amphibolites are underlain by several tens of metres of flat-lying phyllonite (quartz, albite/oligoclase, relic biotite, clinozoisite and carbonate, overgrown by large muscovites). Further downstream retrogressed

porphyritic amphibolites are exposed, underlying the phyllonite zone. These greenstones are tremolitic and chloritized.

J.-O. Arnbom

Stop 4:4 e

Mylonites at top of Lower Allochthon

Location: (19D Åre NV, 70400/13610). In Tvärån waterfall beside Tvåråstugan.

Description: At the top of the waterfall, white and blue-grey quartzites occur, typical of the Vendian/Lower Cambrian (?) lithologies elsewhere. A mylonite zone in the waterfall separates these from the underlying muscovitic grey phyllites. Further downstream greywackes are associated with the phyllites (probably of Silurian age). Walk south (c. 1.5 km) to car-park.

J.-O. Arnbom

Stop 4:5 **Ullådalen E**

Upper Allochthon: Särv Nappe (?)

Location: (19D Åre NV, 70371/13614). A few tens of metres from minor road junction on road from Tvärån southwards to E 75.

Description: The road section from the car-park southwards, contains a few outcrops of greywackes and grey phyllites. At the road junction c. 1 km from the car-park, overlying psammites (in part quartzites) and greenstones (actinolite, oligoclase, clinozoisite) occur. These isoclinally folded rocks are reminiscent of attenuated units in the Särv Nappes.

J.-O. Arnbom

DAY 5. THE DUVED–ENAFORS–STORLIEN AREA

Tännforsen Synform and Sylarna Antiform–Upper and Lower Allochthon

INTRODUCTION

The various allochthonous units of the Jämtland Caledonides can be followed over the Mullfjället Antiform, where they are all considerably reduced in thickness; locally in the western limb of the antiform some are cut out, and the uppermost nappes of the Köli rest directly on the parautochthonous basement. Further west in the southern and northern extensions of the Tännforsen Synform, the Seve units thicken again, only to be reduced to zero in the Sylarna (Riksgränsen) Antiform along the border between Sweden and Norway.

The Köli Nappes are dominated by greenschist to lower amphibolite facies metasediments. Calcareous phyllites, greywackes and conglomerates in the lower units are overlain by calcareous garnet, hornblende, biotite schists (Garbenschiefer)

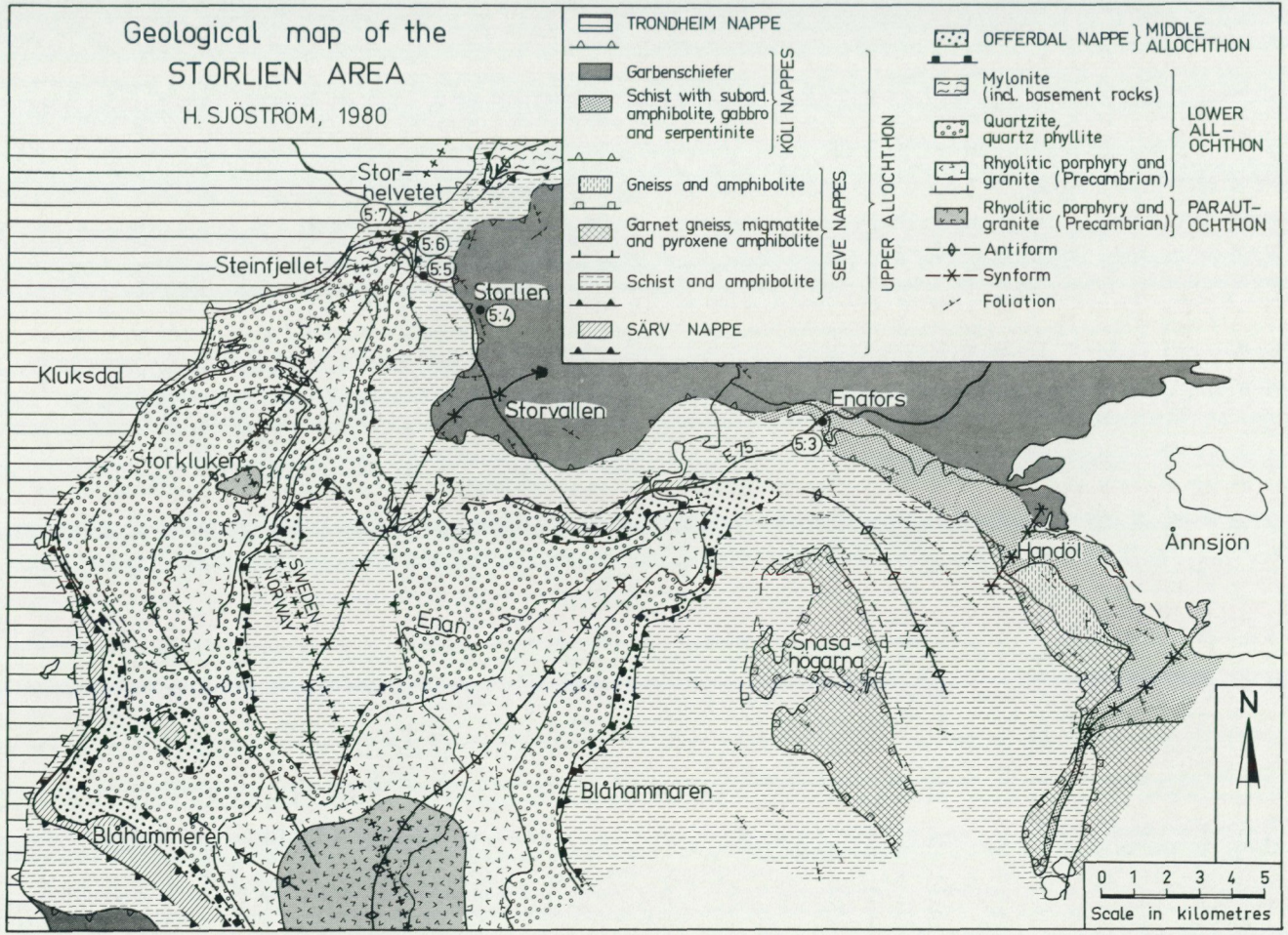

Fig. 21. Geological map of area in the vicinity and south of Storlien, on the border between Norway and Sweden.

higher in the synform; all units apparently thin and wedge out westwards to be overlain in the western limb of the Sylarna Antiform by greywackes and conglomerates of the Kjølhaugene Group of the Trondheim Nappe.

In the Sylarna Antiform (Fig. 21) beneath the thin representatives of the Middle and Upper Allochthon, there occur quartzites and porphyritic rhyolites similar to those in the Parautochthon and Lower Allochthon of the Mullfjället Window. Sjöström (in prep.) has shown that these basement and cover units are allochthonous, being thrust over a parautochthonous (?) core of basement rhyolitic porphyries and granites and a thin veneer of black phyllites and limestones (on Storkluken).

The excursion starts in the eastern limb of the Tännforsen Synform, examining Köli lithologies and structures. It then crosses the synform, pausing on the Köli Garbenschiefer en route to the Sylarna Antiform. Here we examine the thinning of the Seve and Köli units and their excision in the western limb of the antiform before continuing the geotraverse westwards into Norway (Wolff in press).

ROAD-LOG

Stop 5:1 **Duved:** Indalsälven railway bridge
Upper Allochthon: Köli greywackes and conglomerates

Location: (19D Åre NV, 703435/135490). Beneath and on both east and west sides of railway bridge over Indalsälven, c. 1 km west of Duved.

Description: Köli units in the area (Fig. 19) contain a variety of conglomerates, greywackes and grey and graphitic phyllites (Beckholmen 1980). At this locality greywackes and pebbly greywackes (Forsaberget Formation) occur on both sides of the bridge and boulder beds can be observed in the outcrops of the river-bed below the bridge.

Clast compositions are dominated by sandstones and vein quartz; a few limestones and shale fragments are also present. The greywackes contain conspicuous blue quartz. Right way up graded beds are exposed on both sides of the bridge. These conglomerates and greywackes are reminiscent of the Gillicks Formation (Middle Ordovician) of the Köli sequences in Västerbotten County (Table 3).

At least three main phases of deformation influenced the Köli rocks in the Tännforsen Synform. A regional schistosity is developed (approximately parallel to bedding in these outcrops) that elsewhere can be demonstrated to post-date early isoclinal folding. Syn-schistosity, tight to isoclinal folds are present, superimposed by post-schistosity conjugate folds. Muscovite and chlorite crystallized during development of the dominant schistosity.

M. Beckholmen

Stop 5:2 **Duvedsbyn**

Upper Allochthon – Köli calcareous phyllites

Location: (19D Åre NV, 703510/135340). On north side of road E 75 near road junction to the hotel Millesgården.

Description: Much of the Köli of eastern Tännforsfältet is composed of calcareous phyllites. Locally, where these metasediments are better preserved, they exhibit graded bedding and a variety of bottom structures.

At this locality the phyllites are inverted. Sedimentary structures (load casts and graded bedding) can be seen near the top of the easternmost outcrop. The bedding generally dips more steeply than the prominent main schistosity which is inclined at low angles westwards. At other localities in the vicinity, similar bedding/schistosity relationships occur but the sediments have proved to be both the right way up and inverted. This implies early isoclinal folding of the succession prior to development of the main schistosity. The latter is crenulated by later small folds related to the formation of the Mullfjället Antiform.

M. Beckholmen

Stop 5:3 **Enafors**

Upper Allochthon: Köli ''Garbenschiefer''

Location: (19C Storlien SO, 702455/132550). In river Enan a few tens of metres south of the E 75 road bridge.

Description: The higher units in the Köli of the Tännforsen Synform are dominated by calcareous schists, both psammitic and pelitic, with conspicuous crystallization of hornblende ± garnet and biotite. A ''Garbenschiefer'' texture is often developed. Metamorphic grade decreases downwards, eastwards, only to increase again near the contact towards the underlying Seve.

At this locality, the sheaves of hornblende occur in a dominating schistosity that dips at low angles eastwards. Inclusion trails in the hornblendes testify to be existence of an early deformed foliation over which the porphyroblasts grew. The latter were later rotated towards the main schistosity and there is a tendency for orientation in the dominant EW-lineation direction.

M. Beckholmen

Stop 5:4 **Storlien**

Upper Allochthon: Refolded Köli schists

Location: (19C Storlien NV, 702775/131490). Road-cut on east side of approach road to Storlien village, c. 100 m southwest of railway crossing.

Description: Psammitic garnet–hornblende–biotite schists with thin calcareous beds are tightly folded (F2) on N 10° W axes associated with the development of a pervasive

crenulation cleavage (S2). These folds fold an earlier schistosity (S1) which is also visible as inclusion trails in the garnets and hornblendes. The S2 schistosity is folded by F3 folds on N 80° E axes.

H. Sjöström

Stop 5:5 **Klevsjön**

Upper allochthon: Retrogressed Seve

Location: (19C Storlien NV, 702885/131315). E 75 road-cut north side of road beside lay-by with "Turistinformation", c. 1 km west of custom's station.

Description: The Seve units thin rapidly towards the hinge of the Sylarna Antiform. High amphibolite to granulite facies units on Snasahögarna are cut out towards the northwest and the units at this locality, sheet-dipping gently northeastwards, are retrogressed (chloritized and epidotized) amphibolites, schists and thin calcite marbles. Start at the east end of the outcrop and observe the refolded isoclines and detached fold hinges. Further west there occur a variety of low angle shear zones, along with lensing and chloritization of the amphibolites.

Along the road c. 300 m west of this locality (north of a small lake) the sequence underlying these Seve units contains psammites and greenschists possibly related to the Särv Nappes, underlain in turn by phyllites and quartzites of the Lower Allochthon. Särv Nappe dolerites (discordant) and sandstones reappear in the western limb of the Sylarna Antiform, 16 km south-southwest of Storlien, at the same structural level in a tectonic lens.

H. Sjöström

Stop 5:6 **Brudslöjan** (500 m E)

Lower Allochthon of the Sylarna Window

Location: (19C Storlien NV, 70298/131240). Bend on road E 75, c. 1 km east of the international border.

Description: In the hinge of the Sylarna Antiform, the Lower Allochthon is composed of porphyritic rhyolites, granites, quartzites and quartzo-feldspathic schists. Thin "flagstone" units comparable with the Offerdal Nappe metasediments further east have also been recognized locally. At this locality the quartzo-feldspathic units contain a penetrative foliation dipping at low angles northwards (N 80°E/30°N) and a prominent WNW-lineation. A younger semi-penetrative foliation dips steeply westwards; it is apparently related to the development of the Sylarna Antiform.

There is a good view southwards of the western limb of the Sylarna Antiform on Steinfjellet (Fig. 22). A prominent mylonite zone occurs in the east-facing scarp near the top of the mountain, marking the base of the Trondheim Nappe. The same tectonic contact is exposed in the E 75 road section between this locality and the international border.

H. Sjöström

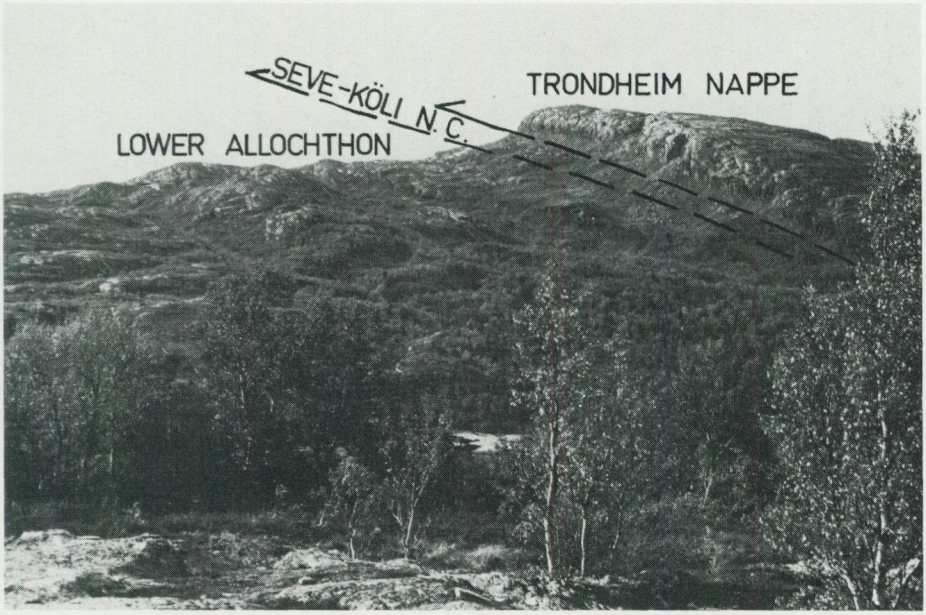

Fig. 22. View southwestwards from Stop 5:6, looking towards Steinfjellet and the basal thrust of the Trondheim Nappe.

Stop 5:7 **Stor-Helvetet**

Lower to Upper Allochthon: Mylonite zone and excision of the Offerdal and Särv Nappes and the Seve-Köli Nappe Complex

Location: (19C Storlien, 703030/131250). Deep road-cut on E 75 c. 200–800 m east of the international border. Walk the section from the previous locality.

Description: At the southern end of the section, W-dipping, foliated basement rocks are overlain by white, blue-grey and rusty quartzites and phyllites, characteristic of the Vendian–Lower Cambrian units in the successions of the Lower Allochthon further east. These metasediments are overlain by phyllonitic and mylonitic lithologies in which relic amphibolite, schist and marble (Seve) and retrogressed ''Garbenschiefer'' (Köli) can be distinguished. Towards the northwestern end of the road-cut, the mylonitization completely obscures the original lithologies. The mylonite zone is c. 50 m thick.

On the Norwegian-Swedish border, overlying units of the Trondheim Nappe contain turbidites of the eastern development of the Kjølhaugene Group. These metasediments (greenschist facies) dip gently westwards, are relatively well preserved and contain abundant graded bedding and other evidence, indicating that the sequence is the right way up.

H. Sjöström

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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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CALEDONIAN GEOLOGY OF THE WESTERN PART OF JÄMTLAND COUNTY, SWEDEN

LEGEND:

- TRONDHEIM NAPPE
- KÖLI NAPPES IN SWEDEN
- SEVE NAPPES
- SÄRV NAPPES

SEVE-KÖLI NAPPE COMPLEX → UPPER ALLOCHTHON

- METASEDIMENTS
- PRECAMBRIAN CRYSTALLINE ROCKS

OFFERDAL NAPPE

- TÄNNÄS AUGEN GNEISS NAPPE
- PRECAMBRIAN CRYSTALLINE ROCKS

VEMAN NAPPE

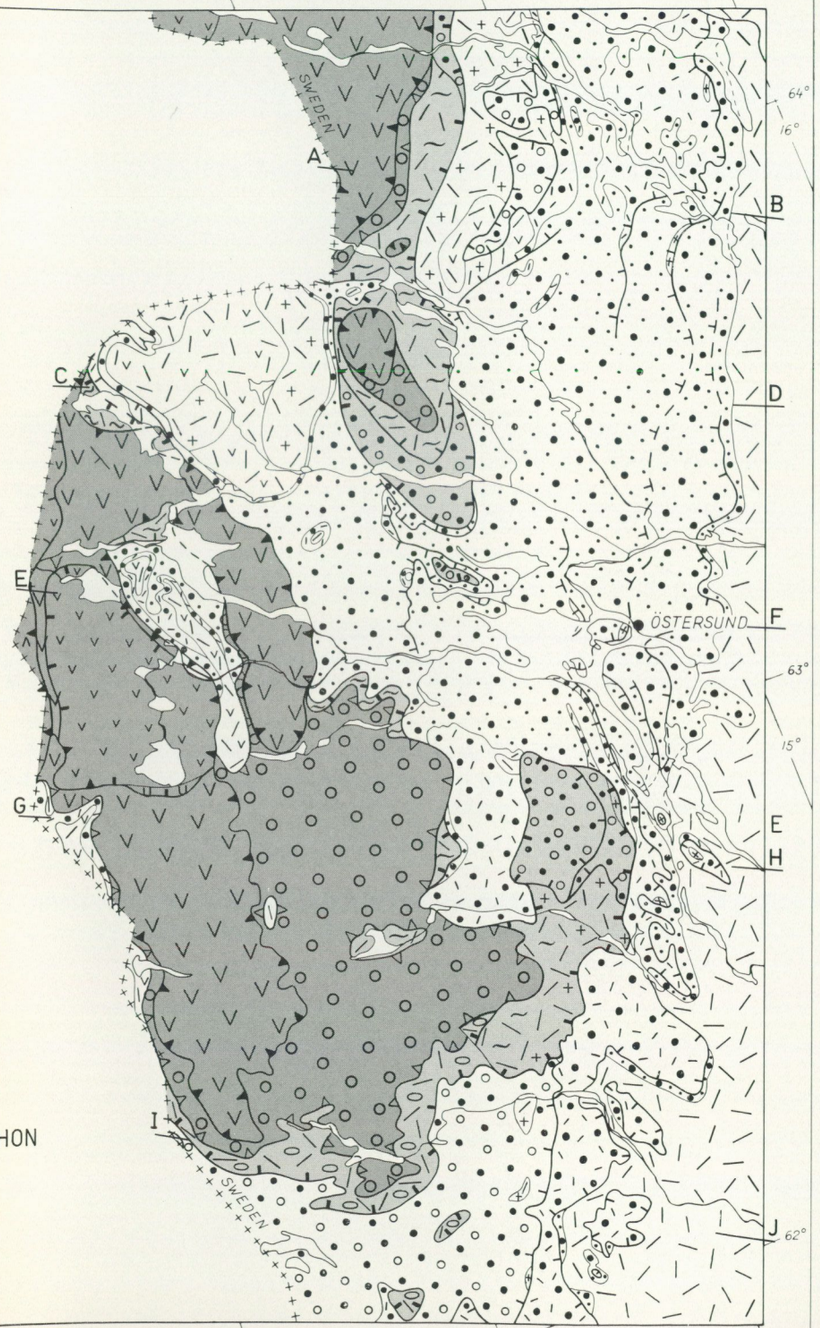
→ MIDDLE ALLOCHTHON

- UNDIFF.
- TÅSJÖN & ÄNGE GROUPS
- SJOUTÄLVEN GROUP
- RISBÄCK & LÅNGÅ GROUPS
- PRECAMBRIAN CRYSTALLINE ROCKS

JÄMTLAND SUPER-GROUP → JÄMTLANDIAN NAPPES → LOWER ALLOCHTHON

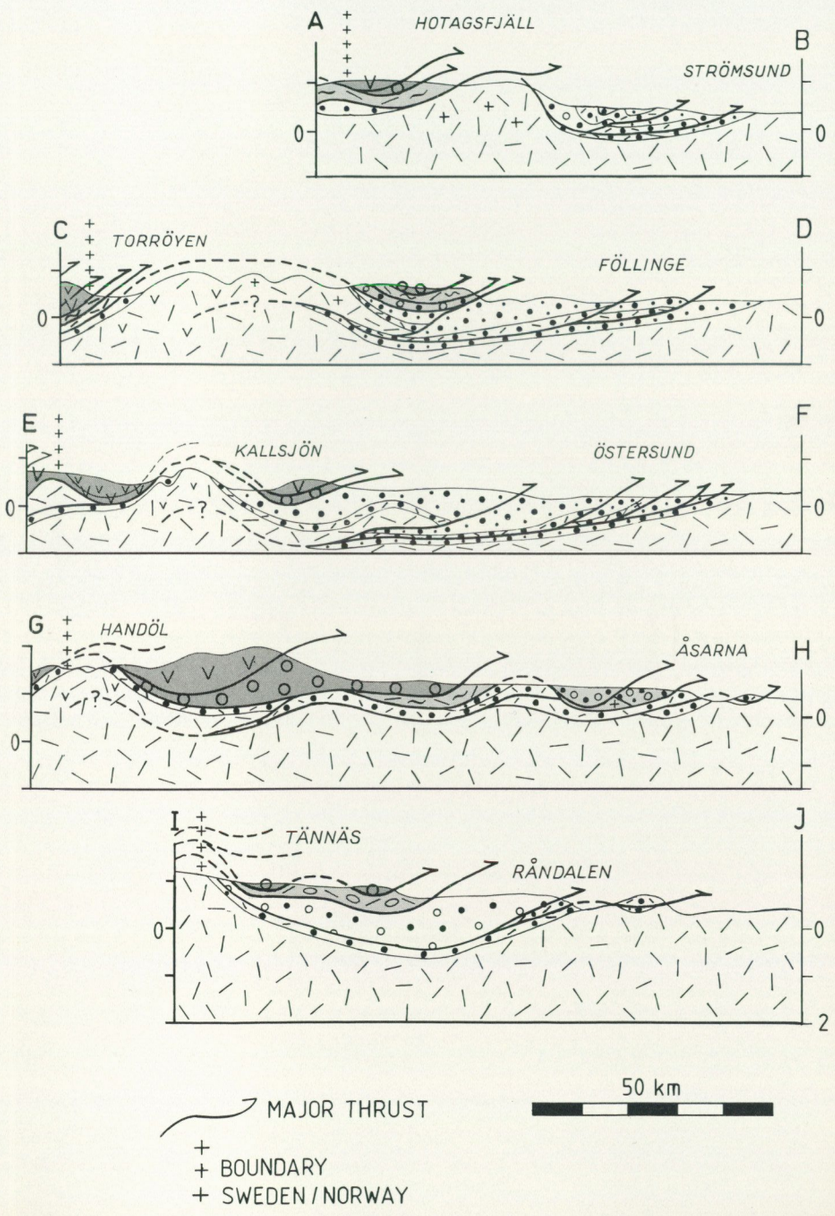
- TÅSJÖN GROUP
- UNDIFF.
- GRANITE
- PORPHYRY

PRECAMBRIAN CRYSTALLINE ROCKS → AUTOCHTHON AND PARAUTOCHTHON



PROFILES

PLATE 1



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