The terrane concept and the Scandinavian Caledonides: a synthesis

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A revised terrane map is presented for the Scandinavian Caledonides, and an outline is given of the principal suspect and exotic terranes and terrane-complexes identified outboard from the Baltoscandian miogeocline. The outermost part of the Baltoscandian continental margin is itself suspect, in the terrane sense, since the true palaeogeographical locations of rocks now represented in the Seve and Sørøy-Seiland Nappes, while inferred, are not known. The orogen-internal exotic terranes embrace the oceanic/eugeoclinal elements of the Caledonides, represented by the magmatosedimentary assemblages of the Köli Nappes, including ophiolite fragments and island arc products. Even more exotic terranes occur in the highest parts of the tectonostratigraphy, including units which are thought possibly to derive from the Laurentian side of Iapetus.

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Introduction

Earlier in this decade much of the research effort in the Caledonides of Scandinavia was channelled through the highly successful IGCP Project 27 'The Caledonide Orogen' (Gee & Sturt 1985). An important aspect of the collaborative work in this project was that of map compilation, in particular the consensus reached at establishing an overall tectonostratigraphy for the orogen (Gee et al. 1985, Roberts & Gee 1985). Since then, many Caledonian workers have maintained the international connection through the current IGCP Project 233 'Terranes in the Circum-Atlantic Paleozoic Orogens'; and the tectonostratigraphic subdivision of the Caledonides in Norway and Sweden into 4 major allochthons, each comprising an assemblage of nappe-complexes and thrust-sheets, has indeed paved the way for an assessment of the orogen in terms of geological terranes.

Since terranes are, by definition (see below), characterised by an internal homogeneity of geology and as their boundaries are of a tectonic nature, any terrane map of the Scandinavian Caledonides will necessarily reflect the basic patterns of tectonostratigraphy. An initial attempt at terrane division and map compilation, at 1:2½ M scale, prepared towards the end of IGCP Project 27 (D.R., manus. map 1983), identified some 15 terranes outboard of the Baltoscandian miogeocline. As yet, the only intra-Nordic collaboration within IGCP Project 233 has been to prepare a preliminary 'terrane map' at 1:5 M scale (Roberts et al. 1986) for a larger, circum-Atlantic compilation. This map, much simplified, is really one of palaeo-environments (marginal basins, volcanic arc complexes, overstep sequences, etc.), and not of terranes in the true sense. Another terrane map, in somewhat simplified form appeared in Stephens (1988), while similar broad-scale subdivisions of the orogen are found in Hossack & Cooper (1985) and Barker & Gayer (1985).

The aim of this short contribution is to present a revised terrane map of the Scandinavian Caledonides (Plate 1) and to outline briefly the principal terranes and terrane-complexes (Fig. 1) which can be identified. It is not the purpose, at this stage, to present detailed descriptions of each terrane; these must await further Norwegian-Swedish collaboration within Project 233. The map compilation and terrane synthesis forms the basis of a presentation given at an IGCP Project 233 symposium in Nouakchott, Mauritania (Roberts 1987).

The terrane concept: principles and definitions

Recognition of the existence of geological 'terranes' in orogenic belts hinges on the initial identification of the relevant passive continental margins or miogeoclines. As the affinity of these miogeoclinal sequences is known,

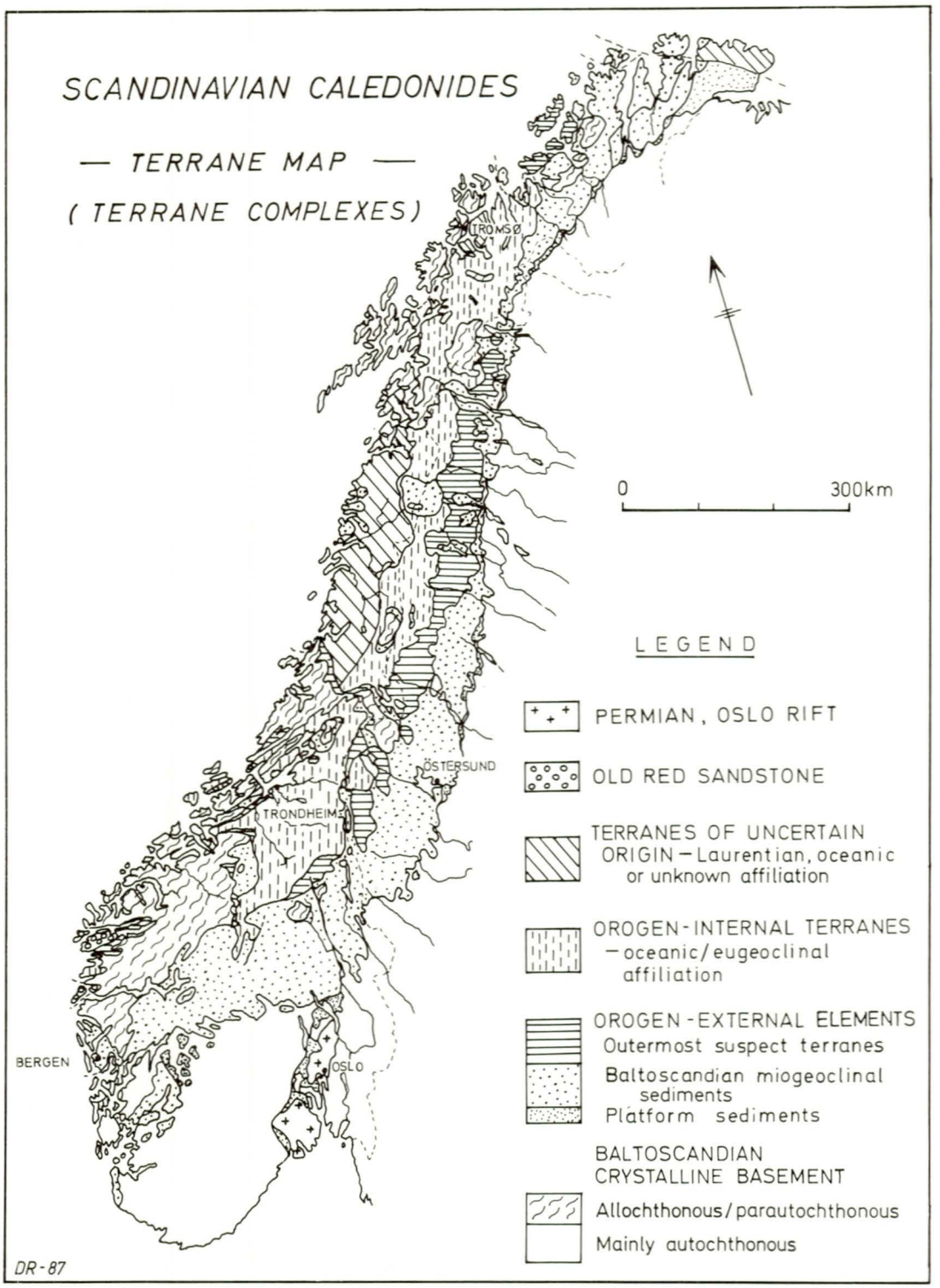

Fig. 1. Simplified map showing the principal terrane-complexes in the Scandinavian Caledonides. Within eash of the three main terrane-complex zones there are several, separate, distinctive terranes. More detailed subdivision is shown in Plate 1.

i.e. they can be linked directly to, and derive from, the nearby craton, then their palaeotectonic setting is not really questioned. Outboard of these continental rise prisms, domains which constitute parts of what has generally been termed the eugeocline may be viewed with varying degrees of suspicion or uncertainty as to their original palaeogeographical setting with respect to the cratonic margin. They thus constitute suspect terranes. Orogen-parallel and transverse strike-slip displacements of many hundreds of kilometres may have been involved, prior to or coeval with post-metamorphic thrusting; and post-accretionary strike-slip and extensional fault movements have added to the complexity.

This, then, was the essence of the terrane concept which evolved as an explanation for the complex Mesozoic and early Cenozoic accretionary history of the North American Cordillera (Monger et al. 1972, Coney et al. 1980). There, rock sequences in large-scale domains, blocks or slices which are now juxtaposed may differ dramatically in terms of faunal age and provenance, palaeomagnetic record or tectonothermal history, and bear evidence of different ages of docking or accretion. Application of the concept, involving suspect and exotic terranes, spread to the Appalachian orogen (Keppie 1981, 1985, Williams & Hatcher 1982, Williams 1984), and helped lay the foundations for IGCP Project 233.

Terranes, as such, are defined primarily on their stratigraphy but also on a variety of features which render them distinctive from their neighbours. A modern definition is as follows (Keppie, in press): «a terrane is an area characterised by an internal continuity of geology (including stratigraphy, fauna, structure, metamorphism, igneous petrology, metallogeny, geophysical properties and paleomagnetic record) that is bounded by faults, melanges representing a trench complex, or cryptic suture zones across which neighbouring terranes (1) may have a distinct geological record not explicable by facies changes (i.e. exotic terranes), or (2) may have a similar geological record (i.e. proximal terranes) that may only be distinguished by the presence of the terrane boundary representing telescoped oceanic lithosphere.»

Analysis of the accretionary histories of terranes may show that two or more may have amalgamated at some time before final accretion on to the miogeoclinal prism of the continental margin. These constitute composite terranes and may carry a common sedimentary overstep sequence (Keppie 1985). Several separate or composite terranes may form what has been termed a terrane-complex (Roberts 1987).

Constraints on the time of accretion of contiguous terranes may be recognised in a variety of factors (Fig. 2):

(a) Strata overstepping two or more adjacent terranes may carry fossils and thus provide a fairly reliable upper limit on terrane accretion (Fig. 2a).
(b) The age of thrusting of one terrane upon another (Fig. 2b) may be determined isotopically or, less precisely, by the age of the youngest fauna in either terrane.
(c) Plutons or dyke swarms which straddle or 'stitch' two or more terranes (Fig. 2c) may be dated isotopically, thus providing an upper limit for terrane accretion.
(d) Regional metamorphism which affects two or more terranes or terrane-complexes (Fig. 2d) may also be dated radiometrically. This, coupled with other timing evidence within the terranes themselves, would help in dating accretion.

The Baltoscandian margin and terranes in the Scandinavian Caledonides

Since terrane boundaries are generally faults of one form or other, Caledonide tectonostratigraphy thus provides a ready scenario for attempts at terrane discrimination. In the map compilation (Plate 1), a threefold grouping of terranes has been made (see also Fig. 1). (1) Orogen-external suspect terranes. (2) Orogen-internal exotic terranes. (3) Exotic terranes of uncertain origin.

Units of Baltoscandian miogeocline affiliation, in part with slices of Precambrian crystalline basement, do not rank as terranes in the strict sense, and have been grouped together as 'orogen-external elements'. Many of these Baltoscandian elements, as well as the terranes proper, carry geographical names (Plate 1), some of which derive from their original designation for nappes or nappe-complexes. These names, as used here, are strictly informal.

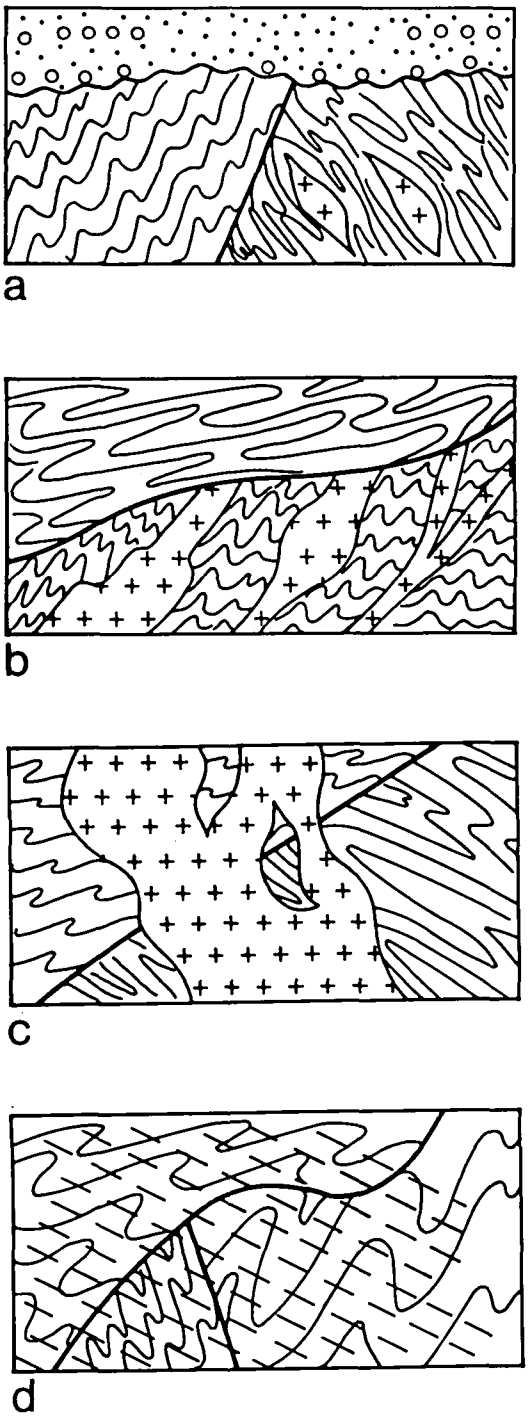

Fig. 2. Diagrammatic sketches showing features or criteria which help to provide upper limits on the time of accretion of juxtaposed terranes. (a) An 'overstep' sequence with basal unconformity blankets two disparate terranes which are separated by a major fault. The type of ornament or fold pattern used in this and subsequent sketches is meant simply to portray the different geological histories in the contiguous terranes. (b) One terrane is thrust upon another. Such a situation could also possibly be taken to represent an original, vertical, strike-slip fault which has subsequently been reactivated and transposed into a flat lying thrust. (c) Two terranes have been juxtaposed along a fault surface, and then transected by a major pluton (or plutonic complex or dyke swarm). (d) Three terranes are shown with two different ages of amalgamation (one fault is cut by the other). The entire complex is then affected by a regional metamorphic overprint, indicated by the dash-line ornament.

Orogen-external elements

Elements in this orogen-external belt are those of Baltoscandian affinity, mostly packages of low- to medium-grade sedimentary rocks of platformal or miogeoclinal affiliation with incorporated tectonic slices or 'windows' of Proterozoic crystalline rocks derived and imbricated from the outer margin of the continent Baltica. These units are essentially those composing the Parautochthon, Lower Allochthon and most of the Middle Allochthon of Caledonide tectonostratigraphic terminology, including the thick 'arkosic sandstone nappes' of the miogeocline. Parts of this orogen-external belt carry isotopic evidence of early Caledonian (*Finnmarkian*) polyphase metamorphism, deformation and thrust dissection (e.g. Särv, Kalak units); although most of the internal deformation, thrust imbrication and back-folding is of Mid Silurian to Early Devonian (Scandian) age. Structures ascribed to vertical shortening — back-folds, associated flat-lying regional cleavages and extensional faults — are even more common in the higher lying exotic terranes.

Orogen-external suspect terranes

Only the westernmost outboard parts of the Baltoscandian miogeocline, including the continent-ocean transition sequences (Andreasson & Gee 1986) — here termed the Seve terrane complex — can be viewed with any measure of suspicion as regard their true palaeogeographic derivation. Hence they qualify as suspect terranes. Rocks of the Seve Nappes are considered to derive from somewhere along the «outer rifted margin of continent Baltica» (Stephens 1988) and locally show high-P metamorphic parageneses, including eclogitic facies rocks (Sm-Nd, 505 Ma — Mørk et al. 1988) retrogressed and uplifted at around 490 Ma

(Dallmeyer & Gee 1986), i.e. during the Early Ordovician.

Rocks of the Sørøy-Seiland terrane, including the synorogenic Seiland Igneous Province, have acquired a gradually more suspect character in recent years, even though one can follow a common lithostratigraphy into the subjacent Kalak unit. The plutonic rocks may possibly derive from a tectonically active rifting milieu (Andreasson 1987, Krill & Zwaan 1987) or a local transtensional situation within a transpressive regime (Roberts, in press) along the deforming outermost margin of Baltica, with involvement of a microcontinental plate (Gayer et al. 1987). This was part of the early Caledonian (Finnmarkian sensu lato) accretionary wedge (Dallmeyer & Gee 1986), such that the most outboard (westernmost) terranes may show evidence of the oldest (?Cambrian) tectonothermal events. These terranes were subsequently accreted to the margin of Baltica during the Scandian thrusting event.

Orogen-internal exotic terranes

Units within this category are far-travelled nappes and thrust-sheets of the Upper Allochthon, exotic terranes derived from the oceanic/eugeoclinal realm of Iapetus (cf. Barker & Gayer 1985, Hossack & Cooper 1985, Stephens & Gee 1985, Stephens 1988). Rock assemblages in these exotic terranes include a wide variety of magmatosedimentary complexes, including fragmented ophiolites, primitive and mature island arc/forearc associations, rifted arc sequences and marginal basin successions. In terms of Caledonide tectonostratigraphy these 'oceanic' units are representative of the Köli Nappes. Nine separate terranes are distinguished in Plate 1; some of these are composite terranes.

Ophiolites have been separated into two age groups based on field and structural criteria (Furnes et al. 1985): (a) An early category, which participated in Early to Middle Ordovician obduction and orogenesis. These were uplifted, partially eroded, and overlain by Late Arenig or younger sediments or volcanites (Brekke et al. 1984, Sturt 1984). (b) A later grouping of Mid to Late Ordovician marginal basin ophiolites (Roberts et al. 1984). Isotopic dating studies are confirming this temporal subdivision (Dunning & Pedersen 1988). Faunal affiliation and suggested provinciality are of importance in deciphering likely source areas of sedimentation for some of these truly exotic terranes (Bruton 1986, Bruton & Harper 1988).

The Smøla terrane is of interest, not just for its North American fauna but also because it carries evidence for a Mid Ordovician tectonothermal event, broadly equivalent to the Taconian of the Appalachians (Hall & Roberts 1988); and in this terrane the Scandian overprint is hardly detectable. The Smøla terrane also contains a considerable volume of Ordovician, calc-alkaline magmatic rocks, which distinguishes it from adjacent terranes.

As mentioned earlier, the terrane-linking overstep sequences are an important element in terrane-accretion analysis. Two principal overstep assemblages are known in Scandinavia, one of which is represented by the Ordovician sediments and volcanites noted above. Where faunas are present they are mainly of North American affinity in the Early Ordovician and mainly Baltoscandian in Late Ordovician time. Overstep thus occurred in diverse locations within Iapetus, with final terrane accretion on to the Baltoscandian margin dating to the Scandian orogeny. The second major overstep sequence is represented by the Late Silurian to Mid Devonian Old Red Sandstone (ORS) molasse deposits of western and central Norway. These sediments blanket a variety of Scandian-assembled terranes (Sturt & Roberts 1987) ranging from exotic ophiolite assemblages to Baltoscandian rocks of the Western Gneiss Region. The ORS rocks are folded, metamorphosed at low grade, and locally affected by Late Devonian thrusting.

Exotic terranes of uncertain origin

The highest and most outboard tectonic units, in the Uppermost Allochthon, are representative of terranes of uncertain origin. The Barents-Varanger terrane is included in this category, even though it is really less exotic or suspect than the other units.

Except for the Barents-Varanger terrane, these particular terranes or terrane-complexes are heterogeneous units of supracrustal, gneissic crystalline and younger Caledonian granitoid rocks which have been considered to derive, in part, from the Laurentian side of Iapetus (Roberts et al. 1985, Stephens & Gee 1985). Fragments of microcontinents may also have been involved. Some terranes, e.g. Helge-

land and Beiarn, are especially heterogeneous and contain slices of assumed Early Ordovician ophiolite complexes with their overstepping Ordo-Silurian sedimentary sequences, tightly imbricated with Precambrian crystallines. The Barents-Varanger terrane of northeast Finnmark, North Norway, is a strike-slip allochthon consisting of Late Proterozoic to Vendian sediments unrelated both sedimentologically and geochemically to the parautochthonous sediments of the Baltoscandian margin. Although originally linked to an unknown palaeogeographical location along a dissected cratonic margin (Kjøde et al. 1975), these sediments may possibly have formed along the northern margin of a microcontinental block which drifted away from Baltica (Gayer et al. 1987, Rice et al. in press).

Summary

The concept of geological terranes, which originated in the Cordilleras of western North America, has been applied with some initial success to the Scandinavian Caledonides. Terranes or terrane-complexes can be grouped according to their fundamental geological characteristics and to their present relationship to the rocks of the Baltoscandian miogeocline. Moving towards the hinterland of the mountain belt, orogen-external suspect terranes of the outermost, rifted, Baltoscandian margin give way to even more suspect and exotic oceanic elements which include ophiolites and magmatic arc products. Further out, and higher in the tectonostratigraphy, terranes consist of heterogeneous units of both Laurentian-continental and oceanic affiliation.

Overstep sequences occur in two main periods, following terrane amalgamation: (1) in the Ordovician, represented by thick volcanosedimentary successions; and (2) during the latest Silurian to Mid Devonian, characterised by the Old Red Sandstone molasse.

At this stage, little work has yet been carried out on terrane analysis in Scandinavia. The map compilation shows the basic terrane subdivisions, but these are informal designations guided in part by personal prejudices. What is required is active joint Norwegian-Swedish collaboration within IGCP project 233, with the aim of producing a truly cooperative cartographic compilation. More detailed mapping and structural studies are needed in order to differentiate more clearly between the individual terranes. Isotopic data are required to help tie down more precisely the ages of terrane amalgamation and subsequent accretion; and more fieldwork and laboratory time should be reserved for the search for fossils, including microfauna, especially in critical areas.

Another important feature is that of strike-slip displacement, so prominent in interpreting the accretionary histories of e.g. the British Isles, Ireland and Newfoundland, but such originally near-vertical structural discontinuities may now be totally masked or transposed by simple shear into the ubiquitous flat-lying thrusts. The map picture is further complicated by extensional faults which post-date the stacking of the nappes and terranes. This component of vertical shortening/lateral extension is essentially of Late Silurian age, but also extended into the Devonian period during deposition of the ORS sediments. A roughly NW-SE horizontal shortening regime, far less intense than during the Scandian orogeny, was subsequently reimposed during latest Devonian time (Sturt & Roberts 1987).

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SCANDINAVIAN CALEDONIDES

- TERRANE COMPLEXES -

EXOTIC TERRANES OF UNCERTAIN ORIGIN

— continental margin, oceanic or Laurentian affinity

- TROMSØ TERRANE
- BEIARN TERRANE
- RÖDINGFJÄLL-BODØ TERRANE
- NAMDAL TERRANE
- HELGELAND TERRANE
- BARENTS-VARANGER TERRANE

OROGEN-INTERNAL EXOTIC TERRANES

— oceanic/eugeoclinal affiliation

- LYNGEN - SALANGEN TERRANE
- VADDAS TERRANE
- GJERSVIK-SULITJELMA TERRANE
- LOWER KÖLI TERRANE
- MERÅKER TERRANE
- GULA TERRANE
- STØREN-STEINKJER TERRANE
- SMØLA TERRANE
- KARMØY-STORD TERRANE

OROGEN-EXTERNAL SUSPECT TERRANES

— transitional, outboard Baltoscandian to oceanic affinity

- SØRØY-SEILAND TERRANE
- SEVE TERRANE COMPLEX

OROGEN-EXTERNAL ELEMENTS

— Baltoscandian miogeocline affiliation, in part crystalline basement

- GAISSA UNIT
- KALAK UNIT
- NABAR UNIT
- SÄRV UNIT
- JÄMTLAND UNIT
- JOTUN-BERGEN UNIT
- WESTERN GNEISS COMPLEX

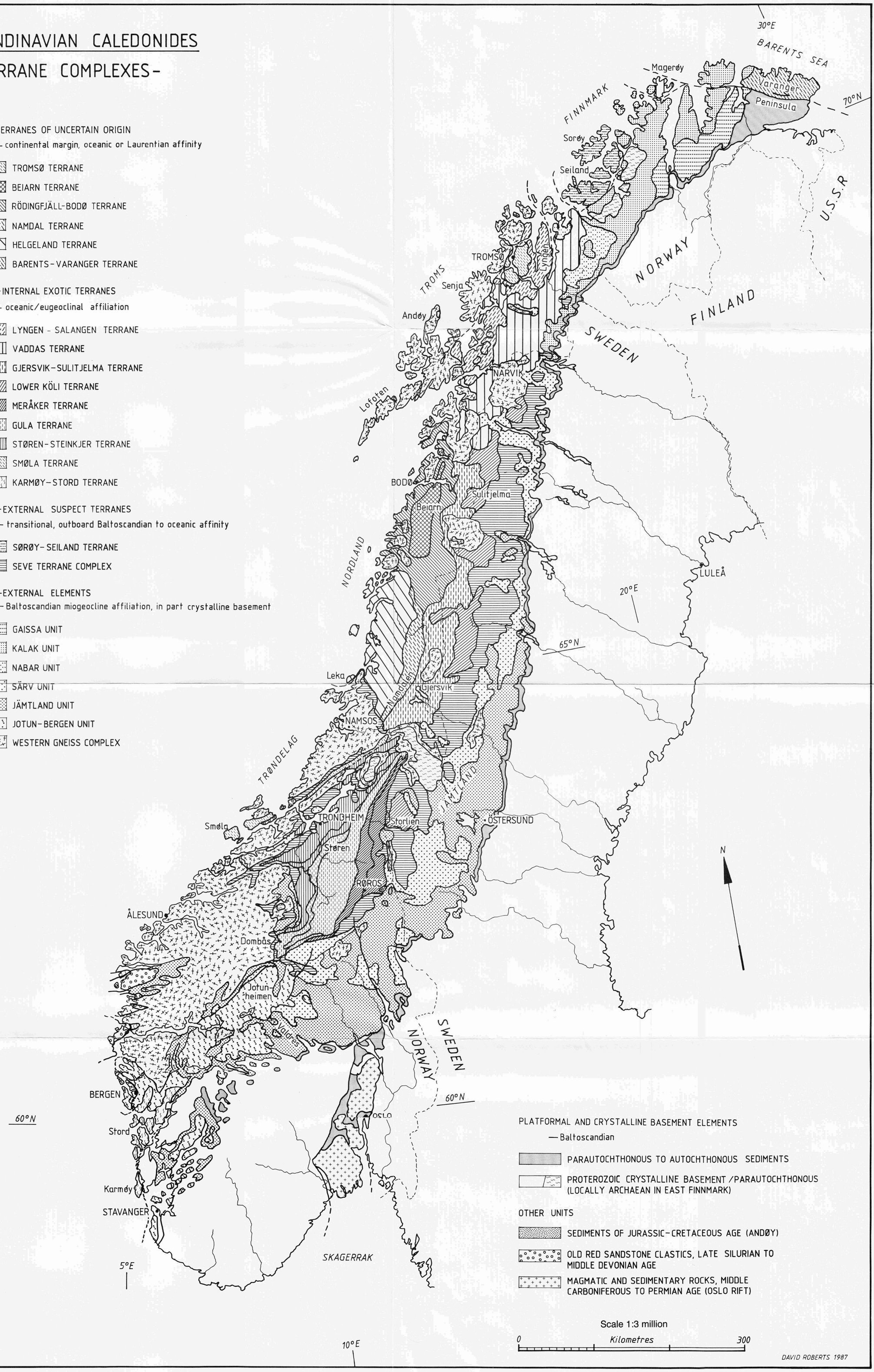

Plate 1. Map of Caledonian terranes and terrane-complexes in Scandinavia.