Developments in map data management and geological unit nomenclature in Finland
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MAJOR THRUSTS AND THRUST-BOUNDED GEOLOGICAL UNITS IN FINLAND: A TECTONOSTRATIGRAPHIC APPROACH

by

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This article summarizes the current knowledge and our general ideas concerning thrust tectonics in Finland. The starting point of this exercise was that the output must: (1) clarify and harmonize terminology and nomenclature related to thrust-bounded geological map units in Finland, (2) be connected to the Finstrati (GTK lexicon for geological units), (3) provide a relevant reference regarding the structural theme layers of the GTK map database, and (4) support understanding of the regional stratigraphic relationships presented in geological maps. In addition, the interpretation forms an overall framework for more detailed structural studies and one constraint for further tectonic and crustal-scale modelling.

In Finland, the foreland fold belts and thrust systems within the metamorphosed and complex folded Precambrian bedrock represent deep structural levels, and the exact locations, even for regionally important thrusts, are not easy to trace. The presented summary of thrust systems is based on our interpretation of previous work, the structural analysis of geological and geophysical maps and application of the presented tectonic models.

The result of our tectonostratigraphic approach is the first country-wide compilation of the major thrust-bounded map units in Finland. The presented units support the understanding of the stratigraphic relationships in regional-scale map compilations. The new division of tectonic and structural provinces was utilized as a framework for the thrust systems. All the thrust-bounded units (nappes, allochthons and thrust stacks) have been named, characterized and linked to the corresponding detachment.

Other scientific key points include: (1) the Raahe–Ladoga thrust system separated from the North Karelia–Kainuu thrust system, (2) the cross-section with thrust-bounded units across the Central Lapland belt, and (3) the spatial connection of the thrust blocks and the coeval shear zones in central and southern Finland. We also briefly discuss the links of the major thrusts and the overall geological evolution of Finland.

Structural and tectonostratigraphic map unit divisions provide a useful toolbox complementing lithology-based classifications. Modern theme-layer-based map databases enable the efficient combination of different interpretations and approaches. The presented results are part of the long-term effort with the country-wide map themes and related non-spatial databases.

Keywords: thrust, thrust system, allochthon, geological unit, geological map, Precambrian, Finland

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CONTENTS

1 INTRODUCTION

Knowledge of the location and nature of the major thrust zones is essential in understanding the overall set-up and pattern of the observed lithological map units. In regional geology, new interpretations always build on previous research and on the presented evolution models. Due to the intimate coupling of tectonic models and interpretation of the observed features (faults, lithological successions), deeper understanding of regional geology requires structural concepts and terminology that provide a context for the actual map units.

Our starting point was the remark that the application of tectonic concepts (such as collision-related nappe tectonics) has substantially improved understanding of the geology of Finland. The increasing availability of geophysical data and their interpretations (e.g. Kukkonen & Lahtinen 2006) have indicated that even the major, crustal-scale shear zones were in the past either neglected or not recognized. The research themes have varied in the course of time and between different regions. Therefore, the understanding of thrust tectonics and the recognition of thrust-bounded map units have not been uniform in all parts of the country. The improved general knowledge of shear zones and awareness of their existence has interacted both with the tectonic models (e.g. Lahtinen et al. 2005, Nironen 2017) and country-wide bedrock map compilations (e.g. Korsman et al. 1997, Nironen et al. 2016). In some cases, the meaningful division of map units requires an indication of their assumed allochthonous nature. A classic example is the Outokumpu allochthon in eastern Finland (e.g. Wegmann 1928, Koistinen 1981). Another case history is the introduction of the Kittilä allochthon concept (Hanski 1997), which opened some stratigraphic deadlocks in central Lapland.

Our primary aim is to **define and describe the thrust-bounded geological units** relevant for understanding the overall regional set-up presented in maps and models. Basically, the approach is pragmatic and conceptually similar to tectonostratigraphy (e.g. NCS 1989): in orogenic belts (or their parts), where thrusts are the dominant and most mappable features, systematic geological description is not possible without thrust-bounded map units and related nomenclature.

The attempted systematic description and characterization of the regional-scale thrust-bounded map units calls for defined terminologies and procedures similar to the classic stratigraphic approach. We build on the ideas that were developed during the compilation of the Geological Map of Finland (Nironen 2017) and in relation to the development of the stratigraphic database of GTK (Luukas et al. 2017). Most of the defined map units are based on previous interpretations or derived from existing descriptions, and in the harmonization process, some generalization and simplification of the original interpretations could not be avoided. The underpinning structural ideas of the authors have influenced the process, and both the overall ambience of the article and the concrete result, the thrust-bounded map units, are ultimately governed by our interpretations.

Thrust-bounded map units (like allochthons) and their bounding surfaces, thrusts, are intimately linked. Therefore, a summary of the current knowledge concerning thrust tectonics and major thrust systems in Finland is presented. Other faults and fault systems, such as normal faults, are outside the current scope. The shear zones and their kinematics are discussed only in relation to thrust-bounded map units and their structural context.

The main objectives of the article are: (1) to outline the thrust systems and thrust-bounded units, which are essential in understanding the stratigraphic relationships displayed in regional-scale geological maps, (2) to explain observed and inferred thrusts in terms of their genesis and relationship with the geological evolution of Finland and (3) to provide interpretation complementing the country-wide structural map theme and the related Finstruct database. Our work is part of a larger development effort: the construction of the new GTK Map Data Architecture with a structured system of spatial data (map themes) and related non-spatial databases (e.g. Finstrati, Finstruct; see Ahtonen et al. 2021; this volume). Therefore, improved terminological consistency and characterization of the geological units are of primary importance. The ultimate goal is to compose a layered system of map themes, which would be capable of storing geological information in all its complexity and provide a versatile source for 3D modelling and various other use cases.

2 THRUST BELTS, THRUSTS AND TECTONOSTRATIGRAPHY

In the literature, the terminology related to thrust systems is not unambiguously defined or, at least, the usage of the terms is not fully consistent and individual usages vary widely. Therefore, we first provide some background and clarify the key terms used. The main references are the AGI Glossary of Geology (Neuendorf et al. 2005) and IUGS-CGI GeoSciML (https://cgi-iugs.org/project/geosciml/) vocabularies. For a more comprehensive terminological discussion, the reviews by McClay (1992) and Poblet & Lisle (2011) are referred to.

2.1 Thrust belts, thrust systems and thrusts

A thrust belt (or **fold-and-thrust belt; FTB**) is a deformed belt in which contractional or transpressional brittle and brittle-ductile structural styles dominate over other types of structures. FTBs most commonly evolve out of either passive margin or intracratonic rift systems, where the extensionally thinned continental crust has accommodated depositional basins. In collision, the weakness of the extended crust concentrates tectonic shortening, which focuses compressional stress, and the basinal rocks subsequently become incorporated into the thrust belt. Reactivated extensional faults and uplifted basement blocks are typical 'basin inversion' features of deeply exhumed FTBs.

Fold-and-thrust belts are generally divided into domains of *autochthonous* (or *parautochthonous*) characteristics and domains interpreted as tectonically emplaced or *allochthonous*. The regional deformation style involving the cover rocks above a decollement is known as *thin-skinned* tectonics. In *thick-skinned* foreland systems, the underlying basement is also involved in the thrust system and deformation. Close to the basement–cover interface, imbricate fans and duplex structures are characteristic and, consequently, the distinction between the genuine autochthon and deep-level duplex or imbricate systems is not always possible.

Most of the best-studied FTBs (e.g. the Alps, the Canadian Rocky Mountains) are relatively high-level foreland fold-and-thrust belts when compared to upper greenschist facies to granulite facies (cf. Hölttä & Heilimo 2017) FTB examples in Finland. Accordingly, instead of ramp-and-flat geometries, features such as ductile fold nappes, imbrication fans, duplexes and basement involving thrust ramps are typical.

In the Glossary of thrust tectonics terms (McClay 1992), a **thrust system** is defined as a zone of closely related thrusts that are geometrically, kinematically and mechanically linked. We use the term for wide zones where the thrusts show kinematic, geometric and genetic similarities. Geologically, thrust systems manifest zones of significant crustal thickening as a response to contractional tectonism. According to the Glossary of Geology, thrust (and thrusting) refers to '*an overriding movement of one crustal unit over another, as in thrust faulting*'. **Thrust** is used here as a structural concept and a general term corresponding to the end result of thrusting (fault, fault zone, shear zone), which may also be interpreted or inferred. **Detachment** is any major break (fault or shear zone) in the structural continuity of a system; the unit above a thrust detachment may show structures (such as folding) that are different from the underlying unit.

In description, the distinction between shallow ***thrust faults*** and steeper ***reverse faults*** may be useful. Nonetheless, early thrust structures are often deformed, potentially steepened in a subsequent contractional process, and the original dip of a shear plane is often not possible to assess. In addition to thrust faults, the thrusting may occur as fold-thrust uplifts and in many cases result in asymmetric folds with highly thinned or thrusted lower limbs. Generally, thrusts cause an older-over-younger relationship and a structural break in the normal stratigraphic superposition, but younger-over-older thrusts by re-activation of early extensional normal faults are common at basin margins.

Sole thrust (*basal thrust, floor thrust*) refers to the lowest thrust and the frontal thrust marks the leading edge of the thrust system (Fig. 1); it may be the major sole thrust, but also a less prominent thrust within the frontal unit of the system. According to the CGI vocabulary, **decollement** is a large displacement (kilometres or tens of kilometres) along a shallowly dipping to subhorizontal fault or shear zone. Typically, a decollement is nearly bedding parallel and occurs along the basement–cover interface or a mechanically weak rock unit. Rock units above a thrust decollement are *allochthonous*.

2.2 Tectonostratigraphic approach

Tectonostratigraphy is not an internationally formalized stratigraphic category, and it is not included in the International Stratigraphic Guide (Salvador 1994) or North American Stratigraphic Nomenclature (NACSN 2005). In the Scandinavian research tradition, tectonostratigraphic classification is widely used, and denoted in the national stratigraphic guides (Norway: NCS 1989; Finland: Strand et al. 2010; Sweden: Kumpulainen 2017). Without caution and care, the different classification categories and their parallel use may lead to complexity and confusion. Our approach and application of thrust-bounded units is very close to tectonostratigraphy and follows the definition by NCS (1989): *Tectonostratigraphy is concerned with the stratigraphic division of bodies of rock which are piled on top of each other and separated by thrusts.*

Nevertheless, we do not entirely follow the map unit division and terminology of NCS (1989). We apply the general term **thrust-bounded unit** to a body of rock that has been displaced along a thrust (sole thrust) and may be delimited uppermost by a roof thrust or the erosion surface. A **tectonostratigraphic unit** is used for a thrust-bounded unit with a formal tectonostratigraphic status. All thrust-bounded units may consist of one or more lithostratigraphic or lithodemic units.

2.2.1 Allochthonous units

Allochthon is a thrust-bounded unit underlain by a decollement with an inferred substantial amount of tectonic transport (several kilometres, at least). The formal tectonostratigraphy incorporates a hierarchy with the following ranks: nappe system (or nappe complex), nappe and thrust sheet (see NCS 1989). Tectonostratigraphic units are applied when the thrust system is well established with published information, and where the major thrusts form the one primary basis for the rock unit division (e.g. Caledonides).

The term **nappe** is reserved for tectonostratigraphic classification, and all other inferred allochthonous units are here simply called **allochthons**. In our text, the assumed allochthonous nature of a unit is indicated by the term 'allochthon', 'nappe' or 'nappe complex' as a part of the unit name. **Thrust sheet** is the lower rank of a nappe, but we use the term primarily for any mappable volume of rock bound below by a thrust. **Klippe** is an outlier (erosional remnant) of an allochthon (or nappe) and **window** is an inlier surrounded by an overlying decollement at the present erosional level.

2.2.2 Other thrust-bounded units

Not all thrusts are low-angle detachment zones, and the steeper fault zones may also delineate map units useful in regional description. We use the term **thrust stack** for imbricated or duplexed thrust sheet systems when the decollement is not identified or the sole thrust is not a low-angle detachment; a typical example is a basement-involved foreland thrust system. **Thrust block** is a special type of a thrust sheet, a relatively rigid, voluminous thrust-bounded body of rock. These are especially useful in the description of large-scale crustal features. Finally, it is emphasized that both conceptually and in practice, the allochthon-thrust stack boundaries and borders between a thrust stack and the adjacent parautochthonous fold belt are arbitrary and dependent on case-by-case interpretation (Fig. 1).

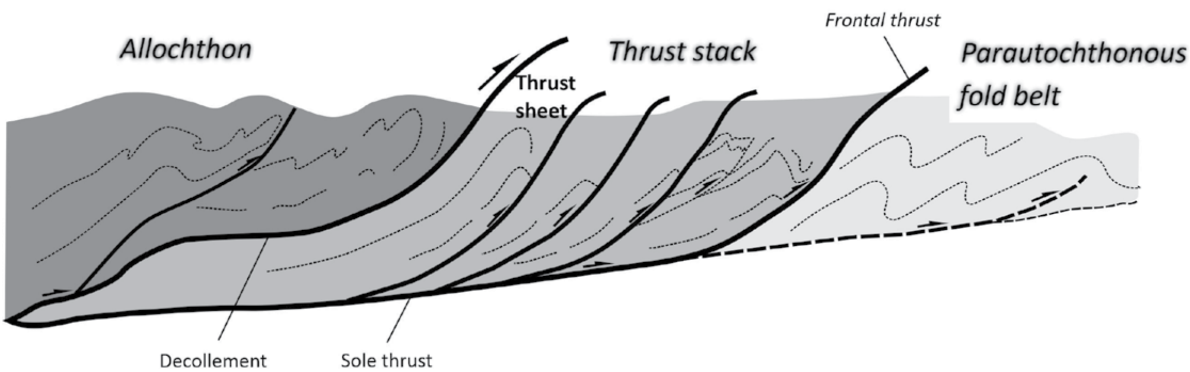

Fig. 1. A simple sketch addressing the concepts of an allochthon, a thrust stack, a thrust sheet and a parautochthonous fold belt (modified after Alvarez-Marron et al. 2006).

2.2.3 Map unit definition

The presented thrust-bounded units, such as allochthons, support the reading of the general geological maps by providing an explanation for lithological units showing neither superposition nor a shared depositional history with the underlying sequences. All the decollements and other thrust planes have been subjected to later deformation, and precise outlining of the thrust plane traces is not always feasible. Especially challenging are: (1) areas where a high amount of ductile deformation followed the thrusting stage; (2) basement-involved thrusts in regions where no cover has been preserved and (3) large unexposed areas and regions with widespread younger intrusives. Therefore, the generalized polygons of the thrust-bounded units display the approximated spatial extent sufficient to bring out the basic idea (see Fig. 3).

It is important to see that reverse faults, thrust faults and shear zones are geological structures, and are not automatically linked to any geological unit. The Finnish bedrock is occupied by minor thrusts and reverse faults, and not all of these are thrust-bounded unit boundaries. The establishment of a thrust-bounded map unit is justified when it simplifies the geological description and substantially aids the representation of the regional geology. Application of the proper tectonostratigraphic classification (NCS 1989) is not appropriate in cases where the locations of the inferred thrusts are uncertain (e.g. poor exposure; complex later deformation) or the overall structural model of the region is ambiguous and not widely agreed.

All thrust-bounded map units are defined (Fig. 2) by their boundaries (sole thrust / roof thrust). Both informal units and formal tectonostratigraphic units are in use. The informal units can be later renamed and formalized as tectonostratigraphic units. To support the structured format of the FinstratiKP, the following attributes are suggested for the characterization:

- **Name of unit** (mandatory)
  - Derivation of name (by lower detachment / other; reference to the published name)
  - Former names of the corresponding unit (if present)
- Boundaries:
  - **Sole thrust of the unit** (name; mandatory)
    - Description (e.g. approximate age; spatial characteristics)
  - Roof thrust of the unit (if identified)
- Description
  - Unit lithology (lithostratigraphic / lithodemic units within the thrust-bounded unit)
  - Other description (e.g. metamorphic features)
- Key references

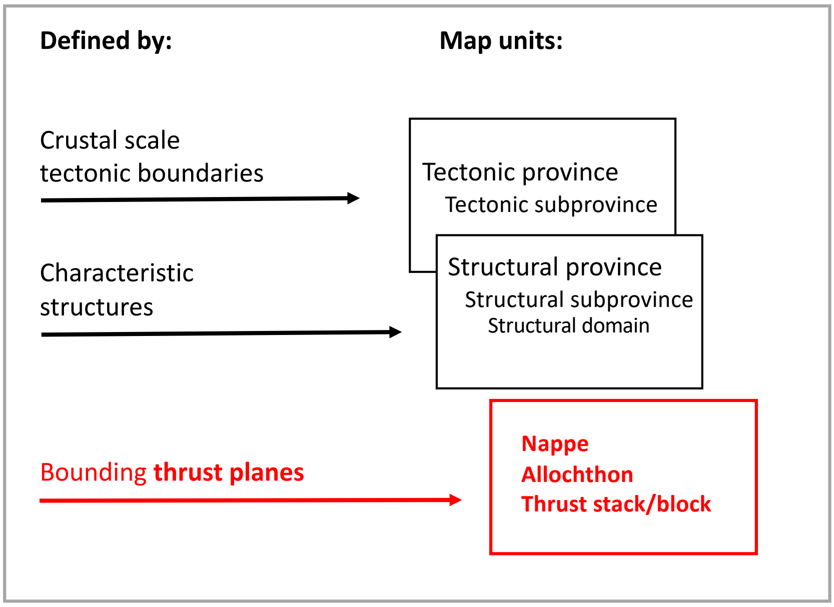

Fig. 2. Thrust-bounded units (in red) as a part of the GTK structural map unit system (for provinces, see Fig. 3).

3 REGIONAL DESCRIPTIONS AND DIVISIONS

Tectonic and structural provinces (Fig. 3) both provide a tectonic context for the presented thrust systems and aid their regional description. A comment is needed to clarify the distinction between the spatially overlapping 'thrust systems' and 'structural provinces'. A thrust system is a zone consisting of a linked network of thrusts bounding the allochthons and thrust stacks, whereas structural provinces are defined by the overall structural characteristics and relationships with sutures (for details, see Kohonen et al. 2021; this volume). Although the province (or subprovince) boundary may follow a major thrust bounding the allochthon, the conceptual difference in the divisions is definite. The underpinning tectonic model forms an essential background, and in description we utilize the nomenclature (shown below *in italics* to avoid repetition of the reference) proposed by Kohonen et al. (2021).

The *Karelia tectonic province* represents the forelands of two opposing collision zones corresponding to the present *Raahe–Ladoga, Kautokeino–Muonio–Tornio sutures*, both with top-to-the-east transport, and *Pechenga–Imandra–Varzuga suture* with the opposite transport direction. The structural provinces reflect the current knowledge regarding the overprinting *Svecofennian* structures within the *Karelia tectonic province* (Fig. 3A).

The *Central Finland* and *Southwestern Finland tectonic provinces* have not been divided into structural provinces. The reasons are the overall tectonic complexity of the assumed collage of several volcanic arc complexes (cf. Lahtinen et al. 2005) and the poorly understood nature of the inferred major collision zone (*Bothnia–Pirkanmaa suture).*

3.1 Karelia tectonic province

The description of the *Karelia tectonic province* is an evolved version of the preliminary ideas presented by Luukas et al. (2017). Within the entire province, the formation of the major thrusts can be bracketed between 1.91–1.88 Ga. The younger deformation and related thrusts in Lapland and central Finland are discussed in Chapter 4.

3.1.1 Svecokarelia structural province

The *Svecokarelia structural province* corresponds to the ancient peripheral foreland fold-and-thrust that resulted from arc-continent collision along the present *Raaha–Ladoga suture*. The framework of the North Karelia-Kainuu thrust system (see Figs. 3 and 4) takes shape by the decollements within cover sequence, the major thrust along the *Jormua-Outokumpu suture* and variable styles of basement involvement. However, many important structural questions have remained open. For example, the northern continuation of thrust system (Fig. 3B) and the structures of the basement-involved system (such as the frontal thrust, depth of the sole thrust) are poorly understood.

The fundamental difference between the North Karelia-Kainuu and Raahe-Ladoga thrust systems is their relationship to the *Raahe-Ladoga suture* (see Fig. 3B). We presume that the sole thrust of the Raahe-Ladoga thrust system is leading on the SW-side of the suture, whereas the North Karelia-Kainuu thrust system represents tectonic thickening within the Karelia province (the Archean basement and the cover sequence). The Raahe-Ladoga thrust system involves *Svecofennian rocks* and is therefore partly described as part of the *Central Finland tectonic province*.

To simplify, the *North Karelia–Kainuu* and *Kuopio–Iisalmi–Oulujärvi subprovinces* (Fig. 3) are understood as a combination of thin-skinned and thick-skinned structural styles; the detached allochthons deformed independently of the underlying strata, but for most of the area, basement-involved thrust stacks with narrow cover outliers and basement thrust sheets (inliers) breaching through the cover are characteristic. Within the less studied *North Ostrobothnia subprovince*, allochthons dominate in the SW part and the overall basement reactivation seems to be less.

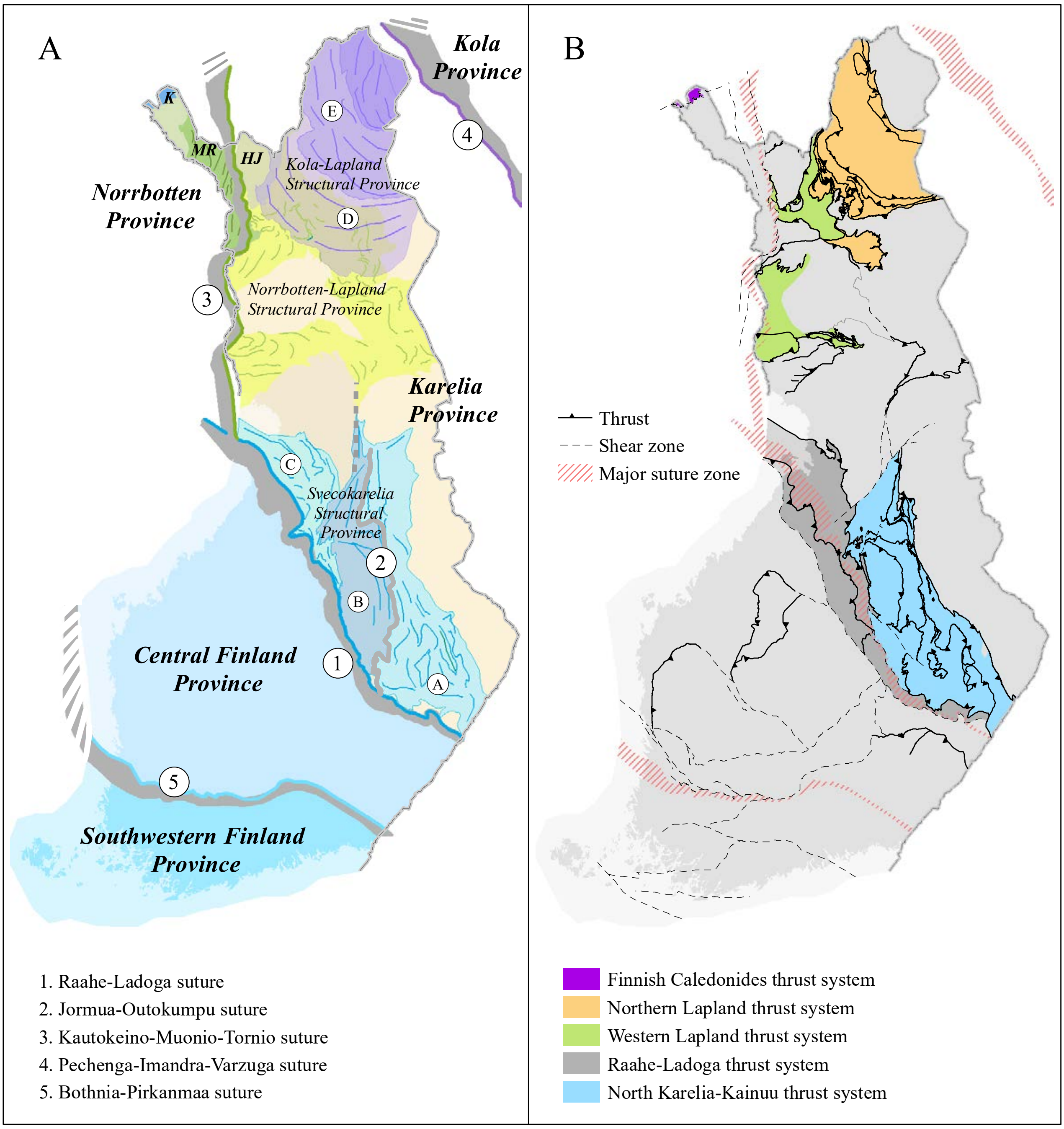

Fig. 3A. Tectonic provinces, suture zones and structural provinces in Finland (modified from Kohonen et al. 2021). A = North Karelia–Kainuu structural subprovince; B = Kuopio–Iisalmi–Oulujärvi structural subprovince; C = North Ostrobothnia structural subprovince; D = Sodankylä structural subprovince; E = Inari structural subprovince; HJ = Hetta–Jergul structural province; MR = Muonio–Ropi structural province; K = Kilpisjärvi structural province. Note the overlap of the structural provinces in Lapland.

Fig. 3B. A simplified map of the thrust systems, major thrusts and prominent shear zones. Tectonic province boundaries (major suture zones) are also shown for comparison with 3A.

3.1.1.1 North Karelia–Kainuu subprovince

Models involving major thrusts and related allochthons have been applied in eastern Finland ever since the pioneering works by Wegmann (1928) and Väyrynen (1939) were published. The original ideas have been developed further by several authors both in North Karelia (e.g. Park et al. 1984, Ward 1987, Kohonen 1995) and in Kainuu (e.g. Laajoki 1991, Kontinen 1992, Luukas et al. 2017).

The subprovince is located on the eastern side of the Jormua–Outokumpu suture. Within the thrust system, the **Outokumpu and Iijärvi allochthons**, with associated ultramafic fragments of Archean subcontinental mantle (Jormua ophiolite; Peltonen 2005 and references therein), represent obducted rocks derived from an ancient (ca. 1.96–1.90 Ga), narrow remnant ocean basin. The Tohmajärvi–Nunnanlahti–YläLuosta and Kainuu thrust stacks were generated as an imbrication fan or duplex system near the basement–cover interface. The thrust stacks involve both the Karelian cover rocks and the Archean basement complex. Across the subprovince, the degree of basement reactivation and ductility varies, and the basement inliers represent both imbricated thrust sheets and cores of semiductile disharmonic folds.

Table. 1. Thrust-bounded units of the North Karelia–Kainuu subprovince.

Unit name	**Sole thrust**	Main references	Lithostratigraphic / Lithodemic units
North Karelia–Kainuu thrust system			
Outokumpu allochthon	Outokumpu decollement	Wegmann 1928, Väyrynen 1939; Koistinen 1981, Korsman et al. 1997	Viinijärvi and Outokumpu suites
***Tohmajärvi–Nunnanlahti–YläLuosta thrust stack**	see Fig. 4 and text	This paper	Lentua complex Höytiäinen suite Tohmajärvi suite
Iijärvi allochthon **>Jormua thrust sheet**	Iijärvi decollement	Korsman et al. 1997, Laajoki 2005, Kontinen & Hanski 2015 This paper	Iijärvi formation Jormua suite ('Jormua ophiolite complex')
Kainuu thrust stack **>Väyrylänkylä thrust sheet** **>Tupala thrust sheet** **>Vihajärvi thrust sheet** **>Tulijoki thrust sheet** **>Oikarila thrust sheet**	Väyrylä thrust	Laajoki 1991, Kontinen 1992 Luukas et al. 2017 (Väyrylänkylä nappe) Luukas et al. 2017 (Tupala nappe) Luukas et al. 2017 (Vihajärvi nappe) Luukas et al. 2017 (Tulijoki nappe) This paper	 Lentua complex, East Puolanka group Somerjärvi group Vihajärvi group Väyrylä group Central Puolanka group

*Not divided into individual thrust sheets

In North Karelia, the major thrusts (see Fig. 4) are divided into two groups: (1) the Outokumpu decollement and the internal detachments of the allochthon and (2) various basement-involved thrusts. The Outokumpu decollement is well defined in the north (*Outokumpu area*), whereas in the southeastern part of the *Outokumpu–Rääkkylä belt*, both the location and nature of the sole thrust are inferred. In Figure 4, we have mainly followed the map compilation by Korsman et al. (1997). In the Juojärvi district, large windows of basement and parautochthonous cover are exposed through the Outokumpu decollement, and further to the west (in the Tuusjärvi–Vehmersalmi district), the sole thrust (Räsälä thrust) plunges down and joins the Jormua–Outokumpu suture zone. The Outokumpu allochthon has tentatively been divided into parts by detachments separating the ophiolite (serpentinite)-containing parts (e.g. Koistinen 1981, Kontinen et al. 2006) from the rest of the system. The geometry and composition of these internal thrust sheets are poorly known, but a slight difference in the greywacke lithologies across the bounding detachments has been proposed (Aatos et al. 2016).

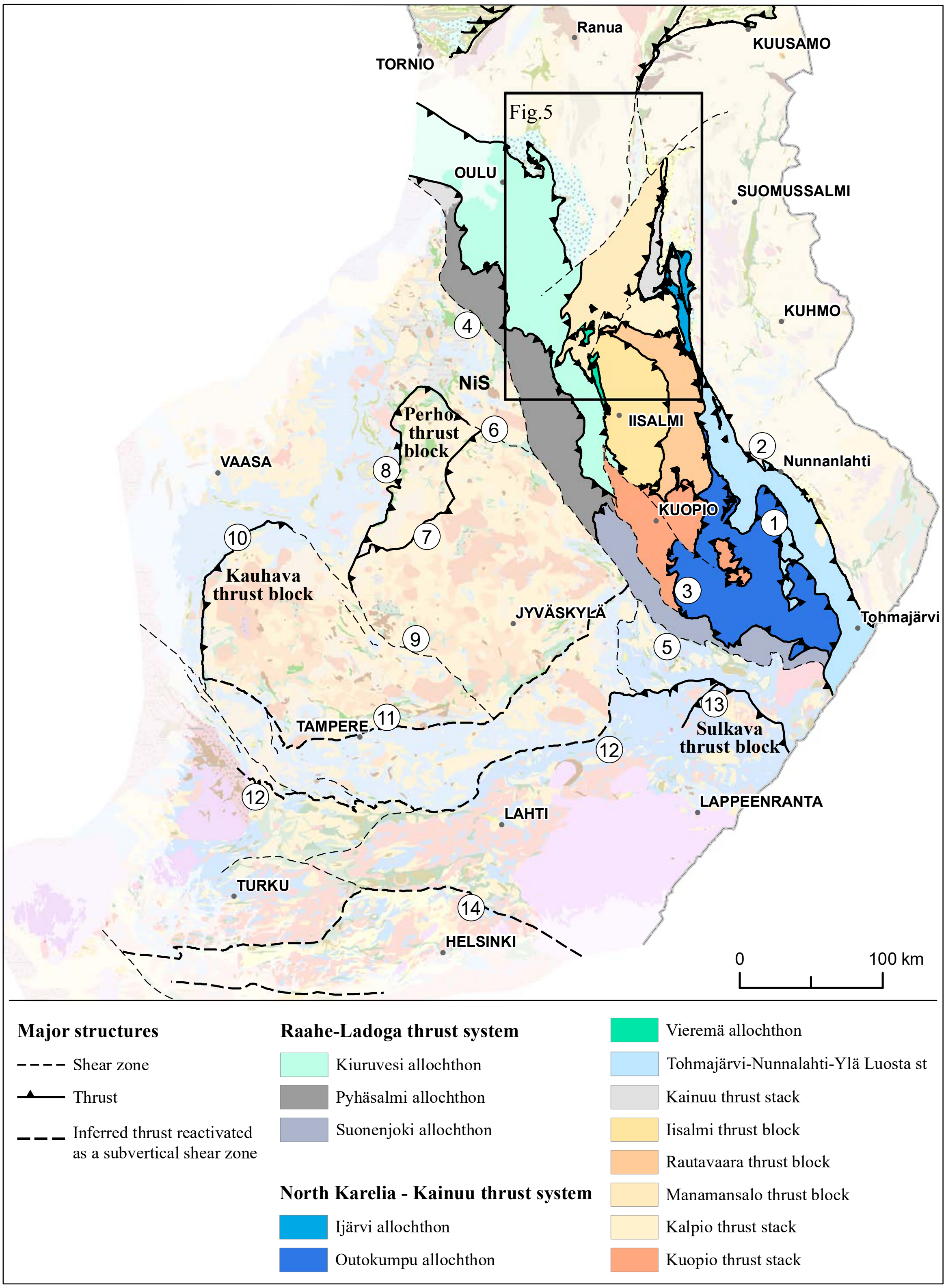

Fig. 4. The overall configuration of the major thrusts, thrust systems, thrust blocks and shear zones in central and southern Finland (see also Chapters 3.2 & 3.3): (1) Outokumpu decollement, (2) the inferred sole thrust of the Tohmajärvi–Nunnanlahti–YläLuosta thrust stack, (3) Räsälä thrust, (4) Ruhanperä shear zone, (5) Haukivesi shear zone, (6) Lestijärvi shear zone, (7) Kyyjärvi thrust, (8) Perho thrust, (9) Virrat–Jämsä shear zone, (10) Seinäjoki–Karijoki thrust zone, (11) Leivonmäki–Kankaanpää shear zone, (12) Otava–Kynsikangas shear zone, (13) Sulkava thrust, (14) Hyvinkää–Kisko shear zone; NiS = the Nivala suite. The location of Figure 5 is indicated as a box. The geological background map is simplified from Nironen et al. (2016).

Within the Höytiäinen belt, the frontal thrust of the **Tohmajärvi–Nunnanlahti–YläLuosta thrust stack** roughly follows the trend of the basement–cover boundary. The basement-involved structure is interpreted to continue towards the NNW from the Nunnanlahti district to the southernmost tip of the Kainuu belt, along the major shear zones with characteristic textures in basement granitoids (blebbed gneiss of Väyrynen 1939; protomylonite of Kohonen 1995; partly mylonitic intense Proterozoic shearing of Paavola 2005). During the continued shortening, the thrust zone first steepened and finally reactivated as a wrench fault during the late stage of the contraction (Kohonen 1995), and both the nature and the accurate location of the sole thrust remain unclear. Examples of basement-involved structures within the Tohmajärvi–Nunnanlahti–YläLuosta thrust stack are the Suhmura thrust zone (e.g. Ward 1987, Kohonen et al. 2019), the Nunnanlahti thrust zone (e.g. Kohonen 1995 and references therein) and the Juuanvaarat–Polvela district, with several stacked thrust sheets and narrow cover outliers within the basement (see Sorjonen-Ward 2006, Bedrock of Finland – DigiKP).

Rock units within a foreland fold-and-thrust belt may exhibit very complex geometries (e.g. Schmidt & Perry 1988), and the *Kainuu belt* is a perfect example. The belt shows an assortment of structures with assumed origins from basin stage via basin inversion to late faulting, and the overall deformation style within the belt is very variable. Due to the lack of detailed structural works and regional analysis, only some general features can be presented. The schist-dominated upper structural levels apparently show a more ductile deformation style compared to the underlying imbricate stacks in the middle parts of the system. Nonetheless, even the quartzites show structural variety from imbrication to tight, ductile folding. Near the basement–cover interface, fragmented quartzite units in places show peculiar overturned blocks (Kontinen 1989) and other features possibly reflecting forceful (semibrittle?) inversion of the early rift basins. Within *Kainuu belt*, the overall shortening of the system is more advanced compared to North Karelia, and steeply dipping or upright structures are typical.

One fundamental question regarding the upper parts of the system is the nature of the proposed Iijärvi decollement. The lower contact of the extensive Iijärvi formation (Kontinen 1986) and Kuikkalampi formation (Kontinen & Hanski 2015) has been interpreted as a thrust detachment and as a sole of the major Iijärvi allochthon. Direct evidence for the decollement is not present, and the stratigraphic relationships presented by Kontinen & Hanski (2015) might as well allow a parautochthonous setting for the Iijärvi formation. The key element of the puzzle is the tectonic interpretation of the Jormua Ophiolite Complex (Jormua suite; see Kontinen 1987, Peltonen 2005) as part of the system. The alternative ophiolite emplacement models and a description of the *Jormua–Outokumpu suture* can be found in Lahtinen et al. (2015b) and in Kohonen et al. (2021), respectively. Nonetheless, at this stage, we stick to the established decollement-based interpretation (e.g. Kontinen & Hanski 2015, Nironen et al. 2016, Luukas et al. 2017), and thus the Iijärvi allochthon is structurally correlated with the steep western parts of the Outokumpu allochthon.

The middle structural levels are represented by the **Kainuu thrust stack**, which consists of imbricated thrust sheets of various lithologies (Laajoki 1991, Luukas et al. 2017, Bedrock of Finland – DigiKP). The Kainuu thrust stack is an attempt to describe the structural style of a system where the original stratigraphic relationships are overrun by thrust-bounded units (Laajoki 1991). In addition, the metamorphic irregularities, such as anomalous low greenschist facies metamorphism of the Oikarila thrust sheet, are difficult to explain without an assumption of major faults (Kontinen 1992). However, the precise location of all the detachments, was not possible to resolve. Furthermore, the transition from the thrust stack to parautochthonous cover of the Hyrynsalmi and Puolanka areas (Fig. 5) is not sharp but a wide zone where the imbrication and basement-involved faults gradually decline. Therefore, the frontal thrust marks the boundary of intense thrust stacking, not the margin of thrust faulting and shortening-related deformation.

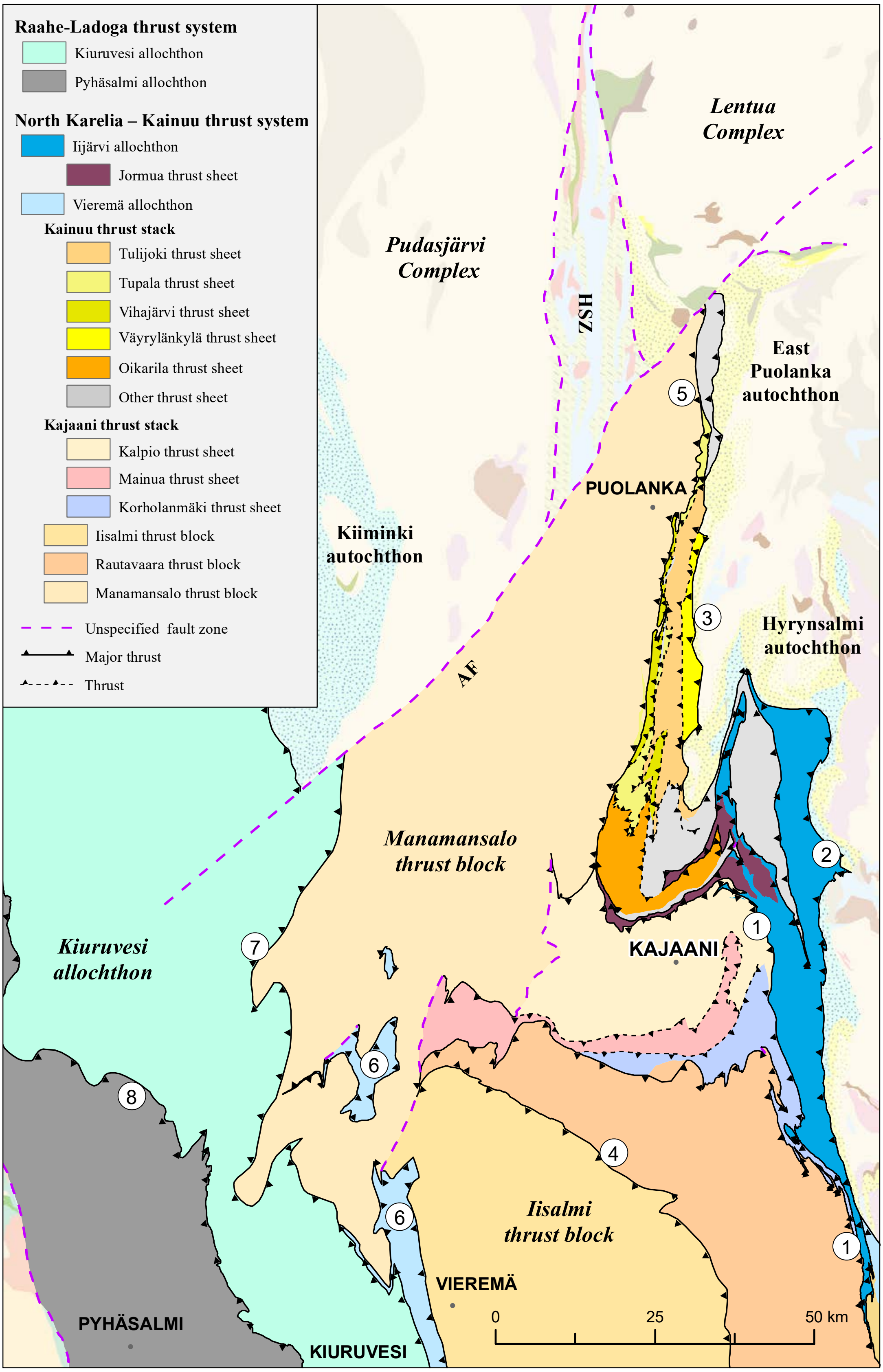

Fig. 5. The northern part of the North Karelia–Kainuu and Raahe–Ladoga thrust systems. The units of the Kainuu and Kajaani thrust stacks are shown and the major thrusts are indicated by numbers: (1) Tuusjärvi–Alanen–Jormua thrust, (2) Iijärvi decollement, (3) Väyrylä thrust, (4) Sonkajärvi thrust, (5) Aittokylä thrust, (6) Vieremä decollement, (7) Kiuruvesi decollement, (8) Pyhäsalmi decollement. HSZ = Hirvaskoski shear zone, AF = Auho fault. Note the parautochthonous cover on the Archean basement; see Figure 4 for location. The geological background map is simplified from Nironen et al. (2016).

3.1.1.2 Kuopio–Iisalmi–Oulujärvi subprovince

The Kuopio–Iisalmi–Oulujärvi structural subprovince represents the western, thrusted flank of the Jormua–Outokumpu suture (Fig. 3A), and the major Tuusjärvi–Alanen–Jormua thrust (Fig. 5) marks the eastern margin of the subprovince. The subprovince is an example of deep-level structures of the thick-skinned foreland fold-and-thrust belt between the western Raahe–Ladoga thrust system and the rather intact basement block (Lentua complex) in the east (see Figs. 4 and 5). Huge bodies of Archean rocks were tectonically pushed towards the east (e.g. Korja et al. 2006), and the sole thrust extends from the Tuusniemi district (east of Kuopio) to the central parts of the Kainuu belt (Paltamo district). This basement-involved thrust forms the roof thrust of the Kajaani thrust stack. Its northern continuation (Aittokylä thrust) represents the basal thrust of the **Manamansalo thrust block** and the roof thrust of the underlying Kainuu thrust stack (Fig. 5).

The Sonkajärvi thrust divides the large basement area (Iisalmi terrain of Sorjonen-Ward & Luukkonen 2005) into the **western Iisalmi and eastern Rautavaara thrust blocks** (Figs. 5 and 6). The internal deformation zones within the Rautavaara thrust block are manifested by the narrow cover quartzite outliers of Nilsiä, Keyritty and Pisa (Paavola 1980, 1984), which all show preservation in the overturned limb of a basement-involved east-vergent fold structure. The **Kajaani thrust stack**, including the Kalpio, Mainua and Korholanmäki thrust sheets, forms the northern extension of the Rautavaara thrust block.

No outliers of cover have been observed within the Iisalmi thrust block, and the rocks mainly lack any thrust-related fabric. We understand the high-grade metamorphic domains within the rigid Iisalmi thrust block as mid-crustal bodies uplifted and exhumed plausibly during both the extension (c. 1.98–1.96 Ga) and subsequent collision (c. 1.90 Ga).

Table. 2. Thrust-bounded units of the Kuopio–Iisalmi–Oulujärvi Subprovince.

Unit name	**Sole thrust**	Main references	Lithostratigraphic / Lithodemic units
North Karelia–Kainuu thrust system			
Iisalmi thrust block	Sonkajärvi thrust	This paper	Iisalmi complex
Rautavaara thrust block	Tuusjärvi–Alanen–Jormua thrust	Laajoki 2005 (Kajaani tectonic zone); this paper	Rautavaara complex; Nilsiä group
Manamansalo thrust block	Aittokylä thrust	This paper	Manamansalo complex; Central Puolanka group
Kajaani thrust stack		This paper	
>Kalpio thrust sheet		This paper	Kalpio complex
>Mainua thrust sheet		Luukas et al. 2017 (Mainua nappe); Kärenlampi et al. 2019 (Otanmäki–Kuluntalahti nappe)	Otanmäki suite
>Korholanmäki thrust sheet		Kontinen 1992	Sotkamo group
***Kuopio thrust stack**	Räsälä thrust	This paper	Kuopio complex; Nilsiä, Neulamäki, Levänen groups; Suonenjoki, Kotalahti suites

*Not divided into individual thrust sheets

Thin basement slivers interpreted as thrust sheets and associated basement cored anticlines are characteristic of the **Kuopio thrust stack**. The area is severely affected by later transpressional deformation, and towards the southwest, both the ductility of the basement and the amount of post-collisional intrusives increase. Regarding the metamorphic grade, Säntti et al. (2006) reported reaction isograds corresponding to ca. 500 °C in the central parts of the Outokumpu allochthon and up to 700 °C at the eastern margin of the Kuopio thrust stack, less than 50 km towards the Raahe–Ladoga suture in the west. In the eastern part of the thrust stack several Archean gneiss inliers (thrust sheets) occur within the supracrustal cover rocks. In the southern part (Kotalahti–Leppävirta area; S of Kuopio), several basement gneiss slices form a complicated system alternating with rocks similar with the Svecofennian paragneisses of the Suonenjoki allochthon (see Table 6) in the southwest. In both areas, the original nature and geometry of the thrusts have been obliterated by the later deformation and intrusions.

3.1.1.3 North Ostrobothnia subprovince

The subprovince is characterized by the eastern part of the Raahe–Ladoga thrust system extending from Oulu to the Kuopio district in the southeast (Table 3 and Fig. 4). The most remarkable feature is that basement rocks have never been found as inliers within the Kiuruvesi allochthon, and we assume that the unit represents the uppermost levels of the entire thrust pile within the *Svecokarelia Structural Province*. The tectonic setting of these allochthonous rocks has been discussed by Lahtinen et al. (2015b).

The Kiuruvesi decollement is underlain by the Archean basement (the Pudasjärvi, Manamansalo and Iisalmi complexes) and within the Kiiminki belt by the autochthonous cover rocks. The large **Kiuruvesi allochthon** represents rocks tectonically transported from the SW side of the Raahe–Ladoga suture, and the allochthon mainly consists of turbiditic sedimentary rocks together with mafic pillow-structured volcanics (Laajoki &Luukas 1988, Lahtinen et al 2015b). The allochthonous nature of these rocks was suggested by Luukas (1991) and Pietikäinen & Vaasjoki (1999), and according to our interpretation, these rocks were never deposited on Archean crust and are thus not considered as part of the cover sequence (or Karelian formations of Laajoki 2005). In the northern part of the subprovince, almost all structures are intruded by voluminous (ca. 1.8 Ga) granites, which obliterate the allochthon and all thrust-related structures.

Table. 3. Thrust-bounded units of the North Ostrobothnia subprovince.

Unit name	**Sole thrust**	Main references	Lithostratigraphic / Lithodemic units
Raahe–Ladoga thrust system (eastern part)			
Kiuruvesi allochthon	Kiuruvesi decollement	Luukas (1991), Pietikäinen & Vaasjoki (1999)	Näläntöjärvi, Lampaanjärvi suites; part of the Kiiminki group
North Karelia–Kainuu thrust system			
Vieremä allochthon **>Itämäki klippe**	Vieremä decollement	Luukas 1991 Luukas et al. 2017	Rotimojoki fm Itämäki fm

The supracrustal cover rocks comprising the **Vieremä allochthon** and the adjacent **Itämäki klippe** rest on the Archean basement of the Iisalmi and Manamasalo complexes, and both are interpreted as tectonically transported units, although an alternative explanation of parautochthonous outliers cannot be fully excluded. The lithological relationships and other features at the basement–cover contact (Vieremä decollement of this paper) have been described by Korkiakoski & Laajoki (1988).

3.1.2 Norrbotten–Lapland structural province

Substantial crustal shortening and thrusting resulted in collision along the present *Kautokeino–Muonio–Tornio Suture* in the west (Fig. 3). The *Norrbotten–Lapland structural province* corresponds to a wide FTB with an indistinct overall N–S structural trend. The structural overprinting extends up to Kuusamo (see Figs. 3 and 6) in the east, whereas the thrust system is limited to western Lapland (Fig. 6). In central Lapland, the models with supposed major thrusting gradually emerged from the Kittilä area (e.g. Kontinen 1981, Hanski 1997, Hanski & Huhma 2005, Peltonen 2005, Hölttä et al. 2007, Lahtinen et al. 2018) to the Sodankylä area (Evins & Laajoki 2002) and finally also to the *Peräpohja belt* (Lahtinen et al. 2015a, Piippo et al. 2019). In the following, we summarize the main features of the Western Lapland thrust system and outline an overall regional reconstruction of the major thrust-bounded units.

First, it is important to see that we consider large areas in Lapland as parautochthonous cover within the foreland fold-and-thrust belt. The main parts of the *Peräpohja belt* (see Perttunen 1991, Perttunen & Hanski 2003, Skyttä et al. 2019), the *Kuusamo belt* (Lahtinen & Köykkä 2020 and references therein) and the *Central Lapland belt* as a whole (e.g. Hanski & Huhma 2005) are all folded and also thrusted, especially along the ancient basin margins. However, in all these areas, the primary stratigraphic relationships are possible to resolve, and we do not presently see any value in the introduction of vague thrust-bounded units.

The **Kittilä allochthon** is well established (Hanski 1997, Peltonen 2005) and linked to the western collision (e.g. Lahtinen et al. 2005, 2018). The Nuttio–Seurukarkea decollement is poorly exposed and difficult to locate exactly. Serpentinite bodies (the ophiolitic Nuttio serpentinite belt of Hanski 1997, Lehtonen et al. 1998) are typical at the proximity of the sole thrust, and their ophiolitic nature provides evidence for significant tectonic transport but the kinematic evolution has not been resolved. The overall geometry of the map unit reflects interference between the Norrbotten and Kola collisions (see Fig. 3), and the western boundary of the allochthon is modified by younger N–S-trending thrusts (see Nironen et al. 2016).

The **Rovaniemi allochthon** is introduced here and interpreted as the southern structural counterpart for the Kittilä allochthon. The decollement is severely obscured by the later granites and the eastern boundary is impossible to trace spatially (Fig. 6). The inferred Rovaniemi decollement, represented by the Korkiavaara and Venejärvi thrusts, is possible to identify in the Korkiavaara district (S of Rovaniemi) and in the Sieppijärvi district (S of Kolari). The lithology of these allochthonous rock units corresponds to that of the Ylitornio allochthon (Lahtinen et al. 2015a, Köykkä et al. 2019).

The **Ylitornio allochthon**, showing a strongly curvilinear geometry of the sole thrust (Martimo decollement; see Fig. 6), was defined and named (Ylitornio nappe complex) by Lahtinen et al. (2019). Within the Peräpohja belt, the inversion of the early rift basin geometry has largely controlled the contractional deformation (Lahtinen et al. 2018, Piippo et al. 2019), and both the allochthons (Ylitornio and Rovaniemi) and the parautochthonous sequence are transposed and show an E–W trend due to later deformation (e.g. Lahtinen et al. 2018, Sayab et al. 2019).

Table. 4. Thrust-bounded units of the Norrbotten–Lapland structural province.

Unit name	**Sole thrust**	Main references	Lithostratigraphic / Lithodemic units
Western Lapland thrust system			
Kittilä allochthon	Nuttio-Seurukarkea decollement	Hanski 1997, Peltonen 2005	Kittilä suite
Ylitornio allochthon	Martimo decollement	Lahtinen et al. 2019	Martimo suite, Mellajoki suite Uusivirka suite
Rovaniemi allochthon	Rovaniemi decollement	This paper	Rovaniemi supersuite

3.1.3 Kola-Lapland structural province

The Northern Lapland thrust system and the *Kola–Lapland structural province* are interpreted to be a result of intense thrusting within a shortened retro-arc foreland basin (Lahtinen & Huhma 2019), which is now represented by the high-grade rocks known as the *Lapland granulite belt*. Foreland deformation and folding of the cover sequence extends further south to Central Lapland (Sodankylä area).

Despite extensive research (e.g. Gaál et al. 1989, Patison et al. 2006, Tuisku et al. 2006), the Northern Lapland thrust system, the pattern of the major thrusts, is poorly understood. The thrust system is apparently bivergent (Fig. 6), but detailed thrust kinematics and the impact of the suggested multiple thrusting phases (Lahtinen & Huhma 2019) are not fully resolved. The Northern Lapland thrust system defines the following units: (1) three main allochthons with the linked klippes, (2) the Lokka and Näätäselkä thrust stacks immediately below the main decollement and (3) the frontal Sodankylä thrust stack further to the south (Table 5 and Fig. 6).

The core element of the Northern Lapland thrust system is the Lapland granulite belt, which has always been defined by structural boundaries. The corresponding thrust-bounded unit is named as the **Inari allochthon**, which is floored by the prominent Angeli–Tankavaara decollement (Table 5 and Fig. 8) against the lower **Vuotso allochthon** (Figs. 6 and 7). According to our interpretation, the sole thrust of the allochthonous system at the southern margin is the Vuotso decollement, and the northern boundary of the entire system is the Utsjoki thrust. Both the Utsjoki thrust and the parallel Kaamanen thrust (Fig. 6) show southwesterly dips, and the sections provided by Patison et al. (2006) and Lahtinen & Huhma (2019) suggest that these structures are younger than the emplacements of the allochthons. Therefore, both the location of the original, major decollement and the nature of the assumed **Kaamanen allochthon** remain unresolved.

The **Vuotso allochthon** below the Angeli–Tankavaara thrust (decollement) mainly consists of high-grade gneisses and amphibolites. In our interpretation, the lithologically similar **Lautaselkä** and **Kotisijamaa klippes** represent dismantled fragments above the Vuotso decollement (Fig. 8). The **Pokka klippe** of plutonic rocks with ages of around 1.92 Ga (Lahtinen & Huhma 2019) is tentatively linked to the Inari allochthon.

Table. 5. Thrust-bounded units of the Kola-Lapland structural province.

Unit name	**Sole thrust**	Main references	Lithostratigraphic / Lithodemic units
Northern Lapland thrust system (Northern Lapland nappe system of Luukas et al. 2017; see also Gaál et al. 1989, Patison et al. 2006, Lahtinen & Huhma 2019)			
Kaamanen allochthon	See text	This paper	Kaamanen complex
Inari allochthon **>Pokka klippe**	Angeli–Tankavaara decollement	This paper	Lapland granulite complex
Vuotso allochthon **>Lautaselkä klippe** **>Kotasijamaa klippe**	Vuotso decollement	This paper	Vuotso complex
Lokka thrust stack	Kurittukoski thrust	This paper	Sodankylä group Savukoski group
Näätäselkä thrust stack	Lisma thrust	This paper	Sodankylä group Savukoski group
Sodankylä thrust stack	Postoaapa thrust Ellitsa thrust	Luukas et al. 2017, Nironen 2017 (Sodankylä nappe) Evins & Laajoki 2002	Sodankylä group Savukoski group

The poorly exposed and studied **Lokka and Näätäselkä thrust stacks** represent in our interpretation an imbrication fan or duplex structures below the allochthonous part of the Northern Lapland thrust system. The Lokka thrust stack consists of rocks correlated with the Kuusamo, Sodankylä and Savukoski groups thrusted over the Archean basement. In the Peurasuvanto district, the older (Kuusamo group) rocks are pushed over the younger cover sequence along the Kurittukoski thrust (see Figs. 7 and 8).

The **Sodankylä thrust stack** is a complex package interpreted as resulting from two overlapping thrust systems. According to our interpretation, the cover rocks were first tectonically transported eastwards (mainly along the basement–cover interface). The easternmost Postoaapa thrust (Fig. 7) still displays the original orientation of the Western Lapland thrust system, but most of these thrusts are transposed to an E–W direction or transected in thrusting with southern vergence. In our model, these thrusts are connected to the Northern Lapland thrust system, and major displacement occurred along the Ellitsa thrust (Fig. 8). Luukas et al. (2017) and Nironen (2017) proposed an allochthonous nature for part of the cover sequence. In Figure 8, the inferred Sodankylä decollement is represented by the Ellitsa and Postoaapa thrusts. The degree of basement involvement within the thrust stack is not well known, but it appears that the later thrusts are in places associated with asymmetric folding of the basement–cover interface. The younger, south-dipping thrusts of the Sodankylä area (e.g. Hölttä et al. 2007) are linked to the Venejoki thrust zone and discussed in Chapter 4.4.

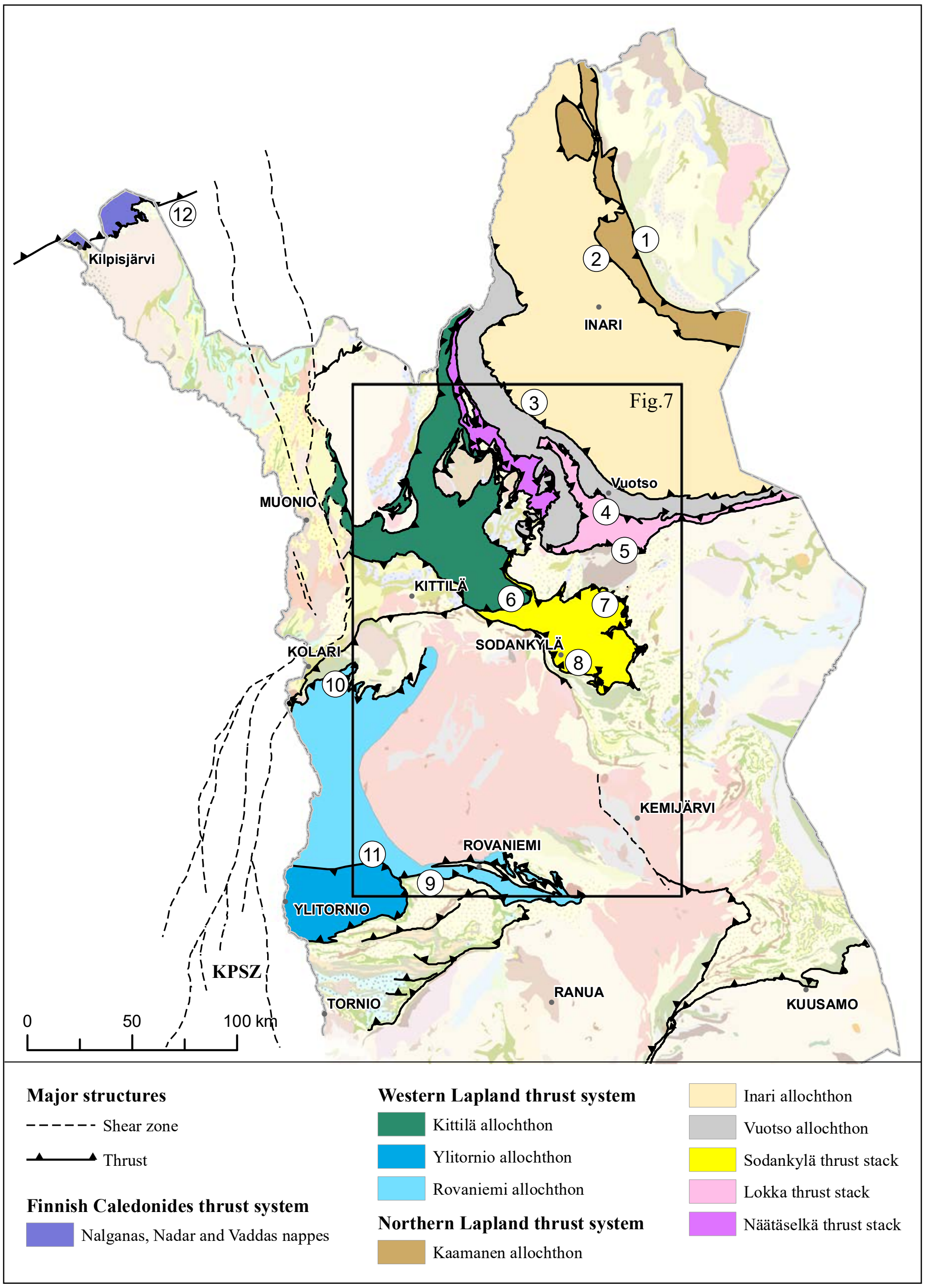

Fig. 6. The overall configuration of the major thrusts, thrust-bounded units and shear zones in northern Finland. 1) Utsjoki thrust, 2) Kaamanen thrust, 3) Angeli–Tankavaara decollement, 4) Vuotso decollement, 5) Kurittukoski thrust, 6) Nuttio–Seurukarkea decollement, 7) Postoaapa thrust, 8) Ellitsa thrust, 9) Korkiavaara thrust, 10) Venejärvi thrust, 11) Martimo decollement, 12) Nalganas sole thrust (decollement). KPSZ = Kolari–Pajala shear zone; the extent of Figure 7 is indicated as a box. Note the parautochthonous cover on the Archean basement. The geological background map is simplified from Nironen et al. (2016).

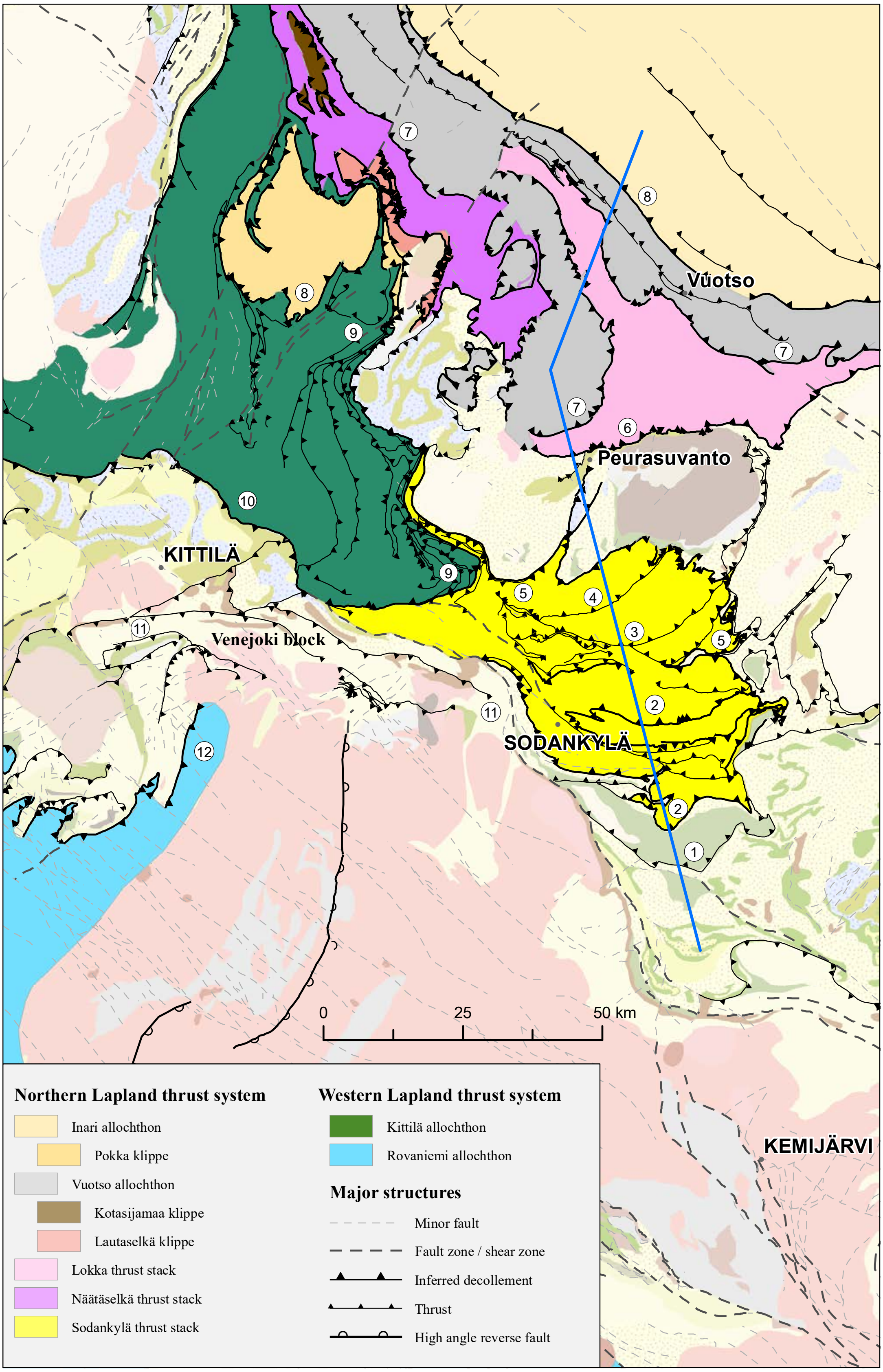

Fig. 7. The Central Lapland belt displaying the complex interplay of the Western Lapland and Northern Lapland thrust systems. The location of the schematic cross-section (Fig. 8) is indicated (blue line) and the numbers 1–8 correspond to Figure 8. Numbers referring to other major thrusts: 9) Nuttio–Seurukarkea decollement, 10) Sirkka thrust, 11) Venejoki thrust, 12) Venejärvi thrust (part of the Rovaniemi decollement). The lithology and minor structures within the parautochthonous cover and Archean basement complex according to the Bedrock of Finland – DigiKP. The geological background map is simplified from Nironen et al. (2016).

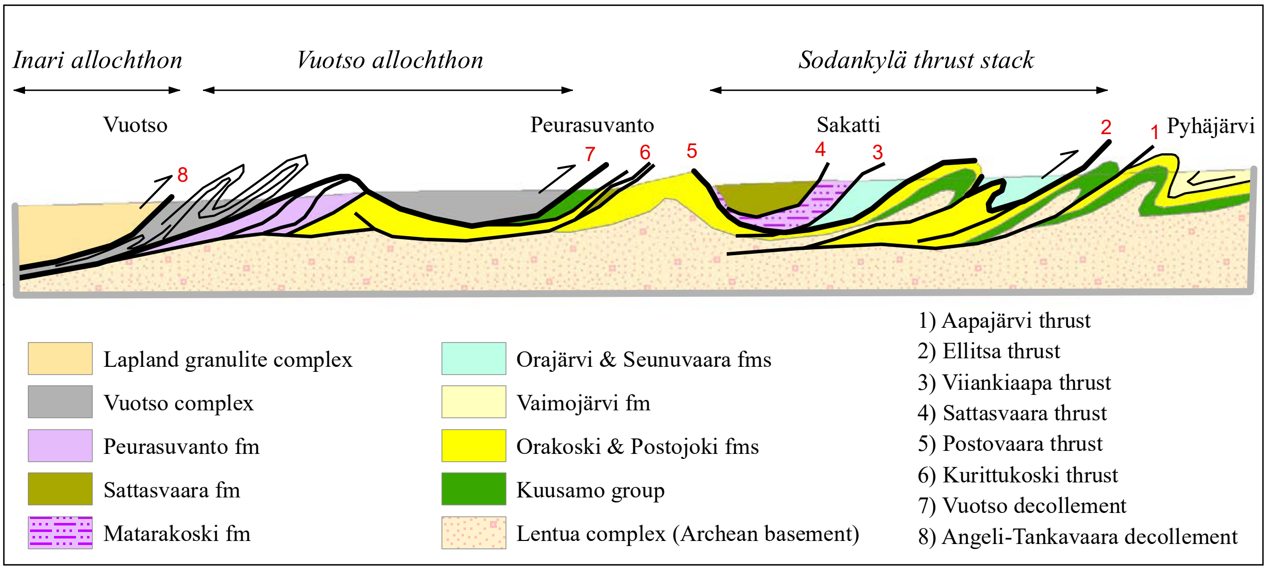

Fig. 8. Schematic cross-section (not to scale) across the Northern Lapland thrust system. Note the sole thrusts following the basement–cover interface in the north and the upper contact of the autochthonous quartzite in the middle part. Within the Sodankylä thrust stack, the basement-involved thrusts reactivate inherited normal faults or occur at the overturned limb of basement-cored anticlines; for the location, see Figure 7.

3.2 Central Finland tectonic province

Major shear zones, several thrusts (e.g. Nironen et al. 2016) and related crustal-scale structures (e.g. Sorjonen-Ward 2006) have been suggested within the *Central Finland tectonic province*, but until now, no thrust-bounded map units have been outlined. The overall structural evolution of the province is rather poorly constrained and, for example, the potential impact of extensional tectonics (e.g. Nikkilä et al. 2015) on the generation of shear zones and on the present map pattern is difficult to evaluate.

It is essential to see that within the *Karelia tectonic province*, all the major thrusts in eastern Finland, and most of them in northern Finland, are consider older (ca. 1900 Ma) than the main crustal growth stage (ca. 1890–1870 Ma) and coeval volcanism of the *Svecofennian orogeny*. The Raahe-Ladoga thrust system (see Chapter 3.1.1) is tectonically significant for two reasons: (1) within the *Central Finland province*, only the Pyhäsalmi and Suonenjoki allochthons consist of rock units older (ca. 1930–1900 Ma; Lahtinen 1994, Lahtinen et al. 2015b) than the major collision affecting the eastern foreland and (2) the thrusts have transported *Svecofennian rocks* of the Kiuruvesi allochthon on their current position within the Karelia province (Fig. 4).

The trend of the inferred decollement flooring the **Pyhäsalmi and Suonenjoki allochthons** (Table 6) follows the Raahe–Ladoga suture zone (Fig. 3B). These thrusts are truncated by voluminous intrusive rocks and affected by intense younger shear zones (see Figs. 3B and 4). The Pyhäsalmi and Suonenjoki allochthons are bounded in the west by the younger Ruhanperä and Iisvesi shear zones, respectively. Along the boundary, voluminous younger intrusions have obliterated all the thrust-related early structures beyond recognition. Nonetheless, the rocks of the Nivala suite, west of the Pyhäsalmi allochthon (Fig. 4), can be correlated with the Suonenjoki and Kotalahti suites (the latter accompanied by Ni-bearing intrusions). Thus, it seems possible that the rock units of the Nivala district could represent still another tectonic package thrusted over the Pyhäsalmi allochthon.

Table. 6. Thrust-bounded units of the Central Finland tectonic province.

Unit name	**Sole thrust**	Main references	Lithostratigraphic / Lithodemic units
Raahe–Ladoga thrust system (western part)			
Pyhäsalmi allochthon	Pyhäsalmi decollement	This paper	Pyhäsalmi and Vihanti groups
Suonenjoki allochthon	Suonenjoki decollement	This paper	Suonenjoki and Kotalahti suites

Younger major thrust zones are recognized within the *Central Finland tectonic province*. The combined interpretation of seismic sections and field observations indicate the existence of crustal-scale thrust blocks, and their provisional boundaries are tentatively addressed in Figure 4. The thrust-bounded crustal domains of this group include: (1) Perho thrust block (Sorjonen-Ward 2006), (2) Kauhajoki thrust block and (3) Sulkava thrust block (Korsman et al. 1988).

The Perho block was identified in the interpretation of the FIRE 3 profile (Sorjonen-Ward 2006). In our interpretation, the Virrat–Jämsä shear zone, with apparent dextral lateral displacement (>20 km), separates the Perho and Kauhajoki blocks. The Perho thrust forms the roof of the Perho block against the Ostrobothnia metasediments, and the floor is defined by the Kyyjärvi thrust (Fig. 4). A prominent, SE-plunging lineation is associated with both faults (Pipping & Vaarma 1993). A similar SE-plunging lineation has been found in Parra within the Seinäjoki–Karijoki thrust (Lehtonen et al. 2005). All these lineations are interpreted to indicate relatively widespread tectonic transport towards the NW (for the age constraints, see Chapter 4).

3.3 Southwestern Finland tectonic province

Many authors (e.g. Väisänen & Hölttä 1999, Pajunen et al. 2008) have assumed low-angle thrusting as an explanation for the early structures within the *Southwestern Finland tectonic province*. However, the problems related to the recognition of early low-angle thrusts are severe. First, the tectonic set-up and structural history (e.g. contractional vs. late extensional stages; see Lahtinen et al. 2005, Pajunen et al. 2008, Korja et al. 2009) are poorly understood or at least controversial. Second, the intensive ductile folding followed by the development of the major shear zones resulted in an overall upright position and discontinuity of the early structures. Third, southern Finland was still the site of intensive granitic magmatism 1.85–1.80 Ga ago, and the possible thrust-bounded units are difficult to identify and trace. Nevertheless, there are some stratigraphic indications of possible thrust stacking. One example is the Hyvinkää–Kisko shear zone (Skyttä et al. 2006, Pajunen et al. 2008), where the southern high-grade rocks (Kimito suite) appear to be thrusted over the rocks of the *Häme belt*. In Figure 4, we tentatively present a set of inferred major thrusts in southern Finland.

3.4 Kilpisjärvi structural province

The Kilpisjärvi Structural Province (see Fig. 3) represents the extent of the Caledonian structural overprint in Finland. The Finnish Caledonides thrust system and the rocks deformed above and immediately below the frontal thrust of the Caledonian thrust belt, have been described by Lehtovaara (1989, 1995). The major thrusts and the tectonostratigraphic division (Lehtovaara 1995) are largely adopted from Norway. The allochthonous units comprise the **Nalganas, Nabar and Vaddas Nappes** (Table 7). Below the Nalganas sole thrust, characteristic features include some imbrication and weak deformation of the cover. The boundary of parautochthonous ('Jerta Nappe') and autochthonous cover (Dividal group) is not distinct but shows a gradational change from deformed to intact sedimentary rocks (Lehtovaara 1995).

Table. 7. Tectonostratigraphic units of the Kilpisjärvi Structural Province.

Unit name	**Sole thrust**	Main references	Lithostratigraphic / Lithodemic units
Finnish Caledonides thrust system			
Vaddas Nappe	Vaddas-Corrovarri thrust (decollement of the Upper Allochthon)	Lehtovaara 1989, 1995	Ridnitsohkka gabbro sill
Nabar Nappe	Nabar thrust zone	Lehtovaara 1989, 1995	Pihtsosnjunni muscovite gneiss, Kovddoskaisi amphibolite
Nalganas Nappe	Nalganas sole thrust (decollement of the Middle Allochthon)	Lehtovaara 1989, 1995	Saana arkose quartzite

4 TIME CONSTRAINTS OF THRUSTING

4.1 General

The abundance of thrusts and the overall structural style of the *Karelia Province* have been well described, but the areal extent of the observed structural overprinting is for the first time presented as structural provinces by Kohonen et al. (2021). The tectonic model and the set-up of the collision zones bordering the *Karelia province* advanced gradually through the milestones provided by Gaál & Gorbatchev (1987), Nironen (1997), Lahtinen et al. (2005) and Lahtinen & Huhma (2019). Nevertheless, many questions are still to be resolved, and major issues include: (1) the kinematic and thermal evolution of the 'Raahe–Ladoga zone' (RLZ) from the early collision zone (the *Raahe–Ladoga suture*) to a dextral transcurrent shear system, (2) details of the Norrbotten–Karelia relationships, including the kinematic evolution and the timing of the structures from collision-related thrusting to the development of the Kolari–Pajala shear zone, (3) the tectonic model for the deep burial and subsequent uplift of the Lapland granulite belt (Inari allochthon in the structural nomenclature) and, finally, (4) the timing and interaction of the Western Lapland and the Northern Lapland thrust systems.

In comparison to the cratonic foreland, the Karelia Province, the Svecofennian deformation style of the Central Finland and Southwestern Finland Provinces (Fig. 4) is fundamentally different. The formation of the *Svecofennian* crust lasted more than 100 Ma (ca. 1.93–1.81 Ga), and even the major structural features are poorly dated. The early thrusts within the Svecofennian province are discontinuous, reoriented and reactivated structures mainly inferred from lithological relationships. In the light of the prevailing tectonic models (e.g. Lahtinen et al. 2005), it appears that during the main magmatic stage (ca. 1.89–1.86 Ga), the rheology of hot juvenile crust was not favourable for localizing deformation in thrust zones and crustal thickening by thrusting (see discussion by Hölttä et al. 2020).

Data concerning the age of different structures is sparse and their correlation requires sophisticated interpretation (e.g. Nironen 2017). The overall dynamic and kinematic model covering the evolution from the main collisions along the sutures (ca. 1.9 Ga) to the voluminous *Svecofennian* granitoid magmatism (ca. 1.89–1.86 Ga) and further to the crustal reactivation (ca. 1.84–1.81 Ga) in the southern Finland is still unclear, and many controversial ideas have been proposed. The construction of a comprehensive age classification of thrusts and other structures was not found possible. Instead, we present a collection of key data, a brief summary and a tentative division (Fig. 9) based on our interpretation.

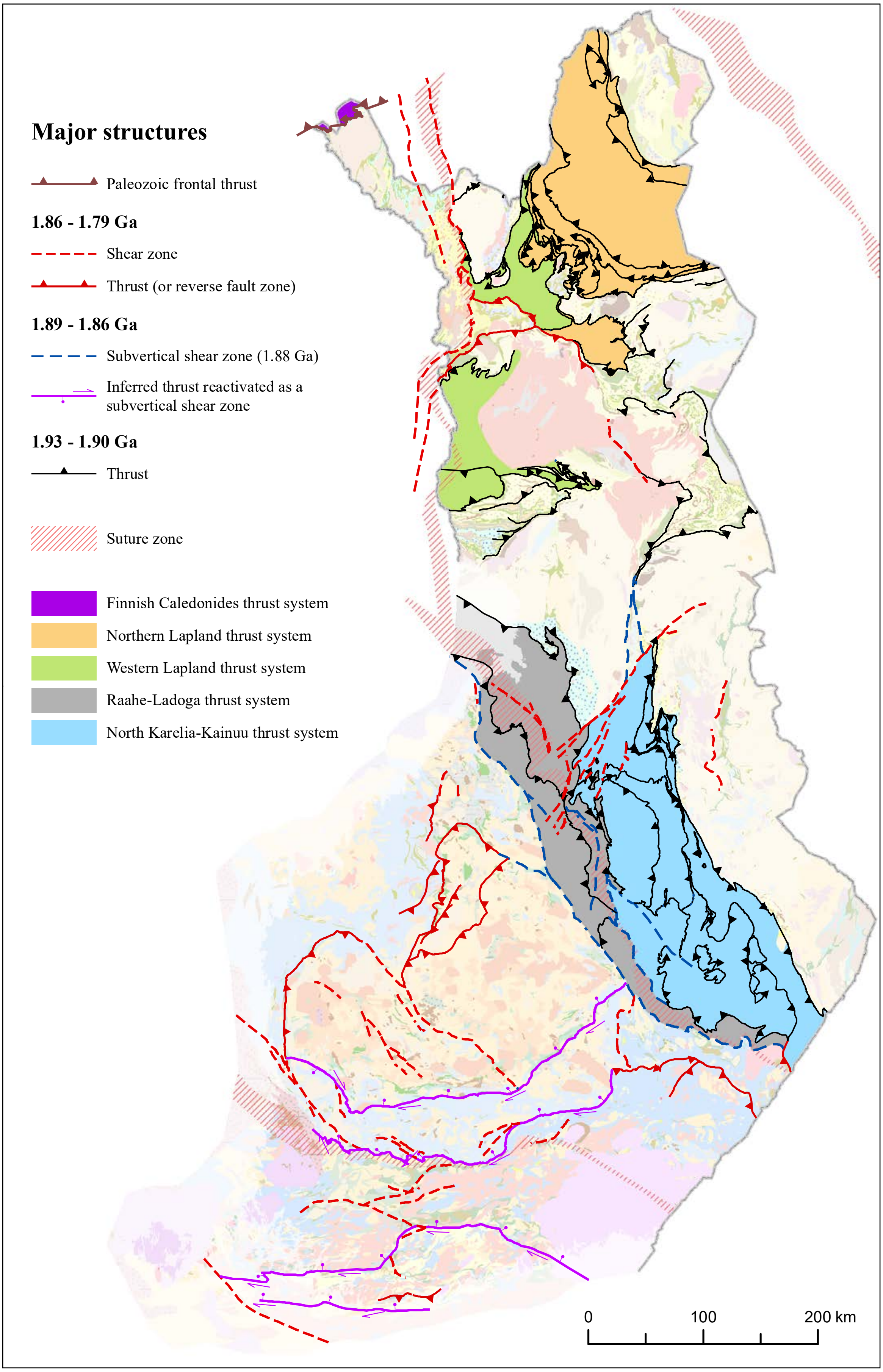

Fig. 9. A simplified map addressing the approximated age groups of the major thrusts and shear zones. The geological background map is simplified from Nironen et al. (2016).

4.2 Main collision stage within the Karelia tectonic province ca. 1.93–1.90 Ga

The upper age limit of the earliest deformation of the Raahe–Ladoga thrust system is provided by the sedimentary rocks within the Vieremä (Salahmi area) and Kiuruvesi (eastern Kansanneva and Loutemäki areas) allochthons, with maximum depositional ages constrained by the detrital zircons at 1.92–1.91 Ga (Lahtinen et al. 2015b). The end of the thrusting stage within the Raahe–Ladoga suture zone can be deduced from the deformation of the early structures, with suggested minimum ages of 1.89 Ga (by Hölttä 1988 and Korsman et al. 1999) and 1.88 Ga (by Lahtinen et al. 2015b).

Along the *Kautokeino–Muonio–Tornio suture zone*, the deformation history and kinematics of thrusting are poorly constrained and partly controversial (e.g. Lahtinen et al. 2015a, 2018, Skyttä et al. 2019, Piippo et al. 2019). The methods for the detailed dating of structures are limited, but for the Ylitornio allochthon, a maximum age of 1.91 was suggested by Lahtinen et al. (2015a). This is in accordance with the estimated thrusting age of around 1.92–1.90 Ga interpreted from metamorphic zircons (Lahtinen et al. 2018). We assume that the development of all the decollements below the Kittilä, Ylitornio and Rovaniemi allochthons roughly corresponds to that age.

According to Lahtinen & Huhma (2019), the *Kola–Lapland Structural Province* represents a retroarc foreland thrust belt. The major thrusting phase occurred ca. 1915–1910 Ma ago and the crustal shortening continued until ca. 1870 Ma. Nevertheless, the tectonic and metamorphic evolution of northern Lapland is not fully resolved, and especially the kinematics and timing of the individual thrusts are open to speculation.

4.3 Evidence for thrusting between 1.89–1.86 Ga

The details of the kinematic evolution of the *Raahe–Ladoga suture zone* from collisional deformation and crustal shortening to a nearly vertical system of transcurrent faults are poorly known. According to the Pielavesi case study (Woodard et al. 2017), the syn-kinematic granitoids, with ages around 1885 Ma, were emplaced in relation to a vertical dextral shear zone, and no indication of further thrusting was reported. We tentatively suggest an approximate age of around 1.88 Ga for the generation of some major shear zones (e.g. Ruhanperä, Suvasvesi, Haukivesi; Figs. 4 and 9). We see no evidence for collision-related thrusting younger than 1.89 along the *Raahe–Ladoga suture zone*, within the entire *Svecokarelia structural province* and in the northern parts of the *Central Finland tectonic province*.

The development of the Western Lapland thrust system along the Kautokeino–Muonio–Tornio suture contains many uncertain and controversial aspects. Lahtinen et al. (2015a, 2018) and Sayab et al. (2019) involve N–S and NE–SW-oriented shortening from ca. 1.90 to 1.87 Ga. Sayab et al. (2019) theoretically model in the Kittilä district some thrusts (e.g. the initiation of the Sirkka and Venejoki thrust zones) to this stage. The major Hirvaskoski shear zone (Fig. 5), which is transected by the Auho fault (part of the Oulujärvi shear zone; see Kärki et al. 1993) and connected to the Kemijärvi shear zone, may also have originated around 1.88 Ga ago.

Piippo et al. (2019) presented an elegant structural model for the Peräpohja belt (S of the Ylitornio allochthon). The model involves folding and associated S-vergent thrusts, and the authors point out the importance of the paleotopography of the Archean basement blocks as the major controlling factor regarding the orientation of structures. Both the age of the reported thrust structures and kinematic connection to the Western Lapland thrust system remain open.

Tuisku et al. (2006) and Lahtinen & Huhma (2019) assume that the Northern Lapland thrust system represents two-stage evolution, with the main collision followed by a repeated shortening phase ca. 1880–1870 Ma ago. They correlate the deformation with the shortening reported in central Lapland (D3 of Lahtinen et al. 2018) and connect the deformation to collisions within the Svecofennian arc complex further to the SW. In practice, we find the distinction between the early thrusts and these younger thrusts (mainly reactivating early thrusts) challenging at the regional scale in Lapland.

In the tectonic model by Lahtinen et al. (2005), the *Southwestern Finland tectonic province* represents a juvenile arc collage laterally accreted along the present *Bothnia–Pirkanmaa Suture* to the previous Central Finland arc collage ca. 1.88 Ga ago. In the southern parts of the Central Finland tectonic province and in southern Finland, all the early structures, including the Leivonmäki–Tampere–Kankaanpää, Otava–Hämeenlinna–Kynsikangas and Hyvinkää–Kisko shear zones, are severely affected by later deformation (e.g. Väisänen & Hölttä 1999, Pajunen et al. 2008, Mikkola et al. 2018). No detailed age data concerning the early deformation are available, but in principle, the age of the early structures is expected to correspond to that of the collision. Without any firm evidence, we tentatively support the overall model of Nironen (2017), and propose a thrust origin followed by (repeated?) reactivation as subvertical transcurrent shear zones for many of these structures (Fig. 4).

4.4 Proterozoic thrusts and deformation younger than 1.86 Ga

Regarding the younger thrust faults, it is appropriate to include vertical shear zones in the overall picture (Fig. 9). Both in central Lapland and in central Finland, the youngest Paleoproterozoic (ca. 1.83–1.79 Ga) dip slip faults are intimately linked with the adjacent strike-slip shear zones (Kousa & Luukas 2007, Bergman & Weihed 2019).

Within the *Karelia tectonic province*, one key structure is the Kolari–Pajala shear zone (Pajala Shear Zone of Kärki et al. 1993), which approximately follows the *Kautokeino–Muonio–Tornio suture zone* and forms the eastern part of the wider Pajala deformation belt (cf. Luth et al. 2018, Bergman & Weihed 2019). The shear zone has a long tectonic history, starting from the collision followed by dextral strike slip movement (Berthelsen & Marker 1986) and finally the sinistral transcurrent fault phase. The age of the youngest fault generation with considerable displacement is around 1.78 Ga or even later (Bergman & Weihed 2019). The Kolari–Pajala shear zone is linked to the southward-dipping Venejoki and Sirkka thrust zones, and both structures are identified in the interpretation of the seismic line FIRE 4 (Patison et al. 2006). The Sirkka thrust zone deforms the Nuttio–Seurukarkea decollement at the southern margin of the Kittilä allochthon (Fig. 7). We suggest that the Sirkka and Venejoki thrusts represent the margin of the rigid Venejoki block transported towards the north ca. 1.8 Ga ago. Some N–S-oriented structures in western Lapland (see the map by Nironen et al. 2016) indicate thrusting of older rocks on the Kumpu group, with maximum depositional age of 1.88 Ga (Köykkä et al. 2019). We tentatively link these thrusts to the development of the Pajala deformation belt.

The age of major thrust faults bordering the blocks (Perho, Kauhajoki, Sulkava) in central Finland can definitely be bracketed by cross-cutting relationships as younger than 1.88 Ga. The age of the structures is not known, but it is assumed that the formation of crustal-scale thrusts necessitates advanced cooling of the juvenile *Svecofennian* crust, and therefore we estimate that these structures were plausibly generated not earlier than 1.83 Ga. A similar age approximation for the Sulkava block was proposed by Korsman et al. (1988).

In southern Finland, the ductile deformation occurred in several phases between 1.85 and 1.79 Ga (e.g. Torvela & Ehlers 2010). According to Väisänen & Skyttä (2007), the major, vertical shear zones within the *Southwestern Finland tectonic province* developed after the main ductile deformation, peak metamorphism and crustal melting at 1840–1810 Ma.

4.5 Paleozoic thrusting related to the Caledonian orogeny

The Kilpisjärvi structural province represents a tiny fragment of the frontal part of the Scandinavian Caledonide Orogen. Caledonian continent–continent collision took place (further to the W) in the Scandian phase (also termed the Scandian Orogeny) ca. 425–400 Ma ago (e.g. Roberts 2003, Gee et al. 2008). Major thrusting occurred late in the Silurian, with emplacement of the Caledonian orogenic wedge across the foreland basin in the Early Devonian (see Gee & Stephens 2020 and references therein).

5 CONCLUDING REMARKS AND SUMMARY

5.1 Nature of Paleoproterozoic thrust belts in Finland

In many orogenic belts, such as the Scandinavian Caledonides, the tectonostratigraphic procedure is a well-established element of the mapping tradition. However, even in the Precambrian of Finland, map unit division based on thrust planes also offers a useful tool complementing the traditional lithology–lithostratigraphy–based method. Informative descriptions of Paleoproterozoic collisional belts with nappe tectonics, such as the Trans-Hudson Orogen (Lewry et al. 1994, Irvine et al. 2005), are available, but ready-for-comparison models for the deep level of foreland thrust systems and structures are sparse. Therefore, the application of thrust systems to metamorphic rocks in Finland needs to be accompanied by a discussion of the geological context.

The Proterozoic thrust systems in Finland represent deep sections of foreland fold-and-thrust belts. The work raised some questions regarding the applicability of some standard FTB concepts and terminologies. In the characterization of thrust systems, the main parameters to be considered are: (1) the distance from the collision zone (internal vs. external FTB) and (2) the depth in the thrust pile (Fig. 10). The minimum distance from the collision zone can somehow be figured out based on the location of suture zones (see Fig. 3), but major uncertainties remain. For example, regarding the Northern Lapland thrust system, the location of the suture separating the Kola and Karelia provinces is poorly defined, and the overall tectonic model of the collision is controversial (e.g. Patison et al. 2006, Lahtinen & Huhma 2019).

The assessment of depth is a complicated issue. The metamorphic peak conditions are mostly reached well after the main thrusting stage. Furthermore, the common metamorphic assemblages are not very sensitive to pressure, and only general estimates (e.g. low pressure vs. medium pressure) are typically presented. The main difficulty arises, however, from the thrusting process as such: a thrust system migrates towards the foreland (the externides) and thickens by piling (the internides) at the same time. During the long FTB evolution, the thrust zones have been active in different P/T conditions before the peak metamorphism.

The integration of thrust systems into the tectonic deformation history would require the combination of major structures, kinematic interpretation and timing of both the deformation and regional metamorphism. Presently, such detailed reconstructions are not possible, but we use the intensively studied southern part of the thrust system (see Sorjonen-Ward 2006 and references therein) as an example to discuss the thrust systems of the Karelia province. Crustal thickening and deep burial of the cover rocks is evidenced by amphibolite facies (or higher) peak metamorphism (see the review by Hölttä & Heilimo 2017). The metamorphic observations (Säntti et al. 2006, Hölttä & Karttunen 2011) indicate late- to post-tectonic pressures corresponding to a minimum depth of ca. 20 km for the rocks of the Outokumpu allochthon. The eastern Tohmajärvi–Nunnanlahti–YläLuosta thrust stack is characterized by medium-grade metamorphic conditions and by basement-involved thrusts with coeval or successive ductile deformation. The parautochthonous quartzites below the thrust stack indicate metamorphism at a depth of around 15 km (Hölttä & Heilimo 2017).

Even considering that the indicated pressures do not correspond to the main thrusting stage, and that the depths as such may be overestimated, it is obvious that the development of the present North Karelia–Kainuu thrust system reached conditions that are not comparable to examples and concepts derived from external, shallow thrust belts. Ramp-flat geometries and other features typical for external parts of a thrust belt are not identified, and the detached allochthonous units are characterized by ductile deformation with tight to isoclinal folding (e.g. Outokumpu allochthon; Koistinen 1981). The transition towards the internal crystalline core of the orogen is first indicated by intensified recrystallization with increasing metamorphic grade and finally by transition to migmatites and intrusive bodies obscuring the previous thrust-related structures (Fig. 10). In deep levels of a thrust belt, even the distinction of structures related to progressive thrusting and later ductile folding has not been straightforward (e.g. Koistinen 1981, Ward & Kohonen 1989, Kohonen 1995), and the causal and temporal connection of the thrusts in different parts of the system has remained unclear.

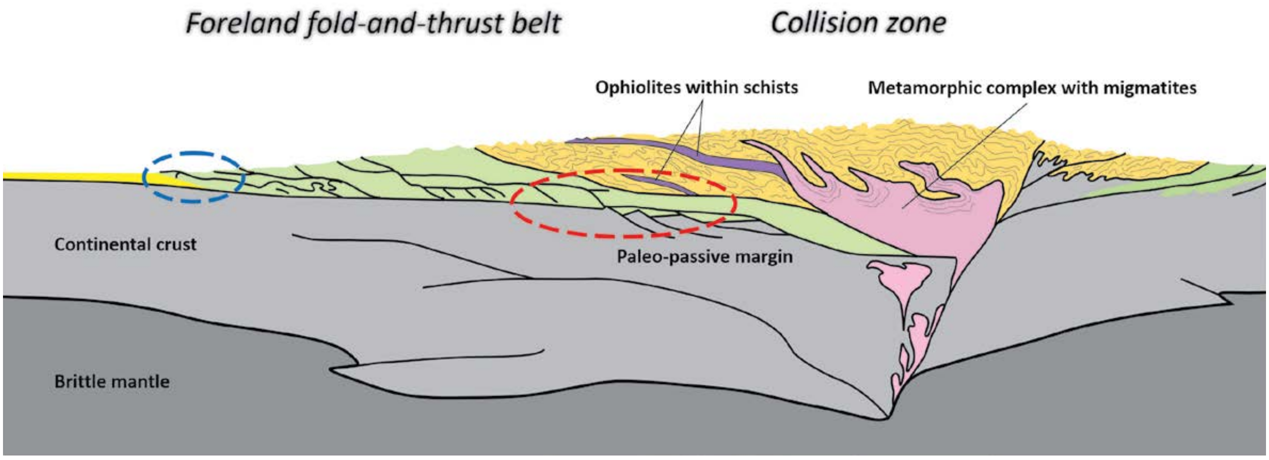

Fig. 10. The assumed approximate positions of the present North Karelia–Kainuu (red ellipse) and Finnish Caledonides (blue ellipse) thrust systems within a simplified and generic foreland fold-and-thrust belt model. (Model modified after Hatcher & Williams 1986).

The North Karelia–Kainuu thrust system shows substantial crustal shortening/thickening, which is possible to explain via crustal-scale "thick-skinned" imbrication plausibly preceded by "thin-skinned" nappe emplacement (e.g. Kohonen 1995). However, considering the tectonically deeply buried setting of the thrust system, the strict division into thin/thick-skinned deformation styles can also be questioned. In medium-grade metamorphic conditions, both the cover rocks and the basement complex have reached conditions where the rheological contrast between them may no longer be distinct. In addition, the lower parts of the supracrustal cover (typically quartzites) are welded to the basement by a network of gabbroic dykes ('Jatulian diabases'). Consequently, the major rheological contrast may occur at the upper boundary of the dyke system, or some other place within the sequence, and not necessarily at the basement–cover interface, as presumed in thin-skinned modelling.

The basement deformation is currently poorly studied, and one major challenge is the recognition of the crystalline thrusts (cf. Hatcher 1995) within the basement areas; although the thrusts are plausibly present, the lack of marker horizons makes them difficult to recognise. The observed basement–cover relationships, such as basement-cored overturned anticlines and narrow cover outliers within the basement complex, are difficult to explain without ductile basement behaviour, in certain zones at least. Evidence of ductile deformation of the basement–cover interface raises not only the thin/thick-skinned issue, but also questions about the overall deformation style and applicability of terms such as decollement in relation to the deformation style characterized by fold-thrust uplifts with tight asymmetric folding rather than definite thrust planes.

Regarding the future research challenges, the major question within the entire *Karelia tectonic province* is the overall style of the basement-involved deformation. The previous interpretations are highly variable, from models assuming imbrication of thin basement slivers (e.g. Park & Doody 1991, Koistinen 1993) to semiductile basement-cored anticlines (e.g. Kohonen 1995). Better knowledge of both the style and location of the major basement-involved thrusts is essential for improved thrust system modelling. Only detailed studies (such as Evins & Laajoki 2002), including kinematic indicators within the shear zones, would substantially help in solving this problem.

5.2 Comments on the selected approach

The justification and practical need behind the presented approach is the conclusion that in many cases, tectonic processes have completely rearranged the primary rock units, and the structural features dominate the resulting bedrock map. The theory behind our approach is the general scientific knowledge of thrust belts and their internal structures. Coupling of tectonic models, thrust system concepts and the observed features, such as fault zones and different lithologies, opens the interpretation process, finally leading to the establishment of thrust-bounded map units (Fig. 11). The thrust-bounded units are, by definition, based on their bounding structural contacts (sole thrust / roof thrust). In practice, however, the identification of bounding surfaces is affected by the lithological units and their relationships with each other. Due to the method, the resulting units are heavily dependent on the judgment of the authors.

We have presented the thrust-bounded units as map polygons. The areas not included in thrust-bounded units (within the Karelia tectonic province) represent either intact Archean basement rocks or parautochthonous cover rocks. The term 'parautochthonous' is fuzzy by definition, and in reality the cover rocks are deformed everywhere: the quartzites in North Karelia are imbricated, the Kuusamo belt is multiply folded and the boundary between the Sodankylä thrust stack and the surrounding fold belt is arbitrary. Our guiding rule was that when thrusting has markedly mixed up the superposition of primary units, the application of thrust-bounded units is justified. However, full consistency in the case-by-case definition of the boundary between a thrust stack and parautochthonous cover has probably not been achieved. An example of this difficulty was the classification of the *Peräpohja belt*. The cross-section provided by Piippo et al. (2019) indicates local thrusting and even features of considerable tectonic transport. However, the stratigraphy is still readable, and at this stage the belt was classified as part of the parautochthonous cover.

The compilation of the cross-section across the *Central Lapland belt* (Fig. 8) brought up the challenges of 3D modelling. Information concerning both the subsurface detachments and internal geometries of the thrust-bounded units is limited to a simple projection of surface structures with some support provided by the interpretation of seismic lines, geophysical data and, in places, by drilling results. Thrust zones are potentially more complex than planes: blind thrusts, fold thrusts, horses and complex duplex geometries can be presumed. An example is the indefinite frontal thrust of the Tohmajärvi–Nunnanlahti–YläLuosta thrust stack (see Table 1). The assumed detachment zone can be described as an anastomosing network of shear planes rather than one continuous thrust plane. It appears that 3D modelling of thrust planes in structurally complex regions, such as southern Finland, will be a very demanding task.

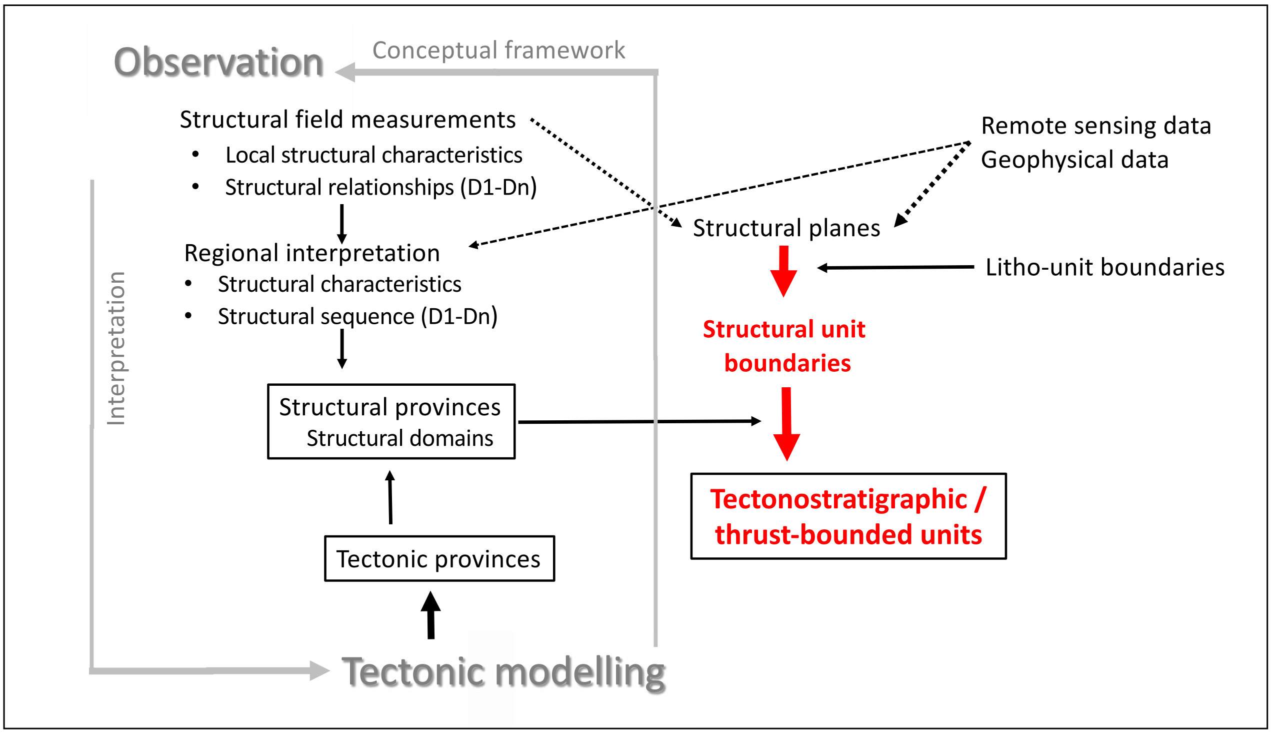

Fig. 11. The complex relationships of observed geological features, interpretations and the overall tectonic framework in the formation of thrust-bounded map units; the map unit categories included in the GTK map data architecture are shown as framed boxes.

5.3 Summary

In geology, the final output (e.g. map, model) is highly dependent on the underpinning conceptual framework, consisting of theories, models, classification rules and research tradition. The national conceptual framework also needs maintenance. From time to time, the field observation-based bottom-up method needs to be complemented by a holistic top-down approach by reviewing the state-of-the-art. We see that the systematic arrangement of structural map units is of growing importance and part of a functional geological framework.

This work is the first attempt to create an overall tectonostratigraphic scheme in Finland. With progressing research, many of the presented unit boundaries will be relocated and new units presented. Basically, the thrust-bounded map units can be seen as a bridge between the conceptual tectonic models (such as schematic crustal cross-sections, tectonic provinces and suture zones) and mapped real-world features, such as structures and lithostratigraphic units.

The main outcome and highlights of our work can be summarized as follows:

1. A systematic, country-wide arrangement of all the thrust-bounded map units is presented for the first time. Tectonic and structural provinces have been utilized as the framework for the division.
2. The presented nomenclature is one step towards more harmonized science-language in Finland.
3. The units within the Raahe–Ladoga thrust system represent Svecofennian orogenic rocks, and the Kiuruvesi allochthon was tectonically transported on the Archean crust. The definition of the thrust system simplifies the description of the complex Raahe–Ladoga suture zone.
4. The presented cross-section with thrust-bounded map units offers an explanation for some stratigraphic questions in Central Lapland (Sodankylä area).
5. The results will aid in the construction of both advanced 3D models and more traditional depositional/stratigraphic models in different parts of Finland.

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REFERENCES

Aatos, S., Heikkinen, P. J. & Kukkonen, I. 2016. Development of mining camp exploration and technologies for the Outokumpu brownfield region. In: Aatos, S. (ed.) Developing Mining Camp Exploration Concepts and Technologies: Brownfield Exploration Project 2013–2016. Geological Survey of Finland, Special Paper 59, 15–30. Available at: http://tupa.gtk.fi/julkaisu/specialpaper/sp_059_pages_015_030.pdf

Ahtonen, N., Kohonen, J., Luukas, J., Ojala, A. E. K., Palmu, J.-P. & Vuollo, J. 2021. GTK Map Data Architecture: the core of the developing National Geological Framework of Finland. In: Kohonen, J. & Tarvainen, T. (eds) Developments in map data management and geological unit nomenclature in Finland. Geological Survey of Finland, Bulletin 412. (this volume). Available at: https://doi.org/10.30440/bt412.1

Alvarez-Marron, J., Rodriguez-Fernandez, R., Heredia, N., Busquets, P., Colombo, F. & Brown, D. 2006. Neogene structures overprinting Palaeozoic thrust systems in the Andean Precordillera at 30°S latitude. Journal of the Geological Society (2006) 163 (6), 949–964. Available at: https://doi.org/10.1144/0016-76492005-142

Bedrock of Finland – DigiKP. Digital map database [Electronic resource]. Espoo: Geological Survey of Finland [referred 1.06.2020]. Version 2.1.

Bergman, S. & Weihed, P. 2019. Archean (>2.6 Ga) and Paleoproterozoic (2.5–1.8 Ga), pre- and syn-orogenic magmatism, sedimentation and mineralization in the Norrbotten and Överkalix lithotectonic units, Svecokarelian orogeny. In: Stephens, M. B. & Bergman Weihed, J. (eds) Sweden: Lithotectonic Framework, Tectonic Evolution and Mineral Resources. Geological Society, Memoirs 50, 27–81. Available at: https://doi.org/10.1144/M50-2016-29

Berthelsen, A. & Marker, M. 1986. 1.9–1.8 Ga old strike-slip megashears in the Baltic Shield, and their plate tectonic implications. Tectonophysics, 128, 163–181. Available at: https://doi.org/10.1016/0040-1951(86)90292-1

Evins, P. M. & Laajoki, K. 2002. Early Proterozoic nappe formation: an example from Sodankylä, Finland, Northern Baltic Shield. Geological Magazine 139, 73–87.

Gaál, G. & Gorbatschev, R. 1987. An outline of the Precambrian evolution of the Baltic shield. Precambrian Research, 35, 15–52. Available at: https://doi.org/10.1016/0301-9268(87)90044-1

Gaál, G., Berthelsen, A., Gorbatschev, R., Kesola, R., Lehtonen, M. I., Marker, M. & Raase, P. 1989. Structure and composition of the Precambrian crust along the POLAR Profile in the northern Baltic Shield. Tectonophysics 162, 1–25.

Gee, D. G. & Stephens, M. B 2020. Regional context and tectonostratigraphic framework of the early–middle Paleozoic Caledonide orogen, northwestern Sweden. In: Stephens, M. B. & Bergman Weihed, J. (eds) Sweden: Lithotectonic Framework, Tectonic Evolution and Mineral Resources. Geological Society, Memoirs 50, 481–494. Available at: https://doi.org/10.1144/M50-2017-21

Gee, D. G., Fossen, H., Henriksen. N. & Higgins, A. K. 2008. From the early Paleozoic platforms of Baltica and Laurentia to the Caledonide orogen of Scandinavia and Greenland. Episodes 31(1), 44–51. Available at: https://doi.org/10.18814/epiiugs/2008/v31i1/007

Hanski, E. 1997. The Nuttio serpentinite belt, central Lapland: An example of Paleoproterozoic ophiolitic mantle rocks in Finland. Ofioliti 22 (1), 35-46. Available at: https://www.researchgate.net/publication/285839297

Hanski, E. & Huhma, H. 2005. Central Lapland greenstone belt. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) Precambrian Geology of Finland. Key to the Evolution of the Fennoscandian Shield. Amsterdam: Elsevier Science B.V., 139–193.

Hatcher, R. D. 1995. Structural geology: principles, concepts and problems. Englewood Cliffs, N. J.: Prentice Hall Inc.

Hatcher, R. D. & Williams, R. T. 1986. Mechanical model for single thrust sheets Part I: Taxonomy of crystalline thrust sheets and their relationships to the mechanical behavior of orogenic belts. GSA Bulletin (97 (8), 975–985. Available at: https://doi.org/10.1130/0016-7606(1986)97<975:MMFSTS>2.0.CO;2

Hölttä, P. 1988. Metamorphic zones and the evolution of granulite grade metamorphism in the early Proterozoic Pielavesi area, central Finland. Geological Survey of Finland, Bulletin 344. 50 p. Available at: http:/tupa.gtk.fi/julkaisu/bulletin/bt_344.pdf

Hölttä, P. & Heilimo, E. 2017. Metamorphic map of Finland. In: Nironen, M. (ed.) Bedrock of Finland at the scale 1:1 000 000 – Major stratigraphic units, metamorphism and tectonic evolution. Geological Survey of Finland, Special Paper 60, 77–128. Available at: http://tupa.gtk.fi/julkaisu/specialpaper/sp_060_pages_077_128.pdf

Hölttä, P. & Karttunen, P. 2011. Metamorphism as a function of depth in metasedimentary rocks of the Outokumpu Deep Drill Hole. In: Kukkonen, I. (ed.) Outokumpu Deep Drilling Project 2003 –2010. Geological Survey of Finland, Special Paper 51, 47–62. Available at: http://tupa.gtk.fi/julkaisu/specialpaper/sp_051_pages_047_062.pdf

Hölttä, P., Huhma, H., Lahaye, Y., Mänttäri, I., Lukkari, S. & O'Brien, O. 2020. Paleoproterozoic metamorphism in the northern Fennoscandian Shield: age constraints revealed by monazite. International Geology Review 62:3, 360–387. DOI:10.1080/00206814.2019.1611488

Hölttä, P., Väisänen, M., Väänänen, J. & Manninen, T. 2007. Paleoproterozoic metamorphism and deformation in Central Lapland Finland. In: Ojala, J. (ed.) Gold in the Central Lapland Greenstone Belt. Geological Survey of Finland, Special Paper 44, 7–56. Available at: http://tupa.gtk.fi/julkaisu/specialpaper/sp_044_pages_007_056.pdf

Irvine, R., Annesley, C. & Madore, P. P. 2005. Geology and thermotectonic evolution of the western margin of the Trans-Hudson Orogen: Evidence from the eastern sub-Athabasca basement, Saskatchewan March 2005. Canadian Journal of Earth Sciences 42(4), 573–597. DOI: 10.1139/e05-034

IUGS-CGI GeoSciML. Available at: https://cgi-iugs.org/project/geosciml/ [Accessed 19.05.2020]

Kärenlampi, K., Kontinen, A., Huhma, H. & Hanski, E. 2019. Geology, geochronology and geochemistry of the 2.05 Ga gneissic A1-type granites and related intermediate rocks in central Finland: implication for the tectonic evolution of the Karelia craton margin. Bulletin of the Geological Society of Finland, Vol. 91, 35–73. Available at: https://doi.org/10.17741/bgsf/91.1.002

Kärki, A., Laajoki, K. & Luukas, J. 1993. Major Palaeoproterozoic shear zones of the central Fennoscandian Shield. Precambrian Research 64, 207–223.

Kohonen, J. 1995. From continental rifting to collisional shortening – Paleoproterozoic Kaleva metasediments of the Höytiäinen area in North Karelia, Finland. Geological Survey of Finland, Bulletin 380. 79 p. Available at: https://tupa.gtk.fi/julkaisu/bulletin/bt_380.pdf

Kohonen, J., Elo, S. & Paananen, M. 2019. Geophysical and geological modelling of the Sotkuma gneiss dome; Implications for the relationships of the Archean basement and the Paleoproterozoic cover in North Karelia, Eastern Finland. Bull. Geol. Soc. Finland, Volume 91 (1–2), 199–219.

Kohonen, J., Lahtinen, R., Luukas, J. & Nironen, M. 2021. Classification of regional-scale tectonic map units in Finland. In: Kohonen, J. & Tarvainen, T. (eds) Developments in map data management and geological unit nomenclature in Finland. Geological Survey of Finland, Bulletin 412. (this volume). Available at: https://doi.org/10.30440/bt412.2

Koistinen, T. 1981. Structural evolution of an early Proterozoic stratabound Cu-Co-Zn deposit, Outokumpu, Finland. Transactions of the Royal Society of Edinburgh: earth sciences, vol. 72, 2, 115–158.

Koistinen, T. 1993. Heinäveden kartta-alueen kallioperä. Summary: Pre-Quaternary Rocks of the Heinävesi Map-Sheet area. Geological Map of Finland 1: 100 000, Explanation to the Maps pf Pre-Quaternary Rocks, sheet 4221. Geological Survey of Finland. 64 p. (in Finnish with English summary). Available at: https://tupa.gtk.fi/kartta/kallioperakartta100/kps_4221.pdf

Kontinen, A. 1981. Kittilän vihreäkivialueen itäreunalla Nolppiossa sijaitsevan pienehkön serpentiinipahkun petrografia ja petrologia. Pro gradu, Helsingin yliopisto, Geologian laitos. (in Finnish)

Kontinen, A. 1986. Early Proterozoic stratigraphy and sedimentation in the Hyrynsalmi area, eastern Finland. In: Sokolov, V. A. & Heiskanen, K. I. (eds) Early Proterozoic of the Baltic Shield: proceedings of the Finnish Soviet symposium held in Petrozavodsk 19th 27th august, 1985, 75–103.

Kontinen, A. 1987. An early Proterozoic ophiolite – the Jormua mafic-ultramafic complex, northeastern Finland. In: Gaál, G. & Gorbatschev, R. (eds) Precambrian Geology and Evolution of the Central Baltic Shield. Special Issue. Precambrian Research 35, 313–341

Kontinen, A. 1989. Hyrynsalmi. Geological Map of Finland 1:100 000, Pre-Quaternary Rocks, Sheet 3443. Geological Survey of Finland. Available at: https://tupa.gtk.fi/kartta/kallioperakartta100/kp_3443.pdf

Kontinen, A. 1992. Southern part of the Kainuu Schist Belt – a brief indroduction to the general geological setting and excursion stops. In: Laajoki, K. & Tuisku, P. (eds) Excursion guide to Kainuu and Kuhmo 29 August – 1 September. Metamorphism, deformation and structure of the crust, Oulu, Finland, 26–28 August 1991. Res Terrae, Ser. A, 7, 34–46. (in Finnish)

Kontinen, A. & Hanski, E. 2015. The Talvivaara Black Shale-Hosted Ni-Zn-Cu-Co Deposit in Eastern Finland. In: Maier, W., Lahtinen, R. & O'Brien, H. (eds) Mineral Deposits of Finland. Amsterdam: Elsevier. Available at: https://doi.org/10.1016/B978-0-12-410438-9.00022-4

Kontinen, A., Peltonen, P. & Huhma, H. 2006. Description and genetic modelling of the Outokumpu-type rock assemblage and associated sulphide deposits. Geological Survey of Finland, archive report M 10.4/2006/1. 378 p. Available at: http://tupa.gtk.fi/raportti/arkisto/m10_4_2006_1.pdf

Korkiakoski, E. A. & Laajoki, K. 1988. The Palaeosedimentology of the early Proterozoic Salahmi Schist Belt, central Finland. In: Laajoki, K. & Paakkola, J. (eds) Sedimentology of the Precambrian formations in eastern and northern Finland: Proceedings of IGCP 160 Symposium at Oulu, January 21-22, 1986. Geological Survey of Finland, Special Paper 5, 49–73. Available at: http://tupa.gtk.fi/julkaisu/specialpaper/sp_005_pages_049_073.pdf

Korja, A., Kosunen, P. & Heikkinen, P. 2009. A case study of lateral spreading: the Precambrian Svecofennian Orogen. Geol. Soc. London, Special Publ. 321 (1), 225–251. Available at: http://dx.doi.org/10.1144/SP321.11

Korja, A., Lahtinen, R., Heikkinen, P., Kukkonen, I. & FIRE Working Group 2006. A geological interpretation of the upper crust along FIRE 1. In: Kukkonen, I. T. & Lahtinen, R. (eds) Finnish Reflection Experiment FIRE 2001–2005. Geological Survey of Finland, Special Paper 43, 45–76. Available at: http://tupa.gtk.fi/julkaisu/specialpaper/sp_043_pages_045_076.pdf

Korsman, K., Koistinen, T., Kohonen, J., Wennerström, M., Ekdahl, E., Honkamo, M., Idman, H. & Pekkala, Y. (eds) 1997. Suomen kallioperäkartta – Berggrundskarta över Finland – Bedrock map of Finland 1:1 000 000. Espoo: Geological Survey of Finland.

Korsman, K., Korja, T., Pajunen, M., Virransalo, P. & GGT/SVEKA, W. G. 1999. TheGGT/SVEKA transect: structure and evolution of the continental crust in the Paleoproterozoic Svecofennian Orogen in Finland. Int. Geol. Rev. 41 (4), 287–333.

Korsman, K., Niemelä, R. & Wasenius, P. 1988. Multistage evolution of the Proterozoic crust in the Savo schist belt, eastern Finland. In: Korsman, K. (ed.) Tectono-metamorphic evolution of the Raahe-Ladoga zone, eastern Finland. Geological Survey Finland, Bulletin 343, 89–96. Available at: https://tupa.gtk.fi/julkaisu/bulletin/bt_343.pdf

Kousa, J. & Luukas, J. 2007. Piippolan ja Rantsilan kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of the Piippola and Rantsila map-sheet areas. Geological Map of Finland 1:100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheets 3411 and 3412. Geological Survey of Finland. 70 p. Available at: https://tupa.gtk.fi/kartta/kallioperakartta100/kps_3411_3412.pdf

Köykkä, J., Lahtinen, R. & Huhma, H. 2019. Provenance evolution of the Paleoprote-rozoic metasedimentary cover sequences in northern Fennoscandia: Age distribution, geochemistry, and zircon morphology. Precambrian Research 331, 105364. Available at: https://doi.org/10.1016/j.precamres.2019.105364

Kukkonen, I. T. & Lahtinen, R. (eds) 2006. Finnish Reflection Experiment FIRE 2001–2005. Geological Survey of Finland, Special Paper 43. 247 p., 15 apps. Available at: https://tupa.gtk.fi/julkaisu/specialpaper/sp_043.pdf

Kumpulainen, R. A. (ed.) 2017. Guide for geological nomenclature in Sweden. GFF, Vol.139, No.1, 3–20. Available at: http://dx.doi.org/10.1080/11035897.2016.1178666

Laajoki, K. 1991. Stratigraphy of the northern end of the early Proterozoic (Karelian) Kainuu Schist Belt and associated gneiss complexes, Finland. Geological Survey of Finland, Bulletin 358. 105 p. Available at: https://tupa.gtk.fi/julkaisu/bulletin/bt_358.pdf

Laajoki, K. 2005. Karelian supracrustal rocks. In: Lehtinen, M., Nurmi, P. & Rämö, T. (eds) The Precambrian Bedrock of Finland – Key to the Evolution of the Fennoscandian Shield. Elsevier Science B.V., 279–342.

Laajoki, K. & Luukas, J. 1988. Early Proterozoic stratigraphy of the Salahmi–Pyhäntä area, central Finland, with an emphasis on applying the principles of lithodemic stratigraphy to a complexly deformed and metamorphosed bedrock. Bulletin of the Geological Society of Finland 60 (2), 79–106. Available at: https://www.geologinenseura.fi/sites/geologinenseura.fi/files/sgs_bt_060_2_pages_079_106.pdf

Lahtinen, R. 1994. Crustal evolution of the Svecofennian and Karelian domains during 2.1–1.79 Ga, with special emphasis on the geochemistry and origin of1.93–1.91 Ga gneissic tonalites and associated supracrustal rocks in the Rautalampi area, central Finland. Geological Society of Finland, Bulletin 378. 128 p. Available at: http://tupa.gtk.fi/julkaisu/bulletin/bt_378.pdf

Lahtinen, R. & Huhma, H. 2019. A revised geodynamic model for the Lapland-Kola orogen. *Precambrian Research* 330, 1–19. Available at: https://doi.org/10.1016/j.precamres.2019.04.022

Lahtinen, R. & Köykkä, J. 2020. Multiply deformed Paleoproterozoic foreland fold and thrust belt in northern Fennoscandia – the peripheral Kuusamo belt as a key example. Precambrian Research 346. Available at: https://doi.org/10.1016/j.precamres.2020.105825

Lahtinen, R., Huhma, H., Lahaye, Y., Jonsson, E., Manninen, T. Lauri, L., Bergman, S., Hellstöm, F., Niiranen, T. & Nironen, M. 2015a. New geochronological and Sm–Nd constraints across the Pajala shear zone of northern Fennoscandia: Reactivation of a Paleoproterozoic suture. Precambrian Research 256, 102–119.

Lahtinen, R., Huhma, H., Lahaye, Y., Kousa, J. & Luukas, J. 2015b. Archean-Proterozoic collision boundary in central Fennoscandia: Revisited. Precambrian Research, 261, 127–165.

Lahtinen, R., Huhma, H., Lauri, L. S. & Sayab, M. 2019. Geochemical and U-Pb and Sm-Nd isotopic constraints on the evolution of the Paleoproterozoic Ylitornio nappe complex, northern Fennoscandia. Bull. of the Geo. Soc. of Finland, Published online 21 January 2019, 31–56.

Lahtinen, R., Huhma, H., Sayab, M., Lauri, L. S. & Hölttä, P. 2018. Age and structural constraints on the tectonic evolution of the Paleoproterozoic Central Lapland Granitoid Complex in the Fennoscandian Shield. Tectonophysics 745, 305–325. Available at: https://doi.org/10.1016/j.tecto.2018.08.016

Lahtinen, R., Korja, A. & Nironen, M. 2005. Paleoproterozoic tectonic evolution of the Fennoscandian Shield. In: Lehtinen, M., Nurmi, P. & Rämö, T. (eds) The Precambrian Bedrock of Finland – Key to the Evolution of the Fennoscandian Shield. Amsterdam: Elsevier Science B.V., 418–532.

Lehtonen, M., Airo, M.-L., Eilu, P., Hanski, E., Kortelainen, V., Lanne, E., Manninen, T., Rastas, P., Räsänen, J. & Virransalo, P. 1998. Kittilän vihreäkivialueen geologia: Lapin vulkaniittiprojektin raportti. Summary: The stratigraphy, petrology and geochemistry of the Kittilä greenstone area, northern Finland: a report of the Lapland Volcanite Project. Geological Survey of Finland, Report of Investigation 140. 144 p. Available at: http://tupa.gtk.fi/julkaisu/tutkimusraportti/tr_140.pdf

Lehtonen, M. I., Kujala, H., Kärkkäinen, N., Lehtonen, A., Mäkitie, H., Mänttäri, I., Virransalo, P. & Vuokko, J. 2005. Etelä-Pohjanmaan liuskealueen kallioperä. Summary: Pre-Quaternary rocks of the South Ostrobothnian Schist Belt. Geological Survey of Finland, Report of Investigation 158. 125 p. Available at: http://tupa.gtk.fi/julkaisu/tutkimusraportti/tr_158.pdf

Lehtovaara, J. J. 1989. Tectonostratigraphic position of the Finnish Caledonides at the Fennoscandian margin of the northern Scandes. Bull. Geol. Soc. Finland 61, Part 2, 189–195. Available at: https://doi.org/10.17741/bgsf/61.2.004

Lehtovaara, J. J. 1995. Kilpisjärven ja Haltin kartta-alueiden kallioperä. Summary: Pre-Quaternary rocks of the Kilpisjärvi and Halti map-sheet areas. Geological map of Finland 1:100 000, Explanation to the maps of Pre-Quaternary rocks, Sheets 1823 and 1842. Geological Survey of Finland. 64 p. (in Finnish with English summary). Available at: https://tupa.gtk.fi/kartta/kallioperakartta100/kps_1823_1842.pdf

Lewry, J. F., Hajnal, Z., Green, A., Lucas, S. B., White, D., Stauffer, M. R., Ashton, K.E., Weber, W. & Clowes, R. 1994. Structure of a Palaeoproterozoic continent-continent collision zone; a Lithoprobe seismic reflection profile across the Trans-Hudson Orogen, Canada. Tectonophysics, 232, 143–160.

Luth, S., Jönsson, C., Jönberger, J., Grigull, S., Berggren, R., van Assema, B., Smoor, W. & Djuly, T. 2018. The Pajala Deformation Belt in northeast Sweden: Structural geological mapping and 3D modelling around Pajala. In: Bergman, S. (ed.) Geology of the Northern Norrbotten ore province, northern Sweden. Sveriges geologiska undersökning, Rapporter och Meddelanden 141, 259–285.

Luukas, J. 1991. Salahmin–Pyhännän alueen stratigrafia ja rakennegeologia. Abstract: Stratigraphy and structure of the Early Proterozoic Salahmi–Pyhäntä area, central Finland. University of Oulu, Res Terrae B 16. 131 p

Luukas, J., Kousa, J., Nironen, M. & Vuollo, J. 2017. Major stratigraphic units in the bedrock of Finland, and an approach to tectonostratigraphic division. In: Nironen, M. (ed.) Bedrock of Finland at the scale 1:1 000 000 – Major stratigraphic units, metamorphism and tectonic evolution. Geological Survey of Finland, Special Paper 60, 9-40. Available at: http://tupa.gtk.fi/julkaisu/specialpaper/sp_060_pages_009_040.pdf

McClay, K. R. 1992. Glossary of thrust tectonics terms. In: McClay, K. R. (ed.) Thrust tectonics. London: Chapman & Hall, 419–433.

Mikkola, P., Hölttä, P. & Käpyaho, A. (eds) 2018. Development of the Paleoproterozoic Svecofennian orogeny: new constraints from the southeastern boundary of the Central Finland Granitoid Complex. Geological Survey of Finland, Bulletin 407. 221 p. Available at: https://tupa.gtk.fi/julkaisu/bulletin/bt_407.pdf

NACSN, North American Comission on Stratigraphic Nomenclature, 2005. North American Stratigraphic Code. AAPG Bulletin 89 (11), 1547–1591.

NCS, Norwegian Committee on Stratigraphy, 1989. Rules and recommendations for naming geological units in Norway. Norsk Geologisk Tiddskrift, Vol. 69, Supplement 2, 1–107.

Neuendorf, K. K. E, Mehl, J. P. & Jackson, J. A. (eds) 2005. Glossary of geology. 5thEdition. Alexandria: American Geological Institute. 779 p.

Nikkilä, K., Korja, A., Koyi, H. & Eklund, O. 2015. Analog modeling of oneway gravitational spreading of hot orogens – A case study from the Svecofennian orogen, Fennoscandian Shield. Precambrian Research 268, 135–152.

Nironen, M. 1997. Nironen, M., 1997. The Svecofennian Orogen: a tectonic model. Precambrian Res. 86, 21–44 The Svecofennian Orogen: a tectonic model. Precambrian Res. 86, 21–44. Available at: http://dx.doi.org/10.1016/S0301-9268(97)00039-9

Nironen, M. 2017. Guide to the Geological Map of Finland – Bedrock 1:1 000 000. In: Nironen, M. (ed.) Bedrock of Finland at the scale 1:1 000 000 – Major stratigraphic units, metamorphism and tectonic evolution. Geological Survey of Finland, Special Paper 60, 41–76. Available at: http://tupa.gtk.fi/julkaisu/specialpaper/sp_060_pages_041_076.pdf

Nironen, M., Kousa, J., Luukas, J. & Lahtinen, R. (eds) 2016. Geological Map of Finland – Bedrock 1:1 000 000. Espoo: Geological Survey of Finland. Available at: https://tupa.gtk.fi/kartta/erikoiskartta/ek_097_300dpi.pdf

Paavola, J. 1980. Nilsiä. Geological Map of Finland 1:100 000, Pre-Quaternary Rocks, Sheet 3334. Geological Survey of Finland. Available at: https://tupa.gtk.fi/kartta/kallioperakartta100/kp_3334.pdf

Paavola, J. 1984. Nilsiän kartta-alueen kallioperä. Summary: Pre-Quaternary Rocks of the Nilsiä Map-Sheet area. Geological Map of Finland 1:100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheet 3334. Geological Survey of Finland. 62 p. Available at: https://tupa.gtk.fi/kartta/kallioperakartta100/kps_3334.pdf

Paavola, J. 2005. Ylä-Luosta. Geological Map of Finland 1:100 000, Pre-Quaternary Rocks, Sheet 4312. Geological Survey of Finland. Available at: https://tupa.gtk.fi/kartta/kallioperakartta100/kp_4312_.pdf

Pajunen, M., Airo, M.-L., Elminen, T., Mänttäri, I., Niemelä, R., Vaarma, M., Wasenius, P. & Wennerström, M. 2008. Tectonic evolution of the Svecofennian crust in southern Finland. In: Pajunen, M. (ed.) Tectonic evolution of the Svecofennian crust in southern Finland – a basis for characterizing bedrock technical properties. Geological Survey of Finland, Special Paper 47, 15–160. Available at: http://tupa.gtk.fi/julkaisu/specialpaper/sp_047_pages_015_160.pdf

Park, A. F. & Doody, J. J. 1991. Structural styles in the deep levels of an Early Proterozoic foreland thrust belt. In: Lewry, J. F. & Stauffer, M. R. (eds) The Early Proterozoic Trans-Hudson Orogen of North America. Geological Association of Canada, Special Paper 37, 465–482.

Park, A. F., Bowes, D. R., Halden, N. M. & Koistinen, T. J. 1984. Tectonic evolution at an early Proterozoic continental margin: the Svecokarelides of eastern Finland. Journal of Geodynamics 1, 359–386. Available at: https://doi.org/10.1016/0264-3707(84)90016-4

Patison, N. L., Korja, A., Lahtinen, R., Ojala, V. J. & FIRE Working Group 2006. FIRE seismic reflection profiles 4, 4A and 4B: Insights into the Crustal Structure of Northern Finland from Ranua to Näätämö. In: Kukkonen, I. T. & Lahtinen, R. (eds) Finnish Reflection Experiment FIRE 2001-2005. Geological Survey of Finland, Special Paper 43, 161–222. Available at: http://tupa.gtk.fi/julkaisu/specialpaper/sp_043_pages_161_222.pdf

Peltonen, P. 2005. Ophiolites. In: Lehtinen, M., Nurmi, P. & Rämö, T. (eds) The Precambrian Bedrock of Finland – Key to the Evolution of the Fennoscandian Shield. Elsevier Science B.V., 237–278.

Perttunen, V. 1991. Kemin, Karungin, Simon ja Runkauksen kartta-alueiden kallioperä. Summary: Pre-Quaternary Rocks of the Kemi, Karunki, Simo and Runkaus Map-Sheet areas. Geological Map of Finland 1:100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheets 2541, 2542,2524, 2543, 2544. Geological Survey of Finland. 82 p. Available at: https://tupa.gtk.fi/kartta/kallioperakartta100/kps_2541_2542_2524_2543_2544.pdf

Perttunen, V. & Hanski, E. 2003. Törmäsjärven ja Koivun kartta-alueiden kallioperä. Summary: Pre-Quaternary Rocks of the Törmäsjärvi and Koivu Map-Sheet areas. Geological Map of Finland 1:100 000, Explanation to the Maps of Pre-Quaternary Rocks, Sheets 2631 and 2633. Geological Survey of Finland. 92 p. Available at: https://tupa.gtk.fi/kartta/kallioperakartta100/kps_2631_2633.pdf

Pietikäinen, P. & Vaasjoki, M. 1999. Structural observations and U-Pb mineral ages from igneous rocks at the Archaean-Palaeoproterozoic boundary in the Salahmi Schist Belt, central Finland: constraints on tectonic evolution. Bulletin of the Geological Society of Finland 71, Part 1, 133–142. Available at: https://doi.org/10.17741/bgsf/71.1.006

Piippo, S., Skyttä, P. & Kloppenburg, A. 2019. Linkage of crustal deformation between the Archaean basement and the Proterozoic cover in the Perapohja Area, northern Fennoscandia. Precambrian Research 324, 285–302. Available at: https://doi.org/10.1016/j.precamres.2019.02.003

Pipping, F. & Vaarma, M. 1993. Kyyjärvi. Geological Map of Finland 1:100 000, Pre-Quaternary Rocks, Sheet 2331. Geological Survey of Finland. Available at: http://tupa.gtk.fi/kartta/kallioperakartta100/kp_2331.pdf

Poblet, J. & Lisle, R. J. 2011. Kinematic evolution and structural styles of fold-and-thrust belts. Geological Society, Special Publications 349, 1–24.

Roberts, D. 2003. The Scandinavian Caledonides: event chronology, palaeogeographic settings and likely modern analogues. Tectonophysics 365, 283–299. Available at: https://doi.org/10.1016/S0040-1951(03)00026-X

Salvador, A. 1994. International Stratigraphic Guide: A Guide to Stratigraphic Classification, terminology and Procedure. 2nd edition. GSA publication No. IUG001. 220 p.

Säntti, J., Kontinen, A., Sorjonen-Ward, P., Johanson, B. & Pakkanen, L. 2006. Metamorphism and Chromite in Serpentinized and Carbonate-Silica–Altered Peridotites of the Paleoproterozoic Outokumpu-Jormua Ophiolite Belt, Eastern Finland. International Geology Review, Vol. 48, 494–546.

Sayab, M., Molnár, F., Aerden, D, Niiranen, T., Kuva, J. & Välimaa, J. 2019. A succession of near-orthogonal horizontal tectonic shortenings in the Paleoproterozoic Central Lapland Greenstone Belt of Fennoscandia: constraints from the world-class Suurikuusikko gold deposit. Mineralium Deposita. Available at: https://doi.org/10.1007/s00126-019-00910-7

Schmidt, C. J. & Perry, W. J. (eds) 1988. Interaction of the Rocky Mountain Foreland and the Cordilleran Thrust Belt. Geological Society of America Memoir 171. 582 p.

Skyttä, P., Piippo, S., Kloppenburg, A. & Giacomo Corti, G. 2019. 2. 45 Ga break-up of the Archaean continent in Northern Fennoscandia: Rifting dynamics and the role of inherited structures within the Archaean basement. Precambrian Research 324, 303–323. Available at: https://doi.org/10.1016/j.precamres.2019.02.004

Skyttä, P., Väisänen, M. & Mänttäri, I. 2006. Preservation of Palaeoproterozoic early Svecofennian structures in the Orijärvi area, SW Finland – Evidence for polyphase strain partitioning. Precambrian Research 150, 153–172.

Sorjonen-Ward, P. 2006. Geological and structural framework and preliminary interpretation of the FIRE 3 and FIRE 3A reflection seismic profiles, Central Finland. In: Kukkonen, I. T. & Lahtinen, R. (eds) FIRE Finnish Reflection Experiment 2001–2005. Geological Survey of Finland, Special Paper 43, 105–159. Available at: http://tupa.gtk.fi/julkaisu/specialpaper/sp_043_pages_105_159.pdf

Sorjonen-Ward, P. & Luukkonen, E. 2005. Archean rocks. In: Lehtinen, M., Nurmi, P. A. & Rämö, O. T. (eds) The Precambrian Geology of Finland - Key to the Evolution of the Fennoscandian Shield. Amsterdam: Elsevier, 19-99.

Strand, K., Köykkä, J. & Kohonen, J. (eds) 2010. Guidelines and procedures for naming Precambrian geological units in Finland. 2010 Edition Stratigraphic Commission of Finland: Precambrian Sub-Commission. Geological Survey of Finland, Guide 55. 41 p. Available at: https://tupa.gtk.fi/julkaisu/opas/op_055.pdf

Torvela, T. & Ehlers, C. 2010. From ductile to brittle deformation: the structural development of and strain distribution along a crustal-scale shear zone in SW Finland. Int J Earth Sci (Geol Rundsch) (2010) 99, 1133–1152. DOI:10.1007/s00531-009-0451-3

Tuisku, P., Mikkola, P. & Huhma, H. 2006. Evolution of Migmatitic Granulite Complexes: Implications from Lapland Granulite Belt, Part I: Metamorphic geology. Bull. Geol. Soc. Finland 78, 71–105.

Väisänen, M. & Hölttä, P. 1999. Structural and metamorphic evolution of the Turku migmatite complex, southwestern Finland. Bull. Geol. Soc. Finland 71, 177–218.

Väisänen, M. & Skyttä, P. 2007. Late Svecofennian shear zones in southwestern Finland. GFF, Vol. 129, 55–64.

Väyrynen, H. 1939. On the geology and tectonics of the Outokumpu ore field and region. Bull. Comm. Geol. Finlande 124. 91 p. Available at: https://tupa.gtk.fi/julkaisu/bulletin/bt_124.pdf

Ward, P. 1987. Early Proterozoic deposition and deformation at the Karelian cratonmargin in southeastern Finland. Precambrian Res. 35, 71–93.

Ward, P. & Kohonen, J. 1989. Structural provinces and style in the Proterozoic of North Karelia: preliminary correlations and discussion. In: Autio, S. (ed.) Geological Survey of Finland, Current Research 1988. Geological Survey of Finland, Special Paper 10, 23–29. Available at: http://tupa.gtk.fi/julkaisu/specialpaper/sp_010_pages_023_029.pdf

Wegmann, C. E. 1928. Über die Tektonik die jüngeren Faltung in Ostfinnland. Fennia, 50 (16).

Woodard, J., Tuisku, P., Kärki, A., Lahaye Y., Majka J., Huhma, H. & Whitehouse, M. J. 2017. Zircon and monazite geochronology of deformation in the Pielavesi Shear Zone, Finland: multistage evolution of the Archaean – Proterozoic boundary in the Fennoscandian Shield. Journal of the Geological Society, Vol. 174, 255–267. Available at: https://doi.org/1