Continental growth by accretion: A tectonostratigraphic terrane analysis of the evolution of the western and central Baltic Shield, 2.50 to 1.75 Ga

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ABSTRACT

Tectonostratigraphic terrane analysis of the western and central Baltic Shield defines a framework for continental growth through the period 2.50–1.75 Ga. Eight discrete terranes can be defined in this part of the Svecokarelian orogen: the older cratonic Kuhmo and Iisalmi terranes, the hybrid Lapland and Savo province allochthonous terranes, the juvenile island-arc-like Skellefte-Savonlinna and south Finland–central Sweden terranes, the back-arc or arc-like Outokumpu nappe, and the ophiolitic (oceanic?) Jormua nappe. Stitching events can also be recognized. These include the ca. 1.88–1.87 Ga Svionian magmatic arc, the ca. 2.44 Ga Koillismaa intrusions, the Kalevian flysch basin, and the Bothnian basin. Constraining the age of these stitching events permits the construction of an accretion history in which the "Svecokarelian orogeny" can be resolved as a number of accretion events, deformation episodes related to accretion or magmato-tectonic episodes. These events, defined here, include the pre-2.44 Ga Pohjolan accretion of the component parts of the Lapland hybrid terrane, the ca. 1.95 Ga Kyllikian accretion of the Karelian collage, the ca. 1.90 Ga Karelian orogeny marked by the development of the Savo thrust belt in response to the accretion of the Skellefte-Savonlinna terrane to the Karelian collage, and the ca. 1.88–1.87 Ga Svionian magmatic arc. The whole Svecokarelian collage had assembled by ca. 1.85 Ga, an amalgamation succeeded and stitched by a diverse collection of igneous and thermal events through the period 1.85–1.75 Ga.

INTRODUCTION

The Early Proterozoic orogens of North America, Greenland, and the Baltic Shield contain evidence of major accretion of new, and major reworking of older, continental crust (Fig. 1; Patchett and Arndt, 1986; Hoffman, 1988). These belts contain some of the oldest evidence for the operation of plate-tectonic processes, for example, the oldest known ophiolite complexes (Kontinen, 1987; Schulz, 1987; St. Onge and Lucas, 1988). Tectonostratigraphic terrane accretion is a predictable consequence of convergent plate margin processes (compare with Jones and others, 1983; Howell and others, 1985), and the discipline of tectonostratigraphic terrane analysis imposes a rigor on the description and interpretation of Precambrian orogenic belts and the processes of continent building (compare with Hoffman, 1988). The discipline involves the definition of terranes as blocks of crust containing coherent evolutionary histories separated by tectonic boundaries. Crucially, the juxtaposing of such blocks cannot be achieved without at least one being allochthonous with regard to the other for all or part of the time interval being considered. In calling a relationship "allochthonous," however, no *a priori* assumption is made as to whether terranes are "exotic" or "suspect"; all that is acknowledged is the tectonic nature of their boundaries.

Within terranes, the recognition of the products of plate-tectonic processes permits the original tectonic settings to be elucidated. The advent of high-resolution geochronology permits the construction of realistic time scales. Accretion and stitching in an evolving collage produces hybrid terranes. It therefore follows that in defining a terrane, both spatial and temporal factors must be considered. The identification and precise dating of stitching events permits the construction of an accretion history of progressive terrane interaction.

Tectonostratigraphic terrane analysis of Phanerozoic mobile belts challenges many of the simplistic geometric solutions offered for the evolution of Precambrian shield areas. It is not feasible to infer plate geometries merely by identifying "Wilson cycles" or "cryptic sutures," "calc-alkaline belts," and "ophiolites." The present configuration of terranes may bear little or no relationship to their relative positions at the time of their formation. Such analysis requires detailed mapping of stratigraphic and structural relationships within and between terranes, and that geochemical and geochronological data be well constrained.

In applying the principles of tectonostratigraphic terrane analysis to the western Baltic Shield (Figs. 2a and 2b), this contribution is acknowledging that this Precambrian shield is particularly well known, in that much of it has been the subject of detailed mapping. The Karelides especially have been the subject of detailed structural analysis for more than 60 yr, beginning with the pioneering work of Wegmann (1928) and Väyrynen (1939), which constituted the first application of Alpine tectonic principles to a Precambrian orogenic belt. Detailed stratigraphic information is available over a large part of the Baltic Shield, presenting the opportunity, for example, to apply geochemical techniques aimed at determining geotectonic settings for igneous rocks, in a well-constrained temporal framework (compare with Pharaoh and Brewer, 1990, and references therein).

DEFINITION OF THE SVECOKARELIAN COLLAGE

Traditionally, the geologic subdivisions of the western Baltic Shield have been resolved as distinct Precambrian belts, defined by the age of lithologies, deformation, and plutonic activity (Eskola, 1963, compare with Gaál and Gorbatschev, 1987). These belts are arranged around the Archean nucleus of the Kola Peninsula, becoming younger to the southwest (Fig. 2a). The Karelides (compare with Eskola, 1963) thus contain Archean rocks with an Early Proterozoic supracrustal cover, deformed and intruded by granitoids through the period 1.95–1.85 Ga, broadly coeval with the Svecofennian belt, which contains no Archean basement

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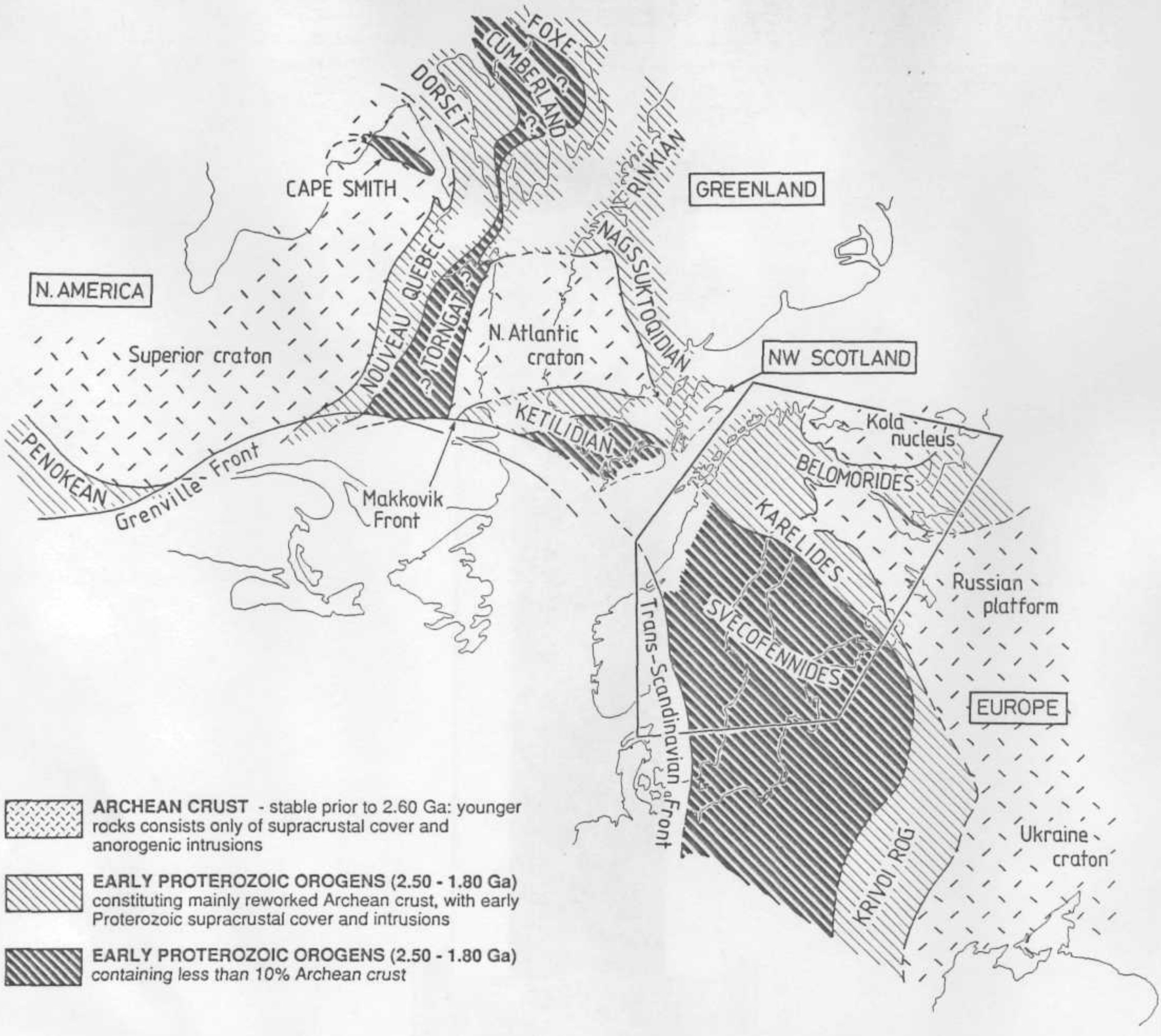

Figure 1. Reconstruction of the mid-Proterozoic supercontinent fragments around the North Atlantic region to illustrate the continuity of Early Proterozoic (2.50–1.80 Ga) orogenic belts (after Patchett and Arndt, 1986; Hoffman, 1988).

(Huhma, 1986; Patchett and Kouvo, 1986). The Trans-Scandinavian or Pre-Gothian belt, with deformation and igneous events in the period 1.75–1.65 Ga, flanks it to the west, whereas farther west still, lies the Gothian belt, deformed and the site of plutonic activity between 1.2 and 0.8 Ga (Figs. 1, 2a, and 2b).

East of the Trans-Scandinavian front, it is now apparent that the entire exposed shield area has been affected by events between ca. 2.50 and 1.85 Ga, of differing types and to varying degrees. Barbey and others (1984) and Gaál and Gorbatschev (1987) correctly challenged the traditional spatial definition of a "Svecokarelian orogeny" as being an event affecting only the Karelides and Svecofennides. The whole of the shield east of the Trans-Scandinavian front has been affected by events during the 2.0–1.85 Ga interval, reflecting the assembling and readjustment of a collage of disparate terranes during this period. Thus the term "Svecokarelian collage," as used here, refers to the entire central, northern, and eastern Baltic Shield and could even be applied to the entire shield area east of the Trans-Scandinavian front.

Throughout what follows, stratigraphic nomenclature is that in use in Finland and the Soviet Union (summarized, with all the terms used herein, in Fig. 3). Some of the correlations with Sweden are tentative and, where they are used without radiometric calibration, are identified as such. The following tectonostratigraphic analysis will be confined to the area between the Trans-Scandinavian and Belomorian fronts (Figs. 1, 2a, and 2b), and reviews of these structures, particularly the latter, and their significance are found in Berthelsen and Marker (1986a) and Gaál (1990); they are not considered in detail herein. Geochronological data quoted herein

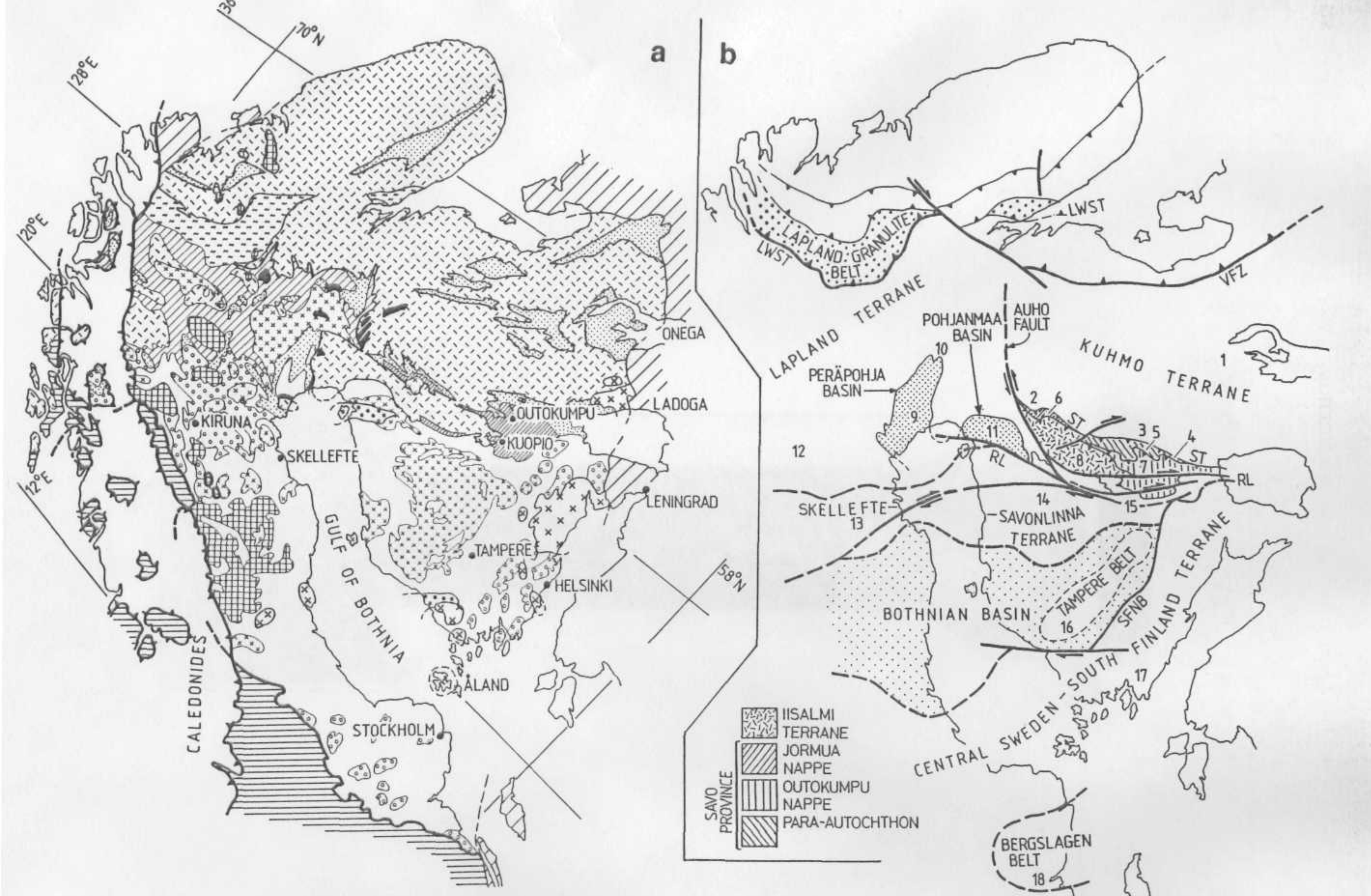

Figure 2. a. Geologic map of the Baltic Shield. b. Terrane map of the Baltic Shield; for definition of terranes and their boundaries, see text. Numbers (1–13) indicate localities for the stratigraphic columns in Figure 3.

FIGURE 2 LEGEND

- Archean gneisses, granitoids, greenstones: pre-2.60 Ga
- Lapponian supracrustal rocks (2.60 - 2.40 Ga)
- Lapponian layered mafic intrusions (Koillismaa suite, c. 2.44 Ga)
- Karelian supracrustal rocks (2.40 - 2.00 Ga, Sariolan and Jatulian)
- Lapland granulites (2.10 - 1.90 Ga)
- Kalevian supracrustal rocks (c. 1.95 Ga)
- Bothnian supracrustal rocks and related intruisions (1.95 - c. 1.87 Ga)
- 1.89 - 1.87 Ga granitoids and related intrusions (Svionian)
- 1.83 Ga granites (late tectonic)
- Post-tectonic granitoids (1.80 - 1.77 Ga)
- Post-orogenic sediments (Jotnian, post-1.70 Ga)
- Rapakivi granite suite (anorogenic, 1.70 - 1.60 Ga)
- Trans-Scandinavian orogen (1.70 - 1.60 Ga)
- Late Proterozoic and Phanerozoic cover

are, where available, U-Pb zircon results and either concordant or discordant upper intercept ages with errors less than ±10 m.y. (compare with Huhma, 1986; Skiöld, 1988). Older data (for example, Marmo and others, 1966; Kouvo and Tilton, 1966) are less precise and are cited, with suitable qualification, when nothing else is available. When the results of other methods are cited, they are identified.

DEFINITION OF THE TECTONOSTRATIGRAPHIC TERRANES

The traditional subdivisions of the Early Proterozoic belts in the central Baltic Shield into Karelides and Svecofennides will be followed herein, with the justification that they reflect two principal groups of terranes, those with and those without Archean components (Figs. 1, 2a, 2b, 3; compare with Berthelsen and Marker, 1986a; Gaál and Gorbatschev, 1987; Gaál, 1990). These two groups are separated by the Raahe-Ladoga lineament in Finland, and its approximate projection into northern Sweden. Stratigraphic nomenclature is that recommended by Meriläinen (1980), Silvennoinen and others (1980), Witschard (1984), Silvennoinen (1985), and Sokolov and Heiskanen (1985), and all terms used are summarized in Figure 3 (for discussion of the correlation and nomenclature problems, see Laajoki, 1986).

Kuhmo Terrane

The Kuhmo terrane comprises an Archean crystalline complex with supracrustal greenstone belts, forming the basement to an autochthonous Early Proterozoic sedimentary/volcanic assemblage occupying a number of discrete but related basins. The western, southern, and eastern boundaries of this terrane are well constrained, the northern one less so (Fig. 2b). They are, respectively, the Suhmura thrust–Auho fault and the Belomorian front (or Lapland–White Sea thrust zone and Vetrenny fault zone; Berthelsen and Marker, 1986a, 1986b; Laajoki, 1986; Gaál and Gorbatschev, 1987; Gaál, 1990). The northern boundary with the Lapland terrane is poorly defined and may be the continuation of the Auho fault where it is obscured by the Lapland batholith. Early Proterozoic metamorphism is restricted to the western and southern margins, where it rapidly passes from sub-greenschist to upper amphibolite facies. Coeval deformation is largely localized in the same areas.

The Archean basement complex is a granitoid-greenstone-gneiss assemblage from which the oldest U-Pb zircon ages lie in the range 2.7–2.9 Ga (Luukkonen, 1985; Luukkonen and Lukkarinen, 1986). Sm-Nd studies suggest the absence of a pre-3.0 Ga inheritance overall, although Huhma (1987) reported detrital zircons in one greenstone belt that are older than this. The Archean evolution in the Kuhmo terrane ended with the emplacement of post-tectonic granitoids in the age range 2.7–2.6 Ga (Kouvo and Tilton, 1966; Huhma, 1986; compare with Fig. 3, columns 1, 2, and 3).

A major hiatus followed end-Archean stabilization, and no rocks ascribed to the Lapponian (2.6–2.45 Ga) are recorded (Luukkonen and Lukkarinen, 1986; Laajoki, 1986). Instead, the period saw the establishment of a planar surface with some fault-bounded relief. The first sediments deposited on this sub-Karelian surface were rudites and poorly sorted arenites of the Sariolan lithofacies, the lowest subdivision of the Karelian Supergroup. They are terrestrial sediments laid down on a well-defined weathering crust, in most cases a residual regolith with locally preserved paleosol. Mafic volcanic rocks are sporadically developed, and a glaciogenic formation is also known (Marmo and Ojakangas, 1984). In the Finnish part of the Kuhmo terrane, two depocenters for Sariolan sediments are recognized, one in the Kainuu area, the other to the south in Finnish Karelia. Two more are known in Soviet Karelia (Sumi-Sarioli of Onega), where the uppermost part of the Sariolan Group includes marine lithofacies (Sokolov and Heiskanen, 1985, and references therein).

Cover rocks of the Jatulian Group constitute the thickest and most diverse sequence on this terrane. They overlie a regional unconformity throughout the Kuhmo terrane, with the lowest members being rudaceous and poorly sorted arenites, overlying a weathering crust where they overstep Sariolan sediments onto Archean basement. Most of the Jatulian succession consists of thick deposits of pure orthoquartzites and sericitic quartzites. Mafic volcanites are widespread and locally very thick (especially in the Onega area, Figs. 2a and 3, column 1). Within the Kuhmo terrane, this arenitic sequence passes upward into marine phyllites and turbiditic sandstones with carbonates. Along the western margin in Finnish Karelia, this marine transgression is both vertical and lateral, reflecting marine incursion onto the continental shelf and the presence in the west of a true continental margin at this time. Along this western margin, depocenters are recognized in Kainuu and Finnish Karelia (Ward, 1987). A similar history of marine transgression and distal-proximal facies relationships is preserved around Onega, relating to a second margin lying to the northeast of the present Vetrenny fault zone (Sokolov and others, 1970). Mafic volcanic activity is associated with a major dike swarm emplaced all across this terrane.

Another terrane-wide unconformity underlies the uppermost supracrustal unit, the Kalevian Group. Traditionally, the Kalevian metasediments have been included in the Karelian Supergroup, but Silvennoinen and others (1980) and Luukkonen and Lukkarinen (1986) included them in the Svecofennian Supergroup, correlating them with the lower Bothnian Group west of the Raahe-Ladoga lineament.

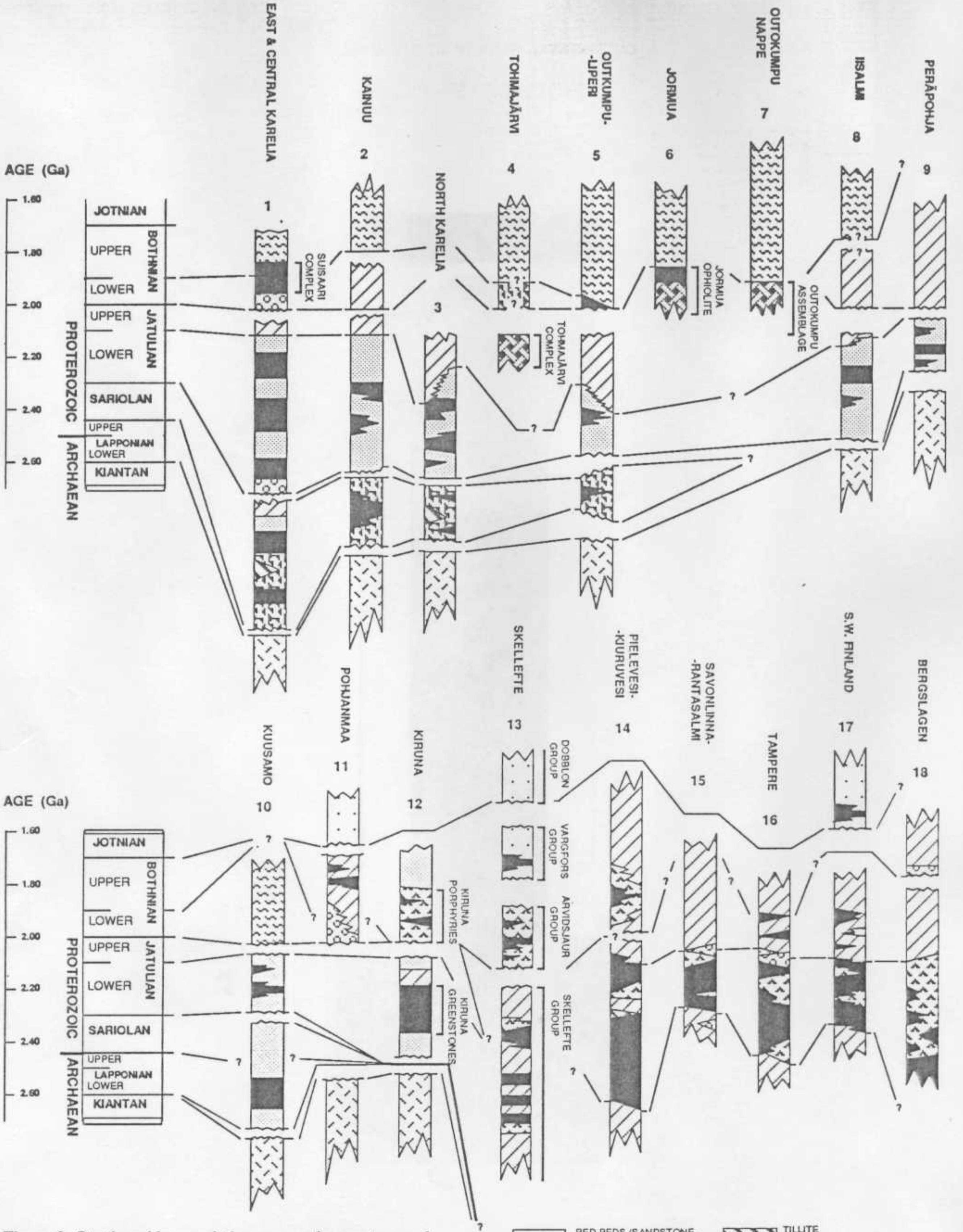

Figure 3. Stratigraphic correlation across the western and central Baltic Shield; data from Sokolov and others (1970), Lundqvist (1979), Lundberg (1980), Meriläinen (1980), Kröner and others (1981), Silvennoinen and others (1981), Hopgood and others (1983), Claesson (1985), Sokolov and Heiskanen (1985), Huhma (1986), Laajoki (1986), Luukkonen and Lukkarinen (1986), Skiöld (1986, 1987, 1988), Kontinen (1987), Oen (1987), Patchett and others (1987), and Ward (1987). Locations for 1–13 are shown in Figure 2b.

The lower Kalevian Group consists of marine turbidites and quartz arenites with rudites of local provenance, laid down in fault-bounded depressions on the sub-Kalevian unconformity. Paleoregoliths are locally preserved where Kalevian rocks overstep onto the Archean basement complex. The upper Kalevian consists of a thick sequence of monotonous psammites and pelites, referred to as the "Kalevian flysch." On the western and northern Kuhmo terrane, no volcanic rocks are reported in the Kalevian sequence, but the volcanic Suisaari complex, in the east, may be coeval (Fig. 3, column 1). A lower Kalevian depocenter has been recognized in Kainuu, but none is seen in Finnish Karelia, where no Kalevian rocks are recognized east of the Suhmura thrust (Ward, 1987).

Deformation of the supracrustal rocks appears to be largely related to the development of the Savo thrust belt (Park and Doody, 1990), the timing of which is constrained by a late tectonic granite emplaced between 1.89 and 1.86 Ga (Huhma, 1981, 1986). Post-tectonic granite emplacement continued in the southern part of the western margin of this terrane until 1.83–1.82 Ga, and small bodies, including gabbros, were intruded as late as 1.79 Ga (Huhma, 1986).

Lapland Terrane

Taken as a whole, the Lapland terrane is the least well defined west of the Belomorian front, and its boundaries are largely tentative (Figs. 2b and 3, columns 9, 10, and 11). This terrane consists of a fragmented older Archean crystalline complex embedded among greenstone belts. Above this, an unconformable supracrustal cover sequence laid down through Late Archean and Early Proterozoic time is intruded by a major suite of layered mafic igneous bodies. Mapping over much of Finnish Lapland is largely of a reconnaissance nature, and stratigraphic analysis is often provisional. In northern Sweden, a quite sophisticated stratigraphy has been erected (Fig. 3, columns 12 and 13), but outside the Skellefte-Arvidsjaur area, this is poorly calibrated radiometrically (Lundqvist, 1979; Lundberg, 1980; Wilson and others, 1985).

Boundaries, such as they can be constrained, are, in the north and west, the Paleozoic Caledonian front and, in the east, the Belomorian front (Berthelsen and Marker, 1986a, 1986b). In the south, they include the northern margin of the Skellefte belt beneath the volcanic rocks of the Arvidsjaur Group, the Raahe-Ladoga lineament south of the Pohjanmaa basin, and the Auho fault zone (Laajoki, 1986).

Archean rocks underlie the whole province, but crop out only around the perimeter. U-Pb zircon ages in excess of 3.1 Ga have been reported in the east (Kröner and others, 1981), and the Archean basement generally appears to have stabilized by 2.6 Ga. In the Finnish sector, the supracrustal cover of the Archean basement is largely of Lapponian age (2.6–2.45 Ga). Supracrustal rocks of the Karelian Supergroup are effectively restricted to the Peräpohja and Pohjanmaa basins, with smaller areas known in the east and north.

The Lapponian supracrustal rocks consist of greenstones of both basaltic and komatiitic affinities (Saverikko and others, 1985; Silvennoinen, 1985; Sjöstrand and others, 1986), with sediments ranging from rudites at the base, through quartzites and banded ironstones, to minor carbonates and pelites toward the top. Volcanic and volcaniclastic rocks dominate, many displaying hyaloclastic features consistent with eruption in shallow water (Saverikko and others, 1985).

A suite of layered mafic intrusions is emplaced here; one coherent group, the fragmented Koillismaa complex, occurs from the Swedish border on the Gulf of Bothnia into Soviet Karelia (Fig. 2a). They were emplaced at or just beneath the sub-Lapponian unconformity around 2.44 Ga (Alapieti, 1982; Huhma, 1986). To the north, the Koitelainen gabbro complex is of approximately the same age (Silvennoinen and others, 1980).

In Swedish and Norwegian Lapland, the extent of Lapponian supracrustal rocks is uncertain. The Kiruna greenstones yield a Sm-Nd mineral age of 1.932 ± 35 Ga (Skiöld and Cliff, 1984; Skiöld, 1986), implying a Svecofennian Supergroup correlation. The underlying quartzites resemble Jatulian lithofacies, and they rest unconformably on the Archean basement complex. Similar lithofacies with similar relationships exist in the Finnmark windows (Lundqvist, 1979; Lundberg, 1980; Witschard, 1984). The same situation pertains to Karelian Supergroup rocks throughout Lapland. Quartzites and metabasites with Jatulian aspect unconformably overlie Lapponian supracrustal rocks in the Kuusamo area, but elsewhere identification is tentative.

Svecofennian Supergroup rocks are more readily identified. The Kiruna greenstones and the sediment fill with mafic volcanites in the Peräpohja and Pohjanmaa basins are all assigned by geochronology or lithofacies correlation, and all are intruded by the ca. 1.90–1.85 Ga granites of the Haparanda suite and its equivalents, including the bulk of the Lapland batholith and the granites of the Jörn suite near Skellefte. These granites are post- or late tectonic with respect to the deformation in the Svecofennian Supergroup. In the Skellefte area, a major unconformity is cut by these ca. 1.88–1.87 Ga granites, and the Jörn granite is regarded as contemporaneous with the overlying volcanic rocks of the Arvidsjaur Group (Wilson and others, 1985, 1987), which are in turn correlated with the Kiruna porphyries (Pharaoh and Brewer, 1990).

Again, in northern Sweden, a series of unconformities and granite intrusion events are recognized. The Vargfors Group of conglomerates, sandstones, and basalts unconformably overlies the Jörn granites and the Arvidsjaur Group volcanites. Events close with the deposition of the Dobblon Group (1.803 Ga, Skiöld, 1988), which is in turn intruded by the Sorsele granitoids at 1.71 Ga. This last phase is related to Trans-Scandinavian activity, the principal locus of which lies farther west.

A thermal event is evident ca. 1.80–1.79 Ga, which led to massive reactivation, by partial melting, of the Archean basement. The Lina (Vettasjärvi) granite in Sweden is a typical product of this event; other remobilized granitoids may be present in the Lapland batholith (Wilson and others, 1985; Huhma, 1986; Öhlander and others, 1987; Skiöld, 1988). A suite of perthitic granites and syenites was emplaced across much the same area ca. 1.80 Ga (Witschard, 1984). Field relationships indicate that most of the deformation preceded the emplacement of these plutons (Berthelsen and Marker, 1986a, 1986b).

Little if any of this igneous activity is recorded in Finnish Lapland, where the emplacement of the Nattanen-type alkali granites ca. 1.77 Ga is the last phase of Early to Middle Proterozoic activity (Huhma, 1986; Haapala and others, 1987).

Iisalmi Terrane

The Iisalmi terrane, the allochthonous nature of which was recognized by Väyrynen (1939), consists predominantly of Archean crystalline basement with Early Proterozoic supracrustal cover. The Iisalmi terrane is bounded in the north by the Auho fault, to the west and south by the Raahe-Ladoga lineament, and to the east by the Savo suture, within the Savo thrust belt (Figs. 2b and 3, column 8; Koistinen, 1988; Park, 1988).

The rocks of the Archean basement complex record a protracted and unusual history, not seen in any other piece of Archean basement west of the Belomorian front. Tonalitic neosomes have yielded zircons with a U-Pb age of 3.1 Ga (Paavola, 1986), and subsequently a thermal climax reached granulite facies at ca. 2.7 Ga, producing the only Archean granulites west of the Belomorian front (Paavola, 1984, 1986). Few Archean supracrustal rocks are known, and they are clastic metasediments rather than greenstones. Archean activity ended with the emplacement of the oldest dated and one of the largest carbonatites known (2.54 Ga; Puustinen, 1971; Patchett and others, 1981).

No Lapponian supracrustal rocks are known from this terrane, and Sariolan sediments are only tentatively recognized (Laajoki, 1986; Luukkonen and Lukkarinen, 1986), but metaquartzites and mafic metavolcanites with carbonates and phyllites are preserved around Kuopio and as tectonic slivers in the basement to the north. Also in the Kuopio area are mica schists and psammites correlated with the Kalevian Group, similar rocks being known along the western margin (Marttila, 1976).

A peculiar Jatulian development is present west of Kajaani. Here, the Jatulian gabbros that host the vanadiferous magnetite deposit of Otanmäki are cut by an A-type granite with rare-element pegmatites, dated at 2.05 Ga (Marmo and others, 1966). Despite the large error on his date (±150 m.y.), field relations support the interpretation and make this the only Jatulian granitoid known. A Jatulian dike swarm is also present throughout this terrane.

Svecokarelian deformation is largely associated with the Savo thrust belt, a large part of the terrane being contained within it (Park, 1988). The Kajaani granite is late or post-kinematic with respect to this feature, and it intruded the Iisalmi terrane prior to 1.85 Ga (Rb-Sr muscovite, Kouvo and Tilton, 1966). Age of deformation is likewise constrained by the emplacement of the Maarianvaara granite (see below) to ca. 1.90 Ga.

In the south, deformation continued, related to the shear zones in the Raahe-Ladoga lineament, for much longer. Emplacement of some of the ca. 1.88–1.87 Ga granitoids in the Kuopio area was clearly related to wrench movements here, and subsequently further movements disrupted these same granites.

Terranes in the Savo Province

The Savo province (compare with Ward, 1987; Park, 1988) contains at least three distinct terranes. It is bounded in the west by the Savo suture, and in the east by the Suhmura thrust zone (Figs. 2b; 3, columns 5, 6, and 7; 4; and 5). In the south, it is circumscribed by the Kotalahti nickel belt within the Raahe-Ladoga lineament (south and southeast of Kuopio). The whole province is contained within, and is disrupted by, the Savo thrust belt. The three terranes defined here are (i) the Outokumpu nappe, (ii) the Jormua nappe, and (iii) the parautochthonous Savo province. This last terrane may be hybrid.

The parautochthon is the only part of the Savo province carrying Archean basement. These granodioritic gneisses resemble those of the Kuhmo terrane and like them have no older Sm-Nd isotopic inheritance. Huhma (1986) dated their crystallization at 2.7 Ga.

No Lapponian or Sariolan sediments are recognized, and the Archean rocks are overlain directly by a heterogenous Jatulian succession. In the north, this consists of the familiar orthoquartzites and basaltic volcanic rocks, passing upward into phyllites with minor carbonates. Near Outokumpu, although quartzites and metabasites are present, they are a minor component in a succession dominated by rudites, arkosites, calc-arkosites, and sericitic quartzites. In the southern part of this terrane, the Jatulian succession ends with a sulfidic black schist with gabbro bodies (Saksela, 1923). Jatulian rocks are overlain directly by the upper Kalevian flysch, the lower part of which carries extensive black schists.

In the southernmost part of the parautochthon, Jatulian sediments are absent, and the Kalevian sediments rest on the Tohmajärvi volcanic complex (Hackman, 1933; Nykanen, 1967). This consists of tholeiitic basalts, spilitic pillow lavas, and doleritic intrusions interlayered with metacherts and black schists. Huhma (1986) has obtained a 2.1 Ga age (U-Pb zircon) from these lavas, implying a Jatulian age for the complex, with no older Sm-Nd inheritance.

In both the Jormua and Outokumpu nappes, not only are Archean rocks absent, but no Lapponian, Sariolan, or Jatulian formations are recorded. In each nappe/terrane, Kalevian flysch (upper Kalevian) rests directly on a post-Archean basement. In the Jormua nappe, depositional basement is the volcanic layer of the Jormua ophiolite; in the Outokumpu nappe, it is the metasediments and meta-igneous rocks of the Outokumpu assemblage. These basal formations are the same age (1.96–1.97 Ga; Kontinen, 1987; Huhma, 1986), and both contain ophiolitic lithologies (that is, pillow basalts, metacherts, gabbro, and serpentinized ultramafic rocks), but only the Jormua complex has an internal stratigraphy consistent with generation at a spreading ridge (crucially the presence of a sheeted dike complex). The Jormua basalts have a truly MORB chemistry, whereas the basalts in the Outokumpu assemblage are derived from a more depleted source, suggesting intra-arc or back-arc affinities (see review in Park, 1988).

Deformation and metamorphism of the Savo province are largely related to the development of the Savo thrust belt, and their timing is constrained by the age of the late to post-tectonic Maarianvaara granite (north of Outokumpu, 1.89–1.86 Ga, Huhma, 1986). Along the northern margin, deformation related to the Suvasvesi-Savonranta shear zone, part of the Raahe-Ladoga lineament, continued until at least 1.79 Ga, marked by disruption of 1.83 and 1.79 Ga granitoids (Halden, 1982). Although peak metamorphic conditions had passed in the north by 1.89–1.86 Ga, and retrogression was well advanced by 1.86 Ga (Rb-Sr muscovite, van Breemen and Bowes, 1977), heating continued south of Outokumpu, where the Kermajärvi migmatites west of Outokumpu formed ca. 1.87 Ga (Huhma, 1986), and retrogression was not truly underway until 1.83–1.82 Ga (K-Ar biotite, Korsman and others, 1984).

Skellefte-Savonlinna Terrane

The Skellefte-Savonlinna terrane forms disconnected outcrops along the traditional boundary of the Karelides and Svecofennides, contained largely within the Raahe-Ladoga lineament (Figs. 2b and 3, columns 13, 14, and 15), and the boundaries with the Kuhmo, Iisalmi, and Savo province terranes to the east are in many cases the various shear zones of this lineament. Lower Bothnian assemblages with similar lithologies and histories occur elsewhere in the Svecofennides and may represent basement of the whole province. In Sweden, it is defined rather more loosely as that part of the Skellefte province lying stratigraphically beneath the unconformable base of the Arvidsjaur Group. The boundary here with the Lapland terrane lies beneath the volcanites of the Arvidsjaur Group, and its nature is unknown. To the south, rocks of this terrane pass transitionally (apparently) into the thick turbidite succession of the Bothnian basin.

Like all of the Svecofennian terranes south of the Raahe-Ladoga lineament, this one contains no Archean basement, or evidence of substantial Archean provenance in its metasedimentary or volcanic rocks. The oldest rocks recognized are the mafic to felsic volcanites and graywackes of the Lower Skellefte group (>2.20 Ga). These are overlain by the mafic to ultramafic volcanites of the Middle Skellefte group (2.20–1.93 Ga; Claesson, 1985; Skiöld, 1987), the probable equivalent of the oldest Svecofennian supracrustal rocks in Finland, the graywackes and mafic (locally ultramafic) volcanites of the lower Bothnian Group at Pielavesi, Kiuruvesi, and Savonlinna (Fig. 3, columns 13, 14, and 15). This lower Bothnian Group is intruded by the now-foliated tonalites, trondhjemites, and layered gabbro-diorites, the ages of which fall in the range 1.93–1.90 Ga (Huhma, 1986; Sakko and Vaasjoki, 1988). At Savonlinna, the oldest graywackes include the Savonlinna conglomerate, the granitic and mangeritic clasts of which indicate the existence of a pre–1.90 Ga crystalline basement, not, so far, identified *in situ* (Gaál and Rauhamäki, 1971; Luukkonen and Lukkarinen, 1986).

The metamorphic grade in the Skellefte area is from greenschist to amphibolite facies, but in Finland, much of this older complex is recrystallized in granulite facies. This thermal event seems to be coeval with the emplacement of a suite of gabbros and granodioritic plutons, in many cases with a charnockitic character, between 1.89 and 1.87 Ga (Aho, 1979; Korsman and others, 1984). Skellefte represents a higher level, where the 1.88–1.87 Ga granitoids of the Jörn suite are regarded as sub-volcanic and related to the volcanites of the Arvidsjaur Group (Wilson and others, 1985). Such high-level relationships are tentatively identified in Finland, where Luukkonen and Lukkarinen (1986) ascribed some mafic-felsic volcanites and graywackes to the upper Bothnian Group, lying unconformably on the older complex recognized by Marttila (1976) at Kiuruvesi (Figs. 2b and 3, column 14). Whether these formations are the equivalent of the Arvidsjaur Group is an unproven possibility. Likewise, their relationship to the ca. 1.88–1.87 Ga granitoids is equivocal.

A very similar lithostratigraphy is preserved in the Tampere belt (Figs. 2a, 2b, and 3, column 16). No ages are available, although the whole assemblage appears to underlie the Bothnian schists, and along the northern margin of this belt, it is intruded by the southern members of the central Finnish batholith, emplaced ca. 1.88–1.87 Ga. This volcanic complex (Kähkönen, 1987) may be the equivalent of the lower Bothnian volcanic sequence to the north, and it is suggested here that the Tampere belt is the southernmost outcrop of the Skellefte-Savonlinna terrane.

South Finland–Central Sweden Terrane

The northern boundary of the south Finland–central Sweden terrane is the southern Finnish nickel belt; the other exposed boundary is the Trans-Scandinavian front. To the south, this terrane runs under Phanerozoic cover (Figs. 2a, 2b, and 3, columns 17 and 18).

Again, no Archean basement is evident here, and no significant Archean contamination is seen in granitoids, whereas only a limited (less than 15%) Archean contribution is evident in the metasediments (Huhma, 1986, 1987; Patchett and others, 1987). The oldest rocks are metasediments dominated by graywackes, some of volcanogenic type, including the felsic leptites. These are intruded by a suite of gabbros, tonalites, and trondhjemites dated in the range 1.95–1.90 Ga, including the "primorogenic granitoids" of the Bergslagen region, the oldest gabbros of Skåldö, and the gabbro-tonalite-trondhjemite suite at Kalanti (Arth and others, 1978; Oen and others, 1982; Hopgood and others, 1983; Huhma, 1986; Patchett and Kouvo, 1986). In Sweden, these early intrusions were emplaced continuously until 1.86 Ga, whereas in Finland, the syn-kinematic granitoids appear to be more concentrated in the interval 1.87–1.86 Ga (Nurmi and Haapala, 1986; Front and Nurmi, 1987).

The timing of deformation and metamorphism appears to reflect what may be a subdivision within this terrane. Outside the Bergslagen area, this reached a peak contemporary with the 1.87–1.86 Ga granites (Oen, 1987). In Bergslagen, syn-kinematic ("sero-orogenic") granites are dated ca. 1.84 Ga, and here sedimentation and volcanism may have proceeded until ca. 1.86 Ga. Late kinematic granites (1.84–1.83 Ga) in Finland postdate most of the deformation and form a coherent belt from the Åland Islands into the Soviet Union (Nurmi and Haapala, 1986; Front and Nurmi, 1987). Here, the final stages of magmatism are marked by a series of small, S-type, post-kinematic granites, forming high-level stocks with such features as explosion breccias and ring dikes (Ehlers and Bergman, 1984; Hubbard and Branigan, 1987). Their ages fall in the period 1.80–1.79 Ga (Front and Nurmi, 1987). A final phase of granite emplacement, represented by the Stockholm batholith, occurred between 1.80 and 1.77 Ga, contemporary with the Revsund granitoids to the north (Patchett and others, 1987).

The Finnish part of this terrane contains a series of late thermal domes marked by an isobaric transition from amphibolite to granulite facies (Korsman and others, 1984; Westra and Scheurs, 1985; Hölttä, 1986). Korsman and others (1984) dated migmatites in the Sulkava dome, south of Savonlinna, at 1.83 Ga, and the hypersthene-in isograd mapped by Westra and Scheurs (1985) cuts the D_2 structures in west Uusimaa, suggesting that this feature is contemporaneous with or slightly later than the 1.83 Ga late kinematic granitoids hereabouts.

Much of the deformation in this segment of this terrane appears to relate to a crustal megashear, producing the *en echelon* lozenge pattern of the supracrustal belts and infracrustal massifs, particularly the early granitoids and migmatites (ca. 1.89–1.87 Ga, Scheurs and Westra, 1986). This megashear may relate to the emplacement of basic bodies at depth below the thermal domes (coincident with large positive Bouguer anomalies, Bouguer anomaly map of Finland, 1973), and possibly to the emplacement mechanism of the post-orogenic rapakivi complexes (Westra and Scheurs, 1985). This raises the question of whether this is a separate terrane in the same sense as those defined above, or whether differences are due to the long-lived effects and related plutonism and metamorphism being superimposed on the southern part of an extended Skellefte-Savonlinna terrane. The Bergslagen segment contains a sufficiently different lithologic, stratigraphic, and igneous history to qualify as a possible distinct terrane; whether the bulk of the south Finland–central Sweden terrane could be so distinguished is less certain.

BOUNDARIES

Most terrane boundaries in the Baltic Shield correspond to major tectonic features, like the Raahe-Ladoga lineament or the Savo suture. Most also show evidence of complex evolution subsequent to terrane accretion. This is illustrated in the cartoons of Figure 4. The boundary between the Skellefte-Savonlinna terrane and the Lapland terrane in north Sweden is something of an exception, in that its position can be fixed quite accurately, but its nature is obscured, lying as it does beneath the volcanic rocks of the Arvidsjaur Group. Its position is determined by the presence or absence of an Archean inheritance in the 1.88–1.87 Ga plutons and volcanites. The Jörn complex, for instance, shows very little or no Archean inheritance (Wilson and others, 1987), unlike the granitoids of the Haparanda suite. Likewise, the later Lina (Vettasjärvi) granite shows a distinct Archean isotopic signature (Öhlander and others, 1987). The identification of this boundary here as a tectonic break is speculative (Fig. 4a) but is consistent with the models proposed by Wilson and others (1987; see also Berthelsen and Marker, 1986b; Skiöld and others, 1988).

The boundaries between the Skellefte-Savonlinna terrane and the Iisalmi terrane and those within the Savo province (Karelian collage) are more complex. These are illustrated schematically in Figures 4b and 4c and examined in more detail below.

Savo Thrust Belt

The Savo thrust belt can be traced from the Kainuu area, where it appears to terminate against the Auho fault, south to Lake Ladoga (Park, 1988). It was first described in outline, although not named, by Wegmann (1928). The geometry of the major movement planes, duplex structures, and subhorizontal shear zones around Outokumpu is outlined in Park and Doody (1990).

All through the central part of the belt (Outokumpu to Kajaani), movement was directed onto the Kuhmo block toward the east or northeast. This direction is maintained through the first two phases of deformation (D_1 and D_2 of Bowes and others, 1984) and, from lineations recorded in the Sotkamo area, near Kajaani (Havola, 1981), appears to be general.

From Outokumpu northward, the latest major horizontal movements (D_2 of Bowes and others, 1984) are coeval with or immediately

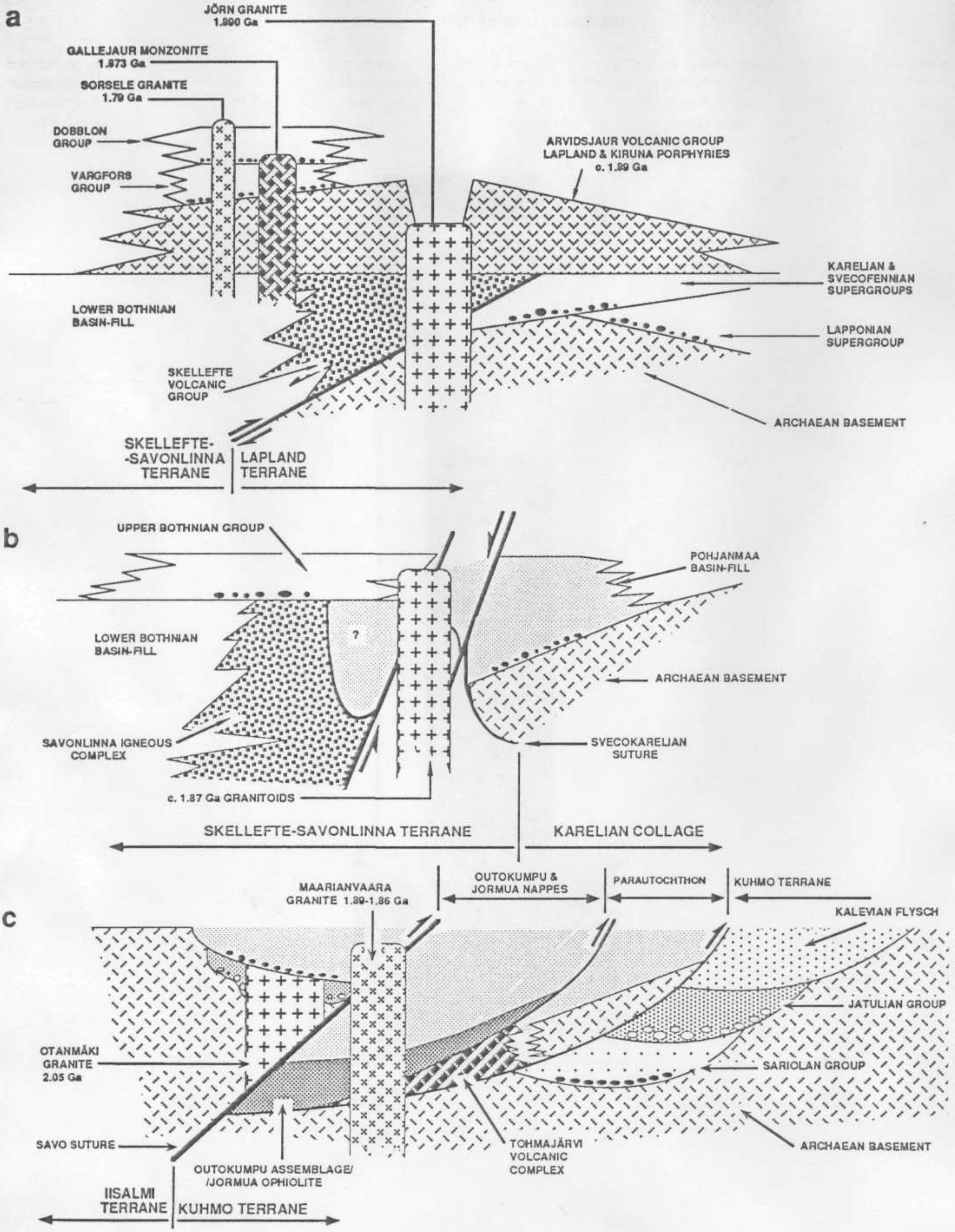

Figure 4. Cartoon of schematic terrane relationships, illustrating relationships of original docking boundaries to later tectonism and plutonism in (a) the Skellefte district, north Sweden, (b) the Kiuruvesi-Pohjanmaa area, Finland, and (c) the Karelian collage, eastern Finland.

predate peak metamorphic conditions. Although no major isograd inversions are evident across individual thrust planes, there is a general increase in grade across the Outokumpu region from epidote-amphibolite/greenschist facies in the northeast to granulite facies and migmatite-bearing amphibolite facies in the southwest adjacent to the Raahe-Ladoga lineament (Figs. 2a and 2b).

Two major granites, the Maarianvaara (north of Outokumpu) and Kajaani plutons, intrude the central part of this thrust belt. The early phases of the Maarianvaara pluton are syn-kinematic migmatites, but the massive, discordant, later granites dated at 1.89–1.86 Ga crosscut the thrusts (Huhma, 1981, 1986; Park, 1988). Deformation had ceased and metamorphic retrogression was underway by the time late Maarianvaara pegmatites and lamprophyre dikes were emplaced at 1.87 and 1.85–1.83 Ga, respectively (van Breemen and Bowes, 1977; Huhma, 1981). Timing of D_{1-2} deformation, when the major horizontal movements occurred, is effectively constrained to the period 1.95–1.90 Ga.

Raahe-Ladoga Lineament

The major Raahe-Ladoga lineament is a complex feature, marking the present boundary of the Karelides and Svecofennides, and is coincident with the southern edge of the Archean craton. It corresponds to a linear gravity anomaly that can be traced beyond Lake Ladoga, under the Phanerozoic cover of the Russian platform (Bouguer anomaly map of Finland, 1973). The history of movement along it is also complex, occurring in one form or another from 1.90 to 1.75 Ga, constrained by the age of the oldest deformed plutons and the youngest, crosscutting intrusions (Huhma, 1986; Vaasjoki and Sakko, 1988). The lineament is marked by a series of large shear zones, interpreted as the deep levels of wrench faults (Kahma, 1978; Halden, 1982). It is coincident with the boundaries between the Savo province, Kuhmo, Iisalmi, and Skellefte-Savonlinna terranes, and the various shear zones played a major part in disrupting the latter terrane (Figs. 4b and 4c). Its continuation under the Gulf of Bothnia into Sweden is necessarily speculative (see Laajoki, 1986; Berthelsen and Marker, 1986b), but the interpretation preferred here relates this lineament to a series of splays in northern Sweden and Pohjanmaa, of which the Auho fault is one (see Fig. 2b).

The Kotalahti nickel belt comprises a series of Cu-Ni sulfide–bearing, mafic to ultramafic intrusions that lie on or close to the boundary between the Karelides of the Savo province and the Svecofennides of the Skellefte-Savonlinna terrane. Several authors have used this juxtaposition as evidence for the existence of a cryptic suture along this line (Koistinen, 1981; Bowes, 1980; see Park, 1988). In detail, this boundary is well known, but poorly understood. The zone is one of steep, in many cases vertical structures lying between the northeast- or east-verging thrusts of the Savo thrust belt to the northeast and the southwest-verging structures recognized between Kuopio and Savonlinna (Gaál and Rauhamäki, 1971; Gaál, 1980). These southward-verging structures, including thrusts, can be constrained to have formed during, or later than, the granulite-facies metamorphism (ca. 1.89 Ga) because they bring granulite over retrogressed amphibolites, now greenschists, south of Kuopio (Korsman and Pääjärvi, 1980; L. Fernandes and T. Koistinen, 1987, personal commun.). They appear to be cut by some of the ca. 1.88–1.87 Ga granitoids (Gaál and Rauhamäki, 1971; Korsman and Pääjärvi, 1980). The nickeliferous gabbroids appear to be intruded into this vertical belt and into the cores of a series of later, tight upright folds (brachyantiforms of D_3, of Gaál and Rauhamäki, 1971; Gaál, 1980) related to dextral shear on the northwest-southeast shear zones. Huhma (1986) has dated one of the gabbroids at 1.88 Ga. The relationship of these gabbroids to the brachyantiforms implies a genetic link between them and the strike-slip movements, rather than to the coincident terrane boundary. Although some of the gabbros are spatially associated with pillow lavas, black schist, and ultramafic rocks (Koistinen, 1981; Grundström, 1980, 1985), the balance of evidence suggests that they are post-accretion intrusions rather than ophiolitic fragments of a vanished Svecokarelian ocean (Park, 1988). Later shear zones, like the Suvasvesi-Savonranta shear zone, evidently played a role in the emplacement of some of the ca. 1.88–1.87 Ga syn-kinematic granitoids and certainly disrupted them. Demonstrably, this shear zone contributed to the emplacement mechanism of 1.83 and 1.79 Ga granitoids (Halden, 1982). These same shear zones disrupt and modify the outcrop pattern of all earlier structures, including the original terrane boundaries, the original nature of which is completely obscured.

Southern Nickel Belt

The southern nickel belt is interpreted as the surface expression of several deep geophysical features (Bouguer anomaly map of Finland, 1973; Gaál, 1985; Hjelt, 1987). Gaál (1982) made the analogy with the Kotalahti nickel belt, and the nickel-bearing intrusions along it are very similar (see reviews in Papunen and Gorbunov, 1985). Again, however, they are intrusions into the zone, dated at 1.88–1.87 Ga. The Kylmäkoski belt of intrusions, to the west, may also be related to strike-slip dextral motion on a later northwest-southeast–trending shear zone.

On the surface, this boundary and the gravity and geoelectrical features are coincident with the northern edge of the granulite massifs at Sulkava, West Uusimaa, and the Turku area (Korsman and others, 1984; Scheurs and Westra, 1985; Westra and Scheurs, 1985). Korsman and others (1984) have modeled the Sulkava massif as a thermal dome, its formation being dated by a 1.83 Ga age on migmatites within it, and K-Ar mineral ages (biotite) date its thermal decay to between 1.80 and 1.76 Ga. The thermal maximum is coincident with the emplacement of the late kinematic granites (Front and Nurmi, 1987).

TECTONIC SETTING OF TERRANES

The Lapland, Kuhmo, and Iisalmi terranes and the parautochthon in the Savo province (in part) are continental terranes, insofar as each contains Archean basement and "miogeoclinal" sedimentary cover. The Kuhmo terrane contains a major ensialic basin (Onega), for which the record of repeated uplift, rifting, subsidence, and tholeiitic to alkaline volcanic activity bespeaks repeated ensialic basin formation through the period 2.6–2.0 Ga (Sariolan, Jatulian) related to the eastern margin. Along the western margin of the Kuhmo terrane, Kontinen (1987) and Ward (1987) interpreted the Sariolan-Jatulian succession as evidence for repeated basin formation, but related to a western continental-margin environment subjected to transtensional and transpressional uplift and subsidence. Within this history, transtension may have locally given way to spreading in rifted basins, the products of which are now preserved as the upper Jatulian Tohmajärvi volcanic complex in the parautochthon of the Savo province, and the lower Kalevian Jormua ophiolite in the Jormua nappe (Ward, 1987).

The Iisalmi terrane is more problematic, containing as it does such radically different Archean and Jatulian histories, both of which include the emplacement of strongly differentiated alkaline rocks (the Siilinjärvi carbonatite and Otanmäki granite). More problematic still is the Outokumpu assemblage, with its island-arc–back-arc basin chemical affinities. Both are candidates for exotic terranes.

The Lapland terrane is also problematic. The Lapponian history, with its development of greenstone belts separated by Archean gneiss massifs, suggests accretion of continental fragments separated by small oceanic basins. The whole hybrid mass appears to have achieved some coherence by the time the Koillismaa intrusions were emplaced at the end of the Lapponian. If this terrane is hybrid, it had accreted into its present form by 2.45 Ga. At which point this terrane was accreted to the Kuhmo terrane is

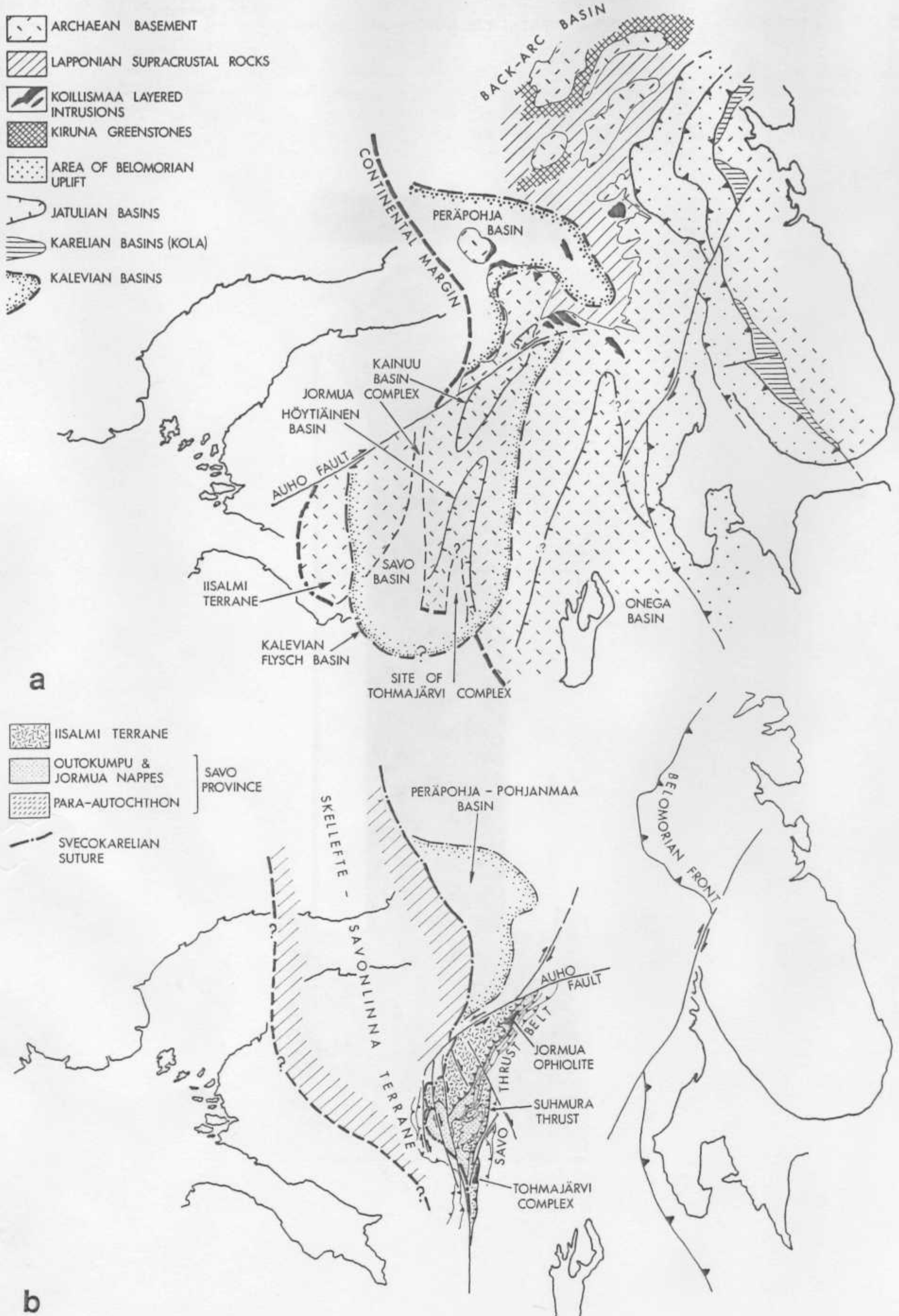

Figure 5. Cartoon maps illustrating the accretion of the Svecokarelian collage from 2.50 to 1.75 Ga; see Figure 6 and text for explanation. a. Kyllikian elements. b. Karelian orogeny. c. Svionian arc. d. Post-Karelian events.

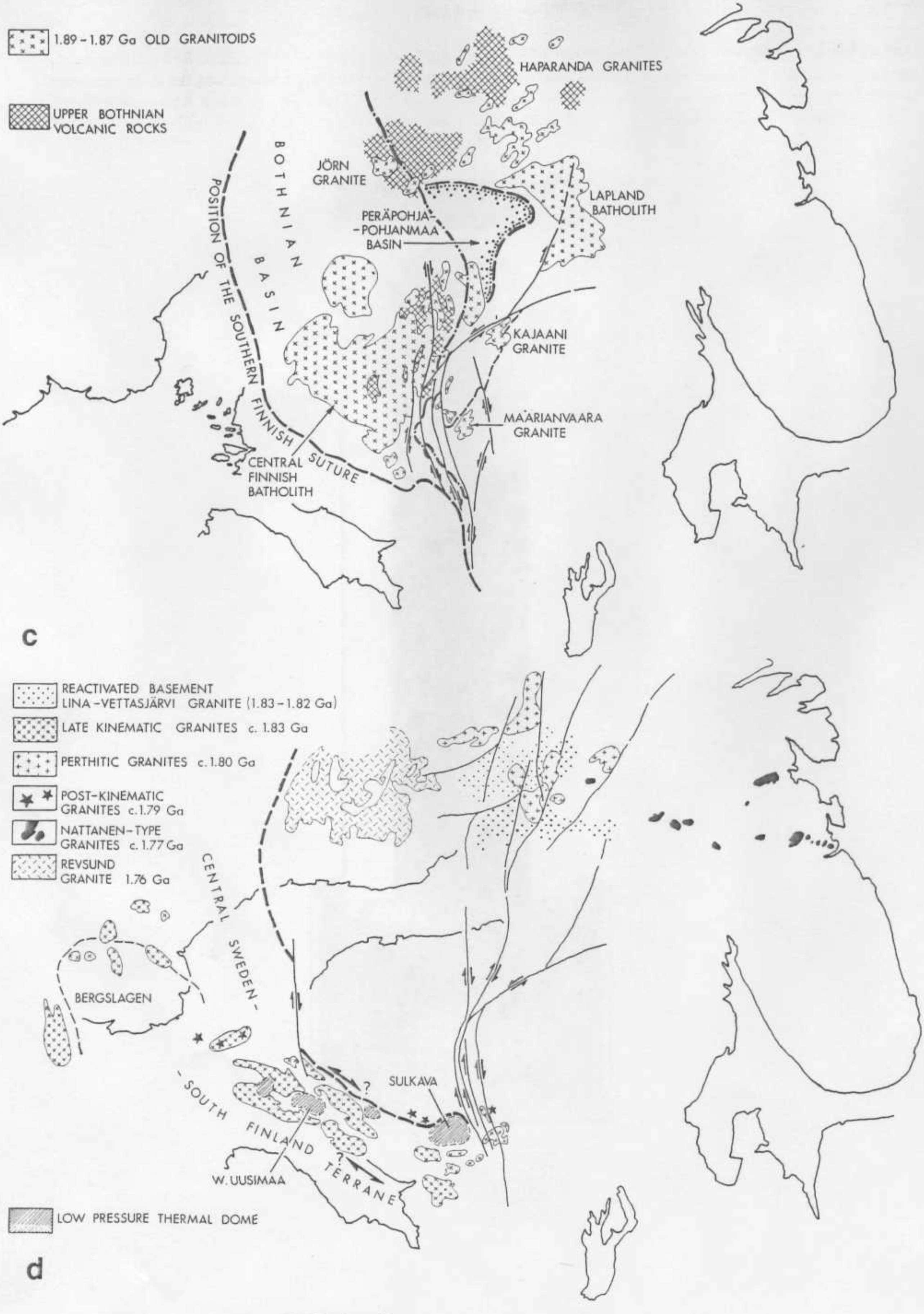

Figure 5. (*Continued*).

difficult to ascertain, depending as it does on the poorly defined relationship of the Auho fault to the Koillismaa intrusions.

The various Svecofennian terranes (Skellefte-Savonlinna, Bothnian, and south Finland–central Sweden) present rather more difficulties. The ca. 1.90 Ga volcanic rocks are of two types, either tholeiitic basalts with minor subalkalic and ultramafic types, or calc-alkaline types ranging from basalts to rhyolites. The Kiruna greenstones have a chemistry consistent with a back-arc setting (Pharaoh and Brewer, 1990), and the contemporary basalts and felsic-intermediate volcanites of the lower and middle Skellefte groups have more arc-like affinities (Claesson, 1985). Similar arc-like chemistry is recorded from the calc-alkaline volcanic belts at Tampere (Kähkönen, 1987), southwest Finland (Edelman and Jaanus-Järkkälä, 1983), and Bergslagen (Oen and others, 1982). Ocean-island or enriched MORB chemistries have been recorded from the tholeiitic- to subalkalic-basalt–dominated successions in the south Finland–central Sweden terrane (Ehlers and others, 1986). The possibility that all of the Svecofennian terranes are themselves hybrid must be entertained.

The ca. 1.88–1.87 Ga granitoids that occur all across the Svecokarelian collage, and their contemporary volcanic relatives, for example, the Arvidsjaur Group in north Sweden, present a very coherent picture. These granites are entirely I type, with morphological differences and radiometric- and stable-isotopic signatures ($^{87}Sr/^{86}Sr$, Pb-Pb, $^{18}O/^{16}O$) related directly to depth of emplacement and the nature of their host. Those north of Skellefte and the Raahe-Ladoga lineament carry an isotopic (U-Pb zircon, Pb-Pb, $^{87}Sr/^{86}Sr$, Sm-Nd) Archean signature; those in the Svecofennides do not (Wilson and others, 1985, 1987; Huhma, 1986; Skiöld, 1988). The volcanic rocks, like the Arvidsjaur Group and Lapland porphyries, have a consistent trace-element signature relating their calc-alkaline affinities to a subduction zone (Pharaoh and Brewer, 1990; Claesson, 1985). Likewise, the granite chemistry indicates a subduction mechanism for their generation. Although the trace-element signature and overall chemical affinity is very clear, no regional trends or spatial zonation related to subduction polarity is evident (Nurmi and Haapala, 1986; Front and Nurmi, 1987).

SUCCESSOR BASINS AND STITCHING EVENTS

Kalevian Flysch Basin

The upper Kalevian flysch accumulated on six discrete depositional basements: the ensialic Kuhmo terrane, the gneissic component of the parautochthon of the Savo province, the Iisalmi terrane, the relatively juvenile Tohmajärvi volcanic complex in the Savo province parautochthon, the Outokumpu assemblage in the Outokumpu nappe, and the Jormua ophiolite (Fig. 5a). Close to the basement contact in all but the last three, local basement detritus is evident in the Kalevian flysch, but the bulk of the succession is exotic in provenance. Sm-Nd isotope studies indicate a post-Archean source terrane, which on a depleted-mantle model, has no crustal residence prior to 2.0 Ga (Huhma, 1987). The composition of the psammites reflects an original source poor in K-feldspar and of calc-alkaline affinities (see Ward, 1987, for review).

Several models have been proposed to account for this flysch deposit; two currently favored suggest that it is either a post-orogenic flysch or a post- to syn-arc flysch (Ward, 1987). The date of deposition is quite well constrained by the age of the Jormua ophiolite and Outokumpu assemblage (1.96–1.97 Ga, Huhma, 1986) and the onset of movement in the Savo thrust belt (ca. 1.95–1.90 Ga; see above). This precludes the flysch from representing detritus from either the ca. 1.88–1.87 Ga magmatic arc or the 1.93–1.90 Ga lower Bothnian magmatic arc (compare with Park, 1985; Gaál, 1990). The best candidate for a source area yet suggested is the Lapland granulite belt, uplifted along the Belomorian front in the period 1.95 to 1.90 Ga (Barbey and others, 1984, and references therein; Berthelsen and Marker, 1986a; Ward, 1987). Although the dating of deposition and uplift regime requires further resolution, this is at least consistent with the isotopic and compositional evidence.

Bothnian, Peräpohja, and Pohjanmaa Basins

The margins of the Bothnian basin are poorly defined. For the purposes of this account, the northern margin is the transition within the Bothnian Group metasediments of the Skellefte-Savonlinna terrane; the southern margin is in part the Tampere belt and elsewhere the southern Finnish nickel belt (Fig. 2b). The basin is filled with a thick sequence of graywackes, some of volcanogenic provenance, belonging to the upper and lower Bothnian Groups (Svecofennian Supergroup). Their age is poorly constrained; interlayered basalts in Sweden have Sm-Nd ages of 1.88 Ga (Claesson, 1987). The basin was intruded by the central Finnish batholith at ca. 1.88–1.87 Ga (Huhma, 1986; Front and Nurmi, 1987).

Sm-Nd isotope studies on the igneous rocks indicate an absence of Archean basement, and similar studies of the sediments, both from the lower volcanites and the overlying graywackes, likewise reveal either no, or limited, Archean provenance overall, although Archean detritus may constitute as much as 30% of the upper sequence in southern Sweden (Patchett and others, 1987). If the correlation of the Tampere belt with the Skellefte-Savonlinna terrane is correct, these formations represent the depositional basement of the Bothnian basin. In Sweden, magmatic activity continued with the emplacement of the Revsund granitoid-gabbro suite until 1.77 Ga (Skiöld and others, 1988).

The Pohjanmaa basin is also filled entirely with metasediments of the Svecofennian Supergroup. Conglomerates and graywackes are interbedded locally with metabasites, all lying unconformably on the Archean basement of the Lapland terrane. Honkamo (1985) suggested that this succession represented a back-arc basin infill, largely derived from the south. The age is ultimately constrained only by the post-Archean unconformity and the intruded Kiiminkii granite, one of the ca. 1.88–1.87 Ga granitoids. The age of the low-grade metamorphism here is not well constrained.

The Peräpohja basin is more complex, its older fill being shelf-type arenites with interbedded metabasites of the Karelian Supergroup (Perttunen, 1985), and may include Lapponian sediments resting unconformably on the Archean basement of the Lapland terrane. Svecofennian Supergroup lithologies resemble those of Pohjanmaa, and a similar back-arc setting is invoked. Interbedded metabasites have a back-arc geochemical signature (Perttunen, 1985; Pharaoh and Brewer, 1990). The uppermost sediments and volcanic rocks may belong to the upper Bothnian Group, but age is ultimately constrained only by the intrusion of the Lapland batholith ca. 1.87 Ga (Huhma, 1986).

The Bothnian, Peräpohja, and Pohjanmaa basins are successor basins. The Peräpohja and Pohjanmaa basins were formed on the Karelian collage and appear to have received detritus from a magmatic arc to the south (Fig. 5c; Honkamo, 1985; Perttunen, 1985). This could be either the 1.95–1.90 Ga lower Bothnian arc, which would indicate the approach of the latter to the Archean nucleus, or the ca. 1.88–1.87 Ga magmatic arc. If the latter were the case, then the Bothnian basin would represent the oceanward fore-arc basin; Peräpohja and Pohjanmaa, the back-arc basin; the volcanic rocks of the Arvidsjaur Group, and their equivalents in Finland, the upper levels of the magmatic arc itself. This whole fore-arc to

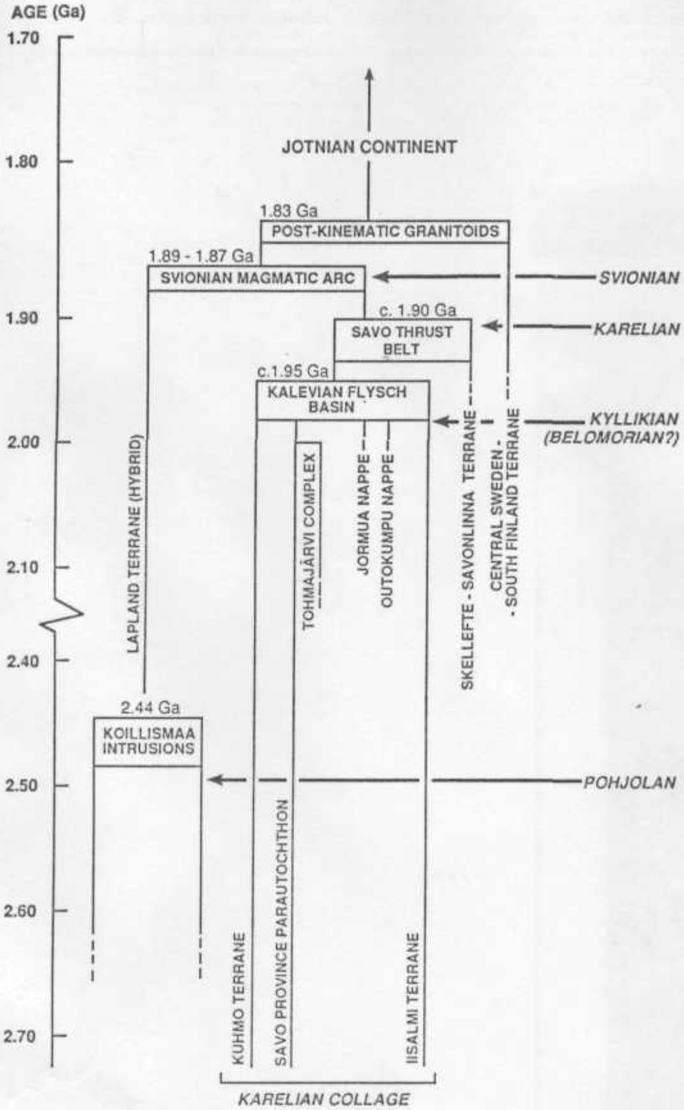

Figure 6. Dendrogram of terrane accretion in the Baltic Shield between 2.50 and 1.75 Ga, identifying stitching events (in boxes) and constraining accretion events (italics).

back-arc assemblage is developed on a terrane collage consisting of the Tampere belt, the Skellefte-Savonlinna terrane, the Lapland terrane, the Iisalmi terrane, the Savo province, and the Kuhmo terrane. The ca. 1.88–1.87 Ga magmatic arc represents a stitching event incorporating all of the Svecokarelian collage, except possibly the south Finland–central Sweden terrane.

CONCLUSIONS

The concept of a Svecokarelian orogeny, as it has developed over the past 70 yr, requires critical reassessment. The orogeny can no longer be restricted in area to the Karelides and Svecofennides; its physical effects can be seen all over the exposed shield east of the Trans-Scandinavian front. If it is used as a time bracket for a series of Early Proterozoic tectonic events, it faces the charge of being quite arbitrary. At the oldest limits, terrane accretion events in the Karelides and in the Lapponian especially differ little in style from those of the Archean, and in truth, a near-continuous history of accretion of continental crust can be traced from at least 3.2 Ga; only its locus shifts. At the younger limit, as exemplified by the events in Sweden, Svecokarelian events run into those of the Trans-Scandinavian belt. As used here, Svecokarelian "orogeny" refers to those events affecting the Baltic Shield between 2.6 and 1.80 Ga, with the realization that this constitutes an arbitrary set of geographic and temporal limits referring to a period of crustal accretion that in fact is recorded from 3.2 to ca. 1.0 Ga.

Within this Svecokarelian interval, tectonostratigraphic terrane analysis permits the recognition of discrete accretion (docking) and readjustment events (Figs. 5 and 6). These are as follows.

1. The mid-Lapponian accretion of the hybrid Lapland terrane ca. 2.44 Ga. The Koillismaa layered intrusions and the late Lapponian clastic-filled basins mark a stitching event and a successor basin, respectively.

2. The late Karelian accretion of the Karelian collage, comprising the Kuhmo, Iisalmi, and Savo province terranes ca. 1.95 Ga. The late Kalevian flysch basin constitutes a successor basin to this major event. This basin may also succeed collision along the Belomorian front (Figs. 5a and 6).

3. The accretion of the Skellefte-Savonlinna terrane, and possibly the basement of the whole Bothnian basin, to the Lapland terrane and the Karelian collage ca. 1.90 Ga. The Savo thrust belt marks the shortening of the foreland at this time (Figs. 5b and 6).

4. Development of the 1.88–1.87 Ga magmatic arc with its contemporary back-arc (Peräpohja and Pohjanmaa) basin and fore-arc/intra-arc (Bothnian) basins. This magmatic arc stitches and succeeds the accretion of all of the Svecokarelian collage except, possibly, the south Finland–central Sweden terrane (Figs. 5c and 6).

5. Accretion of the south Finland–central Sweden terrane, stitched by the 1.83–1.79 Ga late and post-kinematic granitoids (Figs. 5d and 6).

Having defined these accretion events, it is tempting to suggest names (Figs. 5 and 6). The 1.88–1.87 Ga magmatic arc (event 4) approximates to the "Svionian arc" of Hietanen (1975), and this name should be revived for this purpose. Event 3 corresponds to the "Karelian orogeny" of Wegmann (1928) and, of all the events described, most properly relates to mountain building. Event 5 is currently too poorly constrained or defined to warrant a separate name. Event 1 is confined to Lapland, and as "Lapponian" and "Saamian" are both already in use in different contexts, perhaps "Pohjolan" may be more appropriate, after Pohjola, Lord of the North in the Kalevala. Event 3 is clearly of great significance. "Belomorian" is already in use for the collision zone running from Lapland to the White Sea. "Kyllikian" is suggested here, after Kylliki, the daughter of Pohjola, for love of whom Lemminkäinen was hacked to pieces and then stitched together again.

Finally, a number of general points should be emphasized. Firstly, all of the terrane boundaries identified here are structures that postdate actual accretion. With the possible exception of the Svecokarelian suture, they cannot be said to represent accretion coupling surfaces, even if this was their original form. All of the terrane boundaries in eastern and central Finland, for instance, are structural elements belonging to the framework of the Savo thrust belt, a Karelian feature superimposed on the Kyllikian collage. This is an inevitable feature of such terrane collages; unless plate convergence ceases at, or soon after, the time of accretion, stresses in the collage will be resolved by a combination of low- and high-angle dip-slip and strike-slip movement involving the propagation of large-scale shear zones that will modify collage geometry. Some shear zones will reactivate original accretion coupling surfaces. Structural elements developed in and adjacent to these zones are likely to have little or no bearing on the kinematics of accretion. Similarly, mineral isotopic ages from these zones will have more bearing on cooling after post-accretion movements than on the docking event. One consequence of this is that the search for (and characterization of) Precambrian suture zones, defined as accretion coupling surfaces, may well be futile. Secondly, plate movements and evolving plate geometries are deliberately omitted from the reconstructions in Figure 5. The identification of the positions of spreading ridges and subduction zones, even when their products can be identified, is not possible. Such features are defined in the late Phanerozoic record on the basis of criteria not available for older belts.

If the application of tectonostratigraphic terrane analysis to the history of Precambrian shields is to have any value, it must be done critically. The relationships in the Baltic Shield suggested herein will be tested by refinements in stratigraphy (particularly its continued radiometric calibration) and improved understanding of the structural relationship between tectonic blocks. Tectonostratigraphic terrane analysis demands precision and fosters an appreciation of the speed of events. It also forces a separation of the concepts of plate geometry and the recognition of the products of plate-tectonic processes. In so doing, it provides a realistic and actualistic framework for the generation of continental crust.

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