# Tectonic evolution of the Paleoprotezoic Tampere Belt during the Svecofennian orogeny, with reference to hydrothermal alteration at Kutemajärvi

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**Summary:** The Paleoproterozoic, volcano-sedimentary Tampere Belt lies in the centre of the Svecofennian domain between the Central Finland Granitoid Complex and the Pirkanmaa Belt. The east-west striking greenstone belt is dominated by turbiditic metasedimentary rocks, metavolcanic rocks of island-arc type and granitoids. Metamorphic and structural features and age data evidence the rapid tectonic evolution of the Tampere Belt during the Svecofennian orogeny.

The subvolcanic Pukala intrusion, which was emplaced into volcanic sequence of the Tampere Belt before or during the early stages of the main regional deformation, can be linked to the hydrothermal alteration observed at Kutemajärvi. The mineral assemblage of the alteration, geometry of the area, isotope data and presence of the comb quartz banding suggest that the hydrothermal system was driven by the Pukala intrusion. Later on, the hydrothermally altered area was subjected to deformation and metamorphism.

Key Words: greenstone belts, Tampere Belt, tectonics, Svecofennian Orogeny, intrusions, hydrothermal alteration, gold ores, Paleoproterozoic, Tampere, Orivesi, Pukala, Kutemajärvi, Finland

## 1. INTRODUCTION

Tampere region has been in focus of geological interest since the 19th century after Sederholm (1897) released his study on the sedimentary rocks of southwestern Finland. The contributions of a number of distinguished researchers have highlighted the Tampere Belt as a first-class example of a Proterozoic greenstone belt and an integral part in understanding the tectonic evolution of the Svecofennian domain.

The Proterozoic greenstone belts around the world are considered to be highly potential regions for metal exploration and they host a vast amount of the Earth's premier ore deposits. In orogenic belts, intrusives at subvolcanic depths, e.g. magma chambers of volcanoes, often create hydrothermal systems that may carry constituents to and cause mineralisations in the intrusions or their country rocks.

The purpose of this extended abstract is to present a simplified tectonic model for the Tampere Belt (TB) during the Svecofennian orogeny that summarises the investigations of numerous researchers. In addition, the model is intimately linked to the hydrothermal alteration phenomena observed at Kutemajärvi in the eastern flank of the Tampere Belt.

## 2. GEOLOGIC SETTING

The bedrock in Finland belongs to the Precambrian Fennoscandian craton. The two major tectonic collisions that led to the formation of the Finnish crystalline bedrock occurred at 2.8-2.7 Ga and 1.9-1.8 Ga ago. Since the Paleoproterozoic, no major tectonic events have taken place, and the bedrock has been subjected to erosion for an extensive period of time. Therefore, mainly Archean and Paleoproterozoic rocks are exposed at the current erosional level in Finland.

The Tampere Belt (TB) is located in the middle of the Paleoproterozoic Svecofennian domain that formed 1920-1870 Ma ago as a result of orogenic and extensional events (Lahtinen et al., 2005). The bedrock of the domain is mainly composed of metasedimentary rocks, metavolcanic rocks of island-arc type and plutonic rocks that cut the supracrustal sequence (Korsman et al., 1997).

The east-west striking, volcano-sedimentary TB (Fig. 1) extends over 200 km and lies between the Central Finland Granitoid Complex (CFGC) and the Pirkanmaa Belt (PB). The CFGC mainly comprises tonalites, granites and granodiorites with minor proportions of supracrustal rocks and mafic plutonic rocks (Korsman et al., 1997). The collision-related intrusions are 1.89-1.88 Ga and the intrusions post-dating the main stage of crustal thickening 1.88-1.87 Ga old (Korsman et al., 1997). The PB is dominated by migmatitic metasedimentary rocks that are intruded by granitoids and mafic plutons (Nironen et al., 2002).

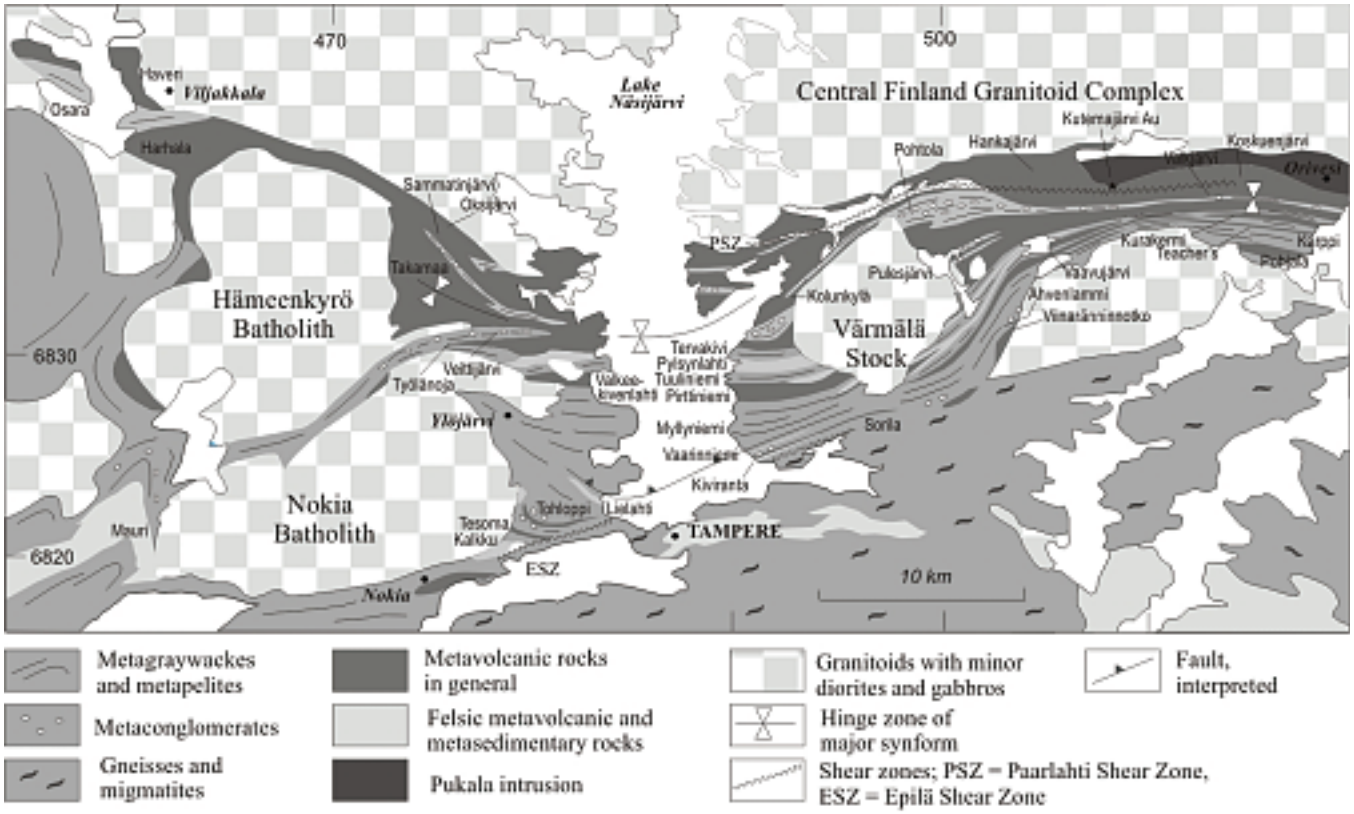

Figure 1. Lithological map of the Tampere Belt. Modified from Kähkönen 1999, Kähkönen 2005 and references therein.

## 3. TAMPERE BELT (TB)

Seitsaari (1951), Ojakangas (1986) and Kähkönen (1989, 1999, 2005) among others have studied the stratigraphy and rock types of the TB. Accordingly, the main rock types are turbiditic metasedimentary rocks, felsic-intermediate arc-type metavolcanic rocks and granitoids (Ojakangas, 1986; Kähkönen, 1989; Kähkönen & Leveinen, 1994; Nironen, 1989). On the basis of the geochemical data, the metavolcanic rocks of the TB were formed in an island-arc or active continental setting, and the absence of carbonate rocks and iron formations, and the presence of turbidites indicate a steep convergent plate margin (Kähkönen, 1989,1999; Luukkonen, 1994) (Fig. 3). In addition, a mantle reflector dipping to the north indicates a norward subduction under a microcontinent (Lahtinen et al., 2005).

The zircon U-Pb ages of the metavolcanic rocks of the TB are 1904-1889 Ma (Kähkönen et al., 1989; Kähkönen et al., 2004). In comparison, zircons from the metasedimentary rocks are mainly 2.0-1.91 Ga old (Huhma et al., 1991), and the U-Pb ages of the synorogenic granitoids within the TB are 1885±2 and 1878±3 Ma (Nironen, 1989). The zircon U-Pb age for the Pukala subvolcanic intrusion, which is located in the northern flank of the TB, is 1896±4 Ma (Talikka & Mänttäri, 2005).

During the Svecofennian orogeny, the supracrustal rocks of the TB were deformed and metamorphosed under low-pressure, greenschist to lower amphibolite facies conditions (Campbell, 1978; Mäkelä, 1980; Kilpeläinen et al., 1994; Kilpeläinen, 1998). According to Mouri et al. (1999), the regional metamorphic peak occurred at ca. 1880 Ma.

## 4. PUKALA INTRUSION AND HYDROTHERMAL ALTERATION AT KUTEMAJÄRVI

The data on the Pukala intrusion is based on publications by Talikka (2003) and Talikka and Mänttäri (2005).

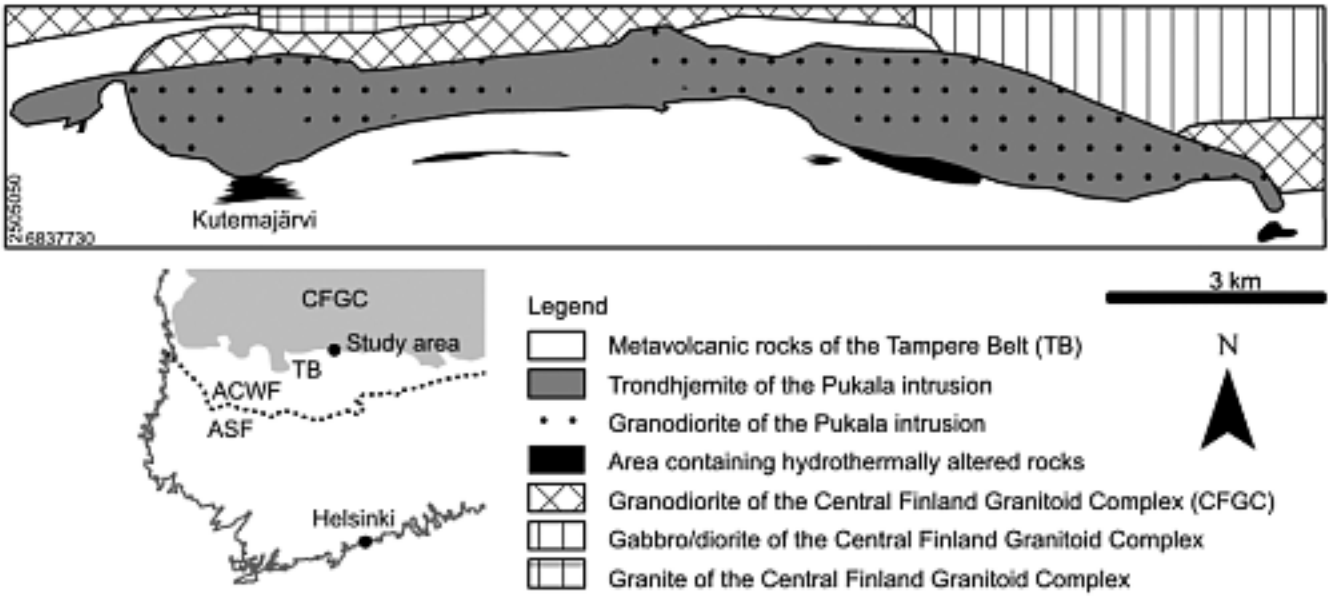


Figure 2. Generalised geological map of the Pukala intrusion (Talikka & Mänttäri 2005 and references therein). ACWF = arc complex of central and western Finland, ASF = arc complex of southern Finland. Inset after Korsman et al. (1997).

According to Kähkönen (1989) and Nironen (1989), the TB forms a large synform whose northern limb is dominated by metavolcanic rocks and the southern limb by metasedimentary rocks. On the basis of the recent age data, Kähkönen et al. (2004) suggested a folded early thrust as a more compatible explanation for the large-scale structure of the TB.

Several east-west striking faults cut the TB (Kähkönen, 1989). The striking mappable structural feature within the TB is the east-west striking, subvertical foliation that formed during the main deformation phase (Kähkönen, 1989; Nironen, 1989; Kilpeläinen, 1998). Latter deformational features include fracturing, kink-folding and movement along narrow shear zones (Nironen, 1989; Kilpeläinen, 1998).

The Pukala intrusion lies in the eastern side of the TB in the contact region between the TB and the CFGC (Fig. 2). The acid, subvolcanic intrusion extends over 20 km in east-west and 1-2 km in north-south direction. The main rock types are porphyritic granodiorite and trondhjemite. The granodiorite has a zircon U-Pb age of 1896±4 Ma and titanite age of 1851±4.6 Ma. Geochemically, the intrusion is a peraluminous, volcanic-arc granitoid.

The Pukala intrusion was emplaced as a sheet-like pluton at subvolcanic depths before or during the early stages of the main regional deformation phase and ca. 15 Ma before the regional metamorphic peak. The main regional foliation is observed in all rock types within the intrusion. On the basis of the stratigraphy observed today, the thickness of the volcanic strata above the Pukala intrusion at 1.9 Ga ago was 1.5-2.5 km. During the Svecofennian orogeny, the intrusion tilted slightly

to the west and steeply to the south along with the adjoining volcanic rocks. This is evidenced by the grain size variations, the presence of abundant xenoliths near the southern margin, and the evidence of magmatic-hydrothermal activity, e.g. comb quartz banding in the contact between the hydrothermally altered metavolcanic rocks and the intrusion at Kutemajärvi.

Several hydrothermally altered domains are located within the metavolcanic rocks of the TB less than one kilometre south of the Pukala intrusion. The largest of the hydrothermally altered areas, Kutemajärvi, is in contact with the Pukala intrusion and hosts a gold deposit, which was mined during 1994-2003 by Outokumpu Mining Oy and Polar Mining Oy. The Kutemajärvi area has been studied by Nurmi et al. (1984), Grönholm (1992), Luukkonen (1994), Poutiainen & Grönholm (1996), Kojonen et al. (1999) and Poutiainen et al. (1999) among others. The continuous hydrothermally altered domain is formed by an outer rim of chlorite-sericite±quartz schist and a centre dominated by sericite-quartz schist, which hosts the pipe-shaped ore deposits (Grönholm, 1992). In addition, massive andalusite, quartz and topaz rocks exist in the centre of the altered area. Monazite from the chlorite schist has a U-Pb age of 1.88 Ga, and a galena with small crustal component in Pb-composition has a model age of 1888 Ma (Mänttäri et al., 1997).

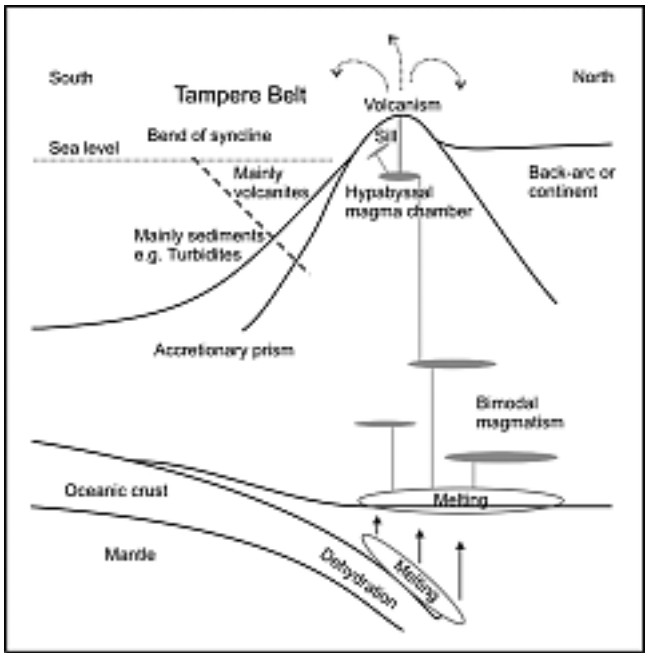


Figure 3. Tectonic setting at ~1.9 Ga. Oceanic crust is subducting under island-arc or active continental margin. The Pukala intrusion may represent a hypabyssal magma chamber. Modified from Talikka (2003).

The intense sericitisation, comb quartz banding, age data and geometry of the area suggest that the pervasive alteration at Kutemajärvi was a resultant of acid hydrothermal fluids of magmatic origin at 1895-1890 Ma ago. After the pervasive alteration, the rocks were deformed and metamorphosed during the Svecofennian orogeny.

## 5. TECTONIC EVOLUTION OF THE TAMPERE BELT

The model for the tectonic evolution of the Tampere Belt during the Svecofennian orogeny is based on the lithologic data, age data and structural and metamorphic features. The tectonic evolution is divided into four stages in relation to the collision between island-arcs or an island-arc and continental margin (Figs. 3 & 4).

*Pre-collision, ←1900 Ma*
- Deposition of turbiditic sedimentary rocks
- Active volcanism
- Structural features include primary features e.g. bedding
- Steep convergent plate margin
- Island-arc or active continental margin

*Early-collision, 1900-1890 Ma*
- Active volcanism
- Compressional deformation → foliation, folding
- Metamorphism
- Emplacement of Pukala intrusion
- Pervasive hydrothermal alteration at Kutemajärvi

*Syn-collision, 1890-1878 Ma*
- Minor volcanism
- Compressional deformation → main foliation, folding, large shear zones
- Main metamorphic phase, metamorphic peak
- Emplacement of synorogenic granitoids
- Deformation and metamorphism of the Kutemajärvi alteration domain

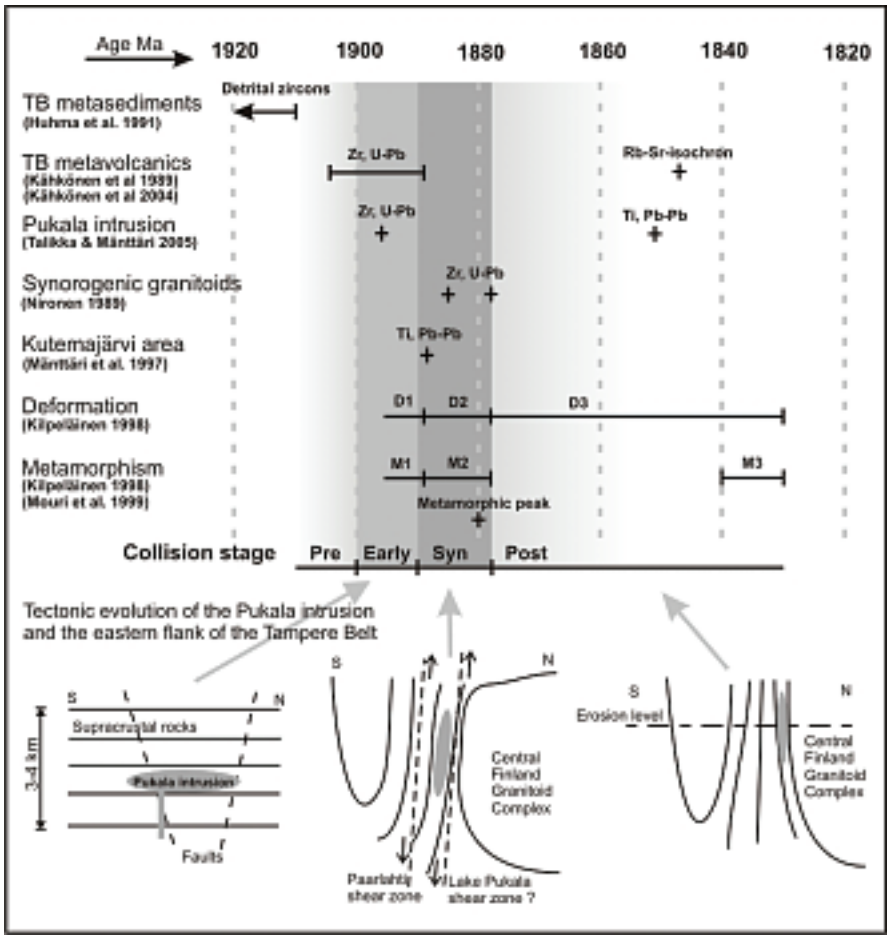


Figure 4. Age data of the rock types, metamorphism and deformation of the Tampere Belt linked to the stages of the tectonic collision. Lower part of the figure illustrates the tectonic evolution of the Pukala intrusion and the adjoining metavolcanic rocks. (Modified from Talikka, 2003).

*Post-collision, 1878-1830 Ma*

- Extensional deformation → shear zones, kink-folding, fracturing
- Retrograde metamorphism, cooling

## 6. CONCLUSIONS

The volcano-sedimentary Tampere Belt mainly comprises turbiditic sedimentary rocks, volcanic rocks of island-arc type and synorogenic granitoids. The range of the isotopic ages of the volcanic rocks and the synorogenic granitoids is ca. 25 Ma, and the main regional metamorphic and deformational phase lasted ca. 10 Ma. Accordingly, the tectonic evolution of the Tampere Belt during the Svecofennian orogeny has been a rapid, continuous process.

The expeditious orogenic processes are also evidenced in the Kutemajärvi hydrothermally altered domain that hosts an economic gold deposit. The Kutemajärvi area is located in the northern flank of the TB and is in contact with the subvolcanic Pukala intrusion, which was emplaced within the metavolcanic rocks before or during the early stages of the Svecofennian orogeny. It is suggested that the magmatic fluids from the Pukala intrusion caused the pervasive alteration including sericitisation and silicification observed at Kutemajärvi. The pervasive alteration preceded the main regional deformation and metamorphic processes that led to changes in geometry and mineralogy of the gold deposit.

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