Unfolding Taivaljärvi

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The Taivaljärvi Fold

The Sotkamo Silver Oy owned Taivaljärvi Ag-Zn-Pb-Au Deposit is hosted by siliceous quartz porphyritic rocks belonging to the metamorphosed and chemically altered volcaniclastic rocks of the stratigraphic Koivumäki Formation which is the lowermost part of the Tipasjärvi Section of the Suomussalmi-Kuhmo Greenstone Belt (TKS), age 2790 +/- 3 Ma (Vaasjoki 1999). Deposit geology has been described by Kopperoinen and Tuokko (1988), Papunen et al. (1989, 2001, 2009), and Eilu (2011), and regional geology has been described by Vartiainen (1970), Taipale (1983), Luukkonen (1992) and Pietikäinen et al. (2008). The Sotkamo Silver Taivaljärvi Project can be followed on the web site of Sotkamo Silver: http://www.silver.fi/.

This study is Part II of the project, ”Taivaljärven hopea-sinkki-lyijy-kulta-esiintymän uuden geologisen 3D-rakennemallin kehittäminen ja hyödyntäminen”, financed by Renlund Foundation. Part I (Parkkinen, 2010) described a “synthesis of structural analysis and geostatistics” ending at a fold model, the “Taivaljärvi Fold”, containing “tight folds with silver enriched in the parasitic stacks inside”. There were no lithologic aids but the fold construction relied on the combining of geostatistically identified mineralization lines and bended structures. Hence the Taivaljärvi Fold is a hypothetical construction.

There are several software programs available for the unfolding of **folded surfaces**, e.g. Dynel, Move, Paradigm, Traptester, but the real problem here was to unfold drill core **assay data** to illustrate grade distributions and to recognize possible paleo-structures. This was done with the Surpac 6.2 coordinate transformation apparatus. I hope this experiment will encourage geologists to develop means for unfolding. Now’s the time!

Regional setting

The TKS greenstone complex represents a symmetrical wide synclinorium with oldest units at the margins and the younging directions pointing to the centre of the greenstone belt complex; “The Taivaljärvi Ag-Zn-Pb occurrence is located in the middle of the felsic succession where a number of quartz veins characterize the ore zone” (Papunen et al. 2009). Deducting from estimates by Silvennoinen (2006) on the depth of the Kuhmo Greenstone Belt I assume that the Tipasjärvi Belt may reach the depth of 3–4 km at most.

So far the only 3D structural interpretation of the Tipasjärvi geology has been given by Taipale (1983). In his model the synclinorium is divided into three major synforms while the Taivaljärvi Deposit can be located near the axial surface of the antiform next to the western synform (Figure 1B). This model was applied by Papunen et al. (1989): “The Taivaljärvi deposit occupies the eastern flank of the antiform” next to the above synform. Among the criteria is the presence of a kyanite-quartz layer. “The kyanite-quartz rock about 90 m above the ore layer is an extensive marker horizon in the Koivumäki Formation” (Papunen et al. 1989). However, known kyanite-quartz occurrences are distributed in a way indicating complex minor folding. In the present interpretation the Taivaljärvi Deposit is located on the SE limb of a minor synform dipping to the SE; moreover, it is located on

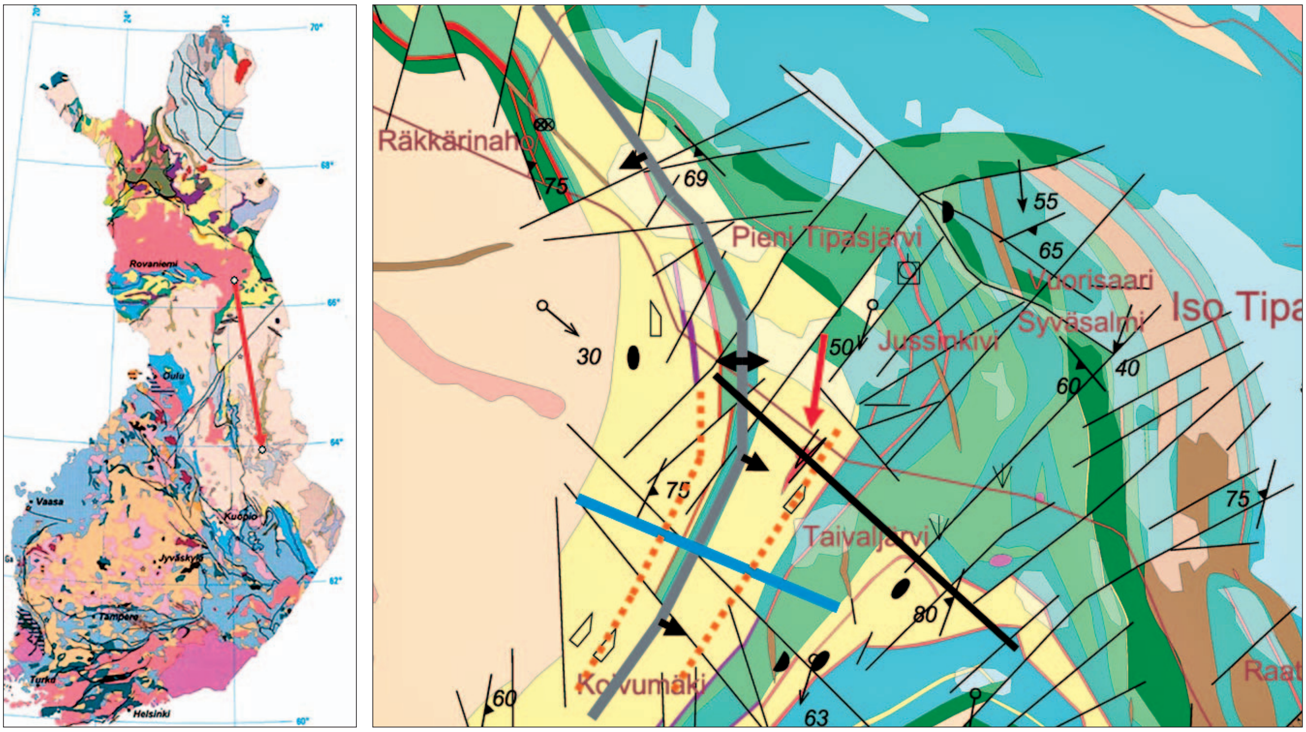


Fig. 1 A, B
A. Bedrock map of Finland (GTK). Taivaljärvi pointed by red arrow.
B. Geological map of the Tipasjärvi Belt (Pietikäinen et al. 2008) with interpretations by Parkkinen. Taivaljärvi Fold pointed by red arrow also showing the plunge of deposit fold axis. Grey line denotes regional synform with axial plane dip direction shown by black arrows. Cyan line denotes regional axial depression. Dashed brown lines stand for kyanite-quartz-layers. Black line stands for the cross section in Fig. 7.

the NE side of a depression and stratigraphically above a kyanite-quartz layer (Figures 1B, 7).

The Taivaljärvi Fold, what if?

According to my interpretation, the Taivaljärvi Deposit is controlled by a pack of flexural slip z-folds, tightly folded beds (Figures 1–3). This interpretation differs from that of Papunen et al. (2009) who interpreted the Taivaljärvi Deposit a simple pile of non-folded volcaniclastic sedimentary beds. To judge between these interpretations, or to find a still different one, a profound lithologic modelling, presently missing should be done. Another problem arose about the proposed left-handed or sinistral asymmetry of the Fold. It indicated that the Deposit was located in the limb of a synform instead of an antiform as proposed by earlier investigators.

If true, the Taivaljärvi Fold would represent the latest regionally significant folding phase, possibly a proterozooic one, in a series of deformation phases D1-D4, of which D3 is the main phase (Luukkonen 1992). Probably simultaneously to the folding a generation of quartz veins, in places mineralized, was formed. This phase was followed by brittle deformation with another generation of barren quartz veins. No remarkable faults have been recognized, except indirectly via aerial geophysics, but the Taivaljärvi pack of folds may be bordered by sub-vertical faults, especially the SE side of the pack.

The unfolding procedure

The Taivaljärvi Fold was constructed by first combining lines of silver mineralization to outline fold skeletons on vertical and horizontal cross sections as well as on sections perpendicular to the average fold axis and at 20 m intervals. Skeletons were triangulated between segments and the resulting three folded surfaces were cut on horizontal sections and a single fold, combination of the three preforms, was constructed. Zinc, lead and manganese grade

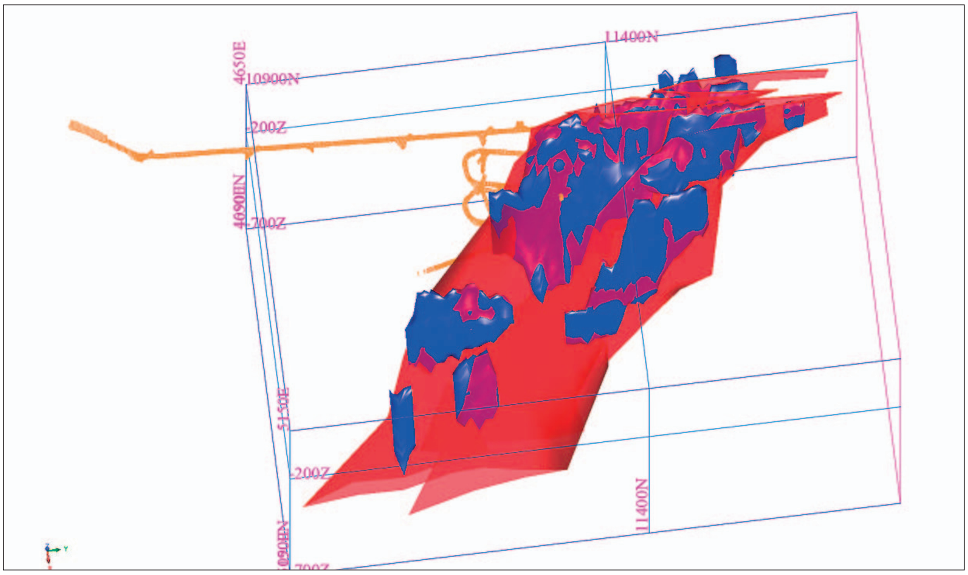


Fig. 2. Taivaljärvi Fold (red), ore lenses, Ag >/~ 50 g/t (blue), and Mine Decline (brown).

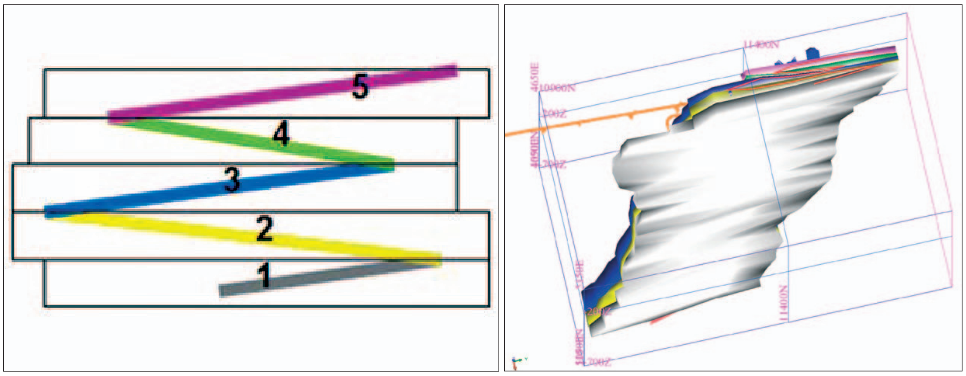


Fig. 3 A, B

A. Taivaljärvi Fold structure with limbs and respective Data Boxes coloured and numbered from 1 to 5.

B. Data Boxes as solids each containing data between two axial surfaces.

distributions were used to fine-adjust the final Taivaljärvi Fold (Figure 2).

For unfolding a 100 m thick pack of five fold limbs were chosen and each limb was closed inside a box where box walls were defined by axial surfaces (Figure 3A). The walls were constructed using wall outlines on horizontal sections at 20 m intervals. The box skeletons were triangulated to make solids (wireframes, Figure 3B). Assay data was then collected into these five "data boxes".

Four boxes were then rotated to the plane defined by Box 2 and around axes defined by the locations of fold hinges (Figures 3–4). Similar rotations were applied to the assay data stored in boxes. The resulting unfolded data box is 1500 m long and 700 m high while the thickness varies from 10 to 40 m.

Variography of this unfolded 3D data gave anisotropy parameters for six elements chosen: Ag, Au, Cu, Mn, Pb, and Zn. It appeared that the best grade continuity was vertical or the original axial direction while there were signs of shorter distance grade continuities perpendicular and in low angle (33°) to the axial direction. In addition to the 3D block interpolation of above grades (Figure 5) a 2D interpolation was done that gave very similar results (Figure 6).

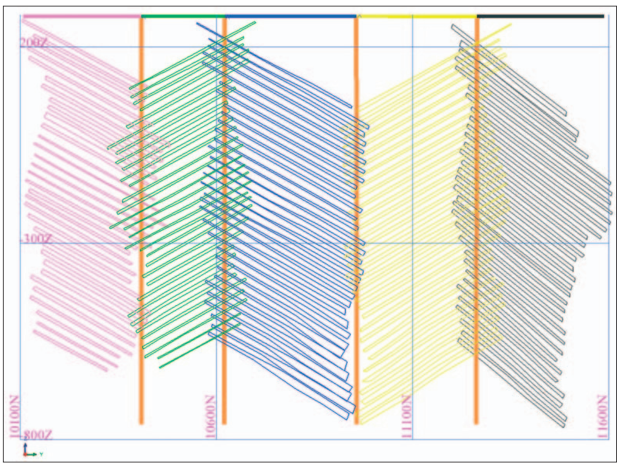


Fig. 4. Skeletons of Data Boxes unfolded to form the "Unfolded Data Box".

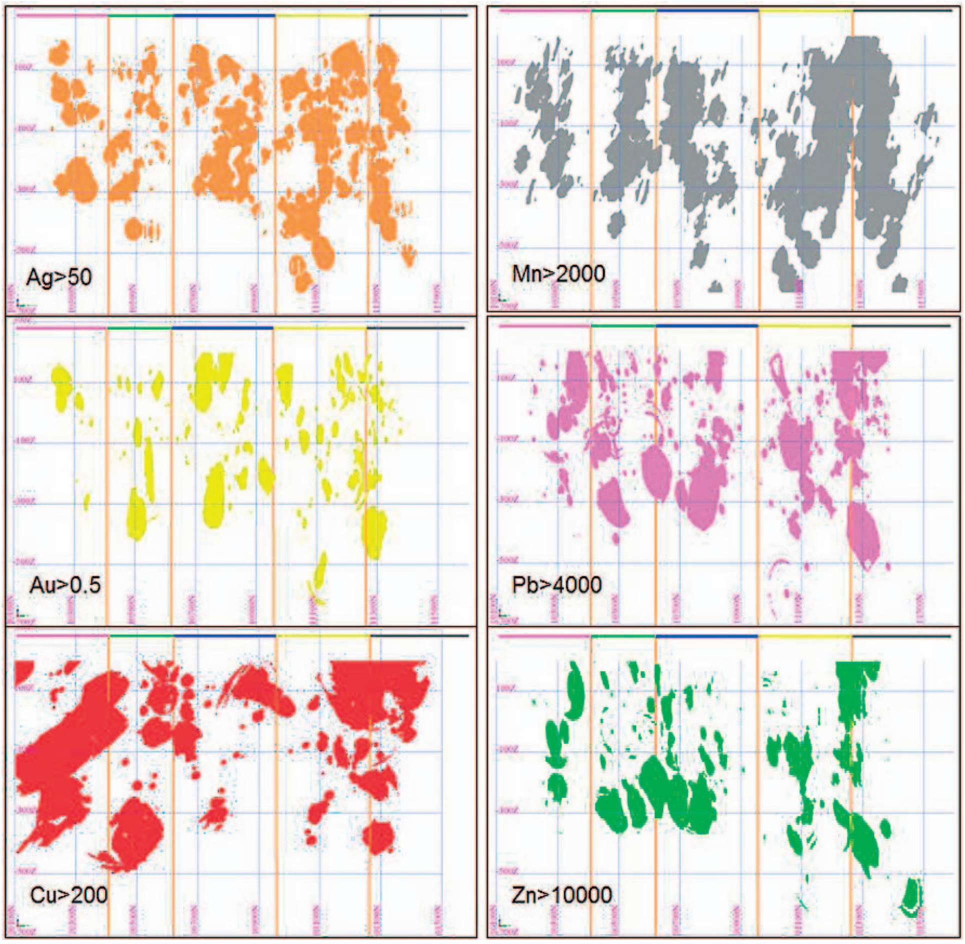
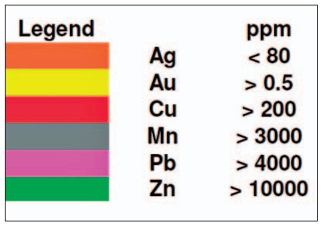


Fig. 5 A, B.Grade iso-surfaces of block interpolations in 3D inside the Unfolded Data Box. Brown vertical lines show the locations of unfolding axes.



Results and discussion

Symmetry features (Figures 5–6) support the conclusion that grade distributions at Taivaljärvi have strong linear structural control. Symmetry features of unfolded grade distributions moreover indicate that the fold hypothesis is a possible interpretation.

In general, it seems that copper, zinc and lead minerals favour fold hinges while silver, gold and manganese minerals favour limbs. It also seems that high grades tend to concentrate near the northerly hinges (Figures 5–6). All these features may well be due to the main deformation and simultaneous re-mobilization. The only observed paleo-features are illustrated in Fig. 6: there is zonality possibly due to extensional fracturing and shear fracturing prior to the main folding phase.

The present interpretation leads to a stratigraphic model different from that of Papunen et al. (1989, 2009) by placing the kyanite-quartz-rock layer below the mineralized zone. Papunen (2012) has demonstrated how his view can be elegantly defended e.g. with the help of a simple fault structure.

This work is still in progress. The latest exploration results of Sotkamo Silver AB together with

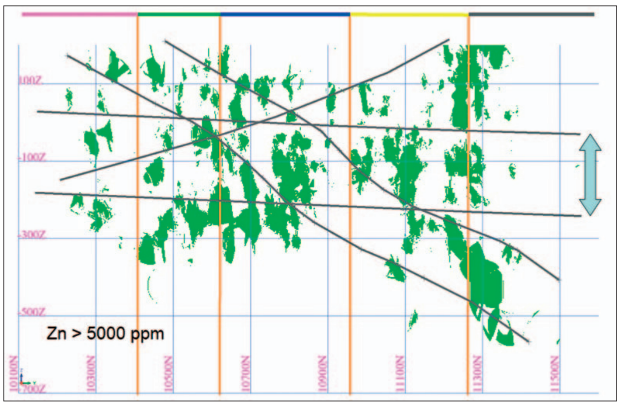


Fig. 6. Unfolded layer as in fig. 5 with isolines of 2D interpolations of Zinc assay grades. Zonality and discontinuities (paleo-structures?) marked by grey lines and a double arrow.

GTK geophysicists imply that the plunge of the Taivaljärvi Deposit may bend to horizontal towards west (Sotkamo Silver 2012). This supports the idea that the presently known Deposit is located in a synform depression and that it may continue to a length of several kilometres at a depth of 500-1000 m.

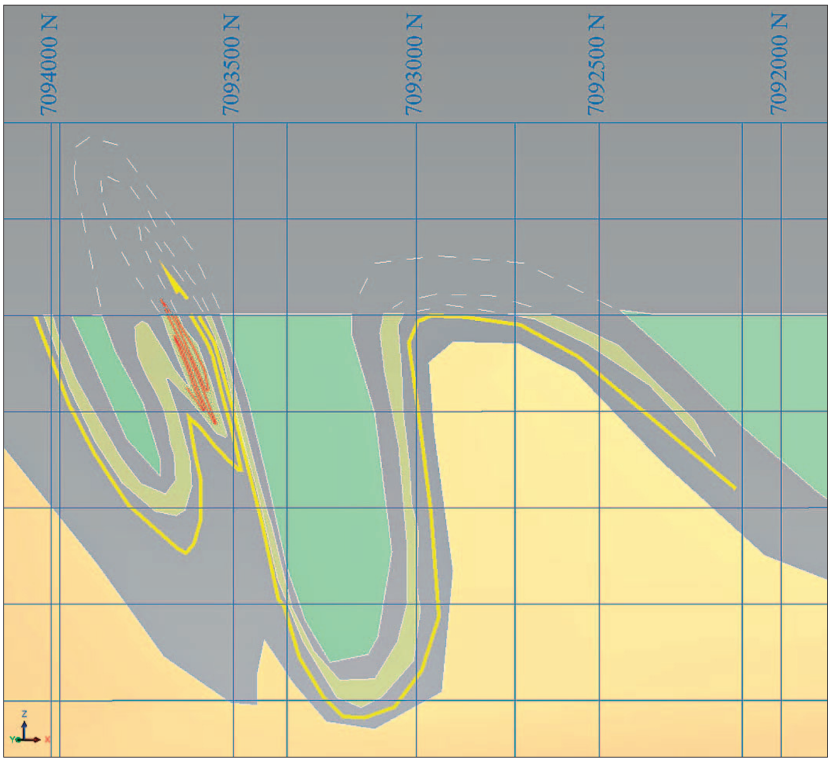


Fig. 7. Schematic cross section (see Fig. 1) across the Taivaljärvi fold (red line). Rock types from top to base: mafites-ultramafites (green), felsites (no colour), zone of mineralization (light yellow), kyanite-quartz-rock zone (yellow line), tonalite (brownish). Elevation lines at 500 m intervals.

Acknowledgements

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