

A regional scale 3D-model of the Skellefte mining district, northern Sweden

Tobias E. Bauer, Saman Tavakoli, Pär Weihed

Division of Geosciences and Environmental Engineering, Luleå University of Technology, SE-971 87 Luleå, Sweden

Pietari Skyttä

Department of Geosciences and Geography, University of Helsinki, FI-00014 Helsinki, Finland

Tobias Hermansson, Rodney Allen

The Boliden Group, SE-936 81 Boliden, Sweden

Mahdieh Dehghannejad, María A. García Juanatey, Christopher Juhlin

Department of Earth Sciences, Uppsala University, SE-75236 Uppsala, Sweden

Abstract. Three dimensional geological modelling was carried out in the Palaeoproterozoic Skellefte district in northern Sweden. Modelled volumes range from regional to semi-regional to deposit scale. A multidisciplinary approach combined both geological studies, such as structural and facies analysis and geochronology with geophysical techniques, such as reflection seismic, magnetotelluric, electrical, potential field, and petrophysical studies. Resulting data was interpreted and visualised as 3D-surfaces and bodies in gOcad. Additionally, modelling uncertainties showing the origin and handling of data were assigned and presented as a colour-coded model. The resulting model reveals a framework of major high-strain zones, key lithological contacts and the setting of deformed VMS deposits in the Skellefte district. The 3D-model of the Skellefte district can act as a background for exploration activities in the region.

Keywords: 3D-modelling, VMS deposit, Skellefte district, Palaeoproterozoic

1 Introduction

The Palaeoproterozoic Skellefte mining district is one of the most important mining districts in Europe hosting 79 volcanogenic massive sulphide (VMS) and several orogenic gold deposits and prospects (Allen et al. 1996; Kathol and Weihed 2005). Currently five active mines are producing Zn, Cu, Pb, As and Au. As most of the near-surface deposits have been discovered, ore deposits at greater depths need to be found. Therefore, 3D-geometry of geological structures and their evolution through time (4D-modelling) need to be constrained.

The project aimed at developing robust 3-dimensional models of the upper 4 km of the Earth's crust in the Skellefte District. Modelling incorporated both geological and geophysical investigations and was carried out in three different scales: deposit-, semi-regional-, and regional-scale (Fig. 1). Based on these data a 3-dimensional multi-scale model was constructed using the gOcad software platform (Paradigm) allowing to visualize geological features from the detailed deposit-scale models of 21 VMS deposits to a regional-scale structural model. The combination of geological and geophysical data reveals the crustal architecture of the Skellefte District and the structural setting of

associated mineral deposits. In addition to the 3D-model, a 4-dimensional model schematically illustrates the geological evolution of the Skellefte District (Skyttä 2012).

2 Regional geological framework

The bedrock of the Skellefte district comprises 1.95 – 1.86 Ga Palaeoproterozoic volcanic arc rocks and associated intrusive rocks (Allen et al. 1996; Kathol and Weihed 2005). The main unit is the c. 1.9 Ga Skellefte Group, comprising mainly felsic, meta-volcanic rocks. The VMS deposits are located in the uppermost part of Skellefte Group stratigraphy at the transition to the overlying Vargfors Group which is characterised by meta-sedimentary rocks (Fig. 1; Kathol and Weihed 2005). The dominant intrusive rocks are represented by calc-alkaline, multiple phase intrusions of the Jörn intrusive complex (1.89 – 1.86 Ga; Bejgarn et al. 2012 and references therein). The rocks were deformed and metamorphosed during the Svecokarelian Orogeny at 1.90 – 1.80 Ga (Weihed et al. 2002). Structures in the Skellefte district are characterised by a distinct pattern of WNW-ESE and NNE-SSW-striking faults. Allen et al (1996), Allen (2005 unpublished company report), Collier (2008 unpublished company report) and Bauer et al (2011) have showed that these faults have a syn-extensional origin and have been reactivated during subsequent compressional events.

3 Geological and geophysical in-data

Regional and semi-regional scale field mapping and associated structural analysis were tested and validated by 2D-forward modelling with MOVE by Midland Valley Exploration Ltd. (Bauer et al. 2011). Combined with sedimentary facies analysis by Bauer (2012) and structural analysis with geochronological studies by Skyttä et al. (2012) a structural conceptual model was developed. This conceptual model was tested and validated by observation of the sparse drill-cores. For the deposit scale models abundant near-mine drill core data, level plans and cross-sections were available (Boliden Mineral AB). For regional scale modelling,

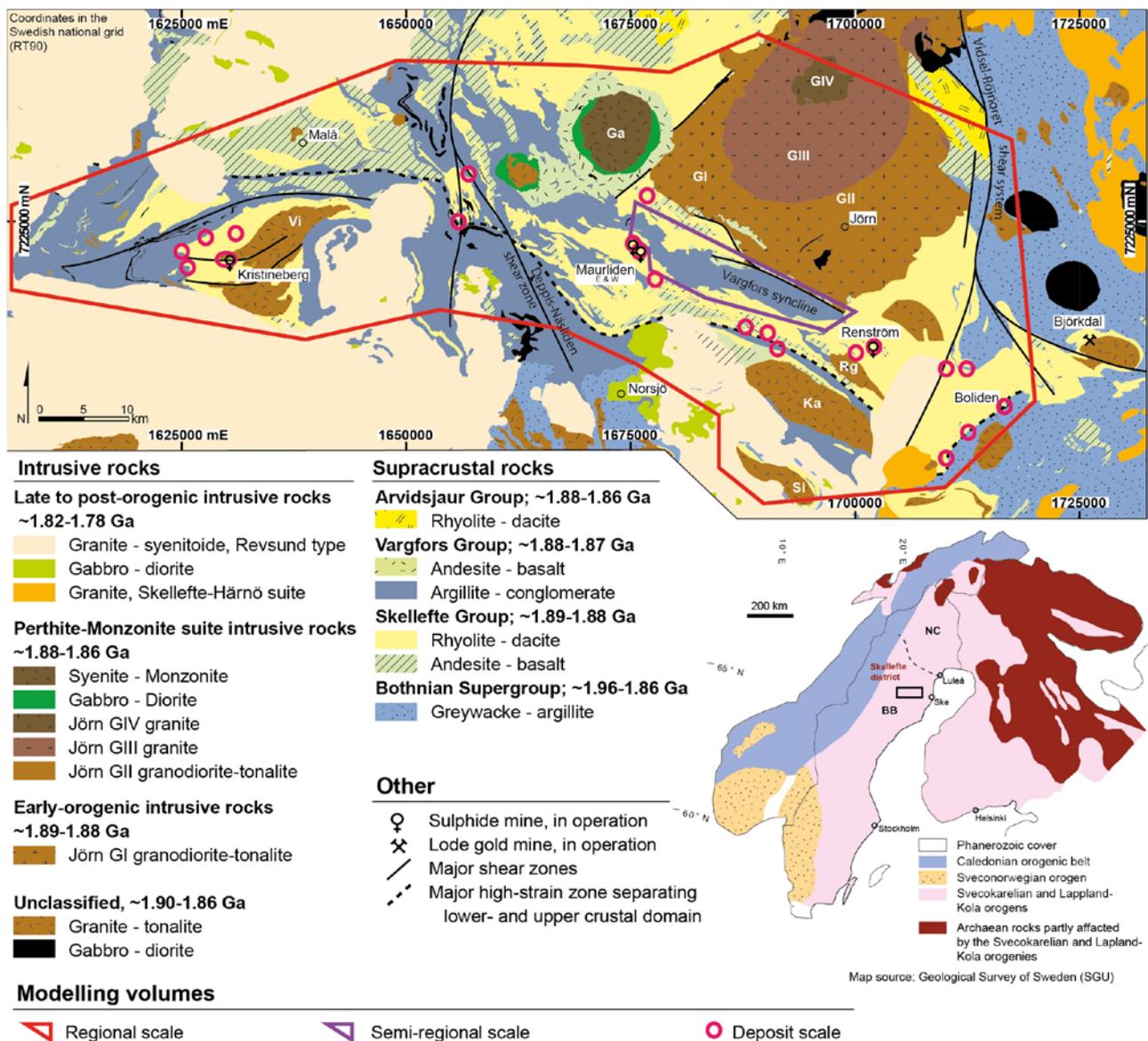


Figure 1. Inset map: Generalized Fennoscandian Shield geology. Geological domains: BB = Bothnian Basin; NC = Norrbotten Craton. The dashed line marks the boundary between the rocks with Archaean and Proterozoic Nd-signatures (Mellqvist et al., 1999). Geology drawn after Koistinen et al. (2001). Main map: Geological overview of the Skellefte district, as loosely defined by the occurrence of the Skellefte Group metavolcanic rocks, and their immediate vicinity. Intrusions: Vi = Viterliden, Ga = Gallejaur, Rg = Rengård, Ka = Karsträsk, Si = Sikträsk, GI, GII, GIII, GIV = Jörn type intrusions, phases I-IV. Geology after Kathol et al. (2005) and Bergman Weihed (2001).

142 km of seismic reflection lines along six profiles in the Kristineberg area, the central Skellefte district, and northwest of the district provided a framework for identifying major shear zones and lithological contacts (Malehmir et al. 2006, 2007, 2009a, 2009b; Dehghannejad et al. 2010, 2012a, 2012b; Ehsan et al. 2012). Additionally, 120 broadband magnetotelluric sites along six profiles and a 3D grid were recorded (Garcia Juanatey et al. 2012; Hübert et al. in review).

Geophysical semi-regional scale modelling in the central Skellefte district utilized electrical, potential field and petrophysical data (Tavakoli et al. 2012a, 2012b; Skyttä et al. 2012).

4 Modelling methodology

Several models were built at three different scales, whereas special emphasis was put at the regional scale model in this work. Three dimensional modelling was mainly carried out in gOcad (Paradigm) using the SPARSE plug-in (Mira Geoscience). To simplify modelling workflows, the regional scale modelling volume was split up into several semi-regional scale sub-projects. For each sub-projects available data was imported in form of maps and cross-sections into gOcad. Drill holes were visualised as lines with attached lithological information. Structural measurements were visualised as disks and lineation vectors with real 3D orientation. Furthermore, strike and dip values of

geological contacts were interpolated along the map traces of the corresponding contacts. Based on these results, structures and lithological contacts were modelled in three dimensions as surfaces (Fig. 2). VMS deposits were either available as 3D-models from the Boliden Group exploration department or modelled from digital and paper level plans and cross-sections.

5 Uncertainties

Modelling uncertainties were assigned for the final 3D-model of the Skellefte district in order to visualise the bases on which 3D-surfaces and bodies were constructed.

The resulting uncertainty model shows the distribution of primary data, interpolation of structural data, interpretation of geophysical data as well as areas without sufficient data. In order to visualise the modelling uncertainties, uncertainty values from 1 to 4 for the relevant regions on the 3D-objects have been assigned and colour-coded (Fig. 2). The assigned uncertainty values represent: 1) observed in field, mine or drill-core; 2) interpreted from geophysical data;

3) Interpreted from structural data or extrapolated from geophysical data, and 4) inferred / unknown.

6 Description of the model

The current 3D-model shows a series of parallel, regional-scale, south-dipping faults which are cross cut by a set of north-dipping ones (Fig. 2). In the central Skellefte district a set of sub-vertical faults approximately perpendicular to the previously named ones are presented. The geometry of the ore bodies, which are mainly adjacent to the faults, generally reflect the deformation features of the associated faults. The lower-strain domains between the major faults are characterized by either semi-regional scale syn- and anticlines with inclined or doubly-plunging fold axes, for example the Vargfors basin, or uniformly-dipping strata sub-parallel to the faults. In general, significantly more domains with gently-dipping bedding have been recognized which allows for enhanced stratigraphical correlations in the future. Several intrusive suits are represented by irregular bodies and coloured according to their age.

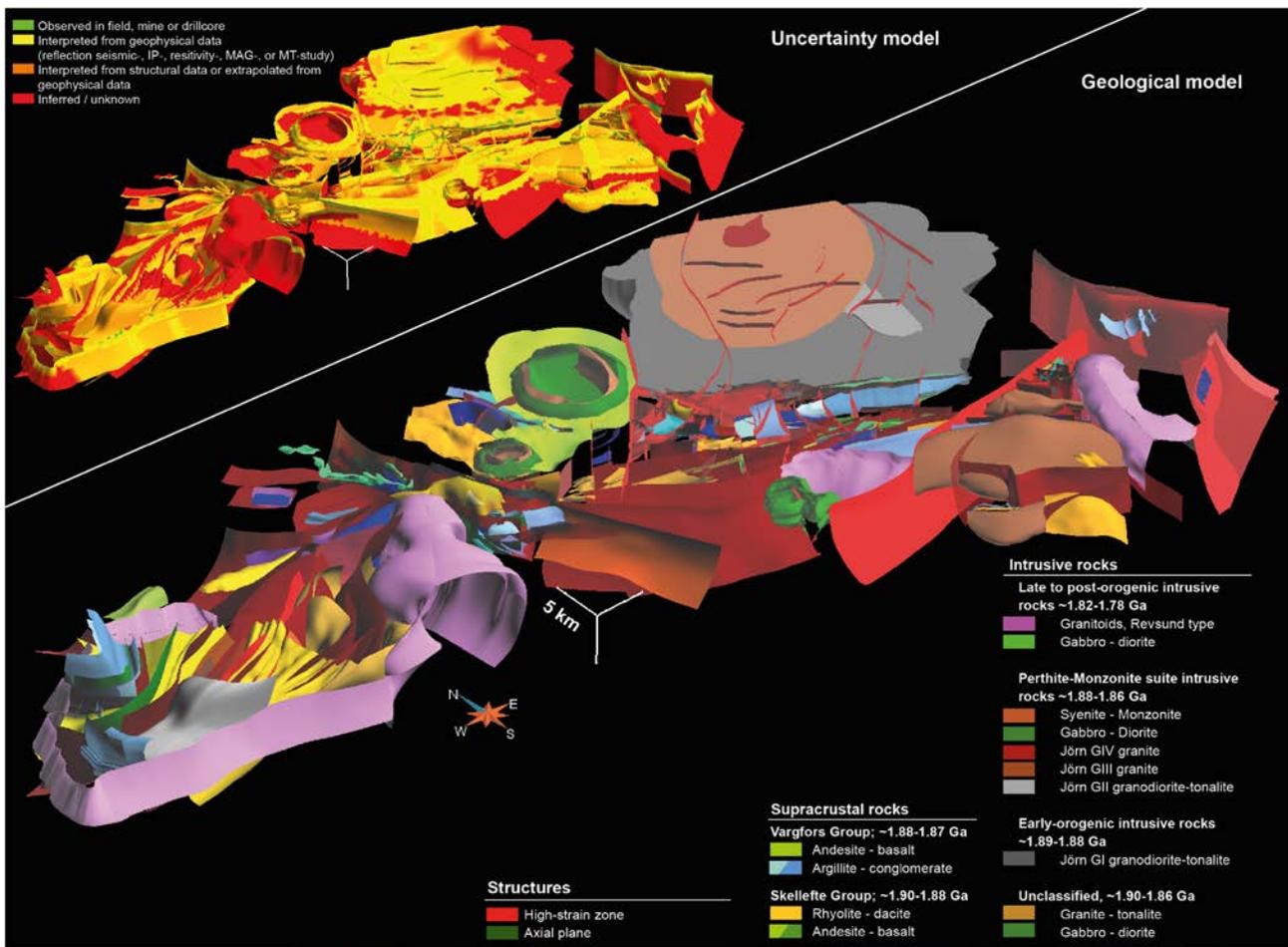


Figure 2. Screenshot from gOcad showing the regional scale, geological 3D-model and the uncertainty model of the ore-bearing Skellefte district.

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