

## 4-DIMENSIONAL GEOLOGICAL MODELLING OF THE SKELLEFTE DISTRICT, SWEDEN

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**KEY WORDS:** 4D-modelling, Skellefte District, ore deposits, Palaeoproterozoic, reflection seismic, inversion modelling, structural geology

### ABSTRACT:

The Skellefte mining District is located in northern Sweden and comprises Palaeoproterozoic, metamorphosed, supracrustal rocks and associated intrusive rocks, which are all host to several ore deposits. Modelling was performed in the GoCAD software platform, using structural geology and petrology as well as magnetic, gravity, seismic, electric and electromagnetic geophysical data, in order to produce robust 3-dimensional models for the upper 3000 m of the Earth's crust in selected areas within the Skellefte District. Further interpretations from the regional structures and tectonics are providing a base for restoring the geological history of the district in time, the 4<sup>th</sup> dimension.

### 1. INTRODUCTION

The project aim is to develop geological models that visualise the key spatial, geological, geophysical, geochemical and economic parameters of the western and central part of the Skellefte mining district, including the known ore deposits, in 3D and 4D. This is achieved by using detailed thematic geo-information gathered at scales from regional down to individual deposits. The distribution of geological units, structure and tectonics as well as magnetic, gravity, seismic, electric and electromagnetic geophysical data are utilised to produce robust 3-dimensional models for the upper 3000 m of the Earth's crust in selected areas within the Skellefte District, combining the results from new high-resolution reflection seismic recordings, and other high-resolution geophysical measurements with results from new detailed structural mapping of the same areas. Data are modelled in the GoCAD software platform (Paradigm) to construct the 3D GIS models, which are further interpreted in the 4<sup>th</sup> dimension with constraints from regional structures and tectonics.

The project is subdivided into two main parts: 1) geological investigations and 2) geophysical measurements and interpretations. The aim of the geological field work is to derive a robust structural evolutionary model which can then be utilised in combination with the geophysical data to derive a 4D evolutionary model for the Skellefte district. In the second subproject, new high resolution seismic data are collected together with new electromagnetic data from the same areas. The seismic data are processed and, if feasible, migrated, then interpreted together with the electromagnetic data and other geophysical and geological information.

### 2. MODELLING

#### 2.1 Geological framework

The bedrock of the Skellefte District is composed of 1.95 – 1.85 Ga Palaeoproterozoic island-arc volcanic rocks and associated intrusive rocks (Allen et al. 1996). The dominant unit is the 1.89 – 1.88 Ga, ore-bearing, Skellefte Group, comprising mainly felsic, meta-volcanic rocks, while the above lying Vargfors Group is characterised by meta-sedimentary rocks (Kathol and Weiher 2005). The intrusive rocks consist of calc-alkaline, multiple phase intrusions (1,9 – 1,85 Ga). The rocks were deformed and metamorphosed during the Svecokarelian Orogeny at 1.90 – 1.80 Ga (Weiher et al. 2002).

#### 2.2 Geological interpretations

The Kristineberg area in the western part of the Skellefte District forms the first focus area of the project. So far, the focus has been on providing reliable background geological data to enable construction of a solid 3D model of the area. These pre-3D modelling steps included studies on the orientation of the magnetic properties of rocks (AMS) and determination of their age. The AMS studies indicate a two-phase crustal evolution, including early, reverse, dip-slip faulting that was overprinted by strike-slip shearing. The first, dip-slip deformation phase is also considered largely responsible for the structural geometry of the area, including the shape of the Kristineberg ore bodies. The geochronological results are still preliminary, and will after processing, give further constraints on the timing of intrusive activity and ore-formation.

The second focus area of the project comprises the Central Skellefte District where structural mapping was carried out in

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the area around the Vargfors basin. Detailed mapping of structures and stratigraphy resulted in a better understanding of the geological history. A part of the Vargfors basin was restored by unfolding and unroofing each single fault (Fig. 1). The restoration reveals the formation of fault bound compartments with varying internal structures and stratigraphy caused by the formation of a complex pattern of pre-sedimentary normal- and transfer faults. The primary geometry and different petrophysical properties of the lithologies control the later structural overprint. This modelling derived a 3D voxel-model of the deformation history and is the base for kinematic modelling in the area.

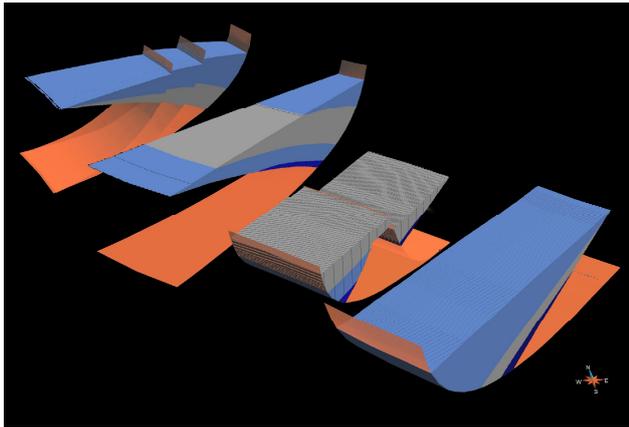


Figure 1. Restored geometry of fault bound compartments within the Vargfors basin. Each compartment is separated from each other by transfer faults.

### 2.3 Geophysical interpretations

Inversion modelling of gravity and magnetic data has been carried out in the central Skellefte District, using petrophysical properties, measured from 220 samples from 30 drill cores in the vicinity of the seismic and resistivity profiles. The apparent resistivity and induced polarization of the shallow subsurface along two seismic profiles in the central Skellefte District were measured, using the pole-dipole method as a survey array, in order to identify geological features with a thickness of >100 meters (Fig. 2). Testing different geological scenarios in 2D and 3D is executed to create a forward model of the resistivity profiles and to check how different geological scenarios will respond after the inversion.

Four new high resolution reflection seismic profiles (85 km in total) have been acquired, two perpendicular profiles in the Kristineberg mining area and two nearly parallel profiles in the central part of the Skellefte District. A series of steeply dipping (Fig. 3; M1 and C1) to sub-horizontal reflections (Fig. 3; E1 and E2) could be identified, allowing correlation with surface geology. Some of these reflections (e.g., M1) appear in direct connection with the main ore horizon in the Kristineberg mine, which extends down to a depth of about 2 km.

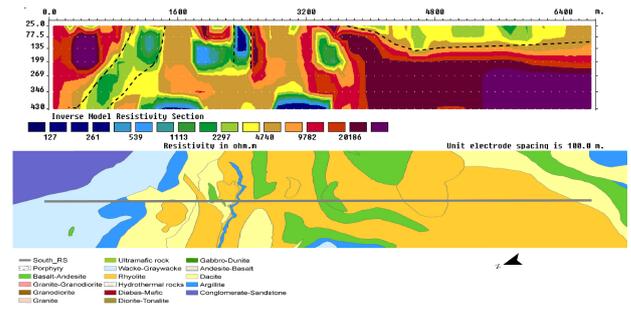


Figure 2. Inversion result from the southern resistivity profile (dashed lines indicate major geological contacts) and the location on the geological map.

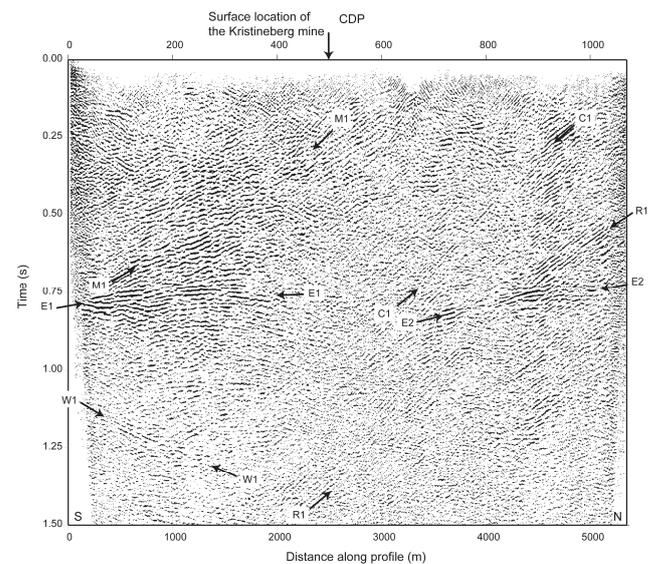


Figure 3. Stacked section of one of the high resolution seismic reflection profiles in the Kristineberg mining area.

Electromagnetic data was recorded along the seismic profiles in the Kristineberg area, showing good correlation with observed reflectors. Further structural information and an approximate extension of the major geological units of the area can be extracted from the models. Moreover, the new models provide a better delineation of conductive features at depth, associated with strong reflections in the seismic profiles, previously interpreted as a structural basement for the volcanic rocks.

### 2.4 Modelling techniques

A multi-scale model was constructed by integrating data from regional to outcrop scales (Fig. 4). Due to a negligible topographic relief at this scale (less than 400 m elevation difference within an area of ca. 2400 km<sup>2</sup>), it is sufficient to construct a digital elevation model (DEM) from regional scale topography data, provided by the Swedish survey (Lantmäteriet), using “triangulated irregular network” (TIN) interpolation methods in ArcGIS (ESRI). Geological surface information was collected, combined and simplified from published maps (Allen et al. 1996, Kathol et al. 2005) and own field mapping.

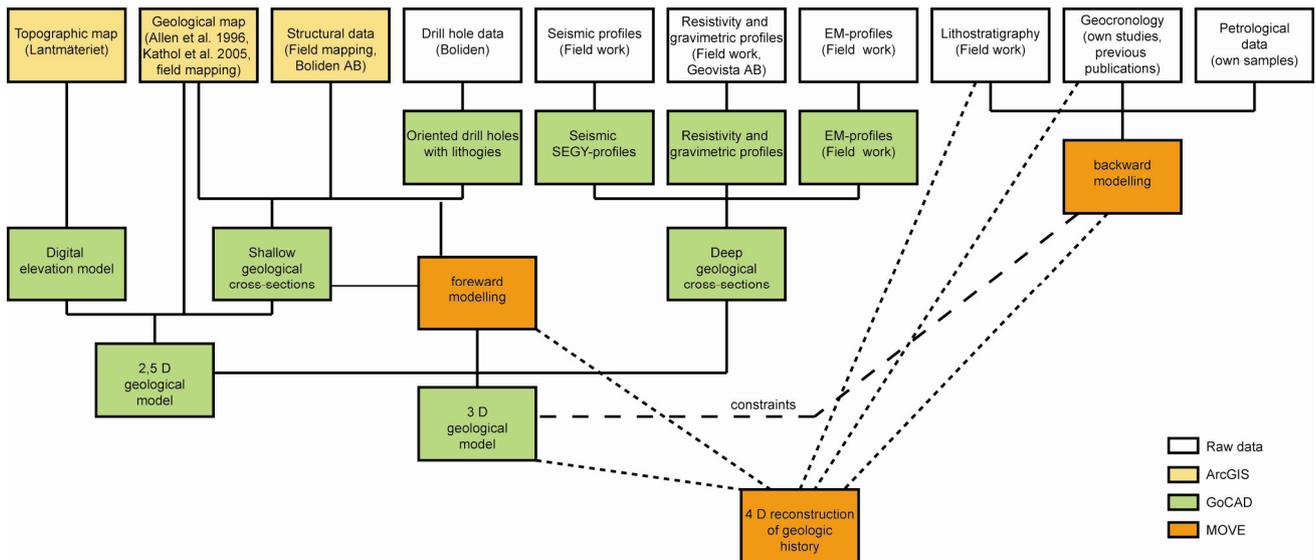


Figure 4. Flow chart visualizing use of primary data (sources in parentheses) and work flow towards the existing 3<sup>rd</sup> and the planned 4<sup>th</sup> dimension.

Structural geological measurements from own field-campaigns as well as data provided by the mining company Boliden AB and the Swedish geological survey (SGU) were integrated. To provide sub-surface depth control on the general geometry of geological bodies, seismic, gravimetric and resistivity profiles as well as drill hole logs were converted to DXF-format and imported into GOCAD (Paradigm).

In the regional scale, the outlines of the main geological bodies were directly drawn onto the profiles. In areas where no profiles were available, geological modelling was carried out by using the sparse-module (Mirageoscience), which allows the import of structural field-measurements in tree-dimensional orientation. After the outline digitalisation of the main geological units and bodies (map traces), the properties of the structural measurements can be transferred onto these map traces and interpolated along them. This allows construction of e.g. mean bedding planes from strike-dip readings but also construction of foliation planes and simple fold structures (Fig. 5). However, prerequisite for this procedure is a certain amount of field data.

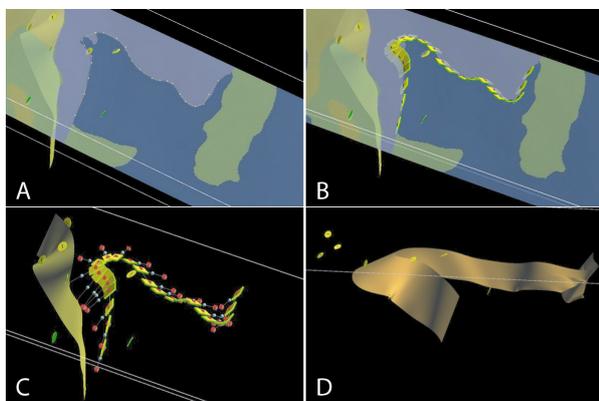


Figure 5. Modelling a folded surface from structural measurements using the Sparse-module in GoCAD. A: Creating a map-trace; B: Transferring and interpolating dip-values; C: Creating a grip-frame; D: Creating a surface

In the deposit scale, the outlines for the main ore bodies were provided by Boliden AB in DXF-format. The models for the minor ore bodies are based on digitalised level-plans and cross-sections, drawn according to drill hole data.

Restoration of small-scale geological profiles (Fig.1) was operated so far manually along selected geological cross-sections, where sufficient knowledge about the deformation history is evident. Due to the complicated kinematic evolution it was needed to understand the complex behaviour of different rock types during their deformation. Thin section analyses showed the role of carbonate-rich basal layers as glide-horizons during crustal shortening. Based on these results tests on different types of kinematics scenarios are analysed at present using the 3D and 4D MOVE software (Midland Valley Exploration Ltd.) as shown in figure 6.

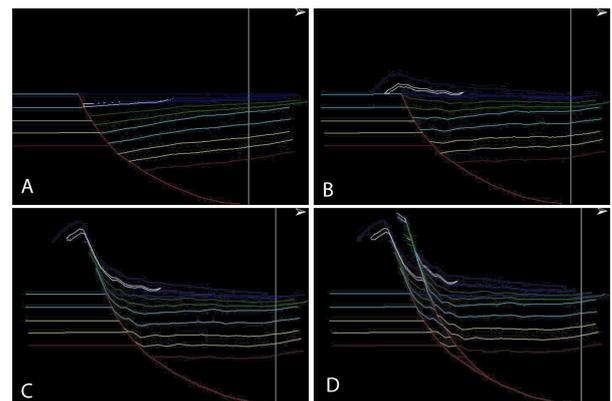


Figure 6. Modelling a small-scale inverted Vargfors basin with simulation of a ductile basal-layer in MOVE. A: primary shape of the half-graben; B: Starting point of folding during crustal shortening; C: Increased gliding along the base; D: Formation of break-back faults during progressive shortening.

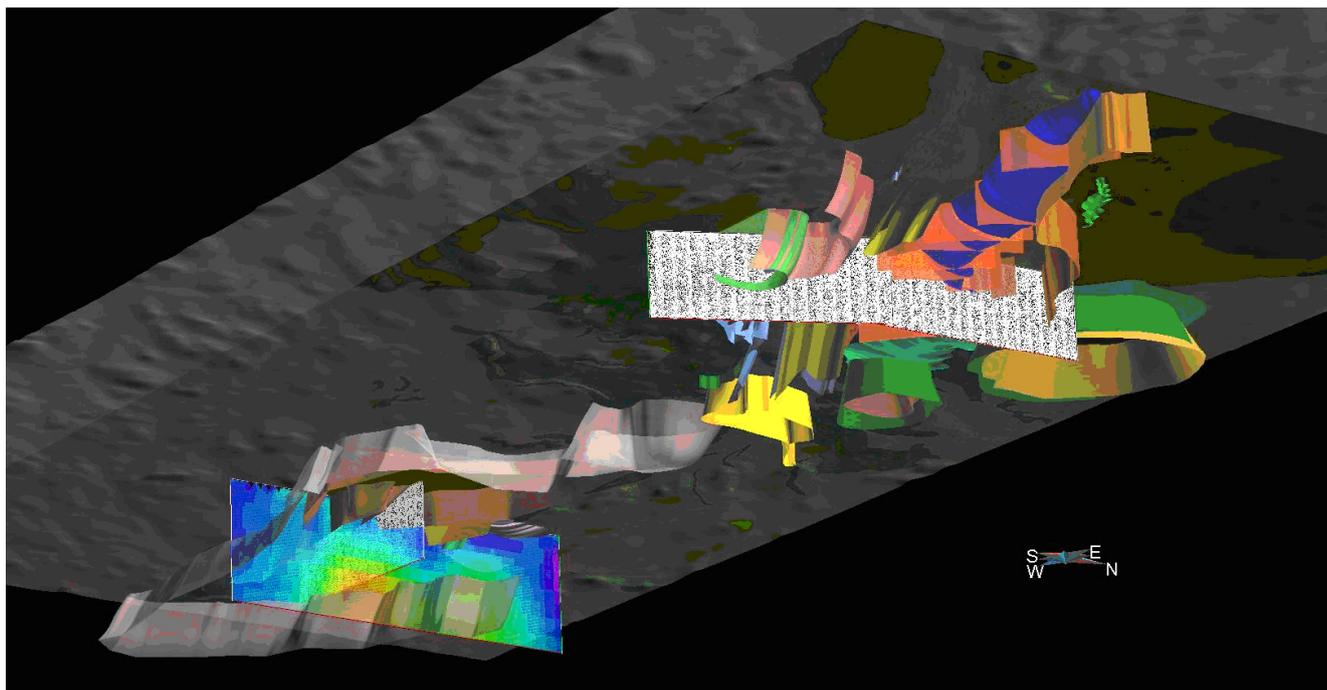


Figure 7. 3D geological model of the Skellefte District (viewed from below and from SE), showing the major geological boundaries, a high resolution seismic reflection profile and the EM-profile. Modelling software: GoCAD. Map source: Kathol et al., 2005.

### 3. FUTURE WORK

The project will after this field season enter a new phase, where all acquired data will be used to refine the existing 3D-model (Fig.7) of the western and central Skellefte district. Results from these studies will be combined with the 3D-model in order to construct the 4-dimensional geological evolution (especially deformation history) of the Skellefte District. Furthermore the results can be used in the future to apply kinematic behaviours of rock packages to areas where little or no surface data is available, to be able to increase predictability of undiscovered ore deposits.

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