4-dimensional geological modelling of mineral belts

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Background

Modelling of the 4D-geological evolution of mineral belts is currently not only an attractive but also an increasingly necessary branch of exploration-related geological research. This because most of the near-surface deposits, in particular in mature ore districts, have already been found, which forces ongoing exploration to aim at greater depths. Consequently, an improved understanding of the 3D geometry of Earth's crust, and its evolution through geological history is required to gain success in future exploration. To achieve this goal, multidisciplinary approaches including various geological and geophysical methods need to be implemented and integrated. Modelling of the Skellefte District in Sweden has been carried out from April 2008 under research projects "VINNOVA 4D-modelling of the Skellefte District" and "ProMine".

Results

Main results of the research project comprise enhanced knowledge on the main geological features involved, e.g. constraints about fault geometry in the uppermost ~5 km in the sub-surface from the seismics, fault kinematics from the surface observations and related microstructural investigations, dip of lithological contacts in the Vargfors Basin from IP, resistivity and potential field modelling. Below we provide a brief overview on the challenges and advantages arising from 3D/4D-modelling in variable scales and with variable source data arising from the geological nature of the modelled sub-areas. Furthermore, main results from the geological and geophysical investigations providing input into the conceptual regional-scale modelling will be summarized.

Multi-scale modelling in 3 and 4 dimensions

Determining the scale and amount of detail for regional 3/4D models is a challenge as both the geological structures and source data typically vary significantly in proportions. The most detailed models from the district, the Kristineberg and the Vargfors Basin, are approximately in the same scale but constrained by completely different types of data: exploration- and production-related drilling in the Kristineberg mine area allows for good control down to ~1500 m below the surface, whereas some of the structures may be correlated to even greater depths by interpreting the two new seismic reflection profiles and new MT-data acquired during the 4D modelling project. The main challenges in the Kristineberg area arise from the lack of outcrops around the mine, and the strong ore-related alteration hampering the control over the primary lithostratigraphy. Contrary to the Kristineberg area, the Vargfors Basin is well-exposed and allows for detailed field-mapping, and thus for good control on the structural geometry and distribution of lithological units. Additional constraints are provided by measurements on apparent resistivity and induced polarization of the shallow subsurface down to ~1200m levels. The main challenge in this sub-area is to define a kinematic framework honouring the displacement sense, style and offset along the compartment-bounding faults. District-scale modelling benefits from the more detailed sub-projects described above. Its focus lies in understanding the larger-scale tectonic evolution of the region, but will eventually provide feedback to the more local-scale models, thus also contributing to the exploration models and ore targeting.

The geological surfaces and solids have been modelled with gOcad software with the Sparse plug-in, from Paradigm and Mira Geosciences, respectively. The step over to the fourth dimension is so far comprised of conceptual modelling, but will in the future be applied to all scales and modelling targets. Initial 4D-animations have been constructed using Midland Valley Exploration's MOVE™ platform (Figure 1). More specifically, the MOVE™ 2D-block was used for initial model construction and later conditioning, whereas the 3D-block served as the platform to the model completion and visualization. Experience from modelling the Skellefte District has shown that the differences in local geology, and thus on the modelling scales, provide interactive feedback between the different sub-projects and, hence, help in constructing regionally valid geological 3/4D-models.

Seismic investigations

Three new reflection seismic profiles with a total length of about 95 km have been aquired in the Central Skellefte District. The processed data shows a series of south dipping reflectors which were correlated with field observations and interpreted as inverted listric faults. North-dipping reflectors in the northern part of the profiles could be assigned to late-compressional break-back faults defining the southern contact of the early-orogenic Jörn intrusive complex. In the area of the Vargfors Basin, a system of synthetic and antithetic faults could be affirmed from seismic reflectors. Flat-lying diffraction- and reflection-packages in the central part of one profile reveals a set of syn-extensional fault blocks. Figure 3 shows a portion of the stacked and migrated section along the new profile, respectively.In the vicinity of the Maurliden VMS deposit, we determined previously unkonown faults which might be responsible for localization and transposition of VMS ore bodies. More work to combine the results of the seismic data with geological observations is going on to constrain the 3D geologic model of the central part of the Skellefte district.

IP, resistivity and potential field modelling

During the first phase of resistivity/IP investigations, two profiles with a total length of 12.4 km were acquired in the central part of the Skellefte District to map the subsurface down to ~430 m depth (Figure 2). After inversion of the geophysical data, major lithological units could be identified. These results were later used as constraints in a more regional-scale potential field modelling. Due to the success of the first-phase electrical measurements, the previous profiles were extended such that they both cross the Skellefte River. The new electrode configurations allowed us to model the data down to 1.5 km, in which the interpretation is still ongoing.

New geochronology data

Five new U-Th-Pb ion-probe age determinations on zircon were performed on samples from the Palaeoproterozoic Skellefte District. The new age results indicate that intrusive and volcanic activity was synchronous throughout the Skellefte District at ~1.89 Ga, when the Viterliden intrusion in the Kristineberg area was emplaced during a period of ~5 Ma from 1892 ± 3 Ma to 1889 ± 3 Ma. Age of the hanging-wall rhyolite, together with correlations between the intrusive units constrain the minimum age for VMS ore deposition at 1889 ± 3 Ma. Furthermore, main compressional deformation within the Skellefte District is constrained between 1875-1865 Ma, ~5-15 Ma after the active volcanism and sedimentation.

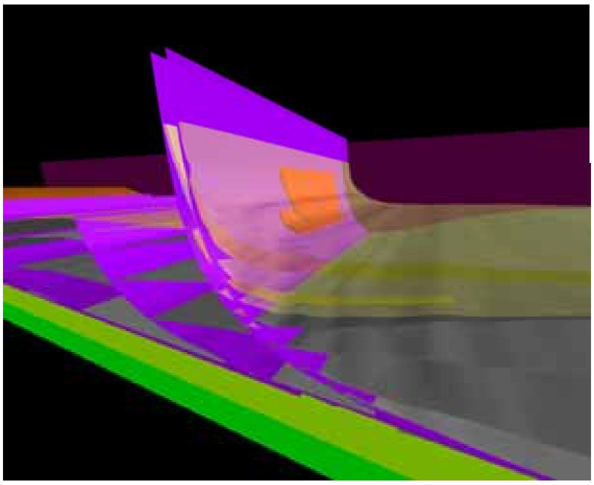

Figure 1. *One step out of the first schematic 4D-animation over the crustal evolution in the Skellefte District.*

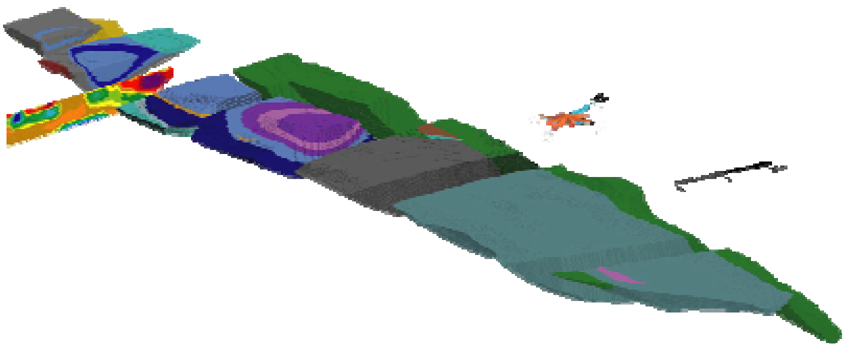

Figure 2. *A voxel model of the Vargfors syncline in the central Skellefte District. The model is constrained by structural geology mapping and resistivity/IP surveys (profile in the western part of the figure).*

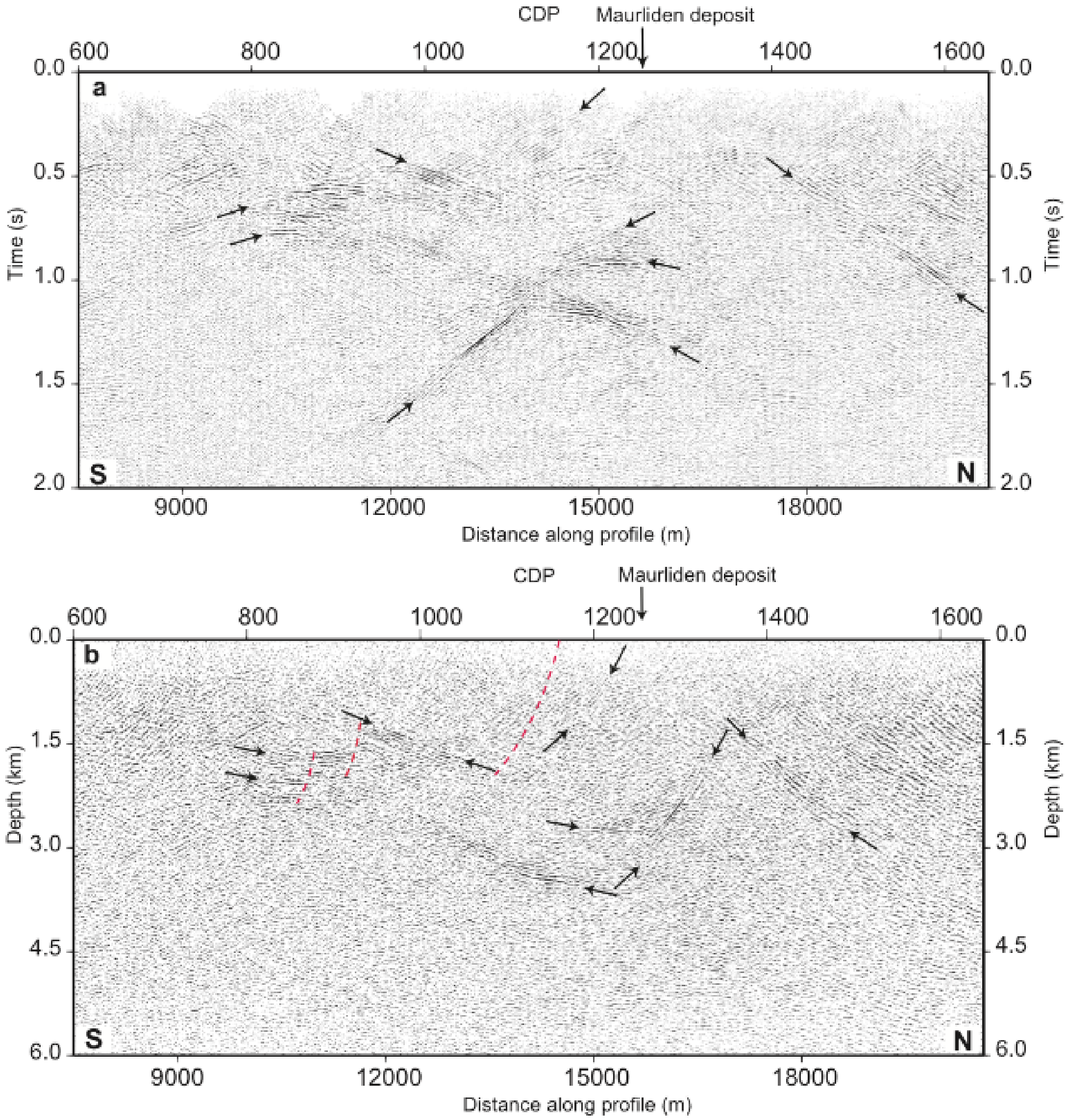

Figure 3. *A) A portion of the stacked section along the new seismic profile, where the profile passes the Maurliden deposit, and B) the migrated section along the same portion of the profile.*