Applying Variscan Metasediments as an EGS Reservoir – Preliminary Stages of Outcrop Analogue Characterization in the Western Harz Mountains, Germany

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Introduction

As the world's need for renewable energy resources increases, the possibilities for deep geothermal exploitation are becoming more viable. Despite having huge potential in Europe, there are only a few commercial geothermal plants using EGS (Enhanced Geothermal Systems), in crystalline, metamorphic rocks. One of the aims of the EU-Horizon-2020-MEET-project (**M**ultidisciplinary and multi-context demonstration of **EGS** exploration and **E**xploitation **T**echniques and potentials) is to explore and bring about this potential in Variscan crystalline and metasedimentary reservoirs *(Trullenque et al, 2018)*.

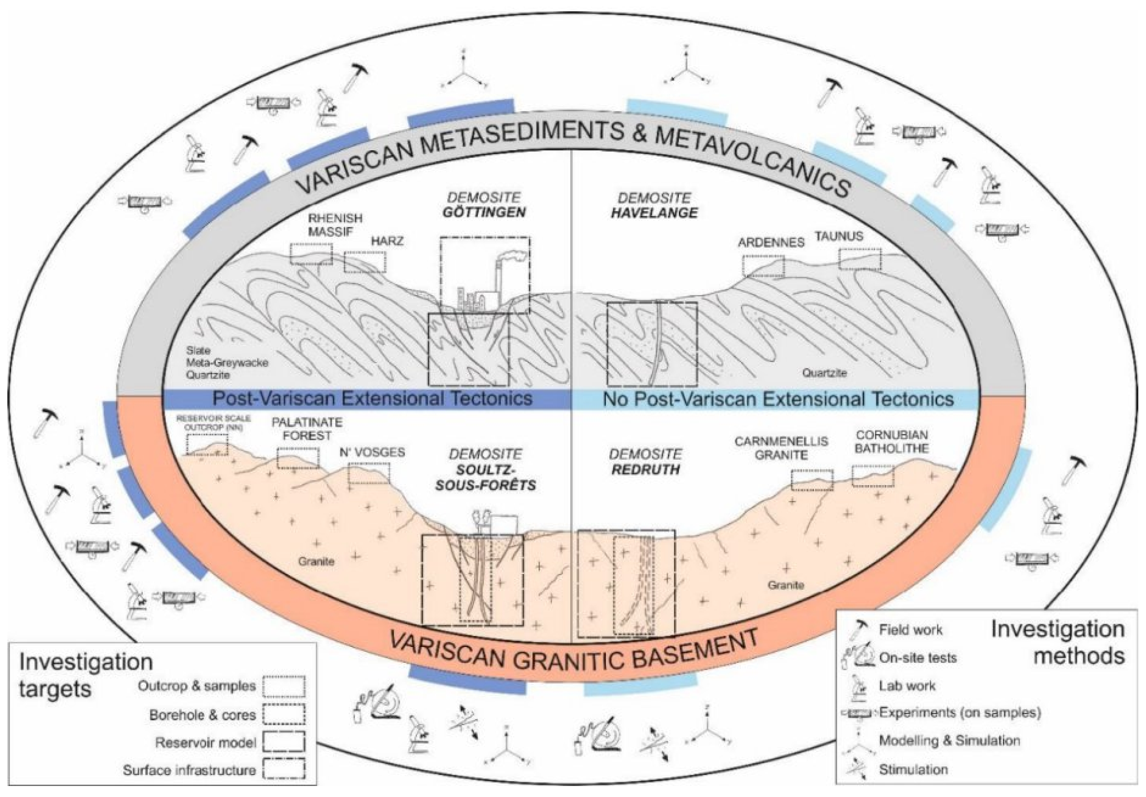

Fig.1 - *Diagram indicating the four demonstration sites in the EU MEET Project, the geological setting and investigation methods. Diagram by Bianca Wagner. Trullenque et al, 2018.*

Göttingen Demonstration Site

The University of Göttingen operates its own natural gas power plant that generates both heating and electricity around the campus. However, it is currently investigating the potential for the district heating of the campus via geothermal power. After two seismic surveys recently undertaken *(Leiss et al, 2011)*, the target horizon has been identified. The Mesozoic sedimentary cover as well as the Permian successions, continues to a depth of 1500 m, with the Variscan basement beneath. It is thought that the basement comprises of Variscan metasediments (meta-greywackes, slates and quartzites) with a very high anisotropy. These have then been over printed by younger tectonics related to the Leinetal Graben system. The aim of this research project will be to create a conceptual 3D-structural model of the subsurface of Göttingen campus, collecting data from various outcrop analogues in similar structural settings. Separately to MEET, an exploration drilling programme is in the preparation phase, drilling to 2000 m depth. This will allow for the characterisation of the basement rock and detect the most appropriate horizon for EGS *(Leiss and Wagner, 2019)*. This will be the first drilling project that extends into the Variscan basement of Göttingen.

Analogue Site

The Western Harz Mountains has been chosen as the analogue site for this project *(Leiss et al, 2016)* for many reasons. It is well known by the Department of Structural Geology and Geodynamics, with fieldtrips often taking place there. As well as this, Göttingen is situated roughly 40 km SW along Variscan strike to the Western Harz itself. Therefore, similar structures are expected to be exposed. The boundary that separates the autochthonous and par-autochthonous zones from the allochthonous can be traced from the Rhenish Massif (SW of Göttingen) along strike to the Harz Mountains. Therefore through interpolation, Göttingen is expected to sit across this boundary.

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Clausthal Culm Fold Zone

The area of data collection is focused in what is known as the Clausthal Culm Fold Zone (Clausthaler Kulmfaltenzone, CCFZ), situated just NW of the boundary previously mentioned, in the autochthonous zone. Lithologically speaking it is characterised by Early Carboniferous, syn-orogenic, pre-flysch and flysch deposits. Flinty slates and alum slates are overlain by argillaceous slates, which grade into thick greywackes. This distal shelf facies has been termed the "Culm facies". The post-orogenic granite body (known as the Oker Granite) has caused the Culm facies surrounding this to be partly subjected to contact metamorphism. Tectonically this zone is characterised by NW-verging folds (NE-SW fold axes), with penetrative fold axial parallel cleavage (as seen in figures 3-6). These fold structures are mostly broken up by parallel striking thrusts *(fig.3)*, *(Mohr, 1998)*, giving the classic Hercynian fold and thrust structures seen throughout Western Europe. Younger WNW-ESE strike slip faults affect the CCFZ heavily and are well known by locals for their abundance of minerals, often termed "The Upper Harz Veins".

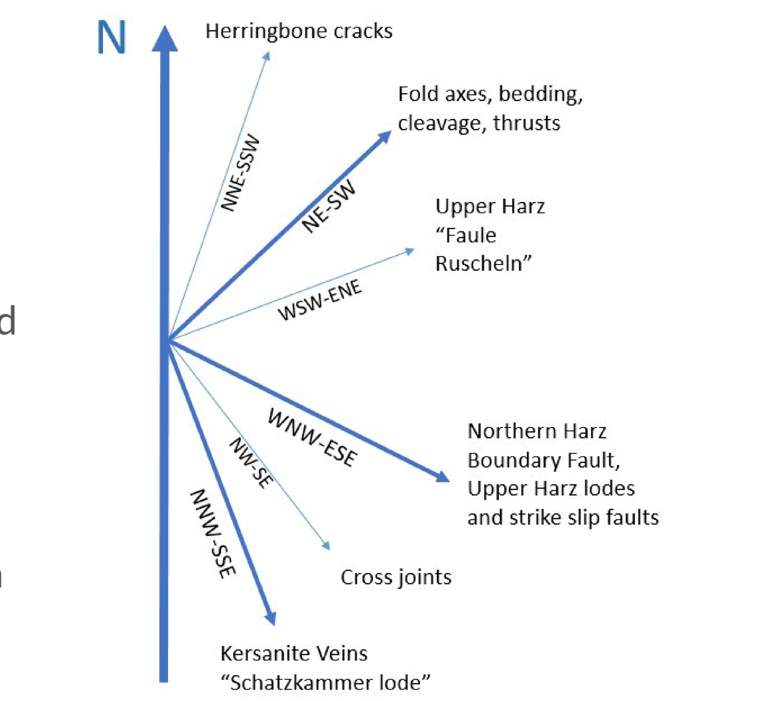
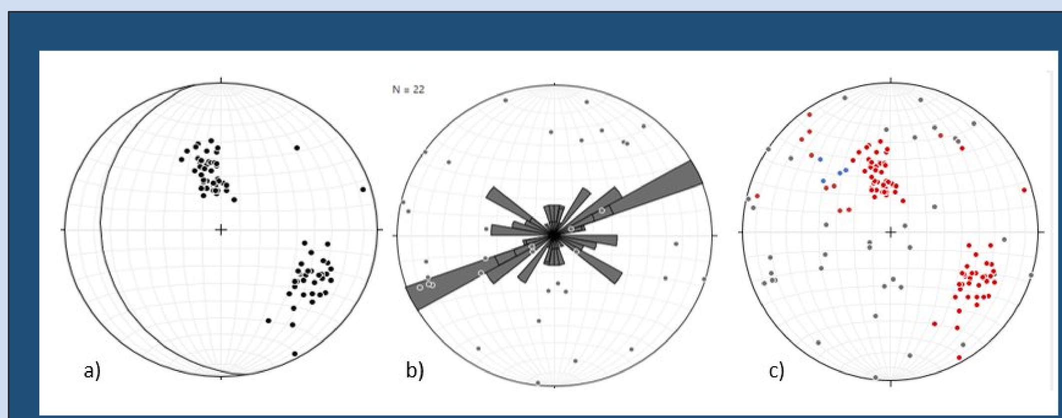


Fig.7 *– Orientation families seen in the Upper Harz. Diagram originally from Mohr 1998, recreated by Zeuner, 2018 unpublished.*



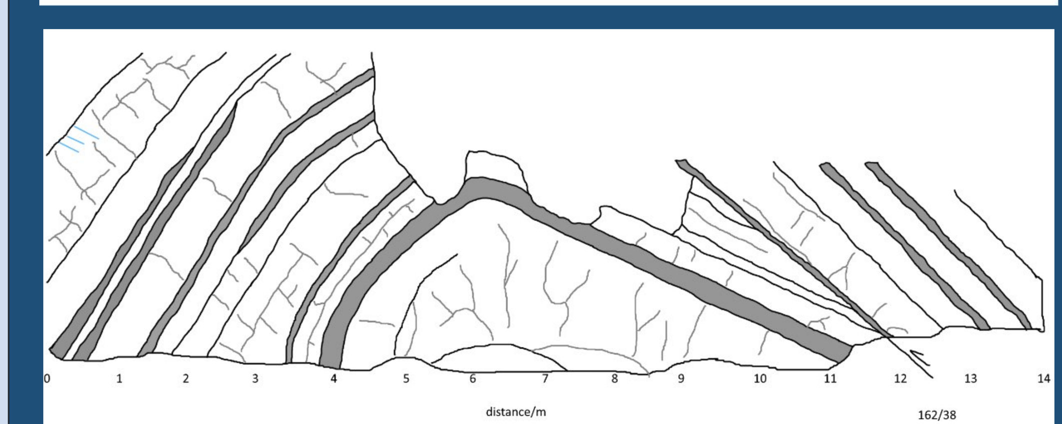
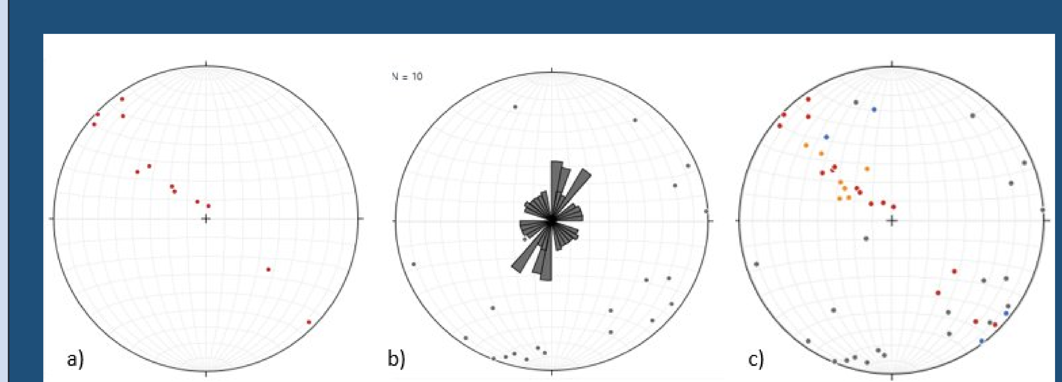


Fig.3a *– Stereonet of the corresponding bedding data for the field sketch. Fold axis in black plane.*
Fig.3b *– Stereonet and rose diagram of fracture data, indicating the clear dominance of the NE-SW orientation set, and a NW-SE trending set that is less dominant.*
Fig.3c *– Stereonet with a summary of data taken from this outcrop. Red-bedding, blue- cleavage, grey-fractures.*
Fig.4 *– Digitised field sketch of a classic fold hinge and thrust relationship as seen in the CCFZ.*



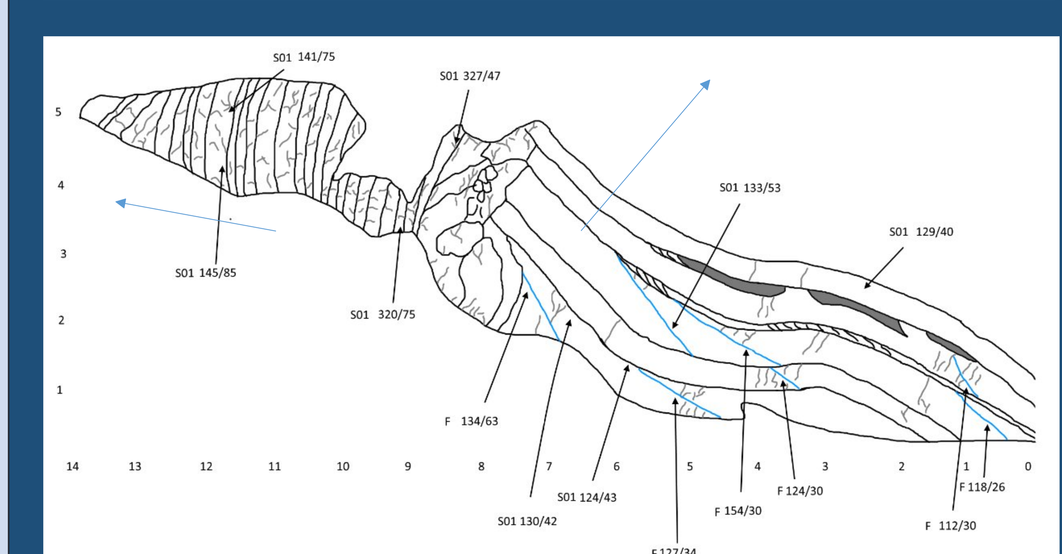


Fig.5a *– Stereonet with projected bedding data for figure 6. Evidence for a classic NW-SE verging fold.*
Fig.5b *– Stereonet and rose plot of fracture orientations measured at figure 6. Showing a heavy dominance for N-S to NE-SW oriented fracture families.*
Fig.5c *- Stereonet with a summary of data taken from this outcrop. Red-bedding, Yellow-thrust structures, blue- cleavage, grey- fractures. Blue arrows indicate direction of younging.*
Fig.6 *– Field sketch showing another way these classic NW-SE verging fold and thrust structures can be seen in the field.*

Methods

Due to the relatively sparse outcrop situation in the Western Harz, outcrop analogues are mostly limited due to accessibility and quality. However, shore areas of water reservoirs are prominent in the Harz as well as road cut walls and a few abandoned and active quarries, providing reasonable quality outcrops. The initial field campaign involved characterising the available outcrops for a clearer general understanding of the deformation styles found in the CCFZ. Further data collection will be much more focused for information on the more localised deformation styles. Structural data was then taken using, digital and manual methods, including photogrammetry. By analysing the data collected in the field, and the literature surrounding the behaviour of fold and thrust structures, a simplified cross section of the field area contained in the CCFZ can be created. Once the fold and thrust behaviour is understood, the changes in the fracture network parameters across these structures can be mapped. Fracture family characteristics, density and distribution can be analysed and their changes in comparison to the fold and thrust structures realised. *(e.g. Stephen et al. 2016,Watkins et al. 2018)*.

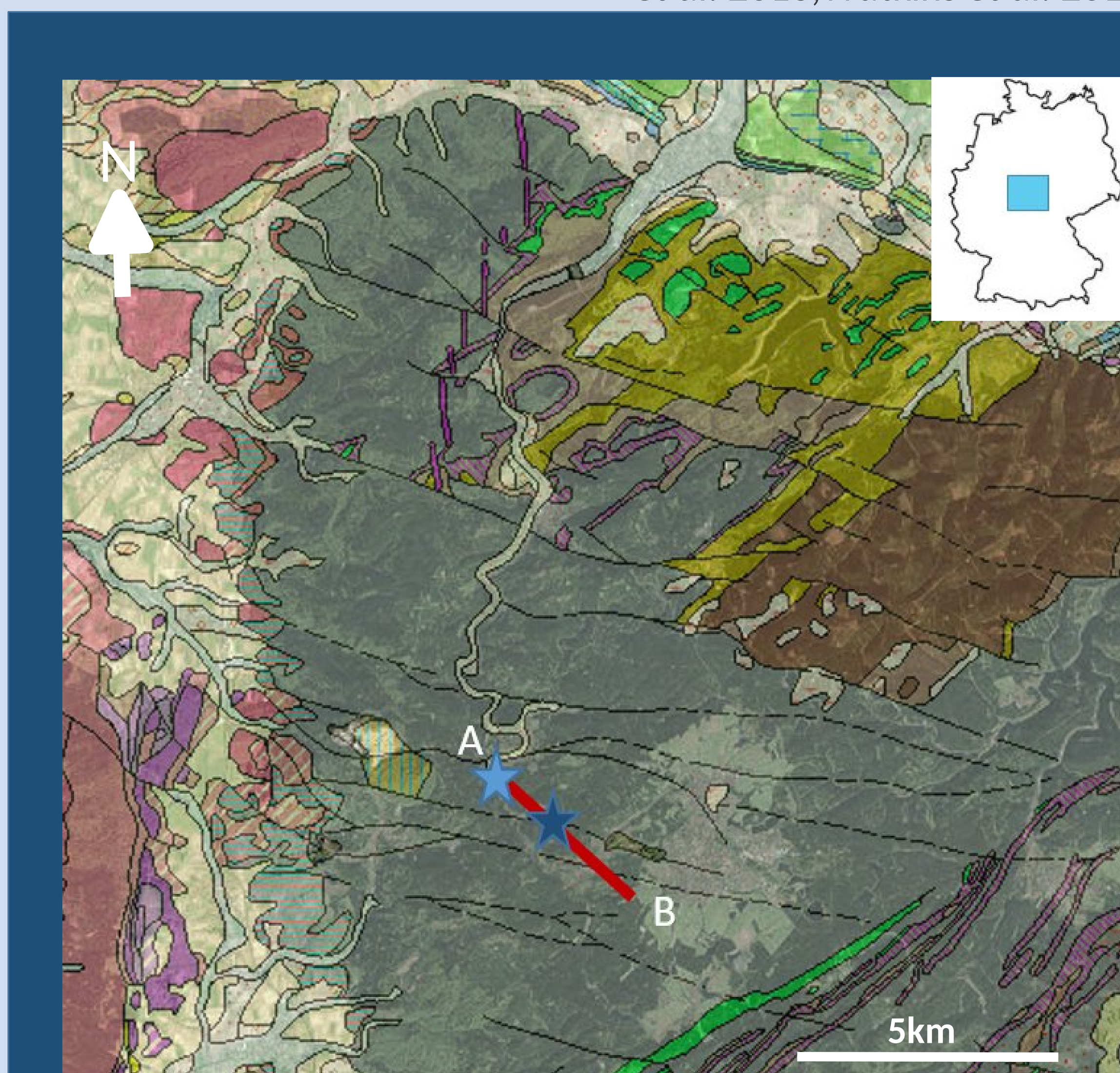


Fig.8 *– Geological map of the Western Harz Mountains. Red line – Cross Section area, light blue star location of fig.4, dark blue star location of fig.6*

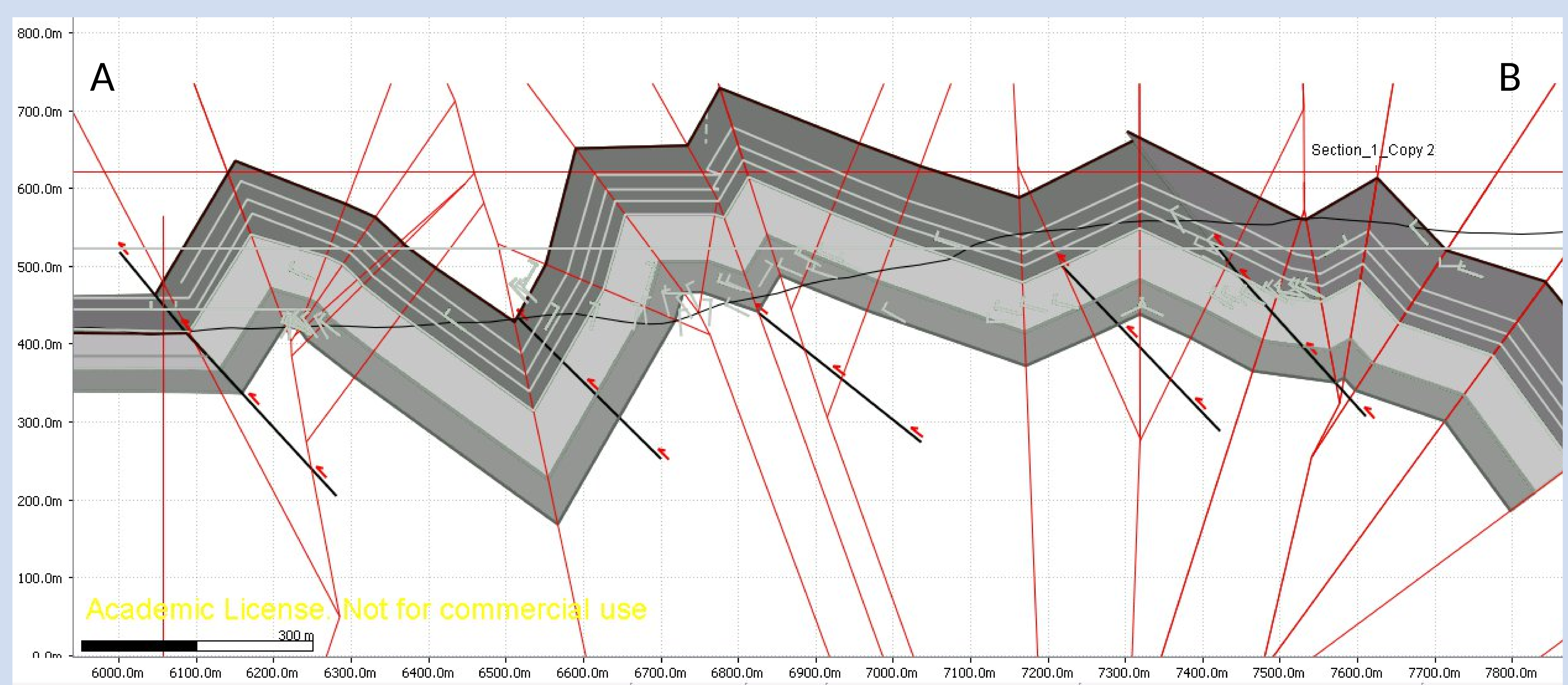


Fig.9 – Cross section for the representation of the deformation near Clausthal, created using collected field data and constructed using the kink band method in MOVE. The grey horizons are purely for visual affect and do not represent stratigraphy. Further data collection on drilling programmes in the surrounding area will take place to determine the depth of the stratigraphic layering.

Data Analysis and Summary

The cross section *(fig.9)* above shows reasonably well the NW-SE vergence of folds expected, the most recognisable marker of these folds at outcrop scale being the way-up indicators and the identification of an "overturned limb" *(fig.6)* . Although few thrust faults were identified in the field on this scale, smaller thrusts were identified striking parallel through the folds. The presence of these at outcrop scale, and the behaviour of the folds leads to the majority of the faults being interpreted, however more data will be gathered and analysed to solidify the presence of these larger faults.
This cross section will act as a guideline for the general structure of the area but further data collection will be needed for a detailed understanding of the internal structures, stratigraphy, fracture network and fault rocks for a more accurate analysis of the structural characterisation of the CCFZ.

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