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LITHOSTRUCTURALLY INDUCED FRACTURE FLOW SYSTEMS AND GROUNDWATER PROVINCES - ROUTE OPTIMISATION OF A DEEP LYING TUNNEL IN THE WESTERN CALCAREOUS ALPS, VORARLBERG, AUSTRIA

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1. Introduction

A hydrogeological study is being carried out to select and optimise a route for a deep lying tunnel (Erzberg Tunnel, Stuben-Zürs/Lech) in the Northern Calcareous Alps west of the Flexen Pass, Vorarlberg, Austria. Besides a lithostructural elaboration of possible routes, a clarification of the fracture flow systems and groundwater provinces is seen as essential in order to understand the interplay between the proposed tunnel and groundwater, and the possible effects of a tunnel on the existing surface and groundwater supplies of the ski resorts of Stuben, Lech and Zürs.

Initial investigation results show, on the one hand, a close connection between the lithostructure of the investigated area and, on the other hand, the distribution of groundwater provinces, the course of the hydraulic systems and the physiochemical properties of the groundwater.

2. Methodology

A detailed lithostructural survey and evaluation of aerial photographs provide the basic data for the palaeo-stress analysis, the objective of which is to determine the orientation of the main stress direction ($\sigma 1$) and the corresponding conjugate main extension direction ($\sigma 3$).

The hydrogeological survey serves to identify and hydrogeologically characterise the lithological units and structural elements, as well as to locate the main groundwater discharges. Taking water samples and analysing the standard chemical parameters, determining the $\delta^{34}S$, $\delta^{18}O$ and tritium values, as well as measuring the physical parameters (°C, µS/cm, discharge) on site, as part a hydrologic status-quo documentation, allows for a typification of the encountered ground- and surface waters.

By overlapping the lithostructural and hydrogeological data, their connections are clarified, and enables the fracture flow systems and groundwater provinces to be located, defined and orientated and their hydraulic properties to be characterised.

3. Lithostructural Framework

As part of the western section of the Northern Calcareous Alps, the investigation area includes the characteristic geological stratigraphic sequence from Permian-Scythian Formations to Cretaceous Carbonate Formations. The distribution and structure of the geological formations within the region reflect the complex deformation history.

Jurassic to Cretaceous extension led to the development of a range (Zürser Schwelle) and deeper lying blocks, which were bounded by steeply dipping normal faults. Later the normal faults were reactivated as strike slip faults during ensuing compressive deformation phases. The Zürser Syncline is located in a distensive area of a sinistral transfer zone of two sinistral strike and slip faults striking NW-SE to N-S. Towards the south, the syncline is bounded by a steep dipping

transfer fault striking E-W (Stubenbach Fault according to May (1998)). The development of the Zürser See Syncline, as a complex extension basin during the compression, can thus be described as an example of the development of Synorogenic Cretaceous Basins in the western Northern Calcareous Alps as postulated by MAY & EISBACHER (1999).

In the course of more recent compressive phases, the older structures were reactivated or sheared. Especially during the most recent compressive phase, faults striking NW-SE formed in the area of dextral transfer zones, along with deep and sometimes very wide open joints and fractures, striking NE-SW. During the construction of the Blisadonna Tunnel, Kloster Valley, Vorarlberg, these fractures were responsible for large water ingressions and therefore significant elements during the tunnelling process, as documented by RIEDMÜLLER (pers. comm. 2000) and STEINDORFER et al.(2000).

4. Hydrogeological Consequences

The complex structural geology is reflected in the distribution of the groundwater discharges, their physiochemical properties and their isotope values ($\delta^{18}O$ and $\delta^{34}S$).

4.1 Structural Influences

The groundwater flow systems are related to karstic geological formations and extension structures created during compressive tectonics. A paleo-stress assessment and division of the region in homogenous tectonic domains (using the methods of FERNANDES & RUDOLPH, 2001) shows that due to a roughly N-S oriented compression, dextral strike slip faults formed, striking NW-SE, in whose dextral transfer zones NE-SW striking extension structures developed which are of significance for the drainage of the southern section of the investigation area. While the southern part of the investigation area drains mainly toward the Kloster Valley, due to the geological structures, the middle and eastern sections drain toward the Flexen Valley.

4.2 Litological Influences

Especially the Ca/Mg-ratio, the SO_4 content and the $\delta^{34}S$ values provide information about hydrochemically important rock in the catchment area. These values also show traces of tunnelling relevant geological formations which do not crop out at the surface (e.g. Reichenhaller Formation). Based on the hydrochemical and $\delta^{18}O$ isotope data it can be ascertained that the lowest lying springs (Flexen Valley) have the highest lying catchment areas. Also, it can be probably ruled out that the eastern and western sections of the N-S striking Flexen Valley are hydraulically isolated, a fact which may significantly influence the amount of water ingress during tunnelling.

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