Stress measurements in the geothermal well Schlattingen, Northern Switzerland

Spannungsmessungen in der Erdwärmebohrung Schlattingen, Nordschweiz

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Summary

Recent stress measurements in the geothermal well Schlattingen 1 in the Swiss Molasse basin constitute a stress profile from shallow levels into the underlying basement. The stress data reach from competent limestones at the top via softer marly units into the granitic rocks of the crystalline basement.

Fourteen successful tests were performed using the minifrac method. The induced fractures show a uniform orientation distribution of the minimum and maximum horizontal stresses. The same directions are indicated by breakouts and drilling induced fractures along the borehole. The stress orientations are consistent with other regional stress direction data (focal mechanism solutions and borehole breakout data) that indicate compression approximately normal to the Alpine Front 60 km to the south of the borehole. A stress decoupling between the basement and the cover rocks is not supported by the stress measurements or the borehole breakouts.

The vertical distribution of the minimum horizontal stress magnitudes is variable and appears closely related to the rock type. Softer rocks like claystones and marls generally bear smaller differential stresses than limestones or the crystalline basement rocks. We speculate that the stress state in the different geomechanical units is controlled by the rock mass strength.

Zusammenfassung

Kürzlich durchgeführte Spannungsmessungen in der geothermischen Bohrung Schlattingen 1 im Schweizer Molassebecken führten zu einem Spannungsprofil, welches vom oberflächennahen Bereich bis in das darunterliegende Grundgebirge reicht.

Die Spannungsdaten reichen von kompetentem Kalkstein über weicheren Mergel bis zu granitischen Gesteinen des kristallinen Grundgebirges.

14 erfolgreiche Minifrac-Tests wurden durchgeführt. Die induzierten Risse zeigen eine einheitliche Verteilung der Orientierung der minimalen und maximalen horizontalen Spannungen. Diese Richtungen wurden auch durch Bohrlochrandausbrüche und bohrungsinduzierte Risse entlang des Bohrloches bestätigt. Die Spannungsorientierung ist auch konsistent mit anderen regionalen Spannungsfelddaten (Herdflächenlösungen und Bohrlochrandausbruchsdaten) aus einem Gebiet etwa 60 km südlich des Bohrloches, die eine kompressive Belastung normal zur Alpinen Front anzeigen. Eine Spannungsentkopplung zwischen dem Grundgebirge und den darüber liegenden Schichten kann weder durch die Spannungsmessungen noch durch die Bohrlochrandausbruchsdaten gefolgert werden.

Die Spannungsmagnituden der minimalen horizontalen Spannung variieren mit der Tiefe und scheinen stark an den Gesteinstyp gekoppelt. Weichere Gesteine wie Tonsteine und Mergel zeigen im Allgemeinen kleiner Spannungsdeviatoren als das kristalline Grundgebirge. Wir vermuten, dass der Spannungszustand in den unterschiedlichen geomechanischen Einheiten durch die Festigkeit des Gebirges kontrolliert wird

1 Introduction

The design of geological repositories for radioactive waste responds to the requirements of technical feasibility and long-term safety in the context of a specific geological setting (Nagra 2002). An important aspect of the geological setting is the primary stress field. To a large extent the stress state controls repository induced effects such as the excavation induced mechanical rock damage and associated changes in the waste isolation properties of the host rock. Therefore the measurement of the stress state receives some attention where the site selection for geological repositories focuses onto relatively weak host rocks such as claystones and marly shales that develop a significant excavation damage zone.

Within the stepwise site selection process for nuclear waste repositories which is lead by the Swiss federal government, Nagra, the Swiss corporative for the disposal of nuclear waste, has proposed 6 candidate regions. For the purpose of further site characterization Nagra is currently re-evaluating the geological and geotechnical situation in the wider region of the candidate regions and the stress situation is one of the aspects considered. Among other activities Nagra has taken the opportunity to make investigations in a few geothermal wells. Here we report on data from the Schlattingen geothermal well, which is intended to provide thermal power for greenhouse farming. The investigations in the Schlattingen borehole (SLA-1) included hydrotesting, geophysical logging and stress measurements. Furthermore cores were retrieved from some sections for laboratory investigations. In this paper we present initial results of the stress measurements in the borehole.

2 Setting

The geothermal well Schlattingen 1 is located 10 km east of Schaffhausen and 0.6 km south of the Rhine. The hilly topography around the SLA-1 location features wide NW striking ridges separated by wide glacially shaped valley floors. The maximum relief is 200 m.

Geologically SLA-1 is situated in the Swiss Molasse Basin between two regional faults. The Randen Fault some 2 km to the North strikes approximately NW and has a maximum normal fault offset of 250 m (Nagra, 2008). The Neuhausen Fault about 5 km the south is well known from Nagras 3D Seismik Survey (Nagra, 2000). It strikes NW as well and has a normal fault offset of 100 m at maximum. Focal mechanisms from the basement are consistent with shortening directed NNW (Kastrup et al. 2004). However in comparison with active tectonic regions the seismicity is low and GPS derived strain rates in the Molasse Basin of north eastern Switzerland are well below 0.5 mm/yr (Sue et al. 2007).

The sedimentary sequence at the location of the Schlattingen borehole comprises marine limestones, shales and marls which are unconformably covered by Tertiary rocks of the Alpine Molasse (Fig.1). Further to the West the evaporitic rocks of the Triassic formations near the base of the sedimentary layer served as a regional detachements and enabled thin-skinned thrusting and the formation of the Jura fold and thrust belt in the Late Miocene. However, at the location of SLA-1 the sediments are considered to be unaffected by the Alpine thin-skinned thrusting.

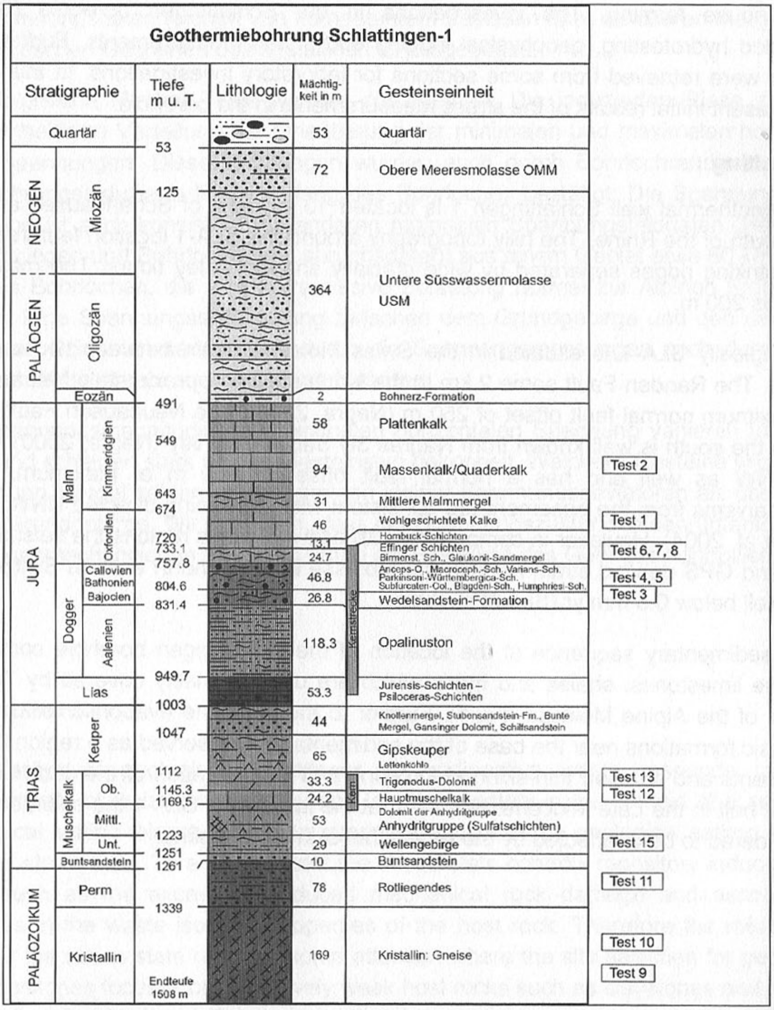

Fig. 1 Geological profile at the location of the geothermal well Schlattingen (SLA-1) and position of the measurements of the minimum horizontal stress.

3 Method

The stress measurements in the borehole SLA-1 have been performed in the open hole by minifrac tests. The method uses a double packer system to isolate a one meter long interval of the open borehole that is then pressurized at injection rates of 2 l/min up to the breakdown of the formation. Repeated pressurization of the interval allows to determine the stress that acts on the newly created fracture. The total injected volume during such a test is in the range of a few liters and the size of the fracture that extends from the borehole normal to the minimum principle stress can be considered to be in the range of a few meters at most. The orientations of the newly created fractures have been determined with the help of BHTV logging runs that compare the borehole wall image before and after the stress measurements. In some cases additional impression packer tests have been performed.

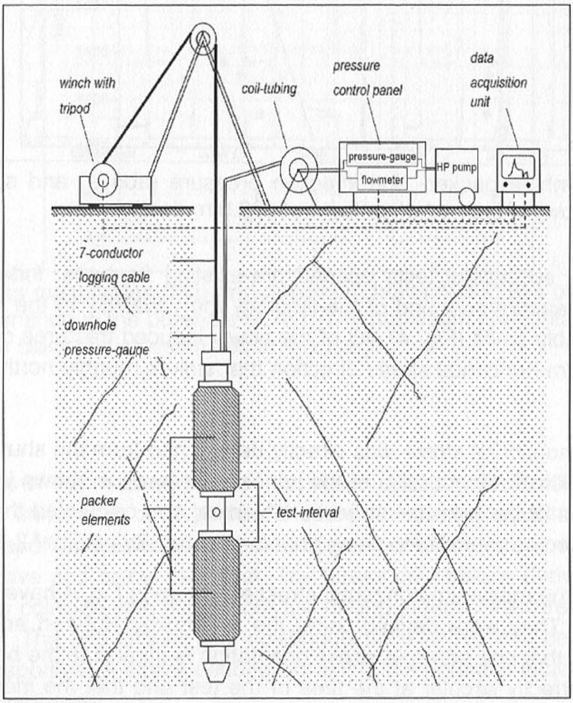

Fig. 2 Schematic view of the wireline packer testing system.

4 Results

Fifteen tests of the minimum stress magnitudes in the Schlattingen geothermal well have been performed of which fourteen can be considered to be successful (Fig. 1). The measurements have yielded a stress profile reaching from 592 m to 1 455 m depth. It straddles several rock units and includes the top of the crystalline basement.

Fig. 3 shows an example pressure recording of one of the stress measurements.

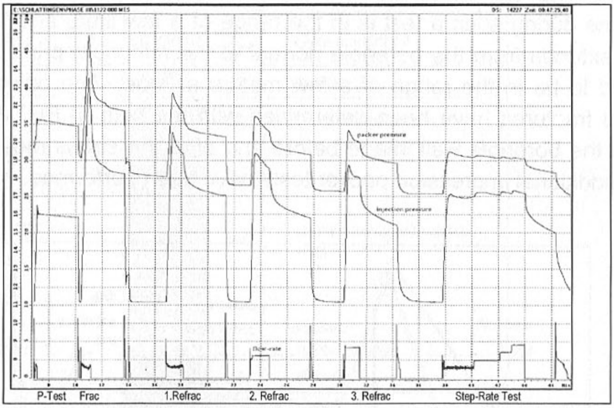

Fig. 3 Downhole packer- and injection pressure (above) and surface flow-rate (below) of the hydrofrac test at 1122.0 m depth

Two of the 14 successful tests opened pre-existing fractures. Independent of the depth of the measurement and of the lithology the variability of the fracture orientation is remarkably small (Fig. 4). All of the newly induced fractures consistently indicate a maximum horizontal stress direction that strikes roughly north-south to north-north-west.

The minimum horizontal stress was directly determined from the shut-in pressures of the data logs. The vertical profile of the principle stresses is shown in Fig. 4. We assumed that one of the principal stresses is vertical and calculated the vertical stress component from the overburden using an average density value of 2 500 kg/m^3.

The values of the maximum horizontal stresses shown in Fig. 4 have to be seen with some caution. They were derived using the relation by Hubbert and Willis (1957), which requires that one principle stress orientation is parallel to the borehole, that the borehole is perfectly circular at the time of the test and that the induced fracture is hydraulically impermeable. For hard rocks the latter assumption cannot be made as it is rather unlikely that the fracture will close completely after depressurization; even small asperities can keep them open. In the case of soft rocks the assumption is likely to be valid. For example Enachescu et al. (2002) have shown that fractures in Opalinus Clay are impermeable if they are loaded by more than 2 MPa effective normal stress. That is valid for all tests; even at the depth of the shallowest stress measurement where the minimum horizontal stress showed to 10 MPa and the pore pressure is close to 6 MPa the effective normal stress is 4 MPa. However, no attempt has been made to analyze maximum stress magnitudes at this stage.

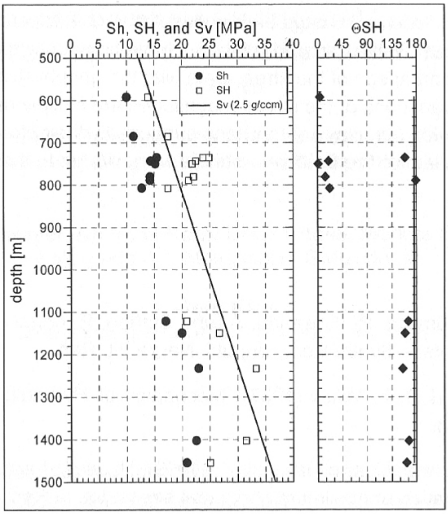

Fig. 4 Stress magnitudes (left) and maximum horizontal stress orientation (right) determined in the borehole SLA-1. The maximum horizontal stresses have to be classified as estimates at this stage.

5 Discussion

The orientations of the maximum horizontal stress direction as depicted in Fig. 4 are vertically rather uniform. In other parts of the basin a stress decoupling at the level of the Triassic evaporites has been postulated based on differences between breakout orientations above and below this level. The stress orientations derived from the induced fractures coincide with those from the drilling induced fractures and the borehole breakouts. The orientations are indistinguishable above and below the level of the Triassic evaporites. A stress decoupling along this potential tectonic detachment is therefore not apparent.

The regional analysis of the maximum horizontal stress orientations in the Molasse basin shows a gradual clockwise rotation from West to East along with the changing trend of the Alpine Front (e.g. Reinecker et al. 2010). The north-north-west strike of the largest horizontal stress in the Schlattingen 1 borehole fits into this regional picture.

The distribution of horizontal stress magnitudes along the borehole is more variable than the stress orientations. This is evident from the ratios of the horizontal to the vertical stress σ_h/σ_v. These ratios range from 0.55 to 0.9. Small minimum horizontal stresses with ratios around 0.6 have been measured in the limestone units and in the basement. In contrast, values around 0.8 to 0.9 have been determined in the marls and shales. The comparison of the stress data with the geophysical logging results indicates that the variations of the stress magnitudes are closely related to their mineralogical composition (i.e. clay content) and supposedly their strength. This suggestion has already made for the Benken borehole some 10 km to the West (Wileveau et al. 2007).

6 References

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