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HYDROLOGICAL CHARACTERISATION OF LAKE OBERNBERG, BRENNER PASS AREA, TYROL

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ABSTRACT

Since the construction of a railway tunnel in the 1990s (Tunnel of Val di Fleres-Pflersch, Italy) the visible high water level fluctuations of the Lake Obernberg and specially its low stands were connected to recorded high water inflows in the tunnel and therefore to the impact which the tunnel has on the hydrological system. Due to a missing hydrological monitoring before, during and after construction of the tunnel an impact assessment on the lake is not straight forward.

The aim of this study is to quantify present lake level fluctuations, to compare the shape and the extension of the lake in the past and present and to show with a conceptual hydrogeological model the reasons for the high water level fluctuations. Therefore historical documents, photos and pictures were collected and local people interviewed. With these results the behaviour of the water level and the morphology of the lake in the past are worked out and compared to recent data. The hydrogeological conceptual model is based on the results of a hydrological monitoring carried out on springs and surface waters and on the results of a detailed geological and geomorphologic mapping. The Lake Obernberg is located next to the Portjoch fault, which separates carbonates of the "Brennermesozoikum" to the west from Palaeozoic metasediments of the Steinach nappe (mainly quartz phyllites) to the east. The lake is embedded in coarse grained Quaternary rockfall deposits and covers an area of approximately 0.08 km². Annual water level fluctuations of up to 10 m were measured. The lake is divided by a morphological ridge which is covered from lake water during water level highstands. Between midsummer and autumn, when temperatures reach their maximum and precipitation is low, the water level drops and the ridge separates the lake into two discrete lakes. Surface runoff discharging into the lake were observed only during periods of water level highstands which are caused by large precipitation events and/or massive meltwater input. Normally the lake is draining to a large spring, located approximately 250 m downvalley of the northern lake border. Only during water level highstands an overflow of the natural dam can be observed. The hydrogeological conceptual model shows that the water level represents the groundwater table of the coarse-grained soft rock aquifer. The aquifer is recharged uphill of the lake by infiltrating rivers and laterally by a carbonatic aquifer of the Tribulaun area, west of the Portjoch fault. The historical documentation shows that water level fluctuations and water level lowstands of present magnitude also occurred before the tunnel construction. A visible impact (m-scale) on the water level due to water inflows in the tunnel can therefore be excluded.

Seit der Konstruktion eines Eisenbahntunnels im Pflerschtal in den 90er Jahren des Vergangenen Jahrhunderts, wurden die deutlich sichtbaren Wasserspiegelschwankungen des Obernberger Sees und vor allem die Perioden niederen Wasserstands mit starken Wasserzutritten im Tunnel in Verbindung gebracht. Die Meinung war, dass der Tunnel das hydrologische System beeinflusst hatte. Da jedoch vor, während und nach dem Auffahren des Tunnels keine wasserwirtschaftliche Beweissicherung durchgeführt wurde, sind die Auswirkungen des Tunnels nicht leicht zu quantifizieren. Das Ziel dieser Untersuchung war, die Wasserspiegelschwankungen des Obernberger Sees zu quantifizieren, die Ausdehnung des Sees in der Vergangenheit mit der heutigen zu vergleichen und mit einem konzeptuellen hydrogeologischen Modell die Ursachen für die starken Schwankungen des Seewasserspiegels zu identifizieren. Dafür wurden historische Dokumente, Photos und Zeichnungen recherchiert und Interviews mit der ansässigen Bevölkerung durchgeführt. Mit diesen Ergebnissen wurde das Verhalten und das Erscheinungsbild des Sees in der Vergangenheit rekonstruiert und mit aktuellen Daten verglichen. Das konzeptuelle hydrogeologische Modell basiert auf den Ergebnissen eines hydrologischen Monitoringprogramms von Quellen und Oberflächenwässern, sowie auf den Ergebnissen detaillierter geologischer und geomorphologischer Kartierungen. Der Obernberger See befindet sich in der Nähe der Portjochstörung, einem wichtigen geologischen Strukturelement, welches die Metakarbonate des „Brennermesozoikums" von den paläozoischen Metasedimenten der Steinacher Decke (überwiegend Quarzphyllite) trennt. Der See liegt in grobblockigem Material eines spätglazialen Bergsturzes (Paschinger, 1953), die Fläche des Sees beträgt ungefähr 0.08 km². Insgesamt wurden im Beobachtungszeitraum Schwankungen von 10 m beobachtet. Ein morphologischer Rücken unterteilt den See in zwei kleine Becken, die bei Wasserspiegelhochständen verbunden sind. Von Hochsommer bis Herbst, wenn die Temperaturen am höchsten und die Niederschlagsmengen am niedrigsten ist, fällt der Wasserspiegel und es bilden sich zwei Seebecken. Oberflächenabfluss erfolgte nur in Perioden mit Wasserspiegelhochstand als Folge von starken Niederschlägen und/oder Schneeschmelze. Der See wird unter normalen Umständen von einer großen Quelle entwässert, die ungefähr 250 m unterhalb des nördlichen Seeufers entspringt. Das konzeptuelle hydrologische Modell zeigt, dass der Seespiegel den Grundwasserspiegel des grobkörnigen Lockergesteinaquifers darstellt, der oberhalb des Sees von versickernden Bächen und lateral vom Festgesteinsaquifer der Tribulaungruppe, östlich der Portjochstörung gespeist wird. Historische Recherchen ergaben, dass Wasserspiegelschwankungen und Wasserniedrigstände vergleichbarer Magnitude bereits vor der Konstruktion des Tunnels auftraten. Eine sichtbare Auswirkung (im m-Maßstab) der Wasserzutritte im Tunnel auf die Seespiegelschwankungen kann daher ausgeschlossen werden.

1. INTRODUCTION

The Lake Obernberg (Obernberger See) is situated at 1594 m a.s.l. at the end of the Obernberg Valley, near the Austrian/ Italian border (Fig. 1). The SW-NE trending Obernberg Valley is a secondary valley at the orographic left side of the Wipp Valley. The study area is limited to the north by the Obernberg Valley (approximately 1300 m a.s.l.) and to the south by the Pflersch Valley (Val di Fleres, Italy, approximately 1200 m a.s.l.). In the east, the N-S trending Wipptal Valley forms a natural boundary and to the west, the Pflerscher Tribulaun (3097 m a.s.l.) is the outmost point of the study area and also the highest elevation in this area. In the 1990s a railway tunnel was built east of the Lake Obernberg. Huge water inflows with a maximum ininitial inflow value of approximately 600 l/s (Agostinelli, 1995) were documented during construction of the tunnel. Recently the stationary outflow is approximately 80 l/s. In the public opinion the visible huge water level fluctuations in the Lake Obernberg are connected to the impact of the railway tunnel on the hydrogeological system. Even the periods of water level lowstands are thought to be longer, and the lowstands even more significant comparing to pre-excavation times. Due to the lack of detailed measurements of the lake level before, during and after the construction of the tunnel, this popular opinion cannot be evaluated with monitoring data. The collection and study of historical documents have been used to reconstruct the shape and extension of the lake in the past during different stages. Past images of the lake (photos, postcards, images in reports) have been compared to recent images. Interviews with resident people were done in order to qualitatively (or semiquantitatively) evaluate the water level fluctuations before and after tunnelling. A hydrological monitoring campaign was done in order to measure recent water level fluctuations and the quantitative and qualitative behaviour of springs and rivers close to the lake. On the base of a detailed geological model and the hydrological data a local hydrogeological conceptual model for the Lake Obernberg area has been developed to represent the reasons for the huge lake level fluctuations. A regional conceptual model is worked out to study a possible hydraulic interaction between the impacted aquifer east of the Portjoch fault and the aquifers west of the fault and close to the lake.

2. METEOROLOGY

The study area belongs to the main ridge of the Eastern Alps, which is a meteorological divide. Three meteorological stations are located close to the study area. These stations record precipitation and temperature; two of them are located in the Gschnitz Valley (Trins and Obertal, see Fig. 1) and one in the Obernberg Valley (Obernberg). Meteorological data from these

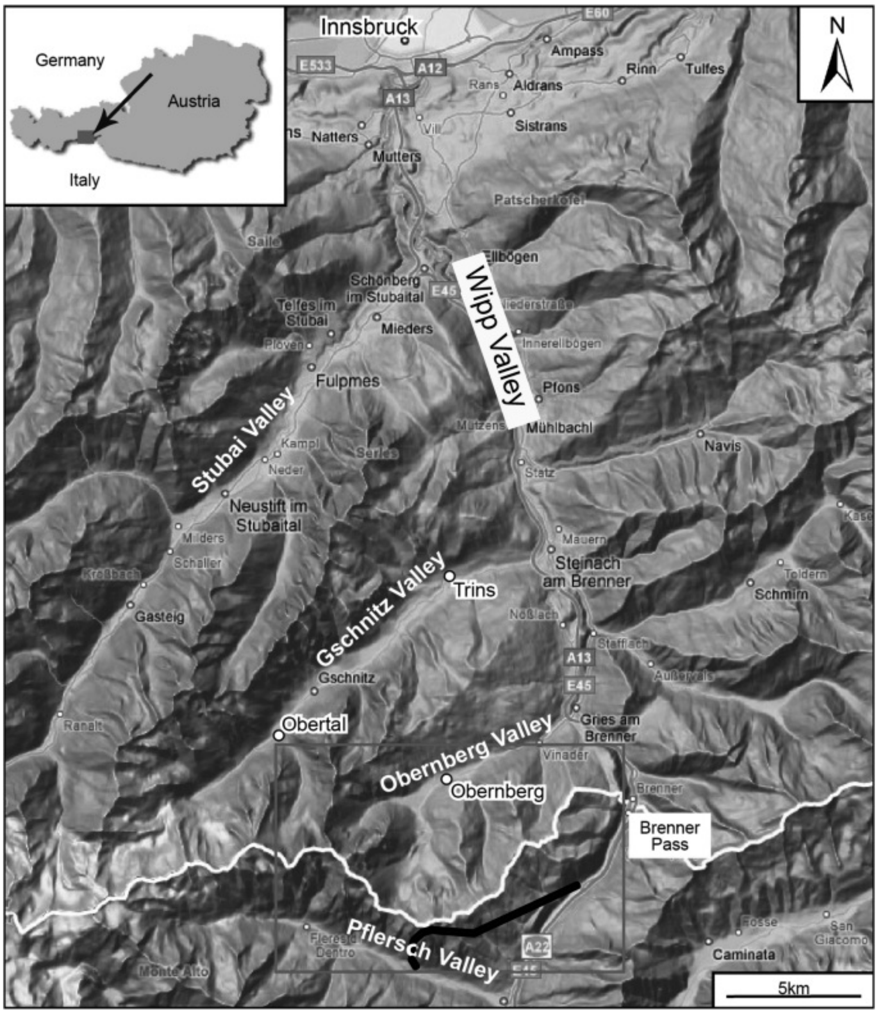

FIGURE 1: Location of the study area (source: Google Maps). Red frame marks the study area, black lines within the red frame indicate the railroad tunnel. More details of the study area are shown in Figs. 2, 3, 5 and 9.

stations for the period 1981-2009 was taken into account. In Obernberg (1360 m a.s.l.) the average annual temperature has a value of 4.3° C (1981-2007) and the mean annual precipitation is approximately 1200 mm. The maximum value for precipitation is 464,1 mm per month in Nov. 2002, the minimum value of 0 mm per month was recorded in Oct. 1995. The station in Trins (Gschnitz Valley) is located at 1235 m a.s.l., with an average temperature of 7,3° C in 2007. The mean annual precipitation for Trins station is 986,8 mm/a in the period from 1980 until 2006, with a maximum of 325 mm during one month in Nov 2002 and a minimum of 0,7 mm in Oct. 1995. The station in Gschnitz/Obertal is located at 1280 m a.s.l., with an average annual precipitation of 1314,3 mm/a (1993 until 2006), a maximum value of 433,8 mm in Nov. 2002 and a minimum value of 0,2 mm in Oct. 1995. The closest station which monitors evaporation is situated on the Patscherkofel at 2246 m a.s.l., approximately 25 km from the study area. It recorded a total of 354,0 mm of evaporation during the monitoring period in 2006. Highest monthly evaporation rate was 106,0 mm in August 1992 (Hydrographisches Jahrbuch von Österreich, 2006). Baumgartner et al. (1983) published values of evaporation of approximately 200-300 mm/a in this area.

3. GEOMORPHOLOGY

The SW-NE trending Obernberg Valley is a tributary valley to the mainly N-S trending Wipptal Valley. Four smaller valleys lead into the Obernberg Valley: the SW-NE trending Hinterenns Valley, the N-S trending See Valley, Frader Valley and Griebenbach Valleys (see Fig. 1, Fig. 2). South of the Obernberg Valley an east-west trending mountainous ridge marks the border to Italy. The lake Obernberg lies in the See valley, at 1594 m altitude, in a depression, which is surrounded by

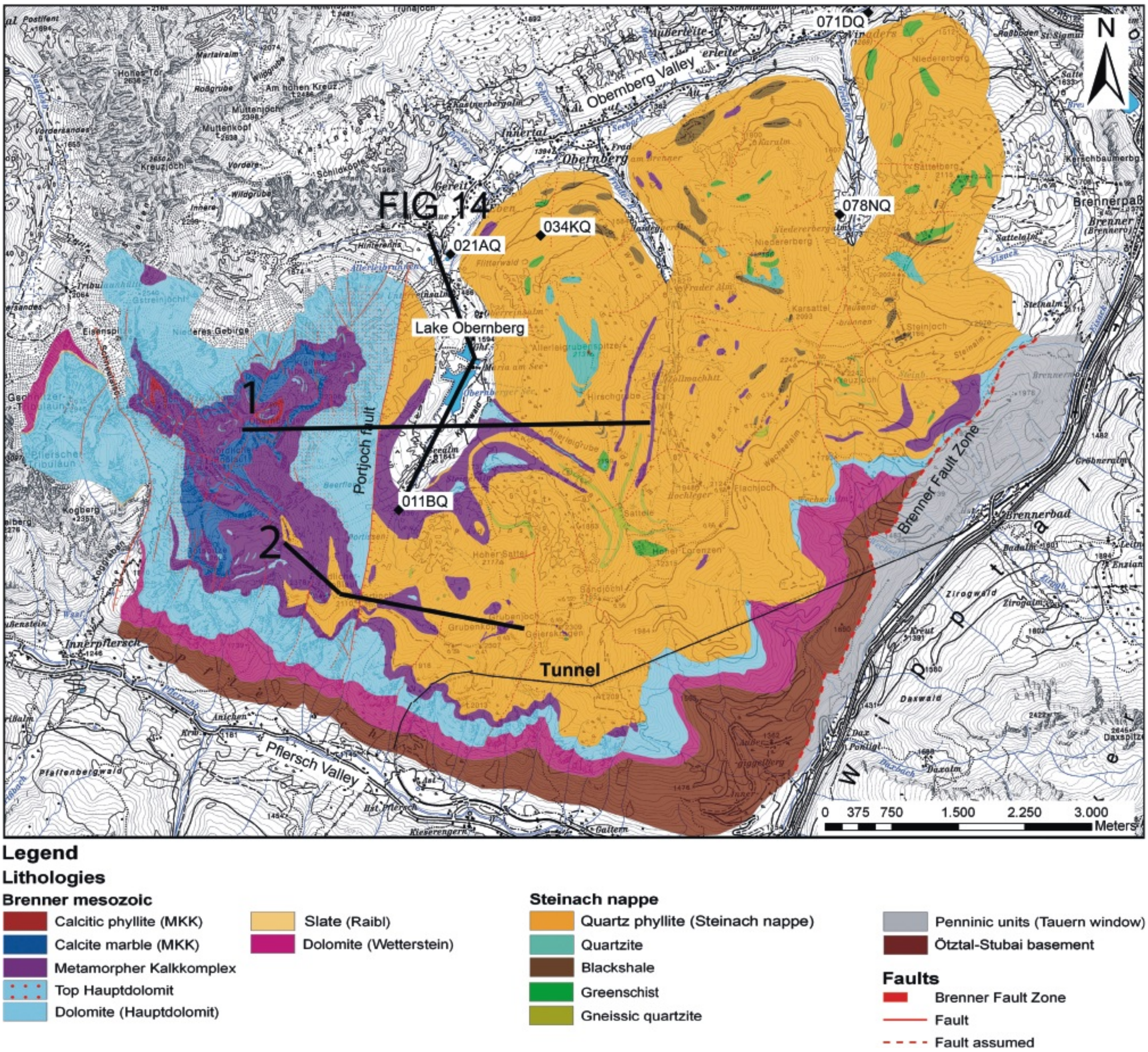

FIGURE 2: Geological map of the study area (based on own data and Rockenschaub et al., 2003; Kübler Müller, 1962; Frizzo, 1976). Locations of representative springs are marked by black diamonds, black lines indicate geological profiles (see Fig. 14 and 15), the tunnel is also shown in this map. The geomorphological situation around Lake Obernberg is shown in Fig. 2.

coarse-grained sediments of a late- or post-glacial rockfall (see Fig. 3). A C14-age from organic matter within a small alluvial fan on top of the rockfall sediments, gave a minimum age for the event: 6980+/-45 BP (Sample: VERA-4980; calibrated Age 5930 BC; M. Ostermann in preparation). From the extension of the rockfall deposits and due to missing evidence of other Quaternary sediments like till it can be assumed that these rockfall deposits lie also below the lake and therefore the lake is embedded in coarse-grained blocky rockfall sediments. West of the See Valley, Mesozoic carbonates of the Brenner Mesozoic build up the mountains of the Tribulaun group which are a typical carbonatic massif with peaks ranging from ~1500 to 2945 m and having steep slopes without vegetation cover (Fig. 4). East of the See Valley, these carbonatic rocks are covered by quartz phyllites of the Steinach nappe, which form a much smoother morphology with vegetation cover (Fig. 4). The peaks of these ridges reach approximately 2.300 m. The mean elevation of the study area is about 2050 m a.s.l. The eastern part of the area shows evidences of mass movements and unstable ridges, while in the west, brittle structures such as faults and deep seated extension fractures of several meters width can be found. Several landslides (north of the Allerleigrube and south of Steiner Alm) are present in the area, but having a shallow sliding plane none of them has an impact on the lake.

A topic of special interest is the mentioned rockfall deposits in the upper Obernberg Valley. The coarse-grained, angular and subangular sediments of the rockfall cover most of the area around the lake and the forested area (Kaserwald) north of the Steiner Alm (Fig. 3). The Kaserwald area shows typical

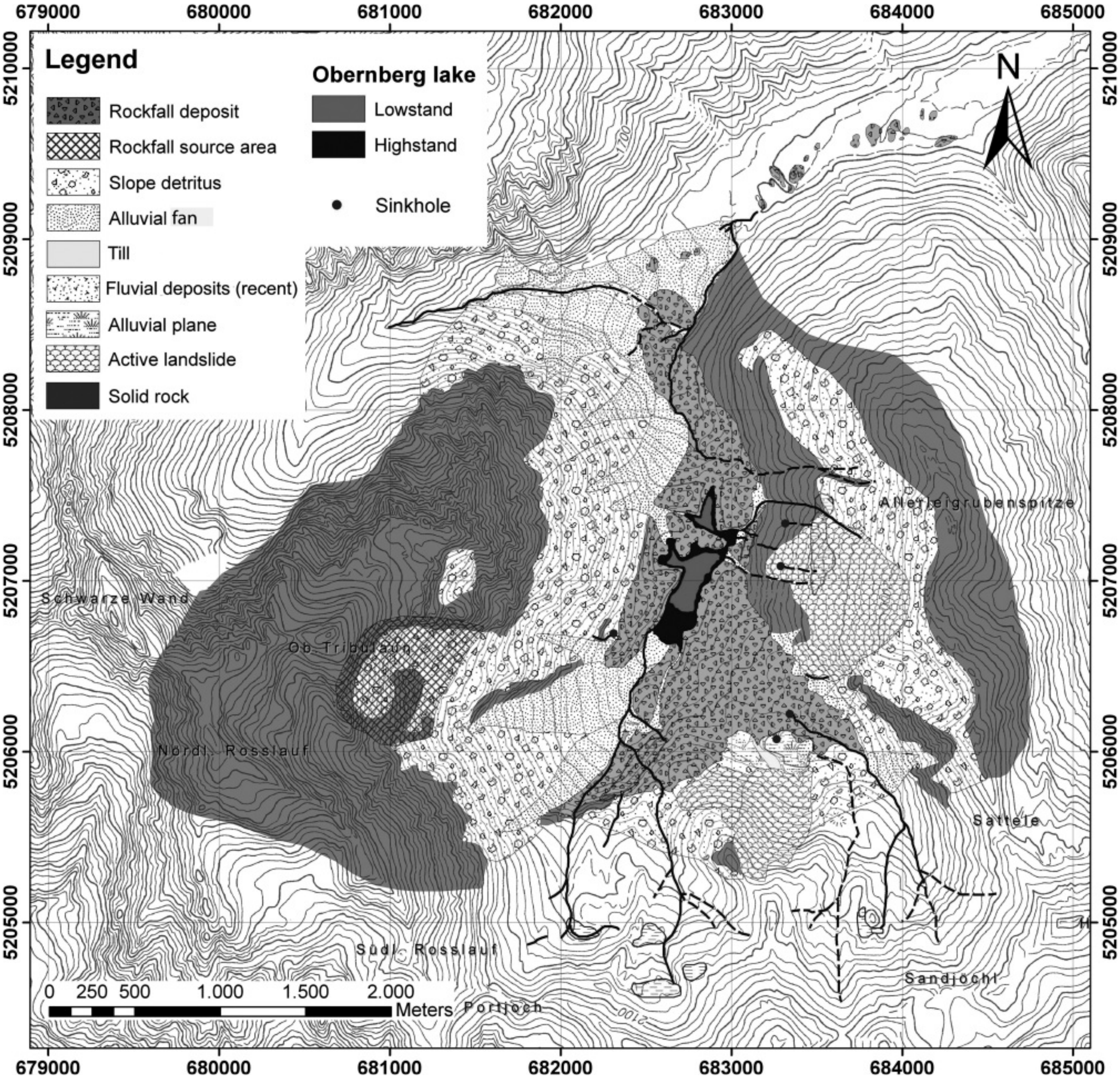

Figure 3: Geomorphological map of the the Lake Obernberg area. The black lines mark streams. The central area, where the lake is located, is dominated by rockfall deposits. The difference between high- and lowstand of the lake is clearly visible. BMZ (Brenner Mesozoic), StD (Steinach nappe).

signs of a rockfall deposit: boulders up to 10 m in diameter, a hummocky surface and small ponds where surface water infiltrates into the subsurface. The sediments of this big rockfall interfinger with a smaller one from the Allerleigrube. Both rockfalls show no evidence of glacial transport. The source of the rockfall-sediments is the so-called "Kachelstube", west of the lake (see Fig. 3). The results of the mapping do not indicate the presence of a glacier during the rockfall-event and the exact succession and timing of events is still under investigation by M. Ostermann. Two models are proposed for how the present-day topography formed: either it is a post-glacial toma landscape or dead ice bodies were covered by the rockfall and melted, causing the present topography with sharp, high and discontinuous wallforms. The sediments of the rockfall extend down to the church of the Obernberg village and cover the original topography (pers. comm. M. Ostermann, 2008; cf. Paschinger, 1953). The distinction between toma hills and till is difficult in this case.

4. GEOLOGICAL SETTING

The study area is built up of several tectonic units, which contain lithologies with different hydrogeological behaviour. The Brenner Mesozoic (BMZ) is the Mesozoic sedimentary cover (mainly carbonate rocks) of the Austroalpine Oetztal-Stubai basement complex (OSK). The dominant lithologies in the BMZ are the Wetterstein Dolomite and the Hauptdolomite outcropping W of the Portjoch fault, the same rocks are tectonically covered by older rocks of the Steinach nappe E of the fault (Fig. 2). As a result of a tectonically-overprinted transgressive contact to the OSK, the BMZ is classified as a parautochthonous unit. During the Cretaceous, Upper Austroalpine nappes (Steinach nappe, Blaser nappe) were thrusted towards WNW upon the BMZ (D1, Trupchun-phase sensu Froitzheim et al., 1994), resulting in metamorphic overprinting of the underlying BMZ. The stratigraphically youngest formations of the BMZ are of Jurassic age and referred to as "Metamorpher-Kalkkomplex" (MKK), first introduced by Kübler und Müller (1962). These rocks consist of calcite marbles, quartzites, quartz phyllites and calcitic phyllites of Plattenkalk-, Kössen- and Allgäu-Formation (after Prager in Rockenschaub et al., 2003). They are overprinted by intense intrafolial and isoclinal folding, ranging from mm- to km-scale. The StD, which was thrusted on top of the BMZ, can be separated in two parts: a lower part (StD I), consisting of retrograde micaschists and garnet-bea-

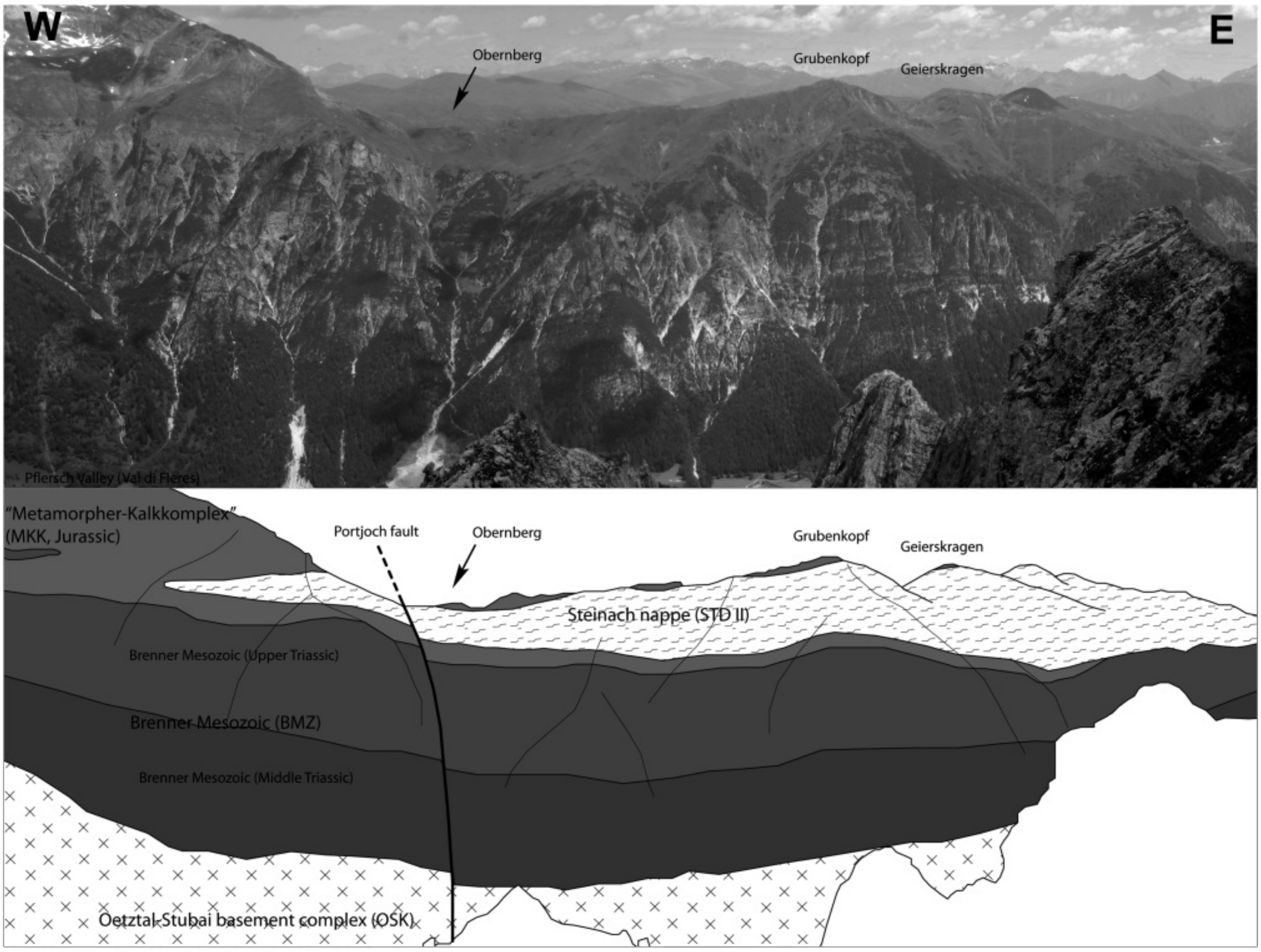

FIGURE 4: Overview of the morphologic and geologic situation in the area. The difference in morphology and elevation between the phyllite dominated area east of the Portjoch fault and the carbonate dominated Tribulaun group west of the Portjoch fault is clearly visible. Photo taken towards NNE. Length of profile approximately 4,5 km.

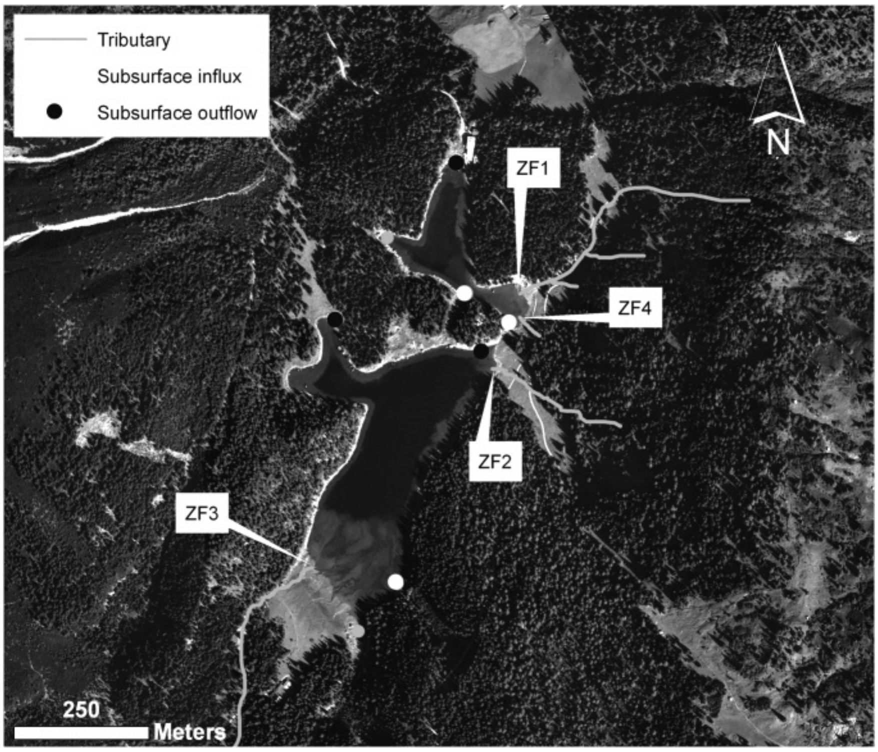

Figure 5: Aerial photograph of the Lake Obernberg area. The most important tributaries (labelled ZF), subsurface influxes (springs in the lake) and outflows are shown.

ring micaschists, and an upper one (StD II), consisting of prograde metamorphic quartz phyllites, greenschists, black shales, calcite marbles and quartzites. Due to tectonic omission during D2, the Steinach nappe I does not crop out south of the Obernberg Valley and the boundary to StD II lies near the bottom of the Obernberg Valley. Extensional tectonics during the Late Cretaceous/Paleocene induced a large SE-dipping low-angle normal fault which reactivated the former thrustline and caused large isoclinal and intrafolial folding of the MKK (D2, Ducan-Elaphase sensu Froitzheim et al., 1994; Fügenschuh et al., 2000). Since the StD and the BMZ comprise similar lithologies, which cannot be distinguished on a macro- nor microscopic scale (i.e. quartz phyllite and calcite marble, which are present in both tectonic units), the exact boundary between these two units can be difficult to constrain. The results of the geological mapping show intense folding of the contact of BMZ to StD during the D2 extensional event. Neogene exhumation of the Tauern Window led to Neogene normal faulting and graben structures west of the Wipp Valley. The W-dipping Brenner normal fault zone (BFZ), which runs parallel to the Wipptal Valley, can be separated into an older ductile and a younger brittle structural element (Fügenschuh and Mancktelow, 2003). One of the brittle elements, the so-called "Portjoch fault", is situated west of the lake and can be traced from the Portjoch south of the lake to the north (see Fig. 2). The fault separates the western footwall, dominated by the Brenner Mesozoic rocks (metamorphic limestones), from an eastern hanging wall, where the phyllites of the Steinach nappe cover the Brenner Mesozoic rocks and dominate the geological map.

The E-down normal fault displacement increases from the Portjoch towards north, from several tens of metres close to the Portjoch up to 450 m in the area of the Lake Obernberg (cf. Fig. 2) and with a maximum displacement of 800 m close to the Gschnitz Valley (cf. Rockenschaub et al., 2003).

5. LAKE OBERNBERG

The lake has a catchment area of approximately 12.6 km^2. During highstand the lake covers an area of almost 0.10 km^2 (Figs. 3, 5). During lowstand, the lake is separated by a ridge into a northern and a southern basin (Figs. 3, 5). The water level of the northern basin can be lower than the level of the southern one (measured maximum difference: 0.73 m; Fig. 5). Due to ice and snow cover in wintertime and the continuously falling lake level beneath this cover it is impossible to measure the minimum extension of the lake, which is less than 0.062 km^2 (lowstand in autumn). The effects of the lake level fluctuations on the landscape are shown in Fig. 6. The maximum range of these fluctuations observed in 2007 was 10 m. The water depth ranged from 3 m to 13 m in the northern lake basin and from 5 m to 15 m in the southern one. Several subsurface in- or outflows were identified in the lake (see Fig. 5) and are also mentioned in Rockenschaub et al. (2003). The inflow points are not covered by ice and snow during the winter and the summer temperature of the water at these points is lower than in the rest of the lake.

The lake has no perennial surface outflow. Approximately 50 m below the northern border of the lake a spring can be observed (023SQ, Fig. 7). The point where this spring emerges in the stream bed of the river Seebach shows seasonal variations in altitude. Only after high precipitation or snowmelt, when the lake level reaches its maximum, a natural overflow stream discharges the lake at its northern end. 2008 was the first time since 2001 that this overflow was active. Several tributaries feed the lake, but most of their water infiltrates into the groundwater body before reaching the lake. In the Kaserwald area a stream from the Sandjoch (average runoff 60 l/sec) infiltrates into rockfall deposits. Surface water also infiltrates on the eastern flank of the See Valley. Another pond where water infiltrates into rockfall deposits is situated in a depression on the western side of the lake, where approximately 20 l/s (average value) of water disappear (Fig. 3).

5.1 HISTORICAL DATA

Lake Obernberg´s first mention in literature was in the 15th

Figure 6: Photos taken in October 2006 showing the lowstand of the lake level (left) and July 2007 showing the highstand of the lake level (right) to demonstrate the large lake-level fluctuations and the lake extension.

century, in a list of fishing grounds of Emperor Maximilian. In 1768 the "landesfuerstliche Oberfischmeisteramt" gave a description of the lakes, specifying that the lakes are connected during large precipitation events (Stolz, 1936). Ludwig von Hoermann wrote in his travel report of 1870: "These [lakes] are like two eyes next to each other; after a long rainfall, especially in spring time, they join together and build up one lake of elliptic form." (translated from a German text). The lake became a tourist attraction in the 19th century, therefore it is mentioned in several travel reports and pictured on several postcards of the early 20th century, which show the lake at different levels. A limnological study of mountain lakes in Tyrol (Leutelt-Kippke, 1934), which also included Lake Obernberg, was the first scientific investigation of the lake. The study covers seasonal changes in the lake and chemical variations of the water. Neither this scientific report, nor the chronicals of the village, give exact values for lake levels. Historic photos and old postcards compared with present-day conditions (see Fig. 8 and 9) underline large lake level fluctuations even in the past (period: approx. 1900 - present). Unfortunately no exact dates are given on the photos. The age of buildings around the lake, which are visible in the photos, allowed to date the pictures. Aerial photos from 16th September 1954 show the lake at low level, while another one from 4th September 1971 shows an intermediate lake level. A newspaper article in 1989, blaming the construction of a railway tunnel nearby to be guilty for lake level fluctuations caused a lot of upset in the area, so most people are prejudiced. Interviews with local people were used to refine the information on the lake´s behaviour in the years from 2000 to the present. Together, the historical studies prove the existence of large lake level fluctuations since the 18th century. Even in the past the lake was separated in two subbasins for long periods; high precipitation and snowmelt led to the connection of the two subbasins. The frequency of fluctuations cannot be quantified, but their extent in height, at least in the 20th century, remained consistent to the present day.

5.2 Hydrological Monitoring

5.2.1 Methods

The hydrological monitoring was carried out from Oct 2006 to Oct 2007 as part of a Master Thesis. As a first step, the discharge, the electric conductivity, and water temperature were measured at 91 measuring points including springs, rivers and the lake. The three main rivers of the project area (rivers Seebach, Fraderbach and Griebenbach) were mapped in detail to investigate changes in runoff and electric conductivity along their course. On the base of this data, 40 springs and 17 rivers were chosen for a regular measurement program. For the locations of the monitoring points see Fig. 12. Variations of the lake level were read off a metre-stick, one for each basin of the lake. Lake depth was mapped

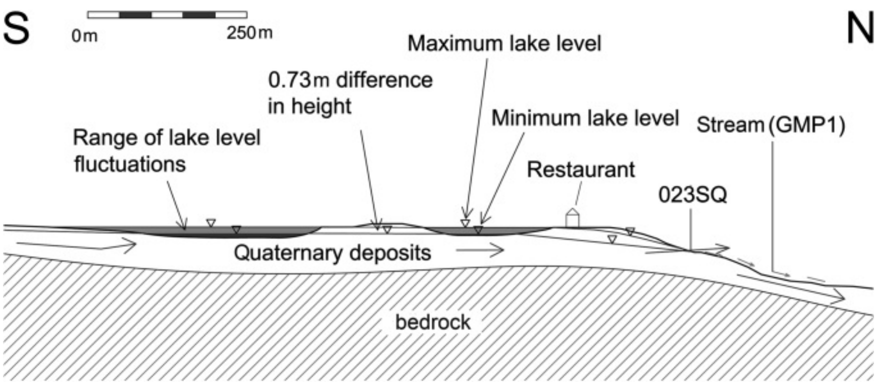

Figure 7: Detailed profile of the Lake Obernberg. The lakes are embedded in Quaternary deposits. Lake level and groundwater level variations are indicated. The main flow direction of groundwater is marked by arrows. In the centre of the figure a ridge separates the northern from the southern basin. At some points along the ridge the highstand of the lake water level is higher than the ridge itself, therefore an overflow from South to North of the central ridge during highstand phases is given.

using an echo sounder and a temperature/conductivity-probe. For the hydrological monitoring and observation of the lake 13 points at the shore of the lake were monitored (temperature and electrical conductivity) and samples of four of these points were analysed. In total, six measuring cycles, including three with hydrochemical analysis were undertaken. Samples for chemical analyses were manually collected three times during the monitoring period: in November 2006, May 2007, and November 2007. Out of 40 springs, 27 were sampled and analysed at the "Sektion für Hygiene und medizinische Mikrobiologie" of the Medical University of Innsbruck. All samples for chemical analyses were untreated, stored in polyethylene bottles, and analysed for anion and cation composition. The oxygen isotopic composition was determined using mass spectronometry at the Institute of Geology and Palaeontology, University of Innsbruck. Precipitation and temperature data for the area were provided by the "Hydrographischer Dienst, Tirol".

5.3 Results

The lake level curve is shown in Fig. 10. The lake level behaviour shows good constraints to precipitation and surface temperature data of the station in the Obernberg village. Data of lake level highstand events in the past allow further correlation with snowmelt and precipitation (see Fig. 11). The analysed spring waters show a similar chemistry which is Ca, HCO3 dominated, with sodium and potassium content (Fig. 13). A detailed examination of the data made it possible to distinguish several subsets of springs which allowed to group the springs regarding their electrical conductivity and their hydrochemical composition. Five groups of springs were separated (see Table 1) and for each of these groups a representative spring was chosen. Table 2 presents the data of the monitoring program for the representative springs.

Group 1: The representative spring 078NQ is located in the Griebenbach Valley, at an altitude of 1724m. It has a low conductivity (80 µS/cm) and a low Ca content of 0.364 mmol/l. The spring shows only low fluctuations in chemistry over one year. The Ca/Mg ratio is 3.9. Low spring flows (< 2 l/s) and low conductivity (< 90 µS/cm) indicates a shallow and short groundwater flow in crystalline catchment. The springs of this group are in general located within quartz phyllites of the StD II, which is classified as a rock with generally low hydraulic conductivity, especially at depth.

Group 2: The representative spring 034KQ is located NW of

Figure 8: Low lake level in the northern basin (view towards north). The left picture was taken around 1930, the right picture in March 2007.

Figure 9: Photos showing the lakes viewed northwards during springtime/summer highstand. Restaurant at lake shore for reference (arrow). The upper picture was taken around 1930, the lower picture in July 2007.

group	electric conductivity [µS/cm]	Ca	Ca/Mg	representative springs
1	70-93	0.31-0.47	3.8-6.4	078NQ 046FQ 084RQ
2	148-164	0.52-0.77	2.2-5.9	034KQ 003ZQ 040ZQ 033KQ 037FQ
3	166-229	0.78-1.03	3.7-7.2	011BQ 008SQ 018PQ 087MQ
4	173-215	0.60-0.82	1.4-2.5	021AQ 020SQ 023SQ 026WQ 030HQ
5	289-386	0.95-1.19	1.5-3.2	071DQ 068GQ 069TQ 082KQ 065KQ 031GQ

Table 1: Classification and characteristic values of selected spring groups. Ca is given in mmol/l, Ca/Mg is the molar relationship.

the lake at an altitude of 1689 m, it has a conductivity of 150 µS/cm and a Ca content of 0.716 mmol/l. The Ca/Mg ratio is 5.8. Lithologies surrounding the springs of group 2 are quartz phyllite-dominated, with lenses of greenschists, quartzites, calcite marble and black shales. This explains the low conductivity and relative wide range of Ca/Mg ratios in this group. Some springs of this group are used for drinking water in the village of Obernberg. 033KQ and 040ZQ show variable outflow rates peaking at 12,89 l/s, while the rest of the springs shows slightly lower and more constant rates in outflow between a minimum of 0,33 l/s (003ZQ) and a maximum of 4,0 l/s (037FQ).

Group 3: The representative spring 011BQ is located SW of the lake at an altitude of 1815 m and it represents a group of four springs situated near the Portjoch fault. The spring has a conductivity of 220 µS/cm and a relatively high Ca content of 0.987 mmol/l. The Ca/Mg ratio is 6.5. All springs of group 3 are located close to each other and can be seen as representative for the carbonatic aquifer in the Tribulaun area. A high Ca/Mg ratio and slightly elevated conductivity demonstrate a link to the calcite dominated marble aquifers. In the area around the lake, calcite-marbles of the MKK were folded into quartz phyllites of the StD. These folds can be considered as discrete aquifers within the StD. Several springs at the base of those calcite marbles support this assumption. 008SQ shows a higher outflow (7,73 l/s) than the rest of the springs which range from a minimum of 0,05 l/s (011BQ) to a maximum of 2,02 l/s (087MQ).

Group 4: The representative spring 021AQ is located N of the lake at an altitude of 1428 m. It has a conductivity of 200 µS/cm and a Ca content of 0.775 mmol/l. The Ca/Mg ratio is 2.3. The springs in group 4 are also situated near the Portjoch fault at the boundary of BMZ and StD. They show an intermediate mineralisation and a low Ca/Mg ratio. 030HQ is the only spring which can be definitely identified as situated in the area west of the Portjoch fault, but the analyses of the spring waters lead to the assumption that all springs are fed from the Tribulaun area. Outflow of all springs ranges from 1,02 l/s (003HQ) up to 250 l/s (023SQ) and is subjected to a big variability e.g. 023SQ has a maximum value of 250 l/s (Sept. 20, 2007) and a minimum value of 13 l/s (Oct. 10, 2006).

Group 5: The representative spring 071DQ is located at the entrance of the Obernberg Valley, between Gries am Brenner and Vinaders, at an altitude of 1270 m. It represents several springs on the valley floor. Compared to the other springs in the study area, this spring shows a relatively high mineralisation of about 300 µS/cm and also high Ca contents of 0.992 mmol/l. Nitrate is exceptionally high (2.918 mmol/l). The Ca/Mg ratio is 1.7. Group 5 represents several springs which are presumably located at the boundary between Steinach nappe I and II. High conductivity values of these springs were attributet to anthropogenic impact of NO3. No investigations were done on the residence time of the water, which might also be a reason for high conductivity. Outflow rates for this group range between 0,08 l/s and 3,24 l/s (both 068GQ) and show no big variations over the two years of monitoring.

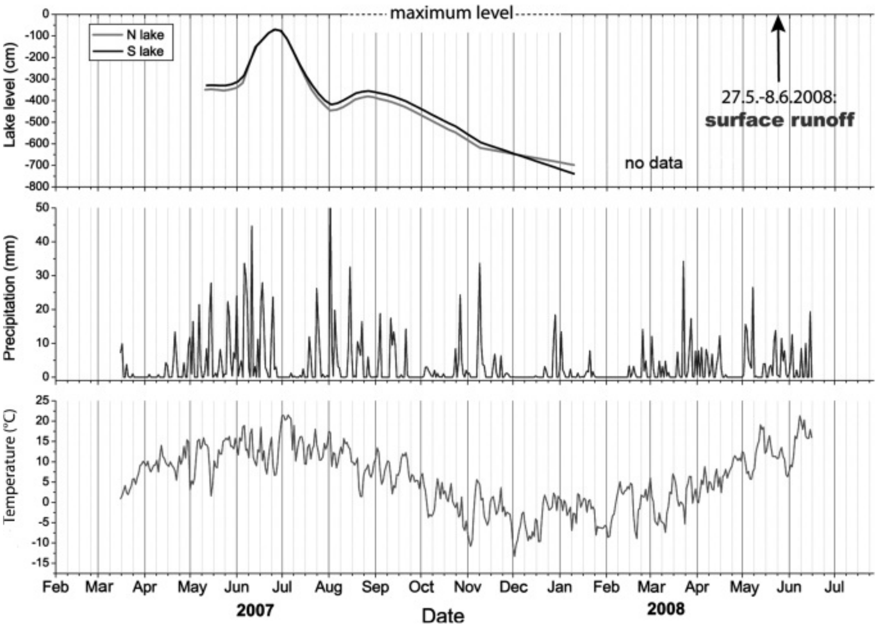

Figure 10: Lake-level changes in the period May 2007 to January 2008. Height difference of the water table between the northern and southern lake basin is depicted in the top figure. Up to 3m below the measured maximum, the lakes are connected. When the lake level falls to 3m below the measured maximum, basins are disconnected. Snowmelt (May/June) and precipitation are responsible for peaks in the lake levels. The inversion in the heights of the two lake levels during wintertime is uncertain because thick ice cover makes measurements difficult.

The spring groups and their behaviour helped to hydrogeologically characterise the lithologies in which the basins lie and to work out a re-

name	011BQ	011BQ	011BQ	021AQ	021AQ	021AQ	034KQ	034KQ	034KQ	071DQ	071DQ	071DQ	078NQ	078NQ	078NQ
HCO3	143,4	136,1	142,2	119,0	125,7	122,0	79,3	82,4	84,8	164,1	166,6	175,1	34,8	34,2	37,8
Ca/Mg-ratio	3,99	3,66	3,70	2,44	2,03	2,30	5,91	5,89	5,67	1,83	1,73	1,67	3,80	3,89	5,41
water hardness	7,11	6,53	7,35	6,10	6,17	6,57	4,66	4,39	5,08	8,72	8,38	9,17	2,62	2,26	2,67
balance	0,050	0,008	0,157	0,070	-0,024	0,186	0,149	0,031	0,242	0,085	-0,056	0,130	0,101	0,062	0,154
cations	2,563	2,351	2,638	2,216	2,228	2,371	1,728	1,623	1,879	3,253	3,110	3,402	0,981	0,848	1,008
anions	2,513	2,343	2,481	2,146	2,252	2,185	1,579	1,592	1,637	3,168	3,165	3,272	0,880	0,786	0,853
basecapacity at pH 8.2	0,060	0,020	0,020	0,040	0,010	0,010	0,050	0,040	0,020	0,150	0,110	0,080	0,100	0,080	0,040
Na	0,5	0,3	0,4	0,7	0,5	0,6	1,1	1,0	1,2	2,7	2,3	2,6	0,9	0,8	1,1
K	0,3	0,2	[0,02]	0,3	0,2	0,2	0,6	0,6	0,7	0,9	0,7	0,8	0,3	0,3	0,3
Mg	6,2	6,1	6,8	7,7	8,8	8,6	2,9	2,8	3,3	13,4	13,3	14,9	2,4	2,0	1,8
Ca	40,6	36,7	41,3	30,9	29,5	32,7	28,5	26,8	30,9	40,3	38,0	41,0	14,8	12,8	16,1
PO4	< 0,10	< 0,10	< 0,20	< 0,10	< 0,10	< 0,20	< 0,10	< 0,10	< 0,20	< 0,10	< 0,10	< 0,20	< 0,10	< 0,10	< 0,20
F	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50	< 0,50
[SO4]2	6,467	4,502	6,678	7,392	7,385	7,392	11,263	9,890	10,105	18,146	17,087	16,145	13,063	9,304	9,754
Cl	0,350	0,108	< 0,10	0,417	0,194	0,180	0,445	0,370	0,326	1,477	1,002	1,224	0,374	0,217	0,249
NO3	1,169	0,975	0,723	1,859	2,040	1,604	1,989	1,612	1,669	3,647	3,192	1,917	1,712	1,602	1,442
NO2	[0,008]	<0,012	[0,007]	[0,008]	[0,004]	[0,007]	[0,009]	[0,004]	[0,007]	<0,022	<0,012	[0,007]	[0,008]	<0,012	[0,007]
NH4	[0,007]	0,031	[0,008]	[0,007]	[0,004]	<0,029	[0,007]	[0,004]	[0,008]	<0,025	0,015	<0,029	<0,025	[0,004]	<0,029
Mn	[0,009]	<0,006	<0,008	[0,009]	<0,006	[0,001]	[0,009]	<0,006	[0,002]	[0,001]	<0,006	[0,002]	[0,001]	<0,006	[0,002]
Fe	[0,021]	<0,019	0,025	[0,021]	<0,019	[0,005]	[0,021]	<0,019	[0,006]	<0,009	<0,019	[0,006]	<0,009	[0,007]	[0,006]
KMnO4	0,5	0,8	0,5	0,8	0,8	0,7	<0,5	0,8	0,6	1,1	0,7	0,8	[0,1]	0,9	0,6
acid capacity	2,350	2,230	2,330	1,950	2,060	2,000	1,300	1,350	1,390	2,690	2,730	2,870	0,570	0,560	0,620
pH at institute	7,63	7,91	7,93	7,69	7,94	8,04	7,49	7,68	7,86	7,36	7,53	7,69	6,58	7,02	7,39
electric conductivity	229	218	225	198	207	196	151	152	151	293	289	302	80	77	76
temperature in °C	4,2	4,5	3,9	7,5	6,5	7,8	3,5	3,9	4,2	7,5	6,8	7,2	4,1	3,7	4,3
date of sampling	28.11.2006	25.05.2007	05.11.2007	28.11.2006	25.05.2007	06.11.2007	29.11.2006	25.05.2007	06.11.2007	28.11.2006	25.05.2007	05.11.2007	28.11.2006	25.05.2007	05.11.2008
name	011BQ	011BQ	011BQ	021AQ	021AQ	021AQ	034KQ	034KQ	034KQ	071DQ	071DQ	071DQ	078NQ	078NQ	078NQ

Table 2: Hydrochemical values in mg/l of representative springs.

gional hydrogeological model showing flow systems and water provenance in the Obernberg area. The model is represented by the profile in the Fig 15.

Lake water: The conductivity of the lake water ranges around 180 µS/cm, peaking at 224 µS/cm. Some points where measurements were done show relatively lower values of about 70 µS/cm. The lowest water temperature recorded during the monitoring, was 1,8° C in Nov. 2006, the highest water temperature was 13° C (May 2007). Ca ranges from 0,66 - 1.48 mmol/l, Mg from 0,24 - 0,38 mmol/l and HCO3 between 1,75 and 3,2 mmol/l. The Ca/Mg ratio is in general 2,3 but some points in the lake show variations with peaks at 6,1 and lowest values at 1,9.

Tunnel water: The water flowing out of the tunnel has a temperature of 9,9° C and a conductivity of 224 µS/cm. Ca content is 0,693 mmol/l and Mg content 0,55 mmol/l, resulting in a Ca/Mg ratio of 1,27. HCO3 content is 1,75 mmol/l. See also pie chart in Fig. 15.

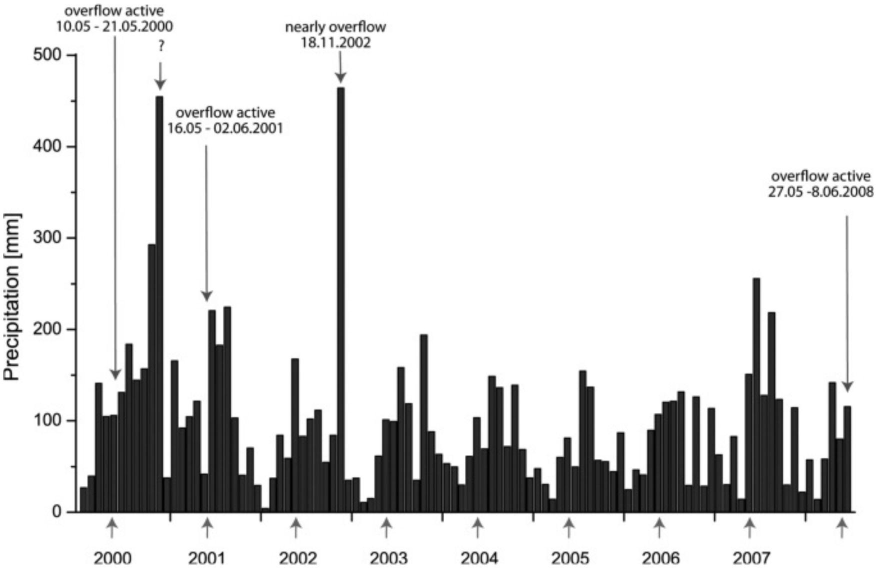

Figure 11: Monthly precipitation from January 2000 until June 2008. Snowmelt periods (upward facing arrows) and overflow events are marked (downward facing arrows). Clearly visible is the relationship between high precipitation/snowmelt and surface overflow. Despite low precipitation in May 2001, overflow was active only due to snow melt. The missing overflow in 2007 can probably be connected to the dry years 2003-2006 with low snow heights and therefore low groundwater tables.

5.4 Discussion

5.4.1 Origin of the Quaternary sediments in the Lake Obernberg area

Big wall forms around the lake, more than 50 m high and covered by rockfall deposits, show sharp ridges and steep flanks dipping to the south. These discontinuous wallforms were classified as moraine ridges from a northward flowing glacier by Paschinger (1953). Detailed geological mapping in the lake area gave no proof for the glacial nature of these wallforms, but a different model has to be proposed. On the base of the geological mapping the deposits of the "Kachelstube rockfall" are covering the whole lake area (see Fig. 3). The rockfall occurred in late-glacial or even post-glacial time, so two different models can be proposed to explain the present-day morphology in the catchment of the lake. The age of the dated matter (see above) is post-glacial, so depending on how much time passed between the rockfall and the deposition of the C14-dated organic matter, the morphology formed either only because of the rockfall (toma landscape) or the rockfall covered dead-ice bodies of a retreating glacier. Following the latter model, the melting of these dead-ice bodies was the origin of the hummocky landscape and the two big depressions, where the two lakes are now situated (Fig. 3). It is even assumed that the See Valley was blocked by the main glacier of the Hinterenns Valley (Fig. 3), which might have formed the southward-dipping moraine ridges. As the large Hinterenns Valley glacier melted back, the rockfall slided down the slope causing E-W trending trenches. Melting of dead-ice bodies and slumping of the rockfall deposits can therefore explain the present mor-

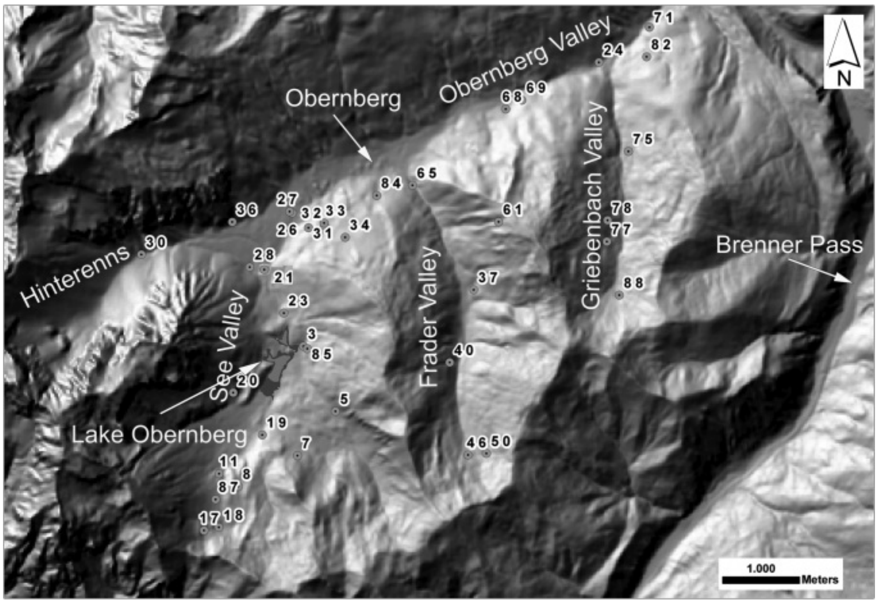

Figure 12: Hillshade illustration of the investigated area with the locations of periodically measured springs. Numbers in the figure represent the numerical part of the spring names. Due to better readability, the letter codes were omitted.

phology in the lake area. The thickness of the Quaternary sediments below the lake is derived from detailed geological and U-shaped topographic cross sections transversal to the valley. On the basis of these cross sections, the thickness can be estimated by approximately 60 m. Due to missing natural and artificial outcrops like core drillings, the composition of the Quaternary sediments could not be investigated in greater depths. The assumption that the lake is embedded in coarse-grained rockfall sediments and that these sediments are also present below the lake are based on the distribution of the rockfall sediments on the hardground surface. The conceptual geological model of the lake area should be proved by geophysical profiling calibrated with core drillings. A geophysical campaign of the Geological survey of Austria in the area of the lake during summer 2009 should give new results on the thickness of the Quaternary sediments and on the succession of events, but the results are not available at the date of submission of this paper.

5.4.2 Local hydrogeological conceptual model for the lake Obernberg area

From a geological point of view the Lake Obernberg is embedded in coarse-grained up to blocky rockfall deposits which have a high hydraulic permeability. These deposits which also cover the Portjoch fault are shown in Figure 3. Below the rockfall deposits, the Portjoch fault separates carbonatic rocks on the western side of the fault from schists with lower hydraulic conductivities on its eastern side (Fig. 2). The rock fall sediments are in hydraulic contact with the carbonatic rocks in the West. The unconsolidated coarse-grained rockfall deposits can be interpreted as a soft rock aquifer. The infiltrating rivers in the SW of the lake are point-recharge sources for this aquifer. Due to the hydraulic contact to the carbonatic rocks in the West and the high topographic levels in the Tribulaun area, a ground water flow from these carbonatic rocks to the rockfall deposits can be assumed. The Quaternary aquifer is discharging in the NE in form of large springs (Seebach spring 023SQ, Aalsee spring 021AQ). The Seebach Spring is the origin of the river Seebach. The outflow location is seasonal varying, higher elevation of outflow coincides with high recharges (for example snow melt periods) and therefore higher water table in the rockfall deposits. On the base of the lake level measurements in the two lakes (lowstand) or in the single lake (highstand) and the height of the spring, the ground water level in the unconfined rockfall aquifer can be constructed (see Fig. 14). The results of chemical analyses show that the lake water and the outflowing groundwater at the spring have a similar composition, indicating that the lake is the source of water for this spring. Conductivity shows a trend towards slightly higher values downgradient. Groundwater level is relatively shallow and discharges partly to the Seebach spring (023SQ) and downvalley to the Aalsee spring (021AQ) (see Fig. 14). The high porosity of the unconsolidated Quaternary sediments around the lake allows a fast subsurface movement of the water in the catchment of the lake and a fast reaction of the ground water level to recharge events like high precipitation or snow melt events (see Fig. 8). The geological model, the chemical analyses and the similar behaviour of the lake water level and the groundwater levels (derived from the behaviour of the spring discharges) led to the hypothesis that the lake level is an outcropping groundwater level as shown in Fig. 14. Groundwater monitoring wells and continuous monitoring of the hydraulic system including the lake levels and main springs could validate the hydrogeological conceptual model for the lake Obernberg area. No investigations were done on the age of the water, therefore all conclusions were drawn done on the assumption that the water has the same age. There is a possibility that the water of the lower springs originates from another groundwater body (see Rank et al., 2003), but the available data points to the presence of only one single body.

5.4.3 Regional Model

The East-West trending profiles in Fig. 15 show the regional geological model. Profile 1 is located near the lake, profile 2 approximately 1.7 km further to the south, near the Portjoch. The Portjoch fault is clearly visible in both profiles: in profile 1 the amount of displacement is about 500 m, in profile 2 approximately 200 m. To the West of the Portjoch fault the carbonatic rocks are outcropping, to the East of the fault zone the carbonatic rocks are covered by phyllitic rocks of the Steinach nappe. The pie charts of the springs 030HQ, 020SQ, SMP9 (monitoring point in the lake) show similar distributions of anions and cations and therefore can be considered as being hydrologically related. 030HQ drains the block west of the Portjoch fault and 020SQ is situated east of it. Both show identical distribution of anions and cations, indicating a direct con-

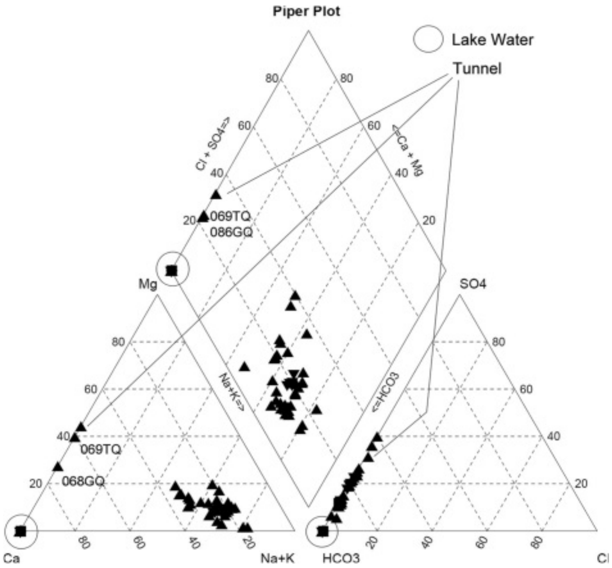

Figure 13: Piper Plot of all analysed samples. Squares represent lake water, upward facing triangles spring waters, downfacing triangles surface waters (rivers). Most of the springs show a similar chemistry, which is Ca and HCO3 dominated, with sodium and potassium content. Some springs (069TQ and 061SQ) are more similar to the chemistry of the tunnel water, which shows slightly elevated values for sulphate content.

nection between the two aquifers, despite the presence of the fault. The easternmost springs (046FQ and 050HQ) show a typical composition of a quartz phyllite-dominated catchment. The Tribulaun group, which has the highest elevation in the working area, dominates the local and regional hydrogeological system. Water recharges in this area which is dominated by the unconfined, carbonatic aquifer and part of it flows as groundwater to the East. The Portjoch fault displaces the eastern block, forcing the groundwater to separate into two groundwater flow systems: one is immediately discharging to the surface or into the rockfall aquifer, the second and deeper could probably feed the confined aquifer to the east of the Portjoch fault. As the fault is a strike and slip fault and the discussed deeper groundwater flow is vertical to the fault, the flow is assumed to be low. There are no monitoring wells in the confined aquifer to the east of the fault and therefore neither the flow nor the direction of the groundwater flow in this deep aquifer is proved. Large springs (071DQ in Fig. 2) in the Obernberg Valley which is hydraulically the lowest point of the even North dipping confined aquifer and the high base flow of the river in this valley (Obernberg Bach) could be an indication that even the groundwater in the confined aquifer is discharging to the North in the Obernberg valley. Chemical composition of the main water inflow in the tunnel (see Fig. 15) and the compositions of the springs in the study area show differences. A direct or big deep seated groundwater flow from the unconfined carbonatic rock aquifer through the Portjoch fault to the tunnel can therefore be excluded, which could validate the assumption of the low hydraulic conductivity of the Portjoch Fault vertical to the trending and therefore low deep groundwater flow system. A high impact on the shallow groundwater flow system in the rockfall aquifer and therefore a visible impact on the lake level can be excluded. On the other side with the results of this study it cannot be excluded that the lowering of the hydraulical potentials in the deeper confined aquifer due to the tunnel had any impact even on hydraulical potentials to the West of the Portjoch fault.

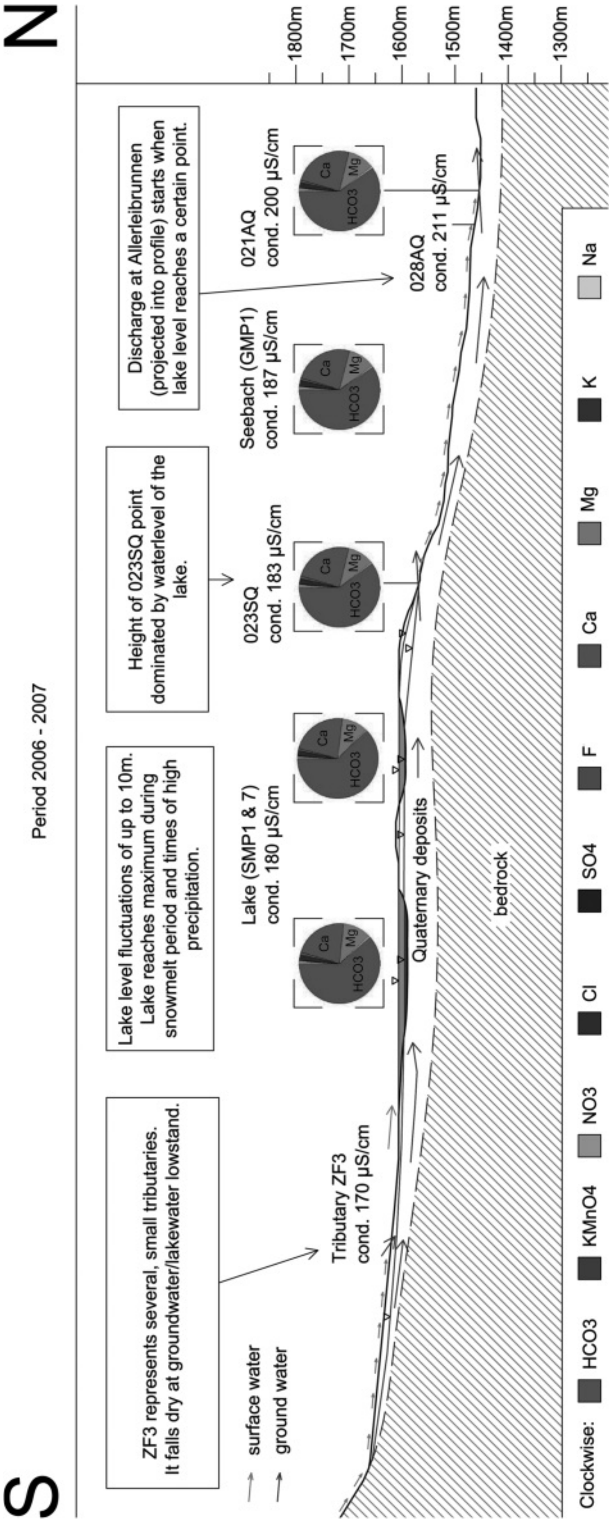

Figure 14: N-S trending profile of the lakes. Pie charts show ionic composition. Dark grey arrows show flow directions of groundwater, light grey arrows indicate surface water.

6. Conclusion

The results of this study indicate that the lake level represents the groundwater table. The rapidly falling and rising lake level, the low water temperature, and subsurface water gain/loss support this conclusion. Monitoring of the lake level over the duration of one year in connection with data from events in the past prove that precipitation and snowmelt are responsible for changes in lake level of up to 10 m in magnitude. Therefore are the lake level fluctuations of the Lake Obernberg of natural origin and, based on inspection of historical data, most likely have existed at least since the 18th century. Since no previous records of lake level are available, assessing a possible human impact on these fluctuations is impossible, but is likely of only minor importance. This local system is controlled by the regional system of the Tribulaun area, which supplies the water. Profiles in Fig. 15 prove that the dolomite aquifer of the Tribulaun area is in contact with folded calcite marbles of the MKK in the Steinach nappe and with the underlying confined aquifer of the BMZ. Interactions between these two aquifers east of the Portjoch fault are not known but possible. This paper shows the results of a low budget study (diploma thesis) in the area, supplying basic data sets which can and need to be extended for future studies. The installation of two fixed

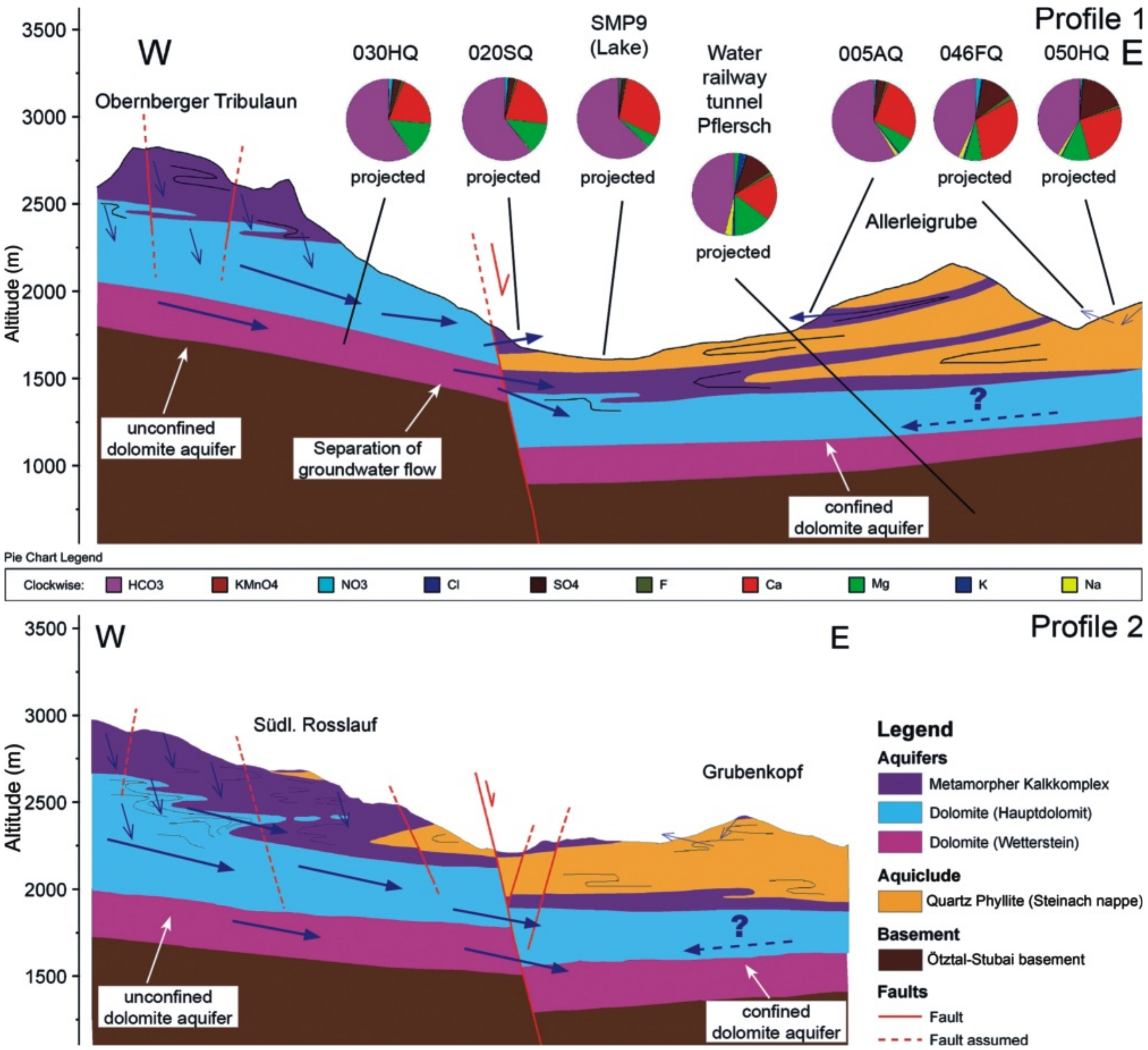

FIGURE 15: Geological cross sections. Blue arrows mark groundwater flow directions. The tectonic contact of Metamorpher Kalkkomplex and Steinach nappe is intensely folded, which is indicated by black lines representing rock cleavage. Geologic units are summarised into hydrogeological regimes for easier interpretation, and the pie charts in profile 1 show the molar distribution of anions and cations of several springs along the profile. After reaching the center of the profile. most the water will move towards the north, due to the tilting of the geological units. Springs with high outflow rates in the Obernberg Valley and Pflersch Valley drain the aquifer.

gauges in the lake basins, tracer experiments, examination of laser scans (which were not available at the time of writing this paper) and investigations on the age of the waters are recommended to get more exact information on the groundwater bodies and their flow directions. The approach of this study is very basic, as it mainly relies on monitoring and sampling springs in combination with detailed geological mapping. It can easily be applicated to other regions and easily be extended for projects with better funding.

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