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The Facies and Hydrogeology of an Inneralpine Pleistocene Terrace Based on an Integrative Study – Deep Well Telfs

PAUL HERBST[1)2)*)], SYLKE HILBERG[1)2)], ILSE DRAXLER[3)], HARALD ZAUNER[4)] & FRANZ RIEPLER[1)]

[1)] GWU Geologie-Wasser-Umwelt GmbH, Bayerhamerstr. 57, 5020 Salzburg, Austria;

[2)] Department of Geography and Geology, Salzburg University, Hellbrunnerstraße 34, 5020 Salzburg, Austria;

[3)] Geologische Bundesanstalt Wien, Neulinggasse 38, 1031 Wien, Austria;

[4)] Hörzingerstraße 60, 4020 Linz, Austria;

[*)] Corresponding author, paul.herbst@gwu.at

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Abstract

In order to explore a new water-supply for the city of Telfs, the terrace sediments west of Telfs, Tyrol („Mieminger Plateau") have been investigated with a multi-disciplinary approach down to a depth of 110 metres. The project resulted in drilling a deep well down to a depth of 110 m from the surface. Via geophysical, geological (drillings, mapping, component analysis, geochemistry) and hydrogeological (hydrochemistry, isotope-hydrology, dye tests, monitoring) explorational methods a model for the sedimentary structure of the terrace-sediments was created, which led to a solid interpretation of the sedimentary history of the area.

The deepest parts of the terrace are built up by gravel, which has been transported a short distance in a braided river system. The sedimentation of this gravel has been interrupted during a short-time interruption of the sedimentation from west possibly caused by a slight climate oscillation sensu Van Husen (1983) with the deposition of banded clays and carbonate gravel from a local catchment area. The uppermost regions of the terrace are built up by basal till of the Last Glacial Maximum (LGM – Würm).

Auf der Suche nach einem weiteren Standbein für die Wasserversorgung der Marktgemeinde Telfs wurden die westlich des Ortes liegenden Terrassensedimente (Mieminger Plateau) einer multidisziplinären Untersuchung unterzogen und als Folge dieser Untersuchungen ein Tiefbrunnen mit einer Ausbautiefe von 110 m errichtet. Mittels geophysikalischer, geologischer (Bohrungen, Kartierung, Geochemie, Komponentanalysen) und hydrogeologischer (Hydrochemie, Isotopen-Hydrologie, Markierungsversuche) Methoden wurde ein Sedimentationsmodell für das östliche Mieminger Plateau erstellt.

Die tieferen Bereiche der Terrassensedimente werden von Kiesen und Sanden aufgebaut, welche nur über kurze Distanzen in einem braided-river system transportiert wurden. Während einer kurzzeitigen Unterbrechung der Sedimentation dieser Vorstossschotter von Westen wurden Bändertone und kalkalpine Kiese abgelagert, welche vorwiegend von Norden, aus dem Bereich der Mieminger Kette, eingetragen wurden. Die hangendsten Partien der Terrasse werden von würmzeitlicher Grundmoräne aufgebaut.

1. Introduction – General Geology

The terraces west of Telfs on the northern side of the river Inn (Mieminger Plateau, Fig. 1) have been well studied and described during the last 100 years via surface exposures (Ampferer (1908, 1915), Machatschek (1934), Bobek (1935), Heißel (1954), Poscher (1993a, b)), while deep drillings have never been done in this area.

The Mieminger Plateau has a maximum width of 3 km and extends between the Tschirgant Mountain in the west and the city of Telfs in the east (Fig. 1 b, c). The plateau extends parallel to the inn-valley, yet at an altitude 200 m higher.

The Plateau is framed by the mountains of the Northern Calcareous Alps (Mieminger Kette with a maximum altitude of approximately 2700 m asl in the north and the so called Achbergzug with a maximum altitude of 1032 m asl to the south – see Fig. 1c). The bedrock within the Quaternary terrace sediments of the Mieminger Plateau has never been detected before.

The Quaternary sediments on top of the eastern part of the Mieminger Plateau can be divided into two main areas (Fig. 2). In the northern part Würmian Pleniglacial, Würmian Lateglacial and Holocene sediments cover the entire area. These deposits are differentiated into remnants of a glacier reaching down to the plateau from the Alpl-Valley (carbonate basal till Fig. 2) within the Mieminger Kette and into young to recent sediments (debris) with small outcrops of bedrock (limestone, dolomites) in lower altitudes at the rim of the terrace. The debris consists of poorly rounded components in loose bedding and therefore shows very high permeability. Above 1100 to 1200 m asl the dolomites can be followed over wide regions at the surface. The southern part of the Plateau is covered by basal till (Machatschek, 1934) from the last glacial maximum (LGM - Wuermian). These sediments were earlier interpreted as older, interglacial terrace-sediments (Ampferer, 1915). However, in a detailed survey by Machatschek (1934) the sediments were definitely defined as basal till ("Inntalmoräne") over wide areas, in parts re-deposited by melting water (Bobek, 1935). During the LGM the Inn-glacier covered the whole valley of the Inn (Fig. 1) up to altitudes of approximately 2200 m asl (van Husen, 1987) with the greatest mass-gain originating from the south (Oetztal, uppermost Inn valley with dominantly crystalline rocks as micaschists, granites). The general flow-direction of the glacier in the research area was from south to north with a southwest to northeast component due to a deflection of the ice-masses from the south along the Tschirgant mountain.

Two gravel pits in the area (Fig. 2) reveal the upper parts of the sediments. One pit (Emat) is situated east of the plateau at an altitude of 765 to 720 m asl showing a delta-complex (carbonate material) of unknown age (Poscher, 1993 a). The pit Meaderloch was closed some years ago but also showed fluviale gravels dipping towards the Inn Valley, covered by basal till (Hantke, 1983).

Two valleys are cutting the terrace reaching depths of up to 80 metres from the terrace surface. Due to the absence of surficial drainage systems these are regarded as dry valleys, which seem to have been eroded during the late Wuermian by glacial streams from the locally glaciated Northern Mountains (Mieminger Kette) together with melt water of the receding Inn Glacier (Bobek, 1935).

2. Results of Preliminary Investigational work – summary

2.1 Methods

After (hydro)geological mapping to achieve a first overview the eastern part of the research area was investigated by refractional seismics. This led to a first determination of a possible location for a deep well. On this place an exploration well was brought down followed by some more drillings in the suspected hydrogeological catchment area. The data of these drilling campaigns together with hydrogeological investigations such as dye-tests, hydrochemistry, and isotope hydrology led to the design and completion of a deep well. During the completion of the deep well more sedimentological as well as palynological and geochemical investigations were done. The geochemical analysis of the clays and silts between 697.20 and 688.40 m asl was performed by F. Finger at the University of Salzburg, Dept. of Geology in order to determine the main elements, the palynological analysis was performed at the palynological laboratory at the Geological Survey of Austria, Vienna (samples Nr. 6622, 6623, 6627, 6628, 6629, 6630, 6631, 6632).

Isotope hydrology has been used to estimate the mean elevation of the catchment area of the investigated aquifer. Therefore values of $\delta^{18}O$ out of two groundwater samples were taken in August 2001 and in January 2002 and interpreted first by using an altitude gradient based on Forster and Weise (1997). New data received in context of later investigations in 2003 and 2004 from a spring with a known local catchment area in combination with long-term measurements of $\delta^{18}O$ values in precipitation at the station of Scharnitz (Humer, 1995) were used to specify the altitude gradient in the investigated area for a new determination of the mean elevation of the catchment area.

2.2 Geophysics

A geoseismic survey (refractional seismics – Schmid, 1998) displayed hints for a multi-layered, complicated internal structure of the terrace sediments. Five profiles with a total length of 2880 metres were established. The first refractor from the surface was interpreted as weathered layer with a thickness of 4 to 8 metres and velocities of 180 – 600 ms^{-1}. Subjacent a layer of interpreted dry, coarse-grained sediments with velocities of 620 – 1220 ms^{-1} was found with thicknesses of 10-20 metres. The third refractor was interpreted as 100 per cent water-saturated sediments or conglomerated material with velocities from 1340 to 1670 ms^{-1} and a maximum thickness of 60 metres. This refractor showed an intense relief. The most relevant refractor with velocities between 2420 and 2830 ms^{-1}, which was interpreted as impermeable limestone-breccia, was found in all five profiles and depicted in a isohypse-map. The position of the exploration well in a clear valley-structure of this refractor was then determined. The deepest layer displaying a distinct relief with velocities of considerably more than 3000 ms^{-1} was found in depths of 100 to 250 metres from the surface.

2.3 Drilling campaigns and geological mapping

On base of the geoseismic survey an exploration well was brought down to a depth of 110 m by airlift-drilling at the same location as the deep well, which provided a first rough insight into the vertical succession of the terrace sediments (first dril-

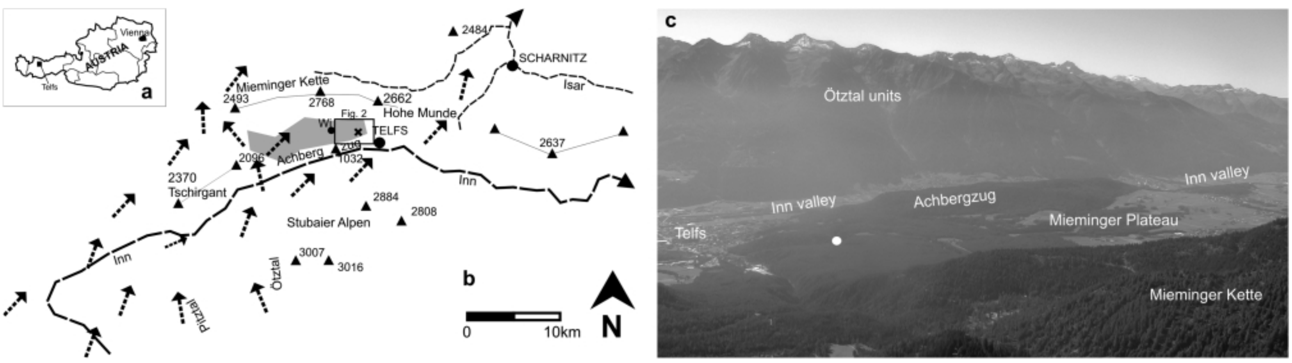

Figure 1: a – Location of the project-area in Austria, b – detailed view of the area – grey: Mieminger Plateau; triangles: mountains with altitude in m a.s.l. dotted arrows indicate ice flow-direction during LGM, c – photograph of the area of investigation, view to south-east. White dot indicates deep well.

ling campaign). A pumping test showed the existence of a sufficient amount of groundwater under a layer of banded silts and clays ("Bändertone") in a depth of approximately 50 - 60 m from the local surface.

After detailed geological mapping, which proved the results from older mappings presented in Section 1, a second drilling campaign was launched during autumn 2001, at which time four boreholes with depths of 65 m (maximum) were drilled (P 1 to P4 in Fig. 2). The goal for these drillings was the exploration of the aquifer within the potential catchment area of the planned deep well. Due to the fact that two of the drillings turned out to be dry (P1, P4) and the third only reached local groundwater (P2), the existing model of the aquifer as described in various unpublished reports had to be revised.

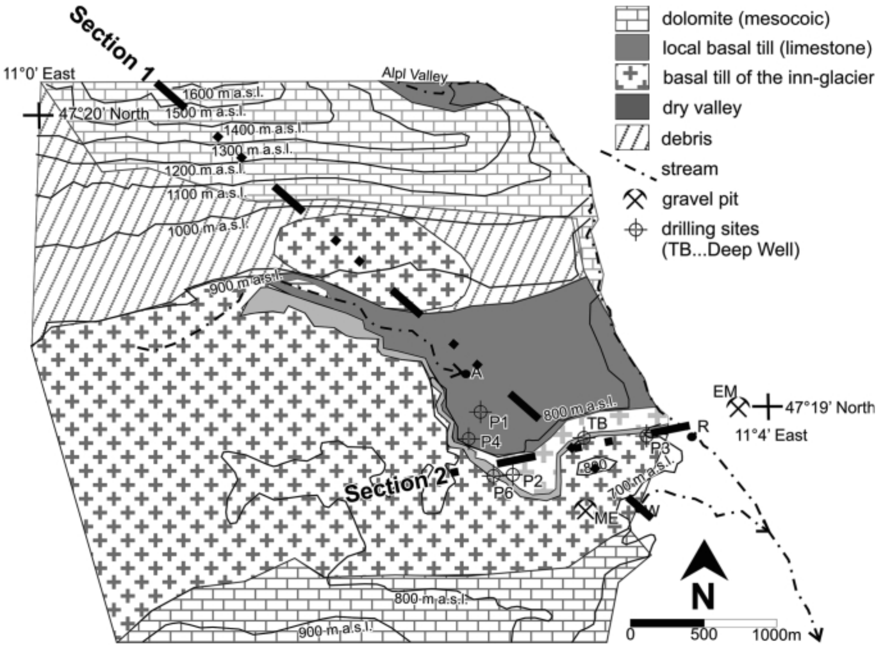

Figure 2: Geological sketch-map of the area of investigations. Hydrogeological features as mentioned in the text (A.... infiltration Angerbach, R....Rollmühlquelle, W....Wassertalquelle). Gravel Pits: EM....Emat, ME....Meaderloch

The results of the drilling campaign showed a thick layer of local basal till with more than 90 percent limestone and a high content of fine-grained sediments (clay, silt, sand). The boreholes north of the dry valley (P4, P1) measured 50 and 64 metres. P2 and P3, which were situated on the base of the dry valley, reached both depths of 20 metres and showed fluvial gravels on top. In borehole P2 these fluvial gravels were followed by basal till with an internal fine-grained layer, while carbonate dominated gravels with a layer of banded clays and silt followed in borehole P3. Both boreholes reached groundwater (Fig. 3).

A third drilling campaign (P6 in Fig. 2) reached groundwater at the predicted depth under a layer of fine grained sediments. This clay and silt layer showed signs of thinning out laterally as suggested by the local thickness as well as the comparatively poorer sorting of the material compared to the material from the exploration well.

2.4 Hydrogeology

The Hydrogeology of the area has never been investigated in detail before. Springs with a discharge of 30 to 50 l/s on the eastern margin of the terrace (Rollmühlquelle, Wassertalquellen - Fig. 2) indicated a strong groundwater-flow fed by precipitation and the infiltration of a small stream (Angerbach) in the northern region of the terrace. Loose recent debris along the northern hillside (Fig. 2) allows precipitation to enter the aquifer. As mentioned above, a surficial drainage within the described valleys is lacking. The internal groundwater-drainage of the sediment body was thus unclear and required further investigations.

Hydrochemical and hydroisotopical investigations as well as a dye-tracer test were done over a period of one year in order to establish possible connections between the described infiltration and the deep well (explorational well). The springs at the eastern margin of the terrace underwent the same tests, which resulted in a more detailed account of the quality and behaviour of the aquifer. A strong connection between the infiltration (Angerbach), the well P 3 and the springs could be proven, while the water in the exploration well (sealed off by banded clays from the surface) merely showed very discrete hints for a hydraulic connection to the local surface.

The $\delta^{18}O$-values were measured two times in different hydrological situations (August -13.15‰ and January-13.06‰). The difference between the values within the limits of the measurement error is an evidence for a mean residence time of more than two years.

To estimate the mean elevation of the catchment area the values for $\delta^{18}O$ first were interpreted by using data from Forster and Weise (1997). Based on regional isotopic data Forster and Weise (1997) determined a gradient of -0.17‰ per 100 m rise in altitude for the region of Innsbruck. This regional gradient displayed a mean elevation of 1250 m asl in the catchment area for the water in the explorated aquifer.

In a second step data of isotopes in precipitation at the station of Scharnitz were used in combination with later $\delta^{18}O$-data of a spring with a known local catchment area to specify the appropriate altitude gradient in the potential catchment area of the well. Using these local data leads to a gradient of about -0.4‰ per 100m. This local based gradient displayed a mean elevation of 1360m a.s.l in the catchment area. The exploration well itself reached the groundwater at a depth of

700 m asl So that the difference in altitude between mean infiltration elevation and groundwater table amounts to 660 m as an indication for an obviously long flow section.

The calculated altitudes can only be reached to the north as shown in Fig. 2 in an area of dolomites and debris respectively.

The marginal difference between the two $\delta^{18}O$-values measured in summer and wintertime is significant for a mean residence time of two or more years which is consistent to the postulated long flow path. The interpretation of isotope data helps to define the catchment area in detail and so to understand the hydrogeological situation and it was the base for the designation of the protective area.

3. Deep well – methods and results

Drilling was performed by using a rotary drill with inverse drilling fluid. This made the permanent presence of a geologist necessary to investigate the cuttings brought up by the drilling fluid. Besides the basic documentation (grain size, shape, lithology etc.) and a progress monitoring, a component-analysis was done every five metres, as well as occasional grain size analysis.

The well was drilled from an elevation of 747.70 m asl to a depth of 110.40 metres corresponding to an absolute elevation of 637.30 m asl.

3.1 General geology

The uppermost layer with a thickness of 33 metres (down to a depth of 714.70 m asl) revealed a sequence of poorly sorted gravels with a high content of boulders, sand and a variable content of silt and clay (Fig. 3). These materials were interpreted as basal till. Between 714.70 m and 692.20 m a layering of sands, gravels and silt could be found. Due to the drilling method no original sedimentary structures were detected. However, on the basis of the clearly layered structure as well as the differences in grain sizes and poor degree of rounding, these sediments were interpreted as fluvio-glacial with short transport distance (proglacial sedimentation). In this layer free groundwater was encountered.

At 692.20 m asl a fine-grained sequence of banded silt and clay was found. As a result of the cohesive properties, these sediments were brought up in lumps, which showed a very fine original sedimentary layering (layers of some mm thickness). These fine-grained sediments could be detected down to 688.40 m asl and are interpreted as lacustrine sediments. After a transitional zone, which consisted of a mixture of fine grained sediments and coarser components (gravels), the drilling showed coarse gravels with a moderate content of boulders and sand as well as a total absence of silt and clay at 678.50 m asl. As predicted, confined groundwater was found within this zone. The water had a pressure of approximately 2.8 bar and rose up to the level of the groundwater above the fine-grained zone. The gravels could be found all the way down to the final depth of the borehole at 110,4 m (at 637.30 m asl). From 662.70 m asl down-section thin layers of silty material some decimetres in thickness) were repeatedly intercalated into these gravel deposits. This deepest sequence from 678.50 to 637.30 m asl (i.e. the gravels below the lake sediments down to the base of the well) is interpreted as (fluvio)-glacial/proglacial.

3.2 Component distribution, grain size and geochemistry

Every five metres a composite sample was sieved and the fraction > 2 mm (gravel) of the sample was separated into carbonates (limestone, dolomite) and crystalline rocks (gneiss, serpentinite, quartz grains and others). The distribution shows three regions which differ in their carbonate-content (Fig. 4): (1) From 747.70 m asl to 692.20 m asl a moderate content of 28 %, (2) between 692.20 and 680.20 m asl a content of al-

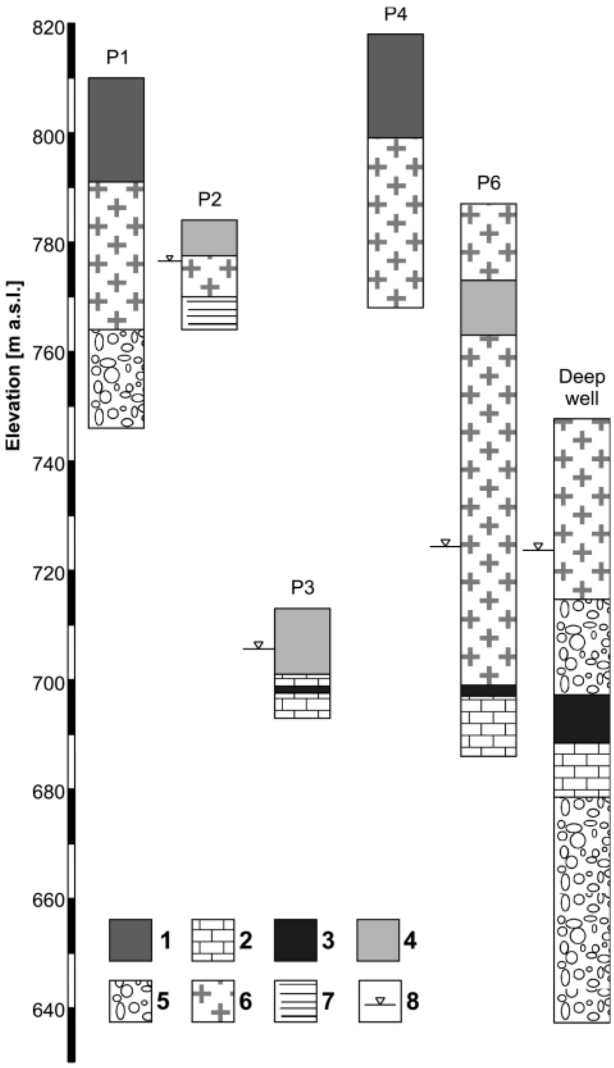

Figure 3: simplified logs of the boreholes P1 – P4, P6. Legend (genetic interpretation in brackets): 1 – Poorly sorted, angular limestone (local basal till); 2 – Well rounded limy gravels (fluvial); 3 – Fine grained sediments - clay, silt with high content of carbonate (lake sediments); 4 - Rounded gravels, both crystalline and limestone (Fill of a dry valley); 5 –Gravels, mixed crystalline and limestone, varying rounding (proglacial); 6 – Poorly sorted material with high content of fine-grained material, mainly crystalline (Basal Till); 7 – Fine grained sediments (Clay, silt) within 6; 8 – Groundwater-level (pressure height in P6, deep well)

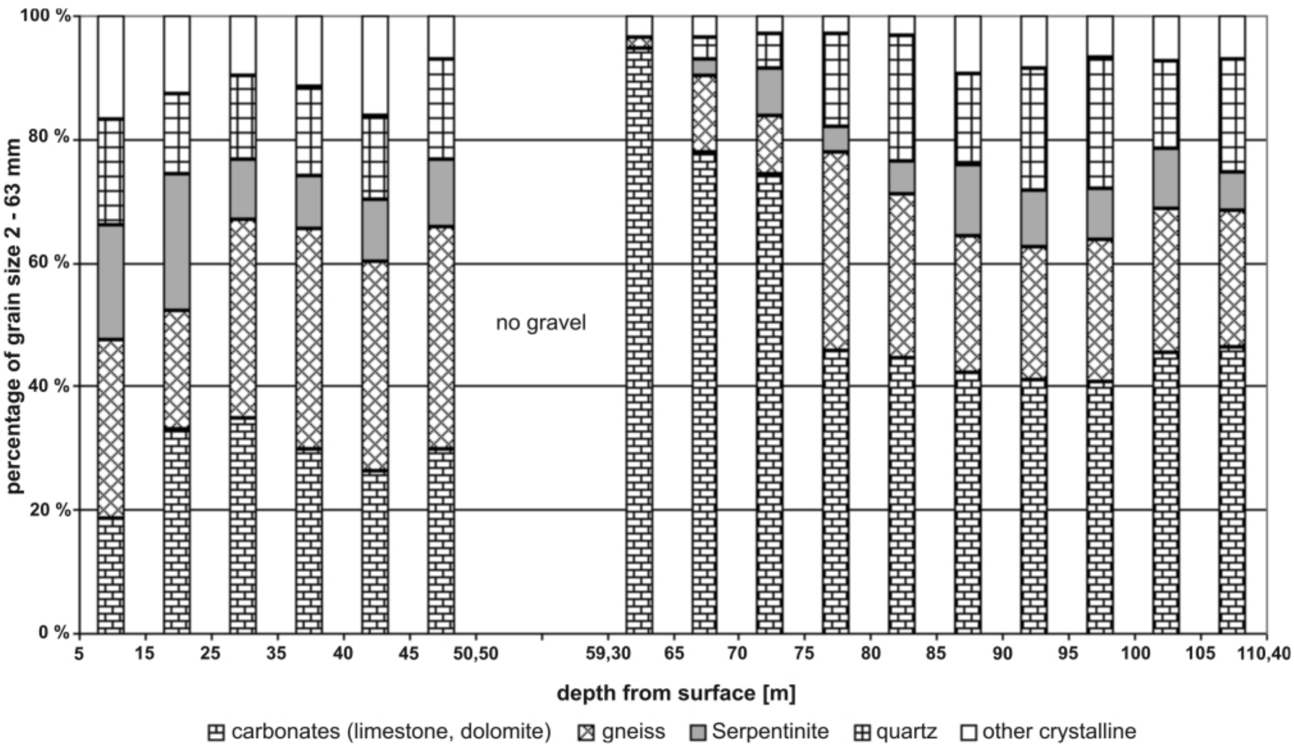

Figure 4: Vertical component distribution in the deep well.

most 100 % and (3) from 680,20 to 637.70 metres asl a percentage of 51 %.

At 662,70 to 661,60 m asl a grain size analysis for the fraction < 63 mm revealed a content of 17,5 % of silt, 25,9 % of sands and 56,6 % of gravels.

The geochemical analysis from the fine grained sediments (Fig. 5) resulted, in comparison to a similar layer from a pit near Innsbruck ("Figge" – Paschinger, 1957), in very high contents of CaO (39 %) and MgO (11 %) and a moderate amount of SiO_2 and Al_2O_3. This proves a sedimentation from a carbonate – dominated area as present in the north (Mieminger Kette) in contrast to the banded clays of the afore mentioned pit "Figge".

3.3 Pollen analysis

Between 697.20 and 688.40 m asl samples for pollen-analysis were taken from the fine-grained sediments (clay, silt) in one metre increments. The results showed strong indications of very cold conditions during the deposition of these lacustrine sediments with almost no detectable pollen. There were however some indicators for cold climate (some pinus pollen and herbs as Asteraceae at 697.70 – 696.70 m, 695.70 – 694.70 m and 693.70 – 692.70 m asl). No radiocarbon - dateable material was found within these sediments.

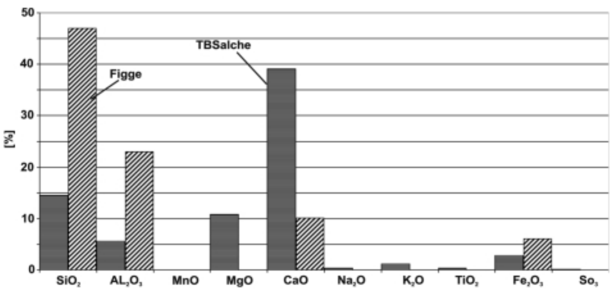

Figure 5: Results of the geochemical analysis of the banded silts and clays

4. Interpretation

A synopsis of all the gathered data leads to a geological/hydrogeological model of the internal structure of the terrace sediments west of Telfs (Fig. 6). The sedimentational history is shown in Fig. 7:

Above the bedrock a layer of fluvio-glacial gravels with embedded lacustrine sediments builds up the deeper parts of the terrace sediments. Further up-section the terrace is made up of basal till of the Inn-Glacier with a high amount of crystalline components and indicator clasts such as granites from Switzerland ("Julier Granite"). Deposits of a local glacier are also present in the topmost part of the section with basal till consisting of carbonate material only.

The described fluvio-glacial gravels between 714 and 640 m asl make up the main volume of the terrace and constitute the main aquifer in the region. These gravels show signs of relatively short fluvial transport distances under a regime of extreme changes of flow, as there is quite a poor degree of sorting as well as a frequent vertical change in grain size. Furthermore, there is a significant difference in the degree of rounding of the components with poorly rounded carbonate-components (from a local catchment area – Mieminger Kette, Fig. 2) and well-rounded crystalline-components (indicating long en/sub- or supraglacial travel distances with presence of running water). The high content of carbonate components (40 to

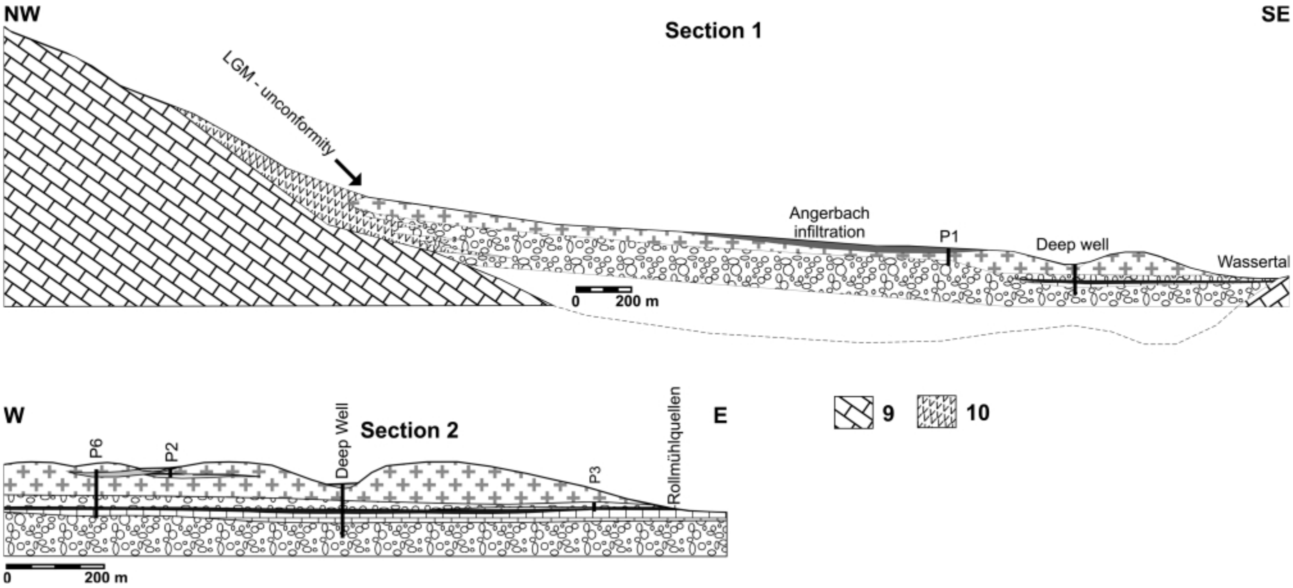

FIGURE 6: Two sections based on the results of geological, hydrogeological and geophysical (top of base rock) investigations. For legend see Fig. 3, except for 9 – dolomite, 10 – loose debris. For location of the sections see Fig. 2.

70 percent) indicates a strong influence of the local drainage system. The thickness of these gravels (i.e. the entire sequence which encompasses the fluvio-glacial gravels with crystalline components and the more locally derived limy gravels) is at least 120 m.

Embedded into these gravels are the banded clays and silts which are directly associated with the well rounded and locally derived limy gravels, (> 70 % of carbonate components – Fig. 3). The banded clays represent an ephemeral lake, fed mainly from catchment situated in the north (i.e. the NCA as indicated by the geochemical analysis) and therefore a different catchment area than the mentioned analysis "Figge". This is a typical sequence of early Wuermian sedimentation in the sence of Van Husen, 1983 a and b with the variation of bottom valley sedimentation controlled by climatic fluctuations, the development of shallow short-time lakes caused by differing current velocities through the advance of alluvial cones from the mountain sides. The high amount of carbonate gravels as well as the high combined totals of CaO and MgO (50 %) supports this fact. Pollen analysis hints strongly at a deposition in a cold period with almost no pollen and a generally very low content of organic material in these clays. This data fits well with the results of Fliri et al. 1970, according to which the pollen-content within the banded clays displayed only loose and scanty vegetation in an adverse climate at the location Baumkirchen, an intensively explored deposit of banded clays, appr. 40 km east of Telfs. Sarnthein (1937) also describes a low content of original pollen within banded clays at two locations in Innsbruck (Figge, Mühlau), appr. 25km east of Telfs, yet discovers an extremely varying content of secondary floated pollen. Data from a dye-test at Angerbach infiltration and the results of the drilling at P6, as well as the fact of the same pressure-height of groundwater below and above the banded clays suggest a limited horizontal extension of the clays to the north and the west as shown in Fig. 6. To the east and south-

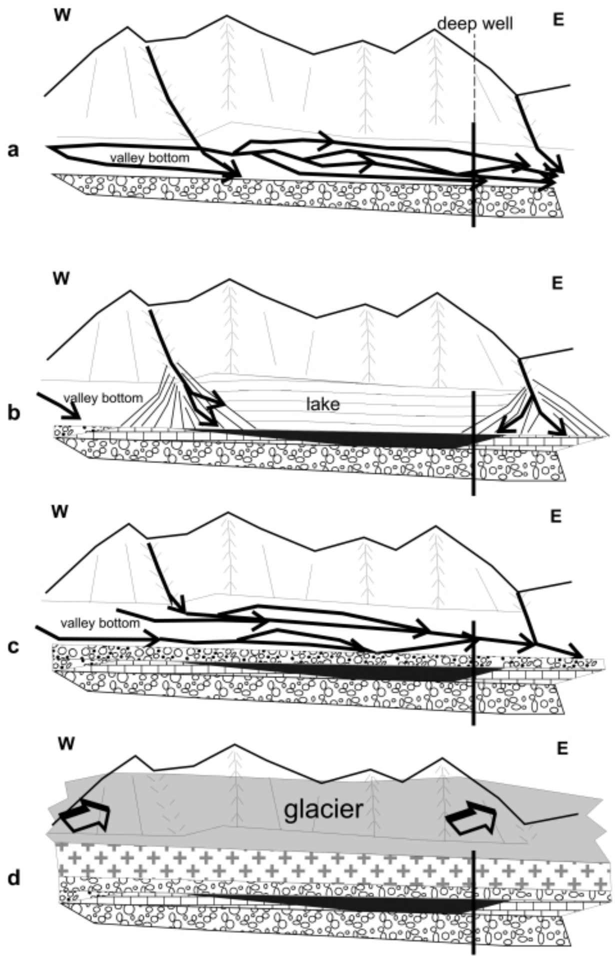

FIGURE 7: Sketches of the sedimetational history of the area, for legend see Fig. 3. View towards north. a – Sedimentation of the fluvial gravels in a braided-river system with input of limy components from the local mountains. b – Cooling with development of fans from the Calcareous Mountains in the north. The supply from west is locally interrupted by cones, sedimentation of material with almost pure limy material in a lake. c – again sedimentation from west (crystalline) and north (limestone). d – glaciation during LGM with deposition of basal till.

east, the clays are reaching the margin of the terrace with multiple crop-outs of springs.

Since there is strong evidence of short fluvial transport distances for the gravels and also a distinct influence of local material, we suggest that the terrace sediments west of Telfs must have been deposited in a cold climate under the influence of the Inn-glacier (Vorstoss-Schotter). The gravel – deposits represent the sediments of a braided river system not far from the glaciers (proglacial sedimentation).

The banded clays with the underlying carbonate-gravels (representing sediment input exclusively from the north i.e. Calcareous Alps), show that the drainage system in the Inn-valley was blocked for a short period of time. Formation of a local (pro-glacial) lake was therefore caused by enhanced sediment delivery from the Mieminger Mountains under cold climatic conditions due to ice-build up. Given a sedimentation rate between 1 and 2,27 cm per year, which were both calculated for the banded clays of Baumkirchen (Fliri et al., 1970; Köhler and Resch, 1983), the time for deposition of the banded clays and silts in Telfs should be in the order of some 100 years or even less. Given the silt content of these sediments (suggestive of higher flow velocities and thus sedimentation rates), deposition could also have been a matter of decades rather than centuries and of a small room of sedimentation. The sedimentation could have happened – as one of more possible reasons - in a short and unincisive climate oscillation, when the glacier changed its volume of run off as described above. Additionally, the input from the north increased, building up at least two fans which allowed the existence of a short-term-lake with relatively quiet conditions for sedimentation to allow the deposition of fine grained sediments (Fig. 7).

The final part of the history of the terrace sediments of Telfs is the climax of LGM (Last Glacial Maximum) with the depositions of the basal tills and – afterwards - the erosion by streams from local glaciers in the north as well as the local glaciation of parts of the terrace with the glacier pushing from Alpl valley.

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PAUL HERBST[1)2)*)], SYLKE HILBERG[1)2)], ILSE DRAXLER[3)], HARALD ZAUNER[4)] & FRANZ RIEPLER[1)]

[1)] GWU Geologie-Wasser-Umwelt GmbH, Bayerhamerstr. 57, 5020 Salzburg, Austria;

[2)] Department of Geography and Geology, Salzburg University, Hellbrunnerstraße 34, 5020 Salzburg, Austria;

[3)] Geologische Bundesanstalt Wien, Neulinggasse 38, 1031 Wien, Austria;

[4)] Hörzingerstraße 60, 4020 Linz, Austria;

[*)] Corresponding author, paul.herbst@gwu.at