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New thermal property data base of the Swiss Molasse Basin sediments: Integrating wireline logs, cores and cuttings

by *Werner Leu [1], Ladislaus Rybach [2], Ulrich Scharli [2], Thomas Mégel [3] & Beat Keller [4]

[1] Geoform Ltd., Anton Graff-Strasse 6, 8401 Winterthur, Switzerland; geoform@access.ch

[2] Institute of Geophysics, ETH Ziirich, 8093 Ziirich, Switzerland; rybach@geo.phys.ethz.ch

[3] Mégel GeoWatt, Sihlfeldstrasse 81, 8004 Ziirich, Switzerland, thmegel@swissonline.ch

[4] Mengis + Lorenz AG, Schlossstrasse 3, 6005 Luzern, Switzerland; mengis@centralnet.ch

Abstract

To improve the development of shallow geothermal resources and underground heat storage facilities, a new data base of thermal conductivity (λ), heat capacity (cp) and bulk rock density (ρ) was compiled for Tertiary sediments of the Swiss Molasse Basin (uppermost 500 m). Laboratory measurements from boreholes and outcrops were used to calibrate empirical relationships between geophysical wireline logs and geothermal parameters. For five different lithologies in three Molasse groups (Lower Freshwater Molasse USM, Upper Marine Molasse OMM and Upper Freshwater Molasse OSM) linear relationships with specific coefficients could be derived. Thermal conductivity can be calculated as a direct function of sonic velocity, whereas heat capacity depends on bulk density. Application of these new empirical laws at locations with only wireline logs, allowed to increase the previously available data density by a factor three. The software tool SwEWS facilitates the evaluation of the data base for any location in the Swiss Molasse Basin. Based on the information of an input spread sheet (Swiss coordinates, elevation, bed thickness, lithology) the program extracts the appropriate thermal properties with error estimates. The thermal conductivity and the specific heat capacity for each bed, as well as the depth dependent temperature, can be exported or displayed graphically.

The statistical evaluation of all data illustrates the regional variation of the petrophysical and geothermal parameters. For most data groups bulk rock density and thermal conductivity increase, whereas heat capacity decreases in the direction towards the Alpine front. Thermal conductivity shows a distinct increase with depth. This new data base allows more precise heat extraction/storage model simulations for planned geothermal facilities.

KEYWORDS

Swiss Molasse Basin, thermal conductivity, heat capacity, shallow geothermal resources.

1. Laboratory measurements

On over 230 new samples from outcrops, cores and cuttings extensive laboratory measurements of thermal conductivity, specific heat capacity and bulk density were carried out (figure 1). Thermal conductivity of core samples was measured with a Quick Thermal Conductivity Meter (QTM) and of cutting samples with a modified TK04 equipment. For the specific heat capacity measurements on cuttings a new high precision measuring device was developed at the ETH-Zürich (Schärli & Rybach, in preparation).

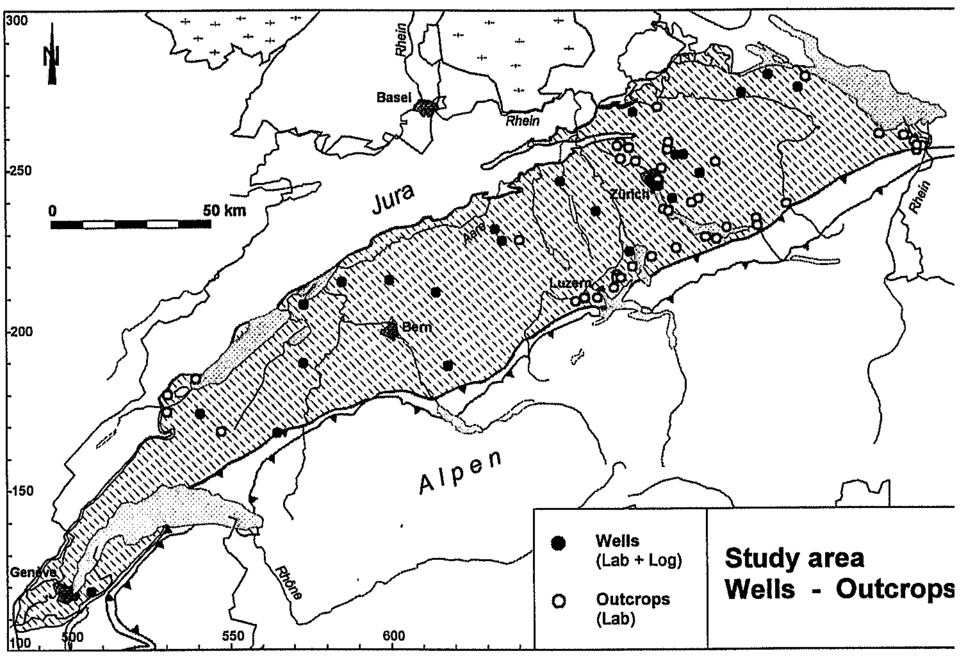


Figure 1: Study area and sample locations.

2. Geophysical log evaluation

Several empirical relationships between geophysical log parameters and thermal conductivity (Blackwell & Steele 1989, Evans 1977, Goss & Combs 1976, Schon 1996) or heat capacity (Kersten 1949, Sattel 1982) have been proposed in the past. Such relationships are very sensitive to lithological or diagenetic characteristics of a specific sedimentary basin. The new data base of laboratory measurements was used to derive calibrated linear relationships applicable for the uppermost 500 m of the **Swiss** Molasse Basin (Leu et al. 1999a).

For the thermal conductivity best results were obtained with a simple linear relationship to the sonic velocity derived from the sonic log (see equation 1).

$$\lambda_{wg} = A \cdot v_p \quad \text{(forced through origin)} \qquad (1)$$

with:

λ_{wg}: thermal conductivity of water saturated rock [W/mK]
A: constant factor specific **for** lithology and Molasse group
v_p: sonic velocity from geophysical log [km/s]

The constant factor **A** was adjusted for each lithology within the different stratigraphic Molasse groups. The results for one data group are shown in figure 2.

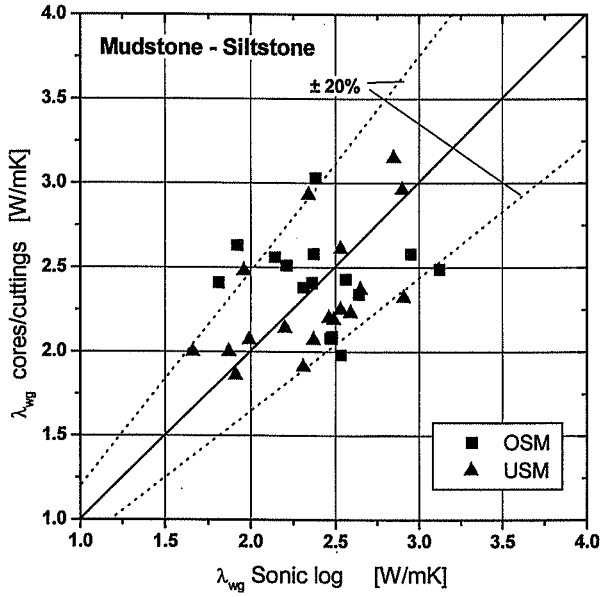


Figure 2: Comparison of measured (laboratory) and calculated (Sonic log;) thermal conductivity for the mudstone/siltstone data group (OSM = Upper freshwater Molasse, USM = Lower Freshwater Molasse, correlation line with A=1.0).

Specific heat capacity was calculated with equation (2). Based on a comparison of laboratory measurements and well log parameters a negative linear relationship with bulk rock density was observed (figure **3).**

$$c_{wg} = B + C \cdot RHOB_{\log} \qquad (2)$$

with:

c_{wg}: specific heat capacity for water saturated sample [J/kgK]
B, C: constant factors specific for lithology and Molasse group
$RHOB_{log}$: bulk rock density from geophysical log [kg/m³]

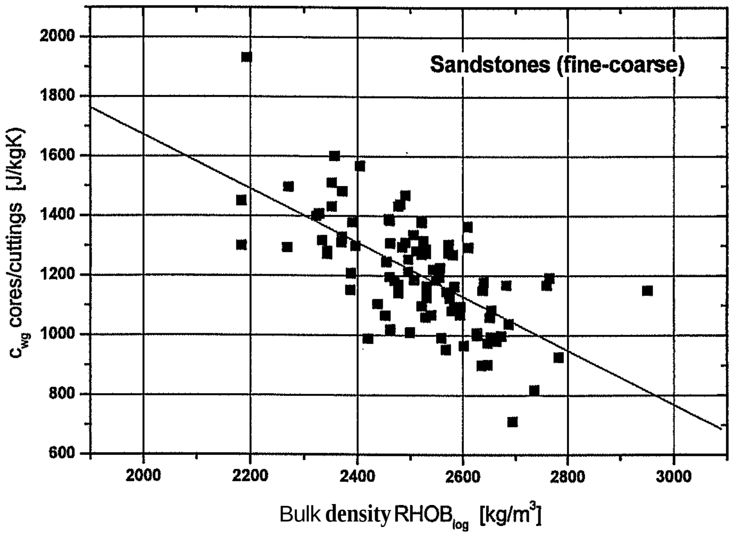
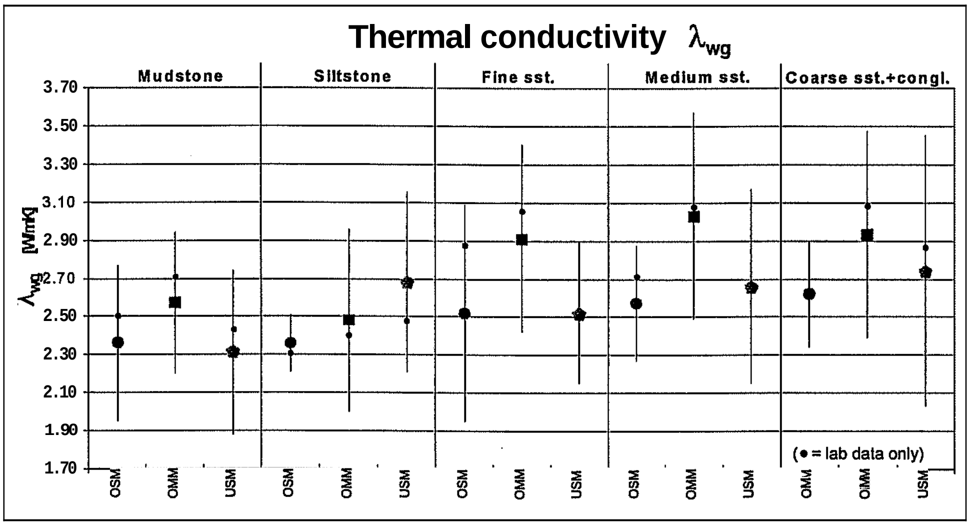


Figure 3: Relation between specific heat capacity measured in the laboratory and log-derived bulk density ($RHOB_{log}$) of sandy Molasse sediments (B=3482, C=-0.904).

3. Thermal property trends Swiss Molasse Basin

The statistical evaluation of all data (laboratory and derived from well logs) demonstrates that geothermal properties are a function of lithology, diagenetic overprint and stratigraphic unit (figure **4).** For most data groups bulk rock density and thermal conductivity increase in the direction towards the Alpine front (figure 5). Specific heat capacity decreases in general in the same direction. Only thermal conductivity shows a distinct increase with depth, independent of lithology or Molasse group.



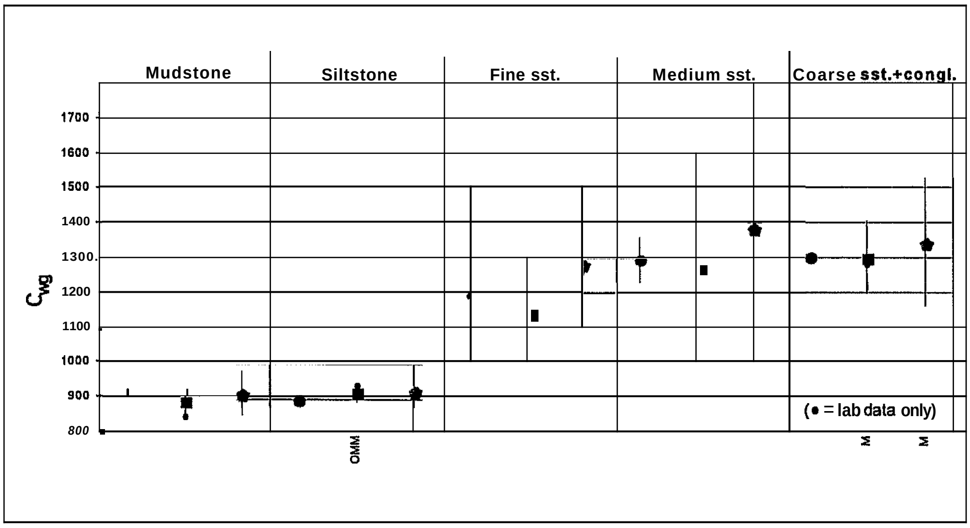


Figure 4: Arithmetic mean (symbols) and standard deviation of thermal properties for different Molasse groups and rock types (sst. = sandstone).

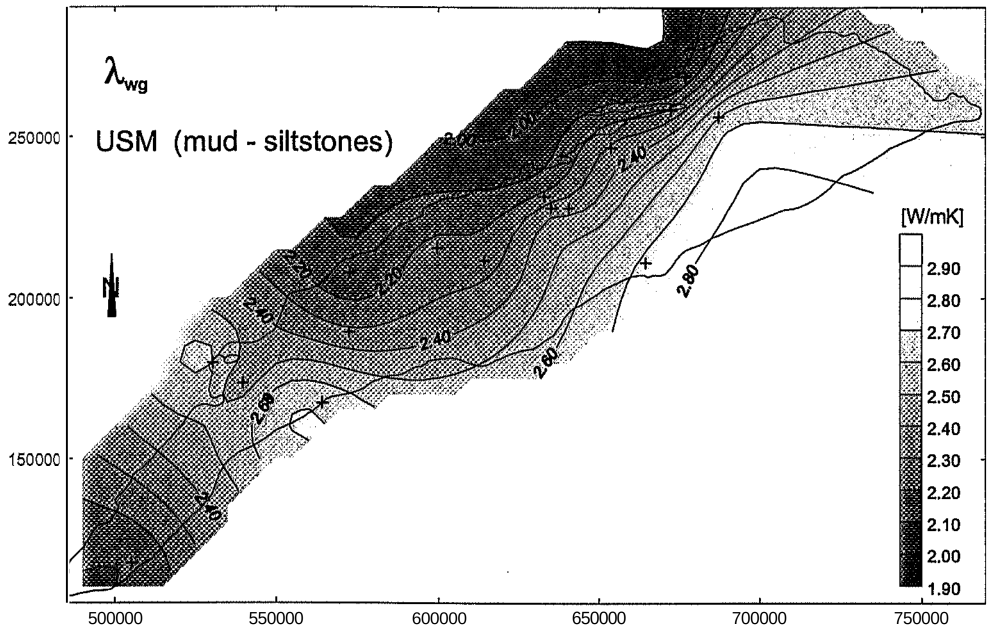


Figure 5: Regional trend of thermal conductivity of mud- and siltstones in the Lower Freshwater Molasse (USM). Crosses mark sample points for this data group (Swiss coordinates).

4. Software evaluation tool SwEWS

To facilitate the evaluation of the new comprehensive data base the PC software tool **SwEWS** was developed as a Microsoft-Access (runtime version) application (Leu et al. 1999b). The software allows the analysis of a specific depth profile defined by the user. Based on the input for the stratal model (location coordinates, thickness, lithology) the program calculates the geothermal parameters for each horizon together with a temperature profile. The results can be analysed in various tables and a graphic display (figure *6).* The data can also be exported for further use in a common ASCII format. The software provides extensive help features with examples and typical values for Quaternary sediments overlying the Molasse sediments.

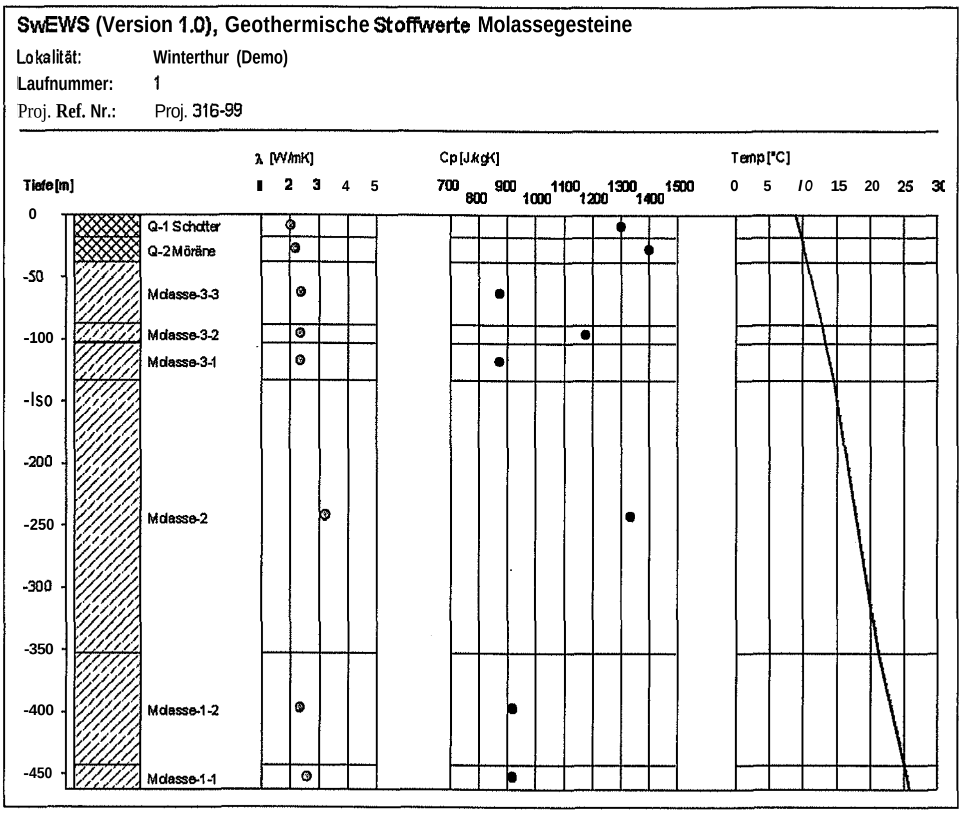


Figure 6: Thermal property profile derived from data base for user-specific location in the Molasse Basin. The geological profile has to be defined by the user.

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References

Blackwell D.D. & Steele J.L. 1989. Thermal Conductivity of Sedimentary Rocks: Measurements and Significance. - In: Naeser, N.D. & McCulloh, T.H. (ed.): Thermal history of sedimentary basins - methods and case histories. Springer-Verlag, p. 13-36.

Evans T.R. 1976. Thermal properties of North Sea rocks. - The Log Analyst, 18/2, p. 3-12.

Goss R. & Combs J. 1976. Thermal conductivity measurement and prediction from well log parameters with borehole application. - In: UN (ed.): Second United Nations Symposium on the Development and Use of Geothermal resources, p. 1019-1027.

Kersten M. S. 1949. Final report laboratory research for the determination of the thermal properties of soils. Research laboratory investigations engineering experiment station. University of Minnesota.

Leu W., Keller B., Matter A., Th., Scharli U. & Rybach L. 1999a. Geothermische Eigenschaften Schweizer Molassebecken (Tiefenbereich 0-500 m) - Datenbank Wärmeleitfähigkeit, Wärmekapazität, Gesteinsdichte und Porosität. - Bericht Bundesamt fir Energie, 79 p. (ENET-Nr. 9723719).

Leu W., Keller B., Mégel Th., Scharli U. & Rybach L. 1999b. Programm SwEWS (Berechnungsprogramm fir geothermische Stoffwerte Molassegesteine (Benutzerhandbuch Version 1.0). - Bericht Bundesamt fur Energie, 31 p. (ENET-Nr. 9723763).

Sattel G. 1982. In situ Bestimmung thermischer Gesteinsparameter aus ihrem Zusammenhang mit Kompressionswellengeschwindigkeit und Dichte. - Diss. Univ. Karlsruhe, 292 p.

Schon J.H. 1996. Physical Properties of rocks: fundamentals and principles of petrophysics. - Pergamon Press, 583 p. Handbook of geophysical exploration, Seismic exploration., 18, 583 p.

Schärli U. & Rybach L. (in prep.). Determination of specific heat capacity of rock fragments. – Geothermics, in preparation.