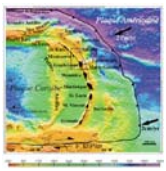
Workshop 2
Exploring high temperature reservoirs: new challenges for geothermal energy
Volterra, Italy, 01-04/04/2007

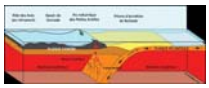
Clay mineral occurrences in volcanic and granitic geothermal contexts: signatures of high temperature fluid circulations in natural permeable fractures

Based on well and surface data, hydrothermal alteration and namely clay minerals have been investigated in the volcanic area of Bouillante (Guadeloupe) and in the European EGS wells penetrating the Soultz granite (France).

The geothermal field of Bouillante is located in the French west Indies on a volcanic island. A geothermal power plant produces 15 MWe. Based on surface sample and recent well data obtained from wells drilled in 2001, a comprehensive study of clay minerals was carried out (Patrier et al., 2003; Mas et al., 2006). Several mineral associations were outlined: (1) dioctahedral smectites with calcite ± quartz ± kaolinite; (2) ordered I/S clay with adularia, silica ± calcite and (3) kaolinite smectite ± halloysite ± kaolinite ± smectite ± silica. The argillaceous signature of the present-day surface geothermal activity (i.e. dioctahedral smectites) can be distinguished from argillization due to weathering, which is dominated by kaolinite smectite mixed-layers and halloysite.

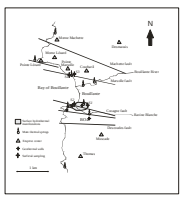


The Lesser Antilles arc from Feuillet *et al.*, 2001



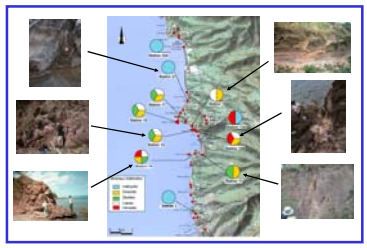
Subduction process in the Atlantic ocean

The volcanic island of Basse-Terre in Guadeloupe



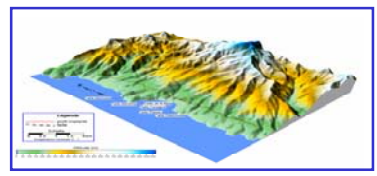
Simplified geological map from the Bouillante area

Three successive zones, dominated, respectively by dioctahedral smectite, illite and chlorite were identified at increasing depths. Alteration petrography indicates that these mineralogical clay zones result from the spatial superimposition of at least two successive hydrothermal alteration stages. The first one, assimilated to a propylitic alteration stage, consisted of crystallization of chlorite or corrensite, zeolite and epidote. The later stage of alteration is related to the circulation of the present geothermal fluids (T=250°C) and is assimilated to argillic or phyllic alteration. It consists of a more or less intense argillization which results from the crystallization of aluminous dioctahedral clay phases (smectite, illite ± I/S mixed layers, and accessory kaolinite) associated with quartz, calcite, hematite or pyrite.

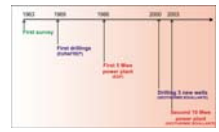


Hydrothermal minerals around the geothermal site of Bouillante

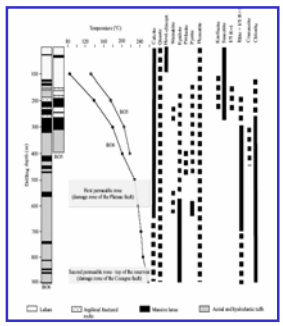
The geothermal power plant of Bouillante



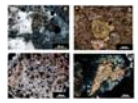
The so-called Pitons of Bouillante surrounding the geothermal area (BRGM, 2004)



Historical exploration of the Bouillante geothermal field

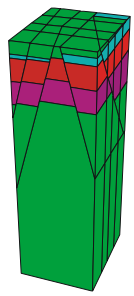


Vertical distribution of hydrothermal minerals (Mas et al., 2006)

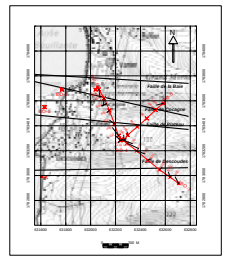


Well BO6
a) Ca and dioctahedral aluminous smectites Sm (200 m),
b) Primary pyroxene pseudomorphosed by chlorite Ch, He: hematite (160 m),
c) Strong illitisation (Il) of the host rock close to the Plateau fault (650 m), Py: pyrite,
d) Vug filled by chlorite Ch and epidote Ep (836 m)

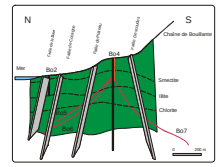
Fracture zone at Marsolle (Bouillante Bay) filled with I/S



3D view of the normal faults in the Bouillante geothermal site

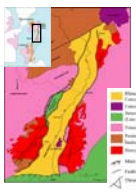


Inclined borehole trajectories and large-scale faults projected on the topographic map at Bouillante

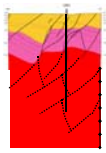


Schematic cross-section oriented N-S through the Bouillante geothermal site. The vertical distribution of hydrothermal clays are presented versus depth. Borehole wells drilled in 2001 are plotted in red. The vertical scale is 2 X the horizontal scale

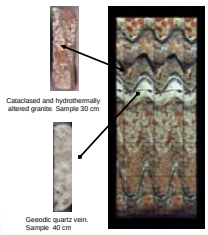
From the EGS Soultz site located in the Upper Rhine graben, clay minerals have been investigated from cuttings collected within the granitic sections of the Soultz wells between 1,5 km and 5 km depth. Two main hydrothermal assemblages have been distinguished: (1) an illite ± quartz ± calcite ± hematite assemblage which characterise vein alteration related to fluid flow circulation in fractures. Locally, the association of tosudite (a regular dioctahedral mixed layered chlorite/smectite bearing lithium, Ledesert et al., 1999) with the illite assemblage characterises permeable fracture zones. (2) A chlorite ± corrensite ± calcite ± epidote assemblage which evidences earlier hydrothermal event defined as propylitic alteration. This assemblage which corresponds to poorly fractured massive granite occurs at the scale of the granite body. It is interpreted as an early hydrothermal event related to small scale fractures and characterises low permeability. On the opposite, the illite-secondary quartz assemblage characterises later hydrothermal events related to the tectonic activity of the Rhine graben. It occurs within some localized rather permeable fluid pathways corresponding to large-scale normal faults that support natural fluid flow (brines, 100g/l).



Geological map of the Rhine graben



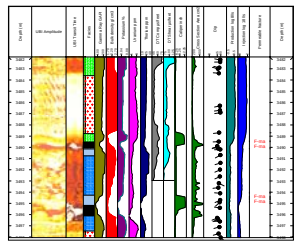
W-E geological cross-section through the Soultz wells



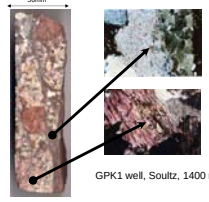
Cataclased and hydrothermally altered granite. Sample 30 cm

Geeodic quartz vein. Sample 40 cm

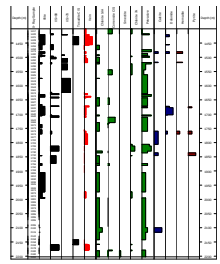
Part of a hydrothermally altered and fractured zone granite at Soultz (EPS1 well). Vertical scale 1 m



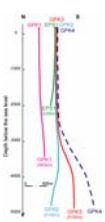
UBI log, geology, geophysical log responses (Gamma ray, bulk density, Sonic) and hydraulic flow log in a a cataclastic permeable shear zone between 3482 and 3498 m depth at Soultz in the GPK1 well. Flow log anomalies matches with fractures partly filled with secondary geodic quartz visible on UBI logs and from well log analysis



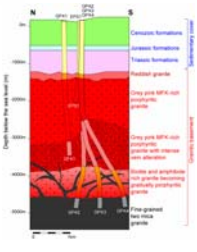
GPK1 well, Soultz, 1400 m



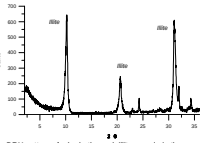
Vertical distribution of hydrothermal alteration in the EPS1 Soultz well



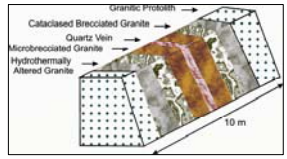
Vertical N-S borehole profiles at Soultz



Schematic W-E lithological cross-section through the Soultz wells (Hooijkaas et al., 2006)



DRX pattern of a hydrothermal illite sample in the Soultz granite



Internal structure organization of a cataclastic shear zone at Soultz (Genter et al., 2000)

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