

# Processes controlling the chemistry of natural waters in the Skagafjörður area, N-Iceland

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The processes regulating the chemical composition of surface and groundwaters in the Skagafjörður area, N-Iceland, are delineated. The valley of Skagafjörður dissects a mono-tonous tholeiitic flood lava succession of Miocene age dipping a few degrees towards south. Thermal and non-thermal springs are widespread in the area with temperatures of up to about 90°C. Drillholes have been sunk at several thermal spring sites. Permeability is low except where recent faulting and fracturing has occurred. Primary permeability increases with stratigraphic height. It is, thus, highest in the interior highlands. The springs are typically associated with fractures and dykes in the bedrock. The lowland area of the valley of Skagafjörður is all vegetated and for the most part covered with thick peat soil. By contrast, the interior highlands are largely barren as are the high mountains on either side of the valley.

## Water types

The waters sampled have been divided into four groups on the basis of geohydrology as (1) surface waters (streams and lakes), (2) waters emerging in organic soil, (3) springs in the interior highlands and (4) groundwaters in the valley of Skagafjörður. Groups (3) and (4) are considered separately because they issue from formations of different permeability and can, therefore, be expected to have different residence times underground and, as a result, reacted with the rock to a different extent.

All water types are low in dissolved solids, 10–300 ppm. In surface water the largest part of the solutes is derived from seawater spray but in soil- and groundwaters most comes from rock material with which the water has reacted.

The partial pressure of CO<sub>2</sub> in surface waters is similar to that of the atmosphere, whereas that of soil waters is higher but that of groundwaters lower, particularly at low temperatures (Fig. 1). The high CO<sub>2</sub> partial pressures of soil waters must be due to CO<sub>2</sub> supply from decaying organic matter. The low CO<sub>2</sub> partial pressures in the groundwaters relate to

the high pH of these waters that results from progressive interaction with the rock in an environment isolated from the atmospheric CO<sub>2</sub> source. The solute content of the water can be correlated with three variables, its CO<sub>2</sub> partial pressure, temperature and the distance from the ocean and elevation.

## Age of the water

Groundwaters in Skagafjörður are very low in tritium, particularly the geothermal waters indicating that they are pre-bomb (Fig. 2). Non-thermal spring waters in the interior highlands contain tritium in the same range as surface waters. The geothermal waters in this part of the area contain appreciable amounts of tritium indicating that they are a few tens of years old at the most.

## Progressive water-rock interaction

As surface waters seep into the ground and are cut off the atmospheric supplies of CO<sub>2</sub> and O<sub>2</sub>, progressive

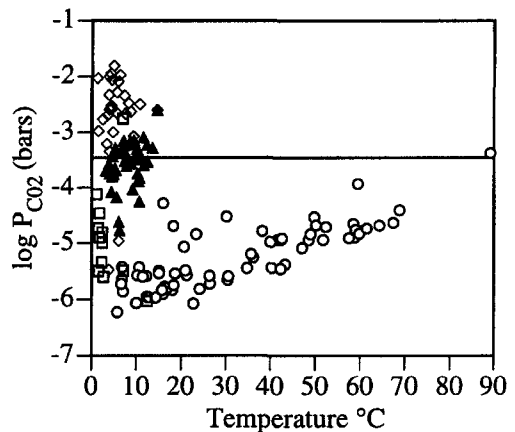


FIG. 1. CO<sub>2</sub> partial pressures vs temperature. Circles: groundwaters in the valley of Skagafjörður; triangles: surface waters; diamonds: soil waters; squares: springs in interior highlands.

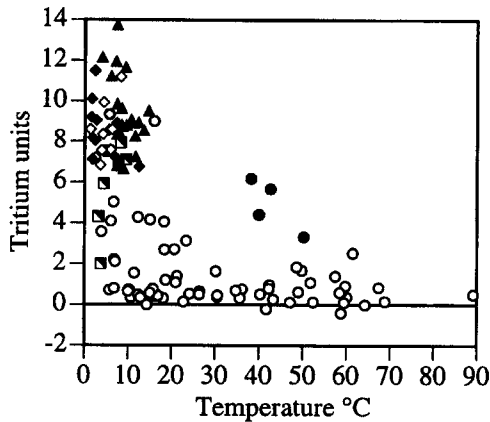


FIG. 2. Tritium in waters from Skagafjörður. See Fig. 1 for symbols. Half-filled squares: glacial rivers; dots: thermal springs from the interior highlands.

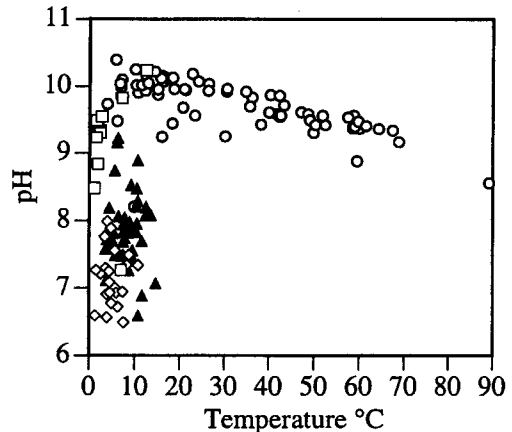


FIG. 3. pH vs temperature. Calculated at the temperature of the water by WATCH (Arnórsson *et al.*, 1982). See Fig. 1 for symbols.

interaction with the rock leads to depletion in dissolved  $O_2$  and an increase in pH. The loss of  $O_2$  is accounted for by oxidation of ferrous iron dissolved from the mafic minerals of the basalt to ferric, which is subsequently precipitated as hydroxide. The increase in pH relates also to the dissolution of the mafic minerals, which act as strong bases and, therefore, consume protons upon dissolution. The observed sharp rise in pH already at low temperatures, as the water seeps into the ground, is considered to be due to the relatively low content of dissolved  $CO_2$  in the parent surface water. Low  $CO_2$  in the parent surface water is certainly the case when it has not had the opportunity to react with organic soil before infiltrating. When the levels of  $CO_2$  are low limited rock dissolution is required to raise the pH. This implies that organic supply of  $CO_2$  has a bearing on water-rock interaction at depth and influences the time required to approach equilibrium.

At the high pH of the groundwaters in Skagafjörður a substantial fraction of the aqueous silica is ionized. When this is the case dissolution of the primary plagioclase of the rock releases protons, whereas olivine and pyroxene dissolution consumes less protons than would be the case at lower pH. It

will depend on the relative dissolution rates of the plagioclase, on one hand, and that of the mafic minerals, on the other, how overall rock dissolution tends to change pH. Precipitation of minerals containing OH (smectite, Fe-hydroxides) lowers water pH.

Surface- and soil waters are undersaturated with the primary basalt minerals. The high pH groundwaters are also undersaturated with plagioclase but close to saturation with the mafic minerals. Some surface- and soil waters have reacted sufficiently with rock debris to attain saturation with some secondary minerals, like K-spar and low-albite. The groundwaters are somewhat supersaturated with many precipitating secondary minerals including calcite, chalcedony, low-albite and microcline. It is evident that the spring waters in the interior highlands are less evolved chemically than the older groundwaters in the valley of Skagafjörður.

## References

- Arnórsson, S., Sigurdsson, S. and Svavarsson, H. (1982) *Geochim. Cosmochim. Acta*, **42**, 1513–32.