Statistical evaluation and world-wide regional comparison of thermal spring discharge and temperature relationship

*Jacek Scibek[1], Tom Gleeson[2], Barret Kurylyk[3], Jeffrey McKenzie[1]

1. Earth and Planetary Sciences, McGill University, Montreal, QC, Canada, 2. Civil Engineering / School of Earth and Ocean Sciences, University of Victoria, BC, Canada, 3. Department of Civil and Resource Engineering, Dalhousie University, NS, Canada

The discharge and temperature of thermal and hot springs provide important information about hydrothermal flow systems, especially regarding the convective heat flow and permeability of fault zones. In Japan, previous studies reported significant correlations between thermal spring discharge and temperature and related these to the underlying processes. However, in other regions of the world, the nature of this discharge-temperature relationship is poorly described, and no regional patterns have previously been investigated. In this study we present an update on the efforts to compile a world-wide database of physical properties of thermal springs, and results of statistical analysis of the relationship between spring discharge and temperature. Japan is compared to other regions along active margins where there are Quaternary volcanic areas: Alaska and western Canada, Oregon and California, Iceland, Italy, New Zealand, and Peru. In the selected regions we performed a regression analysis between the logarithms of spring discharge and temperature. For Japanese thermal springs, we also explored the regional and temporal relationships.

We find no significant correlation of log(discharge) vs. log(temperature) of thermal springs in 5 of 7 regions outside of Japan. There are weak significant correlations in two regions, the USA-Great Basin (r^2 = 0.02) and Iceland (r^2 = 0.16). Both of these regions have large heat flow anomalies and associated hot spring discharges. We confirm the observations by Muraoka *et al.* 2006 that in the modern Japanese hot spring databases there are significant correlations between log(discharge) and log(temperature) of "hot spring sources" that are mainly pumped from wells, with r^2 values 0.32 to 0.47, depending on what depth subset is used. We subdivided the Japanese Islands into five regions (Hokkaido, north Honshu, central Honshu, south-east Honshu with Shikoku, and Kyushu), and found that the discharge-temperature relation exists almost equally in all regions (r^2 between 0.35 and 0.44). Although the hot water production from geothermal wells could explain this effect, on regional scale there is no apparent relationship of either the well "spring source" temperature, nor the discharge rate, with depth of wells. However, we note that the measurements on pre-1915 natural springs in Japan, before geothermal wells were drilled to increase the hot water discharge, appear to have a much weaker correlation between logarithms of discharge and temperature (r^2 = 0.08, significant at alpha = 0.05 level).

The results suggest that in Japan, the production wells in hot spring areas appears to increase the efficiency of tapping into the thermal plumes, that would otherwise discharge into the surrounding aquifers or water bodies, a fact known from previous numerical models. The production wells cluster in historically known hot spring areas, as well as for heat energy efficiency. In contrast to Japan, in other regions of the world, the natural thermal spring discharge is from natural overflow discharge from spring orifices that is controlled by water table conditions and topography, and may be only weakly related to the thermal upflow rate at depth. These results appear similar to pre-1915 Japanese measurements on natural thermal springs. A discharge-temperature relationship linking to the upflow process may exist at depth, but the large variation in on-site conditions obliterates any trend as observed from thermal spring measurements. Therefore, the modern Japanese hot spring well database may fortuitously provide a

closer estimate of the discharge rate of subsurface thermal plume, than the data from natural springs. The completion of world-wide thermal spring database, and the progress on modeling of flow systems can help estimate the permeability of fault zones and convective heat flow in many areas.

Keywords: hot springs, thermal springs, hydrothermal, statistics, onsen, heat flow

