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Geological, geochemical and geophysical studies on the non-volcanic hot springs, Atri and Tarbalo in the Indian shield: potential unconventional renewable energy sources

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In the fast-growing economies around the world, the demand for energy as well as environmental concerns make geothermal energy a potential renewable energy source. Most geothermal provinces across the world have the capacity to generate enormous amounts of hydrothermal energy, and hot springs in these areas are generally associated with active volcanic or tectonic activity. With modern technical advancement, low enthalpy geothermal systems (< 100°C) are also being considered for geothermal energy production. In non-volcanic hot springs, the water temperature remains low compared to volcanic hot springs. We study two such hot springs located within Neoproterozoic granulites of the tectonically stable Eastern Ghats Belt (EGB) of the Indian shield. The source of heat for these amagmatic hot springs may either be deep-seated fracture zones, or alternative heat sources at shallow crustal levels. A combination of geological, geochemical, hydrological and geophysical techniques has been applied to characterize non-volcanic hot springs in India. The hot springs at Atri and Tarbalo are located to the south of the Mahanadi Shear Zone within the EGB. Penetrative granulite facies planar structural fabrics in rocks of the northern EGB are reoriented within an E-W striking, northerly dipping ductile shear zone that is subsequently dissected by WNW-ESE trending, sub-vertical pseudotachylite-bearing faults and fractures. Tube and dug wells around the shear zone yield both hot (~ 60°C) and cold (~ 28°C) water, sometimes spatially only 20 metres apart. Chemical analyses indicate both have distinct compositions, with hot waters rich in Na^+, K^+ and Cl^- while cold-waters have higher Ca^{2+} and HCO_3^- concentration. Stable isotope analyses (δ^2H and $\delta^{18}O$) of both waters indicate that both are meteoric in origin. Tritium (^3H) and ^{14}C analyses indicate that hot spring waters are much older than the non-thermal groundwater. The hot water is 17714 years old, while the non-thermal groundwater indicates modern day recharge. This suggests that both waters come from different reservoirs. VLF-electromagnetic studies indicate that water exists in isolated pockets beneath the crystalline country rocks, but also circulated through WNW-ESE trending fracture systems. Heat production studies reveal that the EGB is a high radiation zone, and some host rocks have exceptionally high heat producing element (HPE) concentrations (primarily thorium) within the minerals monazite and thorite. Hence, meteoric water is entrapped in those "perched aquifers"

near HPE-rich pockets for a long duration and has sufficient time to undergo radiogenic heating, shielded from the non-thermal groundwater circulating within the fracture system. These isolated pockets act as sources for the hot springs,with HPE being the source of heat. The high HPE distribution in the crust resulting from Neoproterozoic geological events has, thus, elevated the present-day equilibrium geotherm in the EGB, forming sources for shallow-level, non-volcanic hot springs within a tectonically inactive terrane. Therefore, the hot springs in these regions, as well as the hot dry rocks of these areas can be considered as potential geothermal resources.