Identifying surface manifestations of epithermal systems: processes and products

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INTRODUCTION

The upper portions of epithermal systems yield a wide variety of silicified surface manifestations and shallow subsurface features (<50 m depth) (Sillitoe 2015) within a sometimes extensive (even regional) halo of hydrothermal alteration (Fig. 1)(Henley and Ellis, 1983; Christie et al 2007). These silicified features are formed by diverse paleothermal fluids as well as varied fluid-rock interactions, which may generate spatially, but not temporally overlapping mineralisation, with some mineralisation phases potentially unrelated to primary events (e.g. some regional silicification) (Henley and Ellis 1983). Distinguishing among different silicified surface features in the geologic record can assist in delineating potential zones of epithermal mineralisation from more distal hydrothermal alteration.

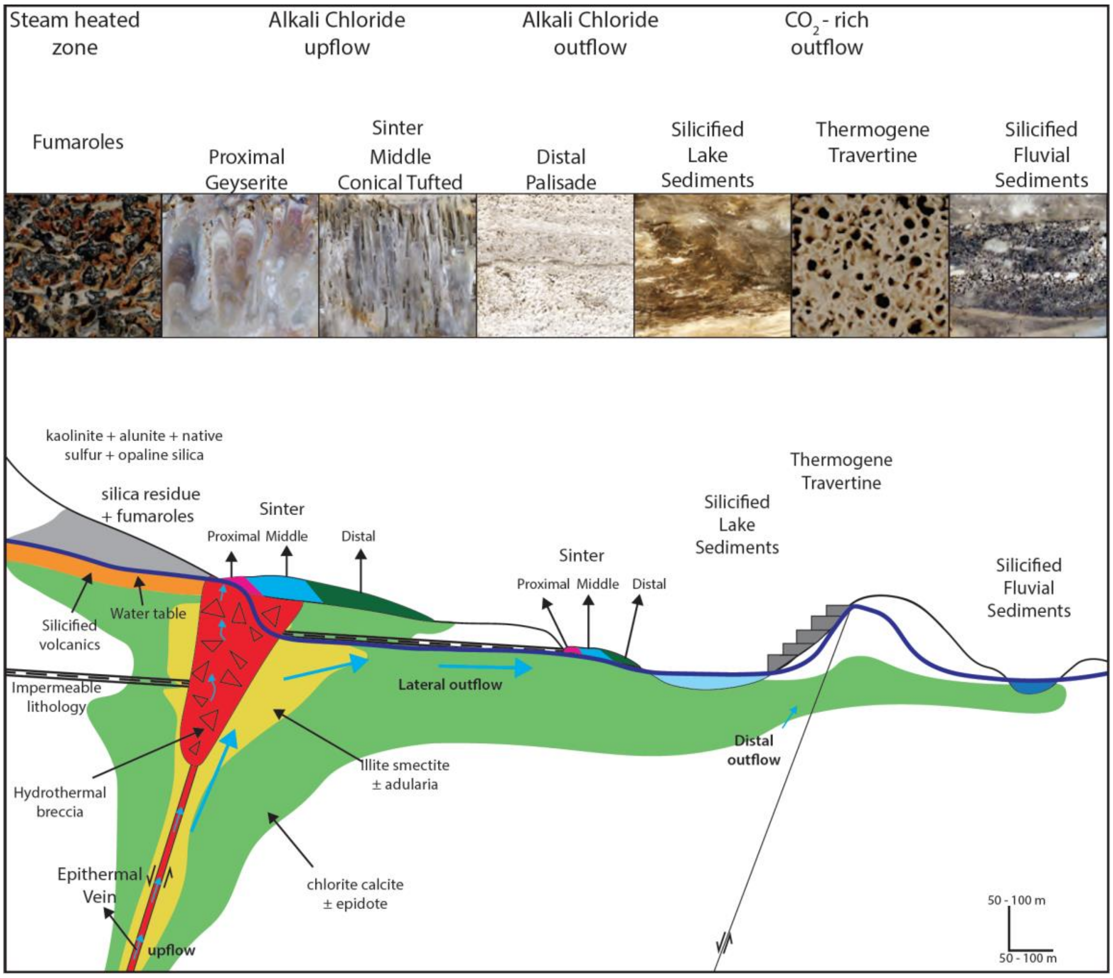

FIG 1 – Schematic diagram showing how siliceous sinters and pseudosinters of thermogene travertines, fumaroles, silicified volcanics, silicified fluvial sediments, silicified lake sediments and epithermal veins relate to geothermal upflow and outflow (modified from Buchanan 1981; Tosdal et al. 2009; and Hamilton et al. 2018), as well as some common diagnostic textures that are associated with these epithermal surface manifestations.

This study demonstrates how textural, paragenetic, and trace elemental analyses of silicified features can be used to distinguish different fluid interactions in epithermal environments. Particularly we show how textures and trace elements of Miocene silicified features within the Coromandel Volcanic Zone (CVZ) can be compared to Sub-recent analogues, from active geothermal systems of the Taupo Volcanic Zone (TVZ) to delineate upflow zones and possibly outflow zones in hydrothermal settings.

THERMAL FLUID DEPOSIT TYPES

Adularia-sericite epithermal ore deposits form within the shallow crust (<7 km) at temperatures <350 °C, where near-neutral alkali-chloride fluids, from deep chloride dominated geothermal reservoirs, boil and mix with groundwaters, causing deposition of precious metals (Lindgren, 1933; Heald et al., 1987; Simmons et al. 2005). Siliceous hot-spring or sinters deposits form thick silica rich deposits that host a variety of environmentally diagnostic sedimentary lithofaices that are produced by focused discharge of near-neutral alkali chloride fluid, which may be related to epithermal mineralisation. These deposits form at the Earth's surface, from alkali-chloride fluids containing dissolved silica via evaporative cooling and wicking (Rodgers et al. 2002). Within the CVZ two sinters are observed to be spatially associated with epithermal Au-Ag ore deposits of Broken Hills and Favona, which have anomalous concentrations of gold and other elements associated with near-neutral pH alkali chloride fluids (Hg, Cr, Mo, As, Sb, Etc). Siliceous sinters are identified by their unique porous, largely microbially influenced sedimentary textures that vary both vertically and laterally over relatively small spatial scales (centimeters to meters) depending on the original geothermal gradient (~100 °C – ambient) of the discharge area that produces distinctive facies assemblages from vent to distal apron areas (Fig. 1), as evident from features forming in present day hot spring environments (Cady and Farmer, 1996; Guido and Campbell, 2011; Lynne 2012; Campbell et al. 2015). Correct identification and understanding of the spatial association of these various lithofacies can be utilised to vector towards thermal fluid out flow and potential epithermal mineralisation (Hamilton et al.2017; 2018). Within the CVZ often only distal sinter lithofacies are preserved in situ, which may have formed distally from epithermal mineralisation.

Within active geothermal systems, thermal fluids may generate other types of surface manifestations, which do not have the same spatial relationship to epithermal mineralisation. Carbon dioxide-rich (so-called bicarbonate) fluids form due to the dissolution of CO_2 to HCO_3^-, often derived from host rock material, and are spatially associated with the margins of geothermal systems. These CO_2-rich fluids form thermogene travertine deposits consisting of carbonate that may be inter-grown with silica, which contain lithofacies similar to those of alkali chloride fluids derived sinters as well as displaying some features unique to travertine formation sedimentary lithofacies (Fig. 1)(Pentecost 2005; Guido and Campbell 2011; 2012). Thermogene travertines are uncommon in the CVZ and TVZ but often occur in other epithermal regions. Although a single thermogene travertine has been observed in the CVZ, which is anomalous in Mn and absent of Au and Ag.

Acid sulphate fluids are produced by separation of volatiles (CO_2, H_2S) in rising steam along tortuous pathways through the subsurface, and which subsequently may condense and boil in perched water tables. These low pH thermal fluids cause dissolution and remobilisation of silica at the surface to form mud pools, silica residue deposits and fumaroles (Fig. 1), with very thin sinters (few cm) deposits associated with mixed acid-sulphate-chloride fluids (Fournier et al. 1966; Fournier 1985; Schinteie et al. 2007; Renaut and Jones, 2011a,b; Guido and Campbell, 2012). Preservation of these features in the geologic record appears to be rare due to the generally thin, localised deposits, as well as their formation in destructional, acidic steam-heated zones, with dissolution of the surrounding host rock (Rodgers et al. 2004; Renaut and Jones, 2011). However, preserved mud pools have been preserved in the CVZ and have a unique trace element signiture of high Hg, P and As.

PSEUDOSINTERS

Geothermal regions also host other, spatially affiliated, silicified surface manifestations and near surface features where fluids with have high concentrations of dissolved silica percolate and precipitate in the host materials, such as sediments (e.g. volcaniclastic, lacustrine, fluvial) as well as subterranean chalcedonic veins. These other silicified deposits may or may not be related to geothermal discharge or to epithermal mineralisation, yet have similar morphologies to those formed siliceous by hot spring deposits (Guido and Campbell, 2011). As they may be misidentified as sinters, herein we designate them collectively as pseudosinters. It is important to determine the formation conditions of all silicified features in shallow epithermal settings to help delineate potential zones of precious metals mineralisation through textural and trace elemental analysis.

Within the shallow subsurface of epithermal deposits host rock material may become The silicifcation of volcanic host rock occurs through thermal fluid infiltration of a pre-existing deposit in phreatic zones of geothermal fields, where condensation of silica-bearing vapour below the vadose zone forms blankets of chalcedony (Sillitoe 1993; Hedenquist et al. 2000). The ensuing deposits are sometimes termed 'silicified water table'. These silicified post depositionally silicified units are identifiable by primary textures that are analogous to modern sedimentary and volcanic textures as seen throughout the CVZ and have a higher concentration of immobile elements and pathfinder elements associated with gas phases of Hg and As. Furthermore, focused silicification of highly permeable host rocks is observed as cross-cutting chalcedonic veinlets, infill and replacement by silica of primary materials, these veins also have a higher concentration of immobile elements than sinter but may contain Au due to their association with epithermal upflow.

Other surface features that can be silicified due to post depositional silicification or hydrothermal input during formation. These Sedimentary deposits of lacustrine and fluvial sediments may form in a variety of setting in epithermal regions as seen within the modern TVZ, over extensive lateral areas, which may be proximal or distal to epithermal mineralisation as seen within the CVZ. These sedimentary deposits are distinctive with fluvial deposits consisting of conglomerates of pebble to boulders of reworked volcanics, quartz clasts and silicified plant material that are generally well-sorted, incorporated into a fine-grained siliceous matrix. Lacustrine sediments Finely laminated to coarse beds of microcrystalline quartz rich sediments, from varved to showing minor low-amplitude undulation and minimal porosity. These post depositionally silicified units can contain gold and other pathfinder elements due to transportation of this material or venting of geothermal fluids. Therefore, paragenetic study at the hand sample and thin section scale, as well as geothermal analysis, may be required to determine primary formation conditions.

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