MINERALOGICAL GUIDES TO INTERPRETING THE SHALLOW PALEOHYDROLOGY OF EPITHERMAL MINERAL DEPOSITING ENVIRONMENTS

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SUMMARY - In recent years, the large number of geothermal systems explored has allowed a close comparison to be made between active and extinct systems so that many hydrothermal ore deposits now have an identifiable active geothermal counterpart. However, there are still several notable differences between active and extinct geothermal systems; for example, many of the former are very much larger in area, and show few effects due to waning.

Despite this, a knowledge of the processes that occur in active geothermal systems *can* be a very useful guide in evaluating a particular hydrothermal ore deposit or prospect. Particularly important are mineralogical and textural guides to temperature, fluid type (pH and salinity), thermal change and the flow regimes that operated. Interpretations from petrographic and structural observations *can* then be used to deduce the paleohydrology of a hydrothermal mineral deposit and to determine conditions under which mineralisation occurred. However, the upper levels of many ore deposits have been removed by erosion, and the nature of this important section of a system is often unknown. For this reason, epithermal geologists need to recognise and understand processes that can occur in the near-surface levels (upper 300 m) of active geothermal systems.

Shallow processes in a geothermal system are controlled by the prevailing terrain which, in turn, affects the reservoir hydrology and its thermal regime. A vertical distribution of different fluid types results, and this is reflected in the alteration mineralogy. For example, where hot alkali chloride water reaches the surface, usually at lowest elevations, different types of silica sinter form (e.g., geyserite, ripples, dunes, microterraces). At some locations, such as Champagne Pool, **Waiotapu,** New Zealand, silica sinter is accompanied by deposition of "ore *grade"* concentrations of gold and silver because earlier-formed amorphous antimony and arsenic precipitates scavenge these precious metals from fluid otherwise undersaturated in them. Where the alkali chloride water becomes appreciably diluted with CO_2-rich fluids or has travelled long distances, it is incapable of precipitating silica but, in some *cases,* calcium carbonate precipitates instead, due to loss of dissolved CO_2.

Above the alkali chloride water, CO_2-rich waters of slightly acid pH commonly form calcite, siderite and interlayered illite-montmorillonite. Where ascending H_2S oxidises the hydrothermal alteration processes are essentially of a destructive nature, producing silica residue, cristobalite, kaolin, hematite, alunite, natroalunite and other sulfates. Most constituents needed to farm these phases derive from the rocks nearby, with only sulfur and, on dons , boron, ammonia and mercury, depositing from ascending **vapour.**

Hydrothermal eruptions are common events in active geothermal fields, and the presence of mineralised breccias and rocks with hydraulically fractured textures shows that they were also frequent during the lives of many hydrothermal ore deposits. Recent studies of hydrothermal eruptions in active geothermal fields in New Zealand show that these eruptions *start* at the surface and progress downwards. It is important to *recognise* this since eruption breccias and brecciated rocks are common hosts for major ore mineralisation.

INTRODUCTION

The conclusion that some ore metals can deposit from hot waters dates back to at least the sixteenth century (e.g. Biringuccio, 1540; Agricola, 1556) but was reasserted very strongly in the late 1950s when hot brines discharging from wells drilled into the Salton Sea geothermal field in California deposited ore grade concentrations of silver and copper (Skinner et al., 1967).

Subsequent discoveries made as a consequence of exploration in many geothermal systems world wide clearly demonstrated the ability of thermal waters to transport and deposit *ore* grade concentrations of base and precious metals (e.g. Brown, 1986,1988). Indeed, many of our ideas about the detailed genesis of hydrothermal ore deposits derives from the geothermal experience and the experiments it spawned *so* that, today, most types of hydrothermal ore deposit now have a recognisable active analogue. For example, the Mississippi Valley-type ores can be compared with the highly saline brines encountered in the geopressured systems of the Texas Gulf and Bohai Basin, China. The large strataform and stratabound base metal deposits, such as those at Mt Isa and the McArthur River in Queensland, show many similarities to submarine geothermal systems located along oceanic rifts and transform faults. The famous Kuroko-style deposits of Honshu are also believed to be the products of subsea floor geothermal activity. Deeper drilling now suggests that even porphyry copper deposits have active analogues such as several of the volcano-geothermal systems in the Philippines and Indonesia, for example, Tongonan on **Leyte** and the now famous Mt Pinatubo Volcano on Luzon (Cabel, 1990; Reyes, 1990; Mitchell and Leach, 1991).

However, the type of mineral deposit which probably has the closest similarity to active systems is the epithermal one. This is because epithermal deposits formed at shallow depths, usually less than 1000 m below the water table, and this is the region which has been made available to scrutiny through drilling into active systems.

Economic geologists have rightly paid a great deal of attention to the occurrence of the base and precious metals in active geothermal systems for the lessons and guidance that they provide in locating epithermal mineral deposits. However, relatively less emphasis has been placed on using the hydrothermal silicate, oxide and sulfate mineral phases to interpret processes that have occurred in epithermal environments. These minerals are abundant and widespread, so that the geothermal experience is here directly applicable. This paper is an attempt to provide mineralogical guidance that can be used to interpret the shallow paleohydrology of epithermal deposits and prospects.

THE EPITHERMAL ENVIRONMENT

In active geothermal systems, the shallowest 500 m is the region where fluid/rock interaction processes are most intense and vigorous. This is because thermal gradients are here at their steepest (i.e. cooling is fastest) and two-phase conditions are common but with a piezometric surface that typically fluctuates, allowing fluids with different compositions to mix. For example, fluids of compositional types that include alkali chloride waters of neutral pH, acid sulfate, CO_2-rich and their admixtures occur, producing alteration overprints. The uppermost 300 m or so of a typical geothermal system are also the most permeable, with numerous channels produced from natural hydraulic fracturing, hydrothermal eruption events, thermal stress and faulting. Epithermal (and geothermal) systems hosted by igneous rocks react much more readily with thermal fluids than do sedimentary or metamorphic rocks, so that hydrothermal alteration is more obvious and intense in igneous rocks.

Nevertheless, there are dangers in overstressing the geothermal/epithermal connection. Most high enthalpy geothermal systems have a very much larger lateral extent than a typical epithermal deposit (about 10 km^2 compared with, say, 2 km^2). Nor are all geothermal systems mineralised with respect to base or precious metals and ore bodies of the **Lihir** type (Plimer et al., 1988) are uncommon, so far as is now known. There are also some hydrothermal deposits which still have no known analogue among the active systems; for example, the famous silver deposits of the Guanajuato and Fresnillo districts, Mexico (Simmons et al., 1988).

SURFACE ALTERATION

The surface expression of active geothermal systems varies greatly; for example, some (e.g. Heber and Brawley in Southern California) have none, but Orakeikorako in New Zealand had over 1100 individual discharge features before about three-quarters of them were flooded (Lloyd, 1977). The extent of the surface expression of an individual geothermal system depends very largely on its shallow plumbing and hydrology, together with factors such as its temporal or spatial relationship with volcanic activity. In recent years, the important effect of terrain has been rightly stressed (e.g. Healy and Hochstein, 1973). Where geothermal systems occur in regions with a rift setting (e.g. the Taupo Volcanic Zone of New zealand), alkali chloride waters of near neutral pH derived from a high enthalpy reservoir commonly (but not always) discharge at lowest elevations.

Steam-heated features, such as fumaroles, steaming ground and mud pots, are present at higher elevations. In the shallow subsurface and on the margins of this type of system, CO_2-rich waters often dominate. There is no reason to doubt that the same relationship between fluid type and hydrology also prevailed during the genesis of epithermal deposits. In these instances, however, the palmhydrology of the extinct systems can be determined only from the distribution and identity of the hydrothermal minerals produced from fluid/rock interactions. An accompanying table (Table 1) summarises the usual alteration minerals and products that occur at the surface of geothermal systems in terms of the types of fluid or setting with which they associated

Alteration in volcano-geothermal systems

Geothermal systems, such as those which occur within the craters and on the flanks of active volcanoes, usually discharge fluid with an appreciable magmatic component represented by SO_2, HCl and even HF gases. These are highly reactive, and readily alter volcanic ashes and lavas at very fast rates. Alteration is most intense closest to fumaroles and vents, with products that commonly include pyrophyllite, silica residue and, where temperatures are below about 180°, sulfur and a wide variety of soluble hydrous sulfates. Further from some vents, alunites then kaolinite and, on the margins, smectites occur sequentially as replacement products that result from the progressive neutralisation of laterally penetrating acid fluids. Despite the presence of often beautiful sulfur crystals, the style of alteration in volcanic-geothermal systems is dominantly destructive in its style.

Alteration associated with acid sulfate discharge features

Acid sulfate fluids which occur in vapour only and two-phase geothermal systems forms a similar hydrothermal assemblage to those more obviously associated with volcanoes (Table 1), but oxidation of ascending H_2S is the key reaction that affects hydrothermal alteration. Kaolins (kaolinite and halloysite), alunite and cristobalite predominate here, and pyrophyllite is rare, absent, or relict. Natroalunite, jarosite, sulfur and black pyrite are also present, and silica residue forms from the dissolution of the precursor rocks (Table 2). Sulphur and, rarely, cinnabar deposit from the ascending vapours, but the alteration process is also one predominantly of destruction. Indeed, dissolution and collapse craters are common in areas where steam alteration is intense, for example at the Rotokawa and Waiotapu systems in New Zealand. In steep terrains, this style of alteration weakens the host rocks to such an extent that the altered material may become unstable and destructive landslides result. Landslides at the Te Kopia and Waihi (Taupo) thermal areas of New Zealand were triggered by the alteration of volcanic rocks by acid fluids produced from condensate.

Deposits from alkali chloride and alkali chloride-bicarbonate waters

These are usually of neutral to slightly acid pH and derive, typically in diluted form, from a geothermal reservoir. They usually, but not always, discharge at lowest elevations. In geothermal systems located in steep terrains, such as many in Indonesia and the Philippines, the chloride waters may not even reach the surface or else do *so,* much diluted, several kilometres from the location of the system's upflow. Where the subsurface reservoir temperatures exceed about 180°C, the alkali chloride waters contain an amount of dissolved silica that reflects the deep reservoir temperatures. Upon cooling at the surface, silica readily precipitates from this water to form deposits of silica sinter, which is the main product of alkali chloride and alkali chloride-carbonate waters. However, at a few locations, e.g. Champagne Pool, Waiotapu, silica sinter deposition is accompanied by ore grade concentrations of gold and silver plus amorphous precipitates of arsenic and antimony (Weissberg et al., 1979; Renders and Seward, 1989). Nevertheless, it is the occurrence of silica sinter itself which is the best guide *to* the paleohydrology of an epithermal prospect.

The style of alteration produced from alkali chloride alkali chloride-carbonate waters is exclusively that of construction by direct deposition and silicification of shallow rocks permeated by these fluids. Although the products of deposition from alkali chloride waters are chemically very simple, silica sinter occurs in several different forms that are important to be able to recognise because of the hydrological clues they provide to help understand extinct systems. Some of these silica forms are:

(a) *Banding.* Silica sinter is commonly banded, with individual layers 1 millimetre or so thick, many being traceable over distances of several metres or more. Sinter is usually hard and dense, but spongey, porous silica occurs in places, usually where silica deposition rates are fast.

(b) *Terraces.* Terracing is a typical feature in silica sinter deposits and is an unambiguous indicator of a paleosurface of alkali chloride water. Individual terrace steps range in height from millimetres to 2 m, and most are arcuate in shape (concave surface points to source of flow) with a width that seems to be proportionate to their height. Terraces are usually closest together where the ground surface is steepest. Individual terraces change constantly in form as the fluid flow paths alter as a result of local silica blockage. In detail they have a complex morphology that requires further study.

Table 1: **Occurrence of surficial hydrothermal minerals commonly associated with thermal fluids in different hydrological settings**

	Deposited	*Reaction Products*
High temperature (>200°), with SO_2, HCl, HF gases in volcano-geothermal systems	sulfur, sulfates hydrous sulfates, iron oxides, black pyrite	kaolin, alunite, silica residue, pyrophyllite, cristobalite, smectites, iron oxides
acid sulfate waters cristobalite,	sulfur, sulfates, hydrous sulfates,	kaolin, alunite, other sulfates, cinnabar smectite, silica residue, hematite
alkali chloride alkali chloride-bicarbonate	silica sinter, amorphous silica, Sb-As precipitates	quartz, cristobalite, amorphous silica
bicarbonate and CO_2-rich	calcite, aragonite	kaolin, calcite

(c) ***Ripples and dunes.*** Where hot water flows quickly, silica may deposit in the form of asymmetric ripples as high as 10 cm. In most, but not all, instances their sharper edges points towards the fluid some.

(d) ***Overhangs.*** Silica sinter surrounding pools and channels discharging alkali chloride water commonly form overhangs from millimetres to several centimetres in thickness. Some of the more sturdy overhangs may be preserved after these waters cease to discharge.

(e) ***Dribbles and*** mushrooms. Many deposits of sinter contain silica with a coral or stromatolite-like appearance. These are pipes up to 1 cm wide and several centimetres long which commonly occur in clusters. Some form as silica precipitates from cooling alkali chloride waters as they descend overhangs or terraces, but some also grow upwards from the ground surface to produce features with the appearance of mushroom stalks topped by a nodule.

(f) ***Geyserite.*** This is also an invariable indicator in extinct and active systems of the presence of alkali chloride water at ground surface. Geyserite comprises nodules of silica forming coalescing, semi-spherical-shaped forms. The diameter of individual nodules ranges from about 1 mm up to several tens of cm, and the largest are closest to the vent of a geyser or spouter; in places, smaller nodules have grown on top of larger ones.

Deposits from acid sulfate-chloride-bicarbonate fluids

Acid waters with both high sulfate and chloride-carbonate contents are known in several geothermal fields with different settings, including volcano-geothermal systems. The most common are systems where direct mixing between alkali chloride-bicarbonate and acid sulfate waters occurs (Leach, 1985). Waters of this same mixed type are also produced where ascending alkali chloride-bicarbonate waters react with buried deposits of sulfur, as at Rotokawa, New Zealand (Ellis and Mahon, 1977).

The surface alteration usually produced by the mixed acid sulfate chloride-carbonate waters consists of kaolinite, cristobalite, alunite, tridymite, sulfur, smectite, and poorly developed silica sinter. The silica-bearing phases are probably a mixture of silica residue derived from the dissolution of near surface rocks, and silica carried by and deposited from the chloride component. Mixed acid sulfate chloride-bicarbonate waters can form a hard, bedded deposit and also silicify surface materials, but any sinter deposits *so* produced *are* not widespread and seldom extend over areas larger than a few tens of metres. Except for its association with kaolinite and alunite, this silica sinter is usually difficult to distinguish in the field from sinter deposited from alkali chloride waters.

Deposits from bicarbonate and CO_2-rich waters

Waters high in bicarbonate or dissolved CO_2 discharge on the margins of many high temperature geothermal fields. In steep terrains, such as those in Indonesia and the Philippines, these waters are of bicarbonate type and usually, but not always, are well below boiling temperature. Calcite is the main material they deposit, and this typically forms white to yellow-brown layers of travertine. Calcite is deposited due to the loss of CO_2, not from cooling of the discharging waters. The forms of calcite deposited in this way mimic those of silica sinter with terracing, banding and dribble-type forms. However, the two materials are easily distinguished in the field because the calcite is softer and reacts readily with acid. Aragonite is also known to deposit from CO_2-rich waters that discharge from drillholes (Browne, 1973) but it has not yet been reported as a precipitate from an active spring.

Distinction between silica sinter and silica residue

Because of their paleohydrological significance, it is important to be able to distinguish between silica sinter and silica residue, but unfortunately this is not always easily done. Sinter is defined (Thrush et al., 1968) as "a chemical sediment deposited by a mineral spring, either hot or cold." Hence, true sinter *can* form only at ground surface, and the adjective 'silica' should precede sinter to distinguish it from calcareous spring deposits. In contrast, silicification is a replacement process whereby surface and subsurface rocks and other materials are replaced by amorphous silica, opal or quartz. Silica residue is a product of the destruction of rocks that react with acid waters, in which liberated silica that does not become accommodated into other phases (such as kaolin) forms a discrete deposit. This occurs both at the surface and in the shallower subsurface, with some silica residue being able to be transported short distances by the acid waters, as has happened at Waiotapu.

Table 2 lists some of the criteria that *can* be used to help distinguish deposits of silica sinter from those of silica residue. In the latter case these are mostly negative features, i.e. silica residue does not form terraces or clusters of nodules with geyserite-like form. However, silica residue is commonly associated with acid-indicating minerals such as kaolins and sulfates.

Resistance of surface hydrothermal minerals to erosion

(a) ***Silica sinter.*** This material is very resistant to both chemical and physical erosion. Several late Tertiary silica sinter deposits occur in the Coromandel district of New Zealand, and sinter of Late Devonian to Carboniferous age, retaining recognisable microterrace structure and plant remains, is associated with two epithermal prospects in north Queensland (White et al., 1989). Geyserite, also of Devonian age, occurs in mineralised sinters in Scotland (Nicholson, 1989). However, ancient sinter no longer consists of amorphous silica but well-crystallised quartz.

Table 2: Characteristics that may help in distinguishing silica sinter from silica residue

Characteristic	*Silica sinter*	*Silica residue*
banding	individual layers may be extensive (m)	rare; very local
geyserite?	yes	no
terraces	yes	no
contains plant material?	yes	very rare
hardness	usually hard	usually friable
associated minerals	cristobalite	kaolins, cristobalite, alunite
ages to:	quartz	quartz

It therefore seems that silica sinter loses water progressively and changes, as it ages, through opaline forms to cristobalite and, finally, to quartz.

However, because sinter is by definition a surface deposit once removed by erosion then there will be no evidence surviving to record the discharge of alkali chloride waters. Feeder fluid channels are likely to be very narrow (centimetres wide at most) and are seldom seen in the field. Silicification is not an exclusively surficial process or even one that necessarily occurs at shallow depth, so that silicification in itself is not a guide to the location of the paleosurface.

(b) *Acid alteration minerals.* The products of alteration by acid sulfate waters are mainly soft clays, sulfate minerals and even water soluble salts that are readily removed by erosion; this is particularly true in the case of steep terrains where landslides are frequent. Sumi (1968,1969) estimates that a volume of rock over 200 m thick has been eroded off the top of the still active Matsukawa geothermal system in north Honshu, Japan. However, because of the pervasive nature of acid water-produced alteration, a record of its former presence can remain despite extensive physical erosion. This is testified to by the widespread occurrence of alunite, kaolin and related minerals in many epithermal prospects even though the position of their former ground surfaces can now no longer be located with confidence.

(c) Calcium carbonate. This material is also soft and easily eroded, but prompt burial or other circumstances may allow its survival so that it can be used as a paleohydrology guide. Travertine deposits of a wide range of ages are known.

DEPOSITS FROM HYDROTHERMAL ERUPTIONS

Hydrothermal eruptions are common events in active geothermal fields, and the breccia deposits they produce are typical features in many geothermal areas and epithermal prospects (Browne, 1991). Hydrothermal eruptions probably start within a few metres, or even centimetres, of ground surface and progress downward until the ejecting steam has insufficient energy to sustain the eruption. The material erupted forms a poorly sorted deposit that rarely extends for more than 1500 m from its vent but offers clues to geothermal and epithermal geologists. This is because many of the ejected clasts derive from the geothermal reservoir. Thus their identity, at least qualitatively, reveals the nature of the subsurface lithology down to the final focal depth of the eruption that ejected them.

The other information that the clasts provide is available through study of their hydrothermal alteration. Many are hydrothermally altered by fluid/rock interactions that occurred within the reservoir prior to clast ejection. Hence the identity of the hydrothermal minerals that they contain can be used to deduce reservoir conditions in the same way as can cores and cuttings recovered during exploratory drilling into an active system. For example, Collar and Browne (1985) found that clasts ejected during a series of Holocene hydrothermal eruptions at the Rotokawa geothermal field, New Zealand, contained a variety of hydrothermal mineral assemblages because some eruptions penetrated to depths of 450 m, thus sampling a range of reservoir conditions.

The minerals observed in these clasts comprise three groups: (a) sulfates and kaolinite; (b) silicates and kaolinite, and (c) iron and titanium oxides and sulfides. The minerals of group (a), including alunite and opal, are the products of reactions between the host rocks and hot acid (pH <3.5) fluids. Clasts of this mineralogy derive from within 100 m of ground surface. The group (b) hydrothermal minerals, which include albite, adularia, quartz, mordenite, clinoptilolite and heulandite, indicate the presence of alkali chloride waters in the reservoir and that highly permeable zones occur there. This mineralogy and the homogenisation temperatures measured on fluid inclusions hosted by quartz indicate that the maximum temperatures prevailing at the depths disturbed by the hydrothermal eruptions were between 220° and 250°C. The group (c) secondary minerals provide no useful information about reservoir conditions.

ALTERATION IN THE SHALLOW SUBSURFACE

Where extinct geothermal systems have been eroded so that no surficial deposits remain, it is usually difficult to deduce the location of the former ground surface. However, some clues are often provided by recognising where subsurface boiling has occurred. For example, the presence of veins composed of adularia, quartz and bladed (or "angel wing") calcite, even where the last is pseudomorphed by quartz, are diagnostic of boiling. Application of fluid inclusion geothermometry methods can also be used to recognise past boiling events in epithermal prospects*and this is possible where both vapour and liquid-rich inclusions occur together within the Same sample. Once a boiling horizon or zone is located, it is a fairly simple procedure to calculate, assuming hydrostatic pressure, the position of the piezometric surface at the time of boiling. However, this surface may not necessarily have coincided with the former ground surface and, indeed, this is seldom the case in geothermal systems in steep terrains. Here, hydrostatic pressures may not have extended to the surface (i.e. alkali chloride waters did not discharge) so that the differences in elevation between the piezometric and ground surfaces are unknown.

Simmons and Browne (1990) have recently described the distribution and style of alteration that occurs at shallow depths in the Broadlands-Ohaaki geothermal system, New zealand. This was possible because of the large number of wells (52) that have now been drilled to explore and exploit this system. The premise for studying the shallow alteration here is that it provides a view of how such a system will appear after erosion, and the way this compares with the alteration seen in some epithermal prospects.

Two main fluids types exist at shallow depths (100 m) at Broadlands-Ohaaki: (a) near neutral pH, alkali chloride waters, mainly present in the two upflow regions, and (b) CO_2-rich waters that are weakly acid and form on the cooler, stagnant margins of the upflows. The latter derive from CO_2 that separates from the deep chloride water and condenses in the shallow subsurface into meteoric water (Hedenquist, 1990). No acid sulfate waters are present at Broadlands-Ohaaki below a depth of a few metres.

The hydrothermal alteration produced in the shallow subsurface by fluid/rock interactions at Broadlands-Ohaaki matches the distribution of these two types of fluid and the thermal regime that prevails there (Browne and Ellis, 1970). The alkali chloride waters present in the upflow zones coincide with the occurrence of quartz, calcite, adularia, albite, illite, chlorite and pyrite, with platy calcite and adularia being present in boiling zones. In contrast, the CO_2-rich fluids, mainly on the margins of the upflow, have produced alteration of variable intensity at lower temperatures. The presence of this fluid matches the occurrence of clays, such as illite, interlayered illite-montmorillonite, montmorillonite and rare kaolin, and also by calcite and siderite. At a depth of 100 m below present ground surface, the products of the CO_2-rich waters are widely distributed, covering an area of about 10 km^2, but at 400 m depth adularia and quartz are common in the chloride water upflow zones. However, even at this depth, montmorillonite and siderite are present on the margins of the system (Simmons and Browne, 1990).

CONCLUSIONS

The near surface alteration of active, high temperature geothermal systems is often overlooked by geothermal geologists because their attention is naturally focussed on the deeper, exploitable parts of the reservoir. However, it is in the shallow geothermal environment where fluid/rock interactions are most intense and processes such as boiling and mixing between different thermal and meteoric fluids are most common. Geologists interested in hydrothermal ore deposits can learn a great deal from understanding the hydrology of active geothermal systems, with those interested in the epithemal environment probably having most to gain. By addressing the shallow hydrology of active geothermal systems, and recognising its mineralogical signatures, it should be possible to determine some aspects of the paleohydrology of individual epithermal prospects. Some of the implications for ore mineral deposition are obvious: for example, in recognising that no metal, except mercury, can be transported with the vapour phase, and that favourable sites for ore deposition include most zones of boiling and places where mixing occurs between alkali chloride and other waters, particularly those of acid sulfate type. Mixing takes place most readily in zones with an effective vertical permeability, such as channels, and deposits produced by events like hydrothermal eruptions and natural hydraulic fracturing. This explains why breccias are favourable hosts for ore mineralisation in many epithermal deposits.

The epithermal mineral exploration programmes that offer the best prospects for success are likely to be those that combine chemical sampling, geophysical exploration and structural studies with an understanding of paleohydrology as revealed by the alteration mineralogy.

Finally, the application of the geothermal experience to the geology of hydrothermal ore &posits is not entirely a one-way transfer. Geothermal geologists can profit by studying hydrothermal ore deposits or prospects because these allow observation of the detailed plumbing of exposed geothermal systems; this view is unobtainable from drilling, even when coring is frequent. Further, hydrothermal deposits, especially those of the epithermal type, provide valuable clues about the timespans of geothermal systems and the ways that they evolve. This information can be obtained by detailed observations of their alteration mineralogy and the textural relations present in the host rocks and accompanying veins.

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