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Geothermal deposits in ancient terrain as a tool in epithermal gold exploration: Examples from Scotland

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ABSTRACT

Ancient (pre-Cainozoic) geothermal activity can be recognised by remnants of silica sinter, manganese and iron oxide deposits, alteration assemblages and hydrothermal eruption breccias. Examples of each of these are found in north-east Scotland, frequently on or near the intersection of major faults and lineaments. They are all probably the product of Early Devonian geothermal activity which appears to have been widespread in north-east Scotland at this time. Six potential gold prospects are identified in the region.

INTRODUCTION

Deposits from active epithermal (geothermal) systems are often easily eroded and consequently poorly preserved in the geologic record. However, given the relationship between geothermal systems and epithermal deposits, recognition of remnant products of ancient geothermal activity is important in gold exploration. Cainozoic geothermal-epithermal systems and their associated deposits are well known, but older equivalents of these systems are more difficult to identify and locate with confidence. This paper summarises criteria to identify geothermal deposits, and illustrates their application in the pre-Cainozoic environment with examples from the Caledonian terrain (Precambrian) of northeast Scotland.

EXPLORATION GUIDES TO PAST GEOTHERMAL ACTIVITY

Silica sinter

The presence of subsurface silicification (i.e. addition of silica) and/or silica sinter on the (palaeo) land surface indicates past circulation of alkali-chloride water and the presence of surface discharges of this fluid from a system with a deep temperature of over 200°C. Subsurface silicification can also be produced by silica deposition from acid-sulphate fluids and steam alteration yielding a silica residue (see below). Silica sinters are often easily eroded, particularly as they are surface features, and may be difficult to recognise if poorly preserved. However, their morphology, mineralogy and geochemistry can be employed to differentiate sinters from other forms of silicification. Browne (1987) identified six morphological features characteristic of silica sinters: geyserite, banding, terracing, dunes and ripples, coral-like overhangs and the presence of plant material and pollen. Mineralogically, ancient sinter is usually only composed of quartz, but inclusions of other minerals (e.g. kaolin, alunite, sulphur and sulphates) may be present. These minerals may have deposited with the sinter from mixed alkali-chloride, acid-sulphate waters, or were formed by an acid-alteration overprint on the earlier sinter (Browne 1987). It should be possible to recognise sinter on a geochemical basis and work to construct such a database is in progress. However, early studies indicate that enrichments in As, Ga, Ge, Sb may be diagnostic.

Example: The Rhynie Chert, famous for preserving examples of the first land-plants and insects, is the only deposit in Scotland to have previously been recognised as a hot-spring deposit (Kidston & Lang, 1921). It was formed by the episodic discharge of thermal water into a bog or swamp environment. Although now excavated, the chert in the discovery outcrop was originally 2.5m thick (Tasch, 1957). Palaeontological evidence yield an Early Devonian, probably Siegenian, age for the deposit (House et al., 1977; Whalley and Jarzembowski, 1981). Recent studies have confirmed the geothermal origin of the chert, or sinter, some specimens of which display a geyserite texture (N.H. Trewin, pers. comm., 1988).

Manganese and iron deposits

Silica is not the only oxide to deposit from geothermal waters, although it is the most common. Manganese and iron oxides also precipitate from hot-springs, frequently adsorbing high levels of dissolved metals (e.g. Hewett & Fleischer, 1960; Seward & Sheppard, 1986). Hydrothermal manganese oxide deposits can be distinguished with confidence on a geochemical basis using a scatter plot (Fig. 2) which is based on the diagnostic hydrothermal enrichments in As, Cu, Mo, Pb, V and Zn (Nicholson, 1986; Nicholson, 1988).

Example: A stratiform manganese deposit of limited extent occurs at Dalroy (Fig. 1). It overlies Precambrian schists and is itself overlain by conglomerates which mark the onset of Middle Old Red Sandstone (ORS« Devonian) sedimentation. Trials in the 1920's removed the discovery exposure, which occurred in a stream section, and present-day studies are restricted to the ore dumps and mine records. The deposit was confined to topographic hollows in the Precambrian basement and appears to have been deposited on a lateritic surface, now represented by a hematite-quartz rich layer below the manganese horizon (Dewey and Dines, 1923; Nicholson, 1983 and unpublished data). Braunite forms the principal ore mineral, with cavities infilled by calcite, rhodochrosite and baryte (Nicholson, 1987).

The ore is clearly of hydrothermal origin as indicated by its mineralogy and geochemistry: Braunite is a common mineral in hydrothermal manganese deposits, and the baryte is strontium-rich, a feature characteristic of a hydrothermal origin (Bonatti et al., 1972). The deposit displays notable geochemical enrichments in Ag, As, Bi, Sb which are typical of hydrothermal deposits, a conclusion supported by the diagnostic scatter plot of Nicholson (1988) (Fig. 2). A hot-spring origin best explains the stratiform, yet limited extent, of the ore and the hydrothermal mineralogy and geochemistry.

Alteration assemblages

Wall-rock alteration created by circulating fluids at depth is well established as an exploration tool and will not be discussed further. However, acid-steam alteration and overprints are not always adequately emphasised. It is particularly important that silica residue is distinguished from silica sinter (or that silicification caused by silica deposition from deep chloride fluids is distinguished from that caused by steam alteration, or deposition from surficial acidic fluids). Recognition of steam alteration also provides information about the relative position in the system and the palaeohydrology.

Silica residue, created by the extensive leaching of the host rocks by steam, can form at the surface and at depth. It lacks the textures displayed by sinter, although relict banding may be present. It is usually very friable, although occasional hard deposits are known (Browne, 1987). Kaolin, alunite, hematite and pyrite are also commonly produced by acid-steam alteration, and can be overprinted on alkali-chloride alteration assemblages following changes in the system hydrology. Recognition of silica and hematite formed by steam alteration rather than direct deposition should be possible on geochemical grounds. Studies in extinct geothermal fields suggest that these steam zones are enriched in volatile elements such as As, Hg, Sb (Henneberger, 1986).

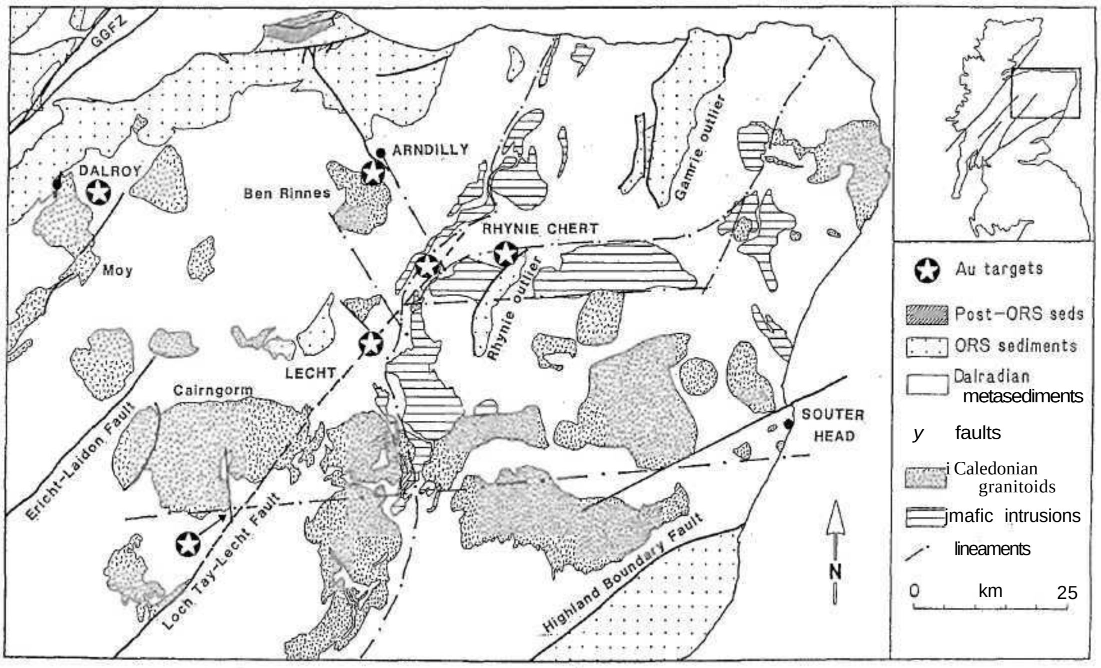

Figure 1. Simplified geology of north-east Scotland. GGFZ = Great Glen fault zone.

Example: A brecciated Precambrian quartzite occurs near Arndilly (Fig. 1). The breccia is locally silicified, with clasts cemented by quartz. However, the breccia has a hematite-goethite cement near the Rothes Fault zone. Multiple brecciation events have occurred in this area as the iron oxide-breccia contains clasts of the silicified breccia. By analogy with extinct geothermal systems, the Arndilly iron-oxide breccia may represent a steam-alteration overprint on a silica cement. Enrichments in the iron oxides of As (< 92ppm), Bi (< 137ppm) and Sb (< 386ppm) lend support to this interpretation.

Hydrothermal eruption breccias

Brecciated zones are important fluid conduits and, together with the structure of the region, exercise a significant control on fluid flow. Eruption breccias, which can have both surficial, stratiform and vent, pipe-like forms, are characterised by poorly-sorted, highly angular to sub-rounded clasts set in a matrix of comminuted rock. The breccias are usually matrix dominated with the clasts often showing fine fractures and a jig-saw assemblage. Silica cements and euhedral quartz lining cavities within the breccias are common (Nairn and Wiradiradja, 1980; Collar, 1985; Hedenquist and Henley, 1985; Nelson and Giles, 1985).

Examples: A complex series of breccias occur as pipes or fissures in the Lecht valley (Fig. 1). The breccias are composed of highly angular to sub-rounded clasts of the local Precambrian-Cambrian phyllites, slates and quartzites, with a comminuted-rock matrix. They are matrix dominated with free-floating clasts which commonly show a jig-saw assemblage. Secondary quartz cement and euhedral quartz lining cavities are common in some breccia varieties. Pyrite-bearing quartz-feldspar veins appear to be associated with the breccias. Boulders in the Lecht valley up to 2m in length, composed of clasts cemented by goethite and quartz, may be the remnants of the surficial eruption breccias. Fragments of siliceous material in the breccias are probably the remains of sinter deposits. These deposits probably represent hydrothermal eruption vent and surficial breccias. Another breccia pipe at Souter Head is intruded in Precambrian-Cambrian gneiss and contains clasts of the local sequence. Pyrite, calcite and molybdenite occur in cavities within the breccia. This is termed an explosion breccia by Porteous (1973), and is probably also a hydrothermal eruption vent breccia.

OVERVIEW OF THE SCOTTISH SYSTEMS : PROSPECTIVE GOLD TARGETS

Nicholson (1983) proposed that north-east Scotland was a region of widespread geothermal activity in the Early Devonian (-Lower ORS). This was a period of intense tectonic activity with movement on the major faults of the region and multiple granitoid intrusions, both possibly related to closure of the Iapetus Ocean to the south, and movement on another destructive plate margin to the north-east (W.S. McKerrow, pers. comm., 1988). Recent work (Harrison and Hutchison, 1987) has placed intrusion of the Moy, Cairngorm and Ben Rinnes granitoids at around 408 Ma, i.e. Early Devonian. The tectonic setting of north-east Scotland in the Early Devonian was thus ideal for the generation of geothermal systems with extensive fault zones for fluid channelways and abundant granitoids as heat sources for the systems. It is thus no surprise to find that palaeontological evidence places the formation of the Rhynie Chert in the Early Devonian, and that the Dalroy manganese ore was also probably deposited at this time. Although the breccias cannot be dated directly, their close spatial association with 408 Ma granitoid intrusions (the Lecht is actually underlain by an extension of the Cairngorm granitoid) make a temporal relationship likely. It is interesting to note that the Arndilly, Lecht and Rhynie deposits are each associated with the intersection of faults, lineaments and shear zones (Fig. 1).

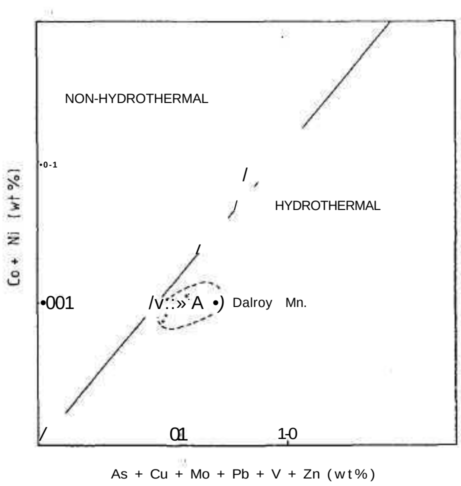

Figure 2. Scatter plot to identify hydrothermal manganese oxide deposits, after Nicholson. (1988).

Gold targets

The high-level of the Rhynie and Arndilly deposits within their respective geothermal systems is encouraging, since any related gold mineralisation will have been preserved at depth. Furthermore, independent evidence from a manganese vein at Arndilly indicates the presence of mineralisation at depth (Nicholson, 1986). The Dalroy area is also prospective as the manganese ore is enriched in gold pathfinder elements, and minor placer gold has been recorded in the district (Mulgrew, 1985). As gold mineralisation can occur in both the surface and vent eruption breccias, the Lecht material requires further investigation to evaluate its mineral potential.

As already noted, the Arndilly, Lecht and Rhynie deposits are located on structural intersections. Other intersections of major faults and/or lineaments should be examined. In selecting these targets it may be worthwhile to recall that the size of the convection cell may prevent deposits occurring closer than at 10-20 km intervals (A. McNabb, pers. comm., 1988). Similar spacings have been recorded between the convection systems associated with the formation of exhalative sulphide deposits (Russell et al., 1981). On the basis of this discussion, at least two additional exploration targets for epithermal gold can be selected (Fig. 1).

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