

THE GEOLOGY AND GEOCHEMISTRY OF THE
GUNUNG PANI GOLD PROSPECT, NORTH SULAWESI,
INDONESIA

by

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VI. DISCUSSION

Although a comprehensive picture has been developed in preceding sections in terms of description and models of geological setting, alteration and nature of mineralisation at the Gunung Pani prospect, little that is conclusive can be said about the chemistry of gold transport and mechanism of deposition.

In typical epithermal deposits (disseminated and vein) this may be partly due to the fact that the nature of fluids (undersaturated weak saline solutions) that are normally accepted to transport gold leave little trace of possible gold complexing agents, since the concentration of all components and gold they carry is very low (in the order of a few ppb for gold). Consequently large volumes of fluid are necessary in these systems to form an economic deposit.

The absence of evidence for large volumes of fluids, or extensive acid alteration typical of disseminated epithermal mineralisation presents an enigma at Gunung Pani, considering that a large area is anomalous in gold. Exactly what is the associated alteration signature for mineralisation remains fairly obscure, since the obvious silicification can also be related to deuteritic alteration upon emplacement and cooling of silicic rocks, and as shown at Gunung Baganite is not necessarily related to mineralisation at depth. Nor, as has been shown, can chlorite alteration be

simply related to gold mineralisation, although it is ubiquitous in the Pani prospect. Gold mineralisation and intensity of sericite alteration, which in any case is weak, do not correlate, and quartz veins are largely absent on Pani ridge where the most important mineralisation occurs.

The best correlation to gold mineralisation is the rock-type itself, the most differentiated and silicic quartz-biotite-sanidine porphyritic rhyodacites of TpI. The alteration can be explained mainly as a consequence of their emplacement. A difficulty is that all rocks in the Pani Volcanic complex are porphyritic rhyodacites and are mineralogically similar. Nevertheless apart from the effects of alteration the geochemistry suggests the mineralised and silicified porphyritic rhyodacites are the most chemically evolved. This relationship is not to specifically suggest silicic differentiates belonging to the Pani Volcanics are primarily enriched in gold, or that gold is of magmatic origin. However the mineralising fluids are closely linked to the intrusives and a magmatic component may be present. Minor early formed pyrite, galena, sphalerite and chalcopyrite, largely preceding gold, may be genetically related to the rhyodacites.

It is thought that the generation of the mineralising fluids is closely linked to emplacement and degassing of the rhyolitic bodies, which may be flows or intrusives. How they have focussed the mineralisation is not clear.

As already noted silicic phenocryst-rich lavas and shallow porphyritic intrusives are rare in environments other than those characterised by major rhyolitic ash-flow magmatism. Silicic porphyritic rhyodacite lava domes with phenocryst contents of 50% or more are to the author's knowledge unrecorded in the literature. Their emplacement requires exceptional conditions that may be limited to volcanic vents, involving early loss of magmatic volatiles and high temperatures to maintain low enough viscosity to reach near surface levels. Sheared and streaked out phenocrysts, cataclastic layers and autobreccias on all scales, which characterise the porphyritic rhyodacite lavas on Pani ridge, are attributable to high viscosities and high pressures, and may be a consequence of this emplacement. Since fabric elements show no evidence of strain deformation petrographically (undulose extinction in quartz, deformation lamellae in plagioclase) it can be argued that emplacement was at high temperature, and these effects are lost, due to annealing.

The volatile history, during crystallisation and emplacement, of these magmas can only be speculated upon, but may have special implications for gold mineralisation. Since no major acid alteration attributable to a high level geothermal system is evident at Gunung Pani, it is thought mineralisation occurred from a small volume of fluids from deep sources of unknown

origin that were capable of carrying higher concentrations of gold.

Consistent with conditions under which phenocryst-rich rhyodacite magmas could be passively extruded as lavas and breccias, it is inferred that the associated fluids were relatively hot.

Studies of the degassing of rhyolite domes (Taylor et al., 1983) indicate magmatic volatiles are lost progressively, and upon emplacement the rhyolites are relatively anhydrous. An initial high volatile content of the rhyodacite magma is evident from abundant fluid inclusions in phenocrysts of quartz and at grain boundaries of composite crystals, and a late stage volatile content is evident from small vesicular cavities along flow banding and vuggy fracturing. In addition the turbid heterogeneous groundmass in intensely flow banded phenocryst-rich rhyodacites may be explicable in terms of sub-microscopic volatile exsolution cavities.

Early loss of considerable primary magmatic volatiles probably accompanied crystallisation. Advanced crystallisation, and a long rest time in the magma chamber, is suggested by the textures of phenocrysts, particularly of composite crystals.

During emplacement from depths of at least several kilometres relatively anhydrous phenocryst-rich magma may have interacted with deep fluids which facilitated intrusion, as well as introduced the gold mineralisation. How these hypothetical mineralising solutions were introduced is not clear, but it is almost certain from

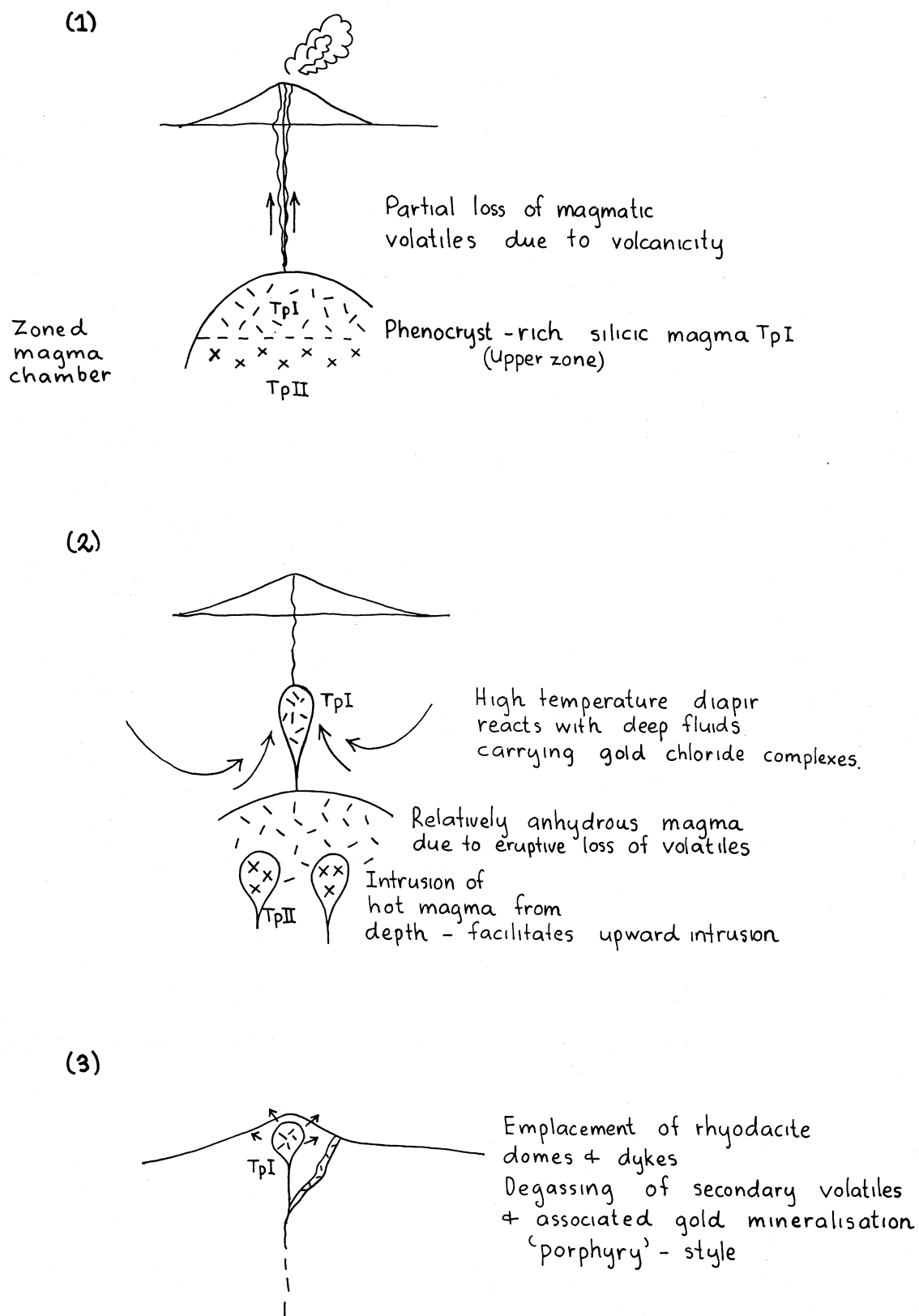
field evidence that the solutions did not simply follow along structures or contacts.

A possibility is that the small vesicles along flow banding are due to secondary volatiles that carried the gold mineralisation. This would help explain the apparent association of gold with vuggy fracturing of the rhyodacites on Pani ridge and the disseminated style of gold in the Baganite rhyodacite. The strongest mineralisation in GPD4 occurs at the base of the rhyodacite intrusive, which is characterised by an unusual 'globular' or quartz-filled (?) vesicular groundmass texture. It can be interpreted as a volatile-rich zone. This model of gold mineralisation, whereby gold is introduced by secondary volatile content of rhyolite magma, is illustrated in Fig. 28, but remains a very tentative hypothesis.

The concept that felsic intrusives can provide the source of fluids as well as heat is, however, well established by a detailed study of As-Sb-Au mineralisation in the Moretons Harbour Area, Newfoundland (Kay and Strong, 1983). Similarly in the Pb-Zn-Ag Toyoha Mine, Japan (Shatoury et al., 1974), filling temperatures of fluid inclusions in quartz phenocrysts in the host quartz porphyry intrusive are similar to temperatures in the mineralised veins, suggesting a genetic relationship.

These studies suggest that even an orthomagmatic origin for gold-silver-base metal mineralisation associated with porphyritic acid intrusives cannot be excluded, although there is no known mechanism.

Fig 28 Model of gold mineralisation.
Transport of gold by secondary volatiles



Despite these arguments more conventional explanations, perhaps involving weak gold mineralisation at a deep level in geothermal systems from low volumes of fluid, cannot be discounted at the Gunung Pani prospect on the basis of the present data.

VII. CONCLUSIONS

- (1) The geology of the Marisa hinterland is poorly known. Important components of the geology include:
 - (a) a suspected older, pre-Tertiary amphibolite-low K-granitoid terrain, essentially the root zone of an oceanic island arc.
 - (b) foliated granitoids of unknown age, compatible geochemically to acid calc-alkaline rocks, intrusive into the older amphibolite basement.
 - (c) the Tinombo Fm basalts, probable island arc tholeiitic basalts of Eocene age, representing a submarine volcanic facies to the subsequent Miocene Bilungala andesitic island arc. The relationship of the Tinombo Fm to the older basement terrain is unknown.
 - (d) the Pani Volcanics and related rocks of possible Pliocene to Recent age.
- (2) The Pani Volcanic Complex is one volcanic centre, probably part of a once extensive acid volcanic field, the limits of which are undefined. For the most part the volcanic field is deeply eroded and no major areal volcanic units have been identified.

- (3) Important components of the geology of the Pani Complex can be understood in terms of the structure of volcanic domes.
- (4) The Una-Una volcano in the Gulf of Tomini, 60km SW of Marisa, may be an active remnant of the Pani Volcanic field. TpII volcanics bear strong resemblance to a sample collected from Una-Una.
- (5) The granitoids and amphibolite basement may have contributed to generation of the Pani Volcanics by anatectic, and subduction related processes (North Sulawesi Trench).
- (6) The tectonic control of the Pani Volcanics may be rift tectonism related to the opening of the Gulf of Tomini (possibly back arc rifting).
- (7) The Pinogu Volcanics are clearly related to rift volcanicity along the central part of the NE arm of Sulawesi, and may be of similar age to the Pani Volcanics.
- (8) The Pani Volcanics can be divided into two units: TpI and TpII.
TpI volcanics composed of quartz-biotite-sanidine porphyritic rhyodacites are restricted to the Pani Volcanic Complex and its associated dyke system.
TpII is the latest stage of volcanicity in the Pani Complex, of similar composition to TpI but with smaller phenocrysts and slightly higher

contents of ferromagnesian minerals, including hornblende. TpII volcanics are characteristically very fresh, with black vitreous biotite. Hornblende bearing microgranodiorites are widespread along the coastline from Tilamuta to Marisa, including the Tabulo ring-dyke Complex, and may be subvolcanic equivalents of TpII volcanics.

- (9) The petrography and geochemistry of the Pani Volcanics indicates they may be classified as I-type magmas. In general the geochemistry suggests these rocks have continental rather than island arc affinity.
- (10) Low grade gold, silver and minor base metal mineralisation is related only to TpI volcanics, which are the most differentiated, silica-rich and potassic rocks belonging to the Pani Volcanics.
- (11) Gold mineralisation at the Gunung Pani prospect is closely associated with silicified rhyodacites, possibly lavas or intrusives. The largest of these intrusives at Gunung Baganite may be interpreted as a shallow intruded porphyritic rhyodacite dome.
- (12) From a detailed study of the alteration and geochemistry in drillhole 4 it is concluded that the Baganite rhyodacite dome is compositionally

zoned, becoming potassic and silicic upward to the upper contact which is pervasively silicified and hydrofractured.

- (13) The silicification and hydrofracturing of the Baganite rhyodacite dome can be compared to the volatile saturated 'silicia carapace' described by Burnham (1979) for porphyry copper deposits. Silicification of smaller porphyritic rhyodacites on Pani ridge is ascribed to mainly deuteric silicification, due to their volatile content. It is possible that the strongest alteration occurred where these intrusives encountered hydrous wall-rock conditions, but in general interaction with fluids from the surrounding environment seems to have been minimal.
- (14) The alteration associated with the gold mineralisation is weak, and is not unusual for silicic igneous rocks emplaced in a hydrothermally active volcanic environment. The alteration includes pervasive silicification, Na-alkali metasomatism, chloritisation of plagioclase phenocrysts, and adularia lining vuggy fractures.
- (15) Two kinds of chlorite are identified from a study of alteration in drillhole 4; CHL1 characterised by <12% MgO is related to the geothermal gradient and occurs irrespective of lithology; and CHL2

characterised by >12% MgO and variable chemistry in any one sample analysed, is spatially restricted to the distribution of the Baganite rhyodacite dome. The reasons for the chemical variations CHL2 exhibits are largely unresolved, but one possibility is alteration during cooling of the rhyodacite intrusive.

- (16) Gold mineralisation is in the form of electrum with about 20% Ag and occurs with pyrite which characteristically contains galena inclusions or exhibits epitaxial intergrowths with galena, and has associated sphalerite and chalcopyrite. Gold is paragenetically the latest phase. The base metal association with gold suggests a deeper level of mineralisation than typical hot spring geothermal systems.
- (17) Gold mineralisation is partly disseminated, but not necessarily matrix-held, most likely the distribution is controlled by fine fractures and presence of sulphides.
- (18) In general typical epithermal alteration features are absent at the Gunung Pani prospect. Gold mineralisation shows little evidence that it was due to the passage of large volumes of fluids through the rock.
- (19) It is concluded that gold mineralisation is related to the emplacement and degassing of the

porphyritic rhyodacite bodies, which also introduced the mineralised fluids from depth.

- (20) Silver mineralisation is associated with quartz-hematite veins in silicified tuff on Gunung Baganite and occurs in the form of acanthite (Ag_2S) or cupriferous acanthite. The silver mineralisation post-dates gold mineralisation and is related to relatively oxidising solutions, possibly generated from the final stages of cooling of the Baganite rhyodacite dome. The nature of these veins and alteration is more akin to typical epithermal mineralisation.

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