The Geology and Au-Mineralization System in The Totopo West Prospect, Gorontalo, Indonesia

Geologi dan Sistem Mineralisasi Emas di Prospek Totopo Barat, Gorontalo, Indonesia

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ABSTRACT
The Totopo Gold Prospect is located within a volcano-plutonic arc setting with basaltic-andesitic lavas of Eocene-Miocene age covered by volcanogenic-carbonate sedimentary rocks intruded by batholiths, stocks, and dykes as a result of south-eastward subduction and then overlain by Plio-Pliocene rhyolitic-dacitic flows and pyroclastics related to a subduction in a north-west direction. The Miocene subduction formed EW to ESE-trending arc parallel and NW to NNW-striking transfer lineaments. Subsequent arc reversal in Pliocene to Recent times resulted in a subduction of a north-west direction reactivating the NW trending Miocene structures and forming NE-ENE trending dilational faults. The complexity of this tectonic setting gives a favourable geological environment for gold deposition, focused on local lithological and structural settings. Hosted by rhyodacitic volcanics, the Totopo Gold Prospect encompasses a large area of low-sulphidation epithermal alteration controlled by the NE-ENE dilational structures. Pull-apart basin and graben structures formed tilting the system such that epithermally-altered Plio-Pleistocene rocks are preserved in the west with erosion down to Miocene “basement” strata in the east. The gold mineralization is associated with quartz-adularia-base metal sulphide veins and stockworks, enveloped by silica alteration and broad pervasive illite-kaolinite-smectite alteration. The area was explored by Newcrest from 1995 - 1999 which undertook stream sediment sampling and scout drilling programmes along with aero-magnetic and radiometric surveys. A more detailed drilling programme in the eastern part of the prospect failed to find a significant deposit as the area was deeply eroded. Avocet Mining evaluated the area and focussed exploration in Totopo West in 2007 - 2008 carrying out Induced Polarisation geophysical surveys, partial-leach grid soil sampling, drill programmes and detailed logging of epithermal vein fabrics, and successfully defined a gold deposit called Bundulipu. The Bundulipu consists of parallel pinch and swell shaped zones in a dominant ENE-WSW direction with a minimum length of 600 m and widths varying from 1 - 30 m. The gold tenor of drill hole samples is fairly high (i.e. > 5.0 g/t Au), however, the high grades found are deep and tend to be narrow. An Inferred Mineral Resource estimate of 5.4MT @ 3 g/t Au for 500,000 oz Au was estimated, but this has not been developed in accordance with the JORC Code. Drilling has not yet defined a bonanza zone at Bundulipu or fully tested the mineralization in the whole area. A number of alteration and gold mineralization occurrences at Totopo still remain under explored including areas in the west and middle part of the Totopo Gold Prospect.

Keywords: geology, Au-mineralization system, Totopo West prospect, Bundulipu

SARI
Prospek emas Totopo terletak dalam suatu tataan busur vulkano-plutonik dengan lava andesitis dan basaltis berumur Eosen-Miosen yang ditutupi oleh batuan sediment karbonat vulkanogenik dan diterobos oleh batolit, stock, dan retas sebagai hasil proses subduksi berarah tenggara. Kemudian,

Kata kunci: geologi, sistem mineralisasi Au, Prospek Totopo Barat, Bundulipu

INTRODUCTION

The Totopo epithermal low-sulphidation as one of the best prospects defined during extensive regional mineral exploration in Gorontalo area during 1980 and 1990s is located about one kilometre to the South of Trans Sulawesi Highway near Bumela town. It was relatively under explored until 2007 when an exploration campaign was held at the western part of Totopo.

The area is part of a Contract of Work (CoW) granted in July 20, 1994 to Newcrest Indonesia, Pty. Ltd. in Gorontalo (formerly part of the North Sulawesi Province) and Central Sulawesi Province. In 2007, the remaining COW covered an area of 20.06 sq. km, since it has been reduced from original land tenure of 1,129,598.18 ha. The Totopo Area resides about 60 km to the West of Gorontalo, the Capital city of Gorontalo Province, Indonesia. Gorontalo has Jalaluddin airport, supported by daily basis regular flight from Jakarta and Makassar (Figure 1).

The Totopo prospect was discovered in 1995 using regional BLEG (Bulk Leach Extractable Gold) stream sediment sampling techniques and the anomalies were found encompasses a large area of about 4 km x 3 km, spread out in E-W trend. The encouraging results of a following exploration program including soil sampling, aero-
magnetic-radiometric surveying, and scout drilling suggested the works to be more focused at Totopo East, but the program was failed to find a significant deposit as the area was deeply eroded. In the same time, the economic crisis suffered the company that left the area remain underexplored.

The ground review later on, led to the thought that the most preserved mineralization would be on the western part of Totopo. Since 2007, exploration programme has been focused on Totopo West which has defined a Bundulipu Deposit with reported a non-JORC resource of 5.4MT @ 3 g/t Au for 500,000 oz Au using a sectional-polygon method.

### METHODOLOGY

This paper is the result of a review and evaluation of the data that has been available since the prospect of Western Totopo was discovered. The data used comes from a variety of field activities until laboratory analysis; mapping of alteration/mineralization, geochemical analysis and geophysical analysis and drilling program.

### GEOLOGICAL SETTINGS

The Totopo District lies within a volcano-plutonic arc of Cretaceous to Recent age which extends along the west side of Sulawesi, through Northern Sulawesi and Sangihe Islands to eastern Mindanao in the Philippines (Carlile et al. 1990, in Santos, 1999). The Late Tertiary tectonics of Northern Sulawesi is relatively complicated (Hamilton 1979, in Santos, 1999). Subduction during the Miocene is interpreted to have been terminated by collision of the Sula Platform that caused a rotation of North Sulawesi by 90° to its current position. A NE-trending belt of Miocene andesite vol-
canic and diorite intrusions occur along the northern part of North Sulawesi (Santos, 1999).

Subsequent arc reversal in Pliocene to Recent resulted in a subduction in a north-west direction. In North Sulawesi, epithermal style quartz Au-Ag, sediment host Au, and carbonate base metal Au-mineralization all related to this Pliocene to Recent activity (Santos, 1999). The Sulawesi tectonic setting can be seen Figure 2 that show the regional geology of Gorontalo Province.

A reactivating Miocene NW-NNW transfer lineament during Pliocene formed a NE-ENE trending dilational faults due to changing from Miocene south-eastward subduction to relatively northwest direction. This structural preparation introduced NE-ENE extensional fault which provided a space for mineralization. Structural field data supported this interpretation and suggests the occurrences of northwest mineralized structure as conjugate sets of the extensional structures. Another important feature of this structural setting is the development of pull-apart basin and graben structures at Totopo area which tilt the system such that epithermally-altered Plio-Pleistocene rocks are preserved in the west area with erosion down to Miocene “basement” strata in the east.

The Totopo area is situated at the NW margin of a caldera structure. It lies within a structural depression bounded by major

![Figure 2. Sulawesi Tectonic (Caira, 1999).](image)
NW to NNW and NE trending lineaments and faults namely Bumela, Paguyaman, Solupite, Totopo River, Bundulipu, and Oletanggunga lineaments and faults (Figure 3; Santos, 1999). The NNW striking Bumela lineament is an arc-parallel regional feature that eventually follows the EW trending structural grain of the north arm of Sulawesi. The NE trending Solupite Fault occurs as an escarpment and is obscured in the NE by arcuate features. The Oletanggunga Fault cuts through a steep cliff at Oletanggunga Hill and mainly passes through alluvium and colluviums through a NW trending offset of the Totopo River. This structural setting and sinistral reactivation of the major NW trending structures could have led to the down-throwing of the Solupite-Totopo River valley block, forming a graben or pull-apart basin feature and opening up the NE and ENE trending faults.

Figure 4 shows a simplified interpreted geology of the Totopo Prospect. The distribution of Miocene lithologies at the west part clearly shows a consequence of a relative position where the east block is higher compare to the west. Plio-Pleistocene volcanic rocks, including the mineralization, are preserved at the west despite of its downstream position.

In the Totopo Prospect, generally, basement rocks of probably Miocene in age consisting of volcanic andesite, are intruded by polyphasic batholiths comprising granodiorite, quartz diorite, and diorite. Unconformably overlying the basement rocks are Pliocene dacitic volcanics, and then all of lithologies are intruded by contemporaneous microdiorite, diorite, and dacite porphyry dykes. Pleistocene to Recent colluvium and alluvium occupy the valleys and major lineaments.

Totopo West area is underlain by a thick sequence of Pliocene-Pleistocene rhyolitic-dacitic volcanic rocks consisting of lithic tuffs, crystal tuffs, and vitric tuffs. These are...
intruded by porphyritic dacite domes which can be recognised in several locations by their protruding shape that may correspond to the mineralization event at Totopo. The basement volcanic andesites are exposed in the northwestern part of West Totopo and have also been encountered at depth in drill holes.

The volcanic rhyodacite exhibits a light grey to whitish colour due to acid-intermediate composition and clay altered feldspars. They are fine- to coarse-grained, euhedral-subhedral, mainly composed of quartz and feldspar with minor biotite and hornblende. Fragments of volcanic bombs, rhyodacite, and mineralised clasts are commonly found in the lithic sequences. The rock units gradationally change from ash, lithic, to mainly crystalline tuff textures. The bedding has a shallow-moderate NW dip. Widespread accretionary lapilli indicates a relatively moist environment during volcanism whilst sag textures of volcanic bombs on wet surfaces of fine-grained volcanic tuff may indicate the presence of water during volcanism, i.e. a volcanic lake. Sedimentary rocks have been recognised in the northwest of Totopo, mainly occurring as fine-grained laminated sandstone. This appears to have an interfingering relationship with volcanic rhyodacite.

The dacite domes are characterised by grey to dark grey, fine-coarse grained, euhedral, porphyritic textures; composed of feldspar, biotite, and hornblende with minor quartz. No alteration has been observed except some clay and chlorite which is probably due to weathering processes.

The basement volcanic andesites are fine to medium-grained, porphyritic, mainly composed of feldspar and biotite, dark greenish grey due to pervasively chlorite.
altered. Mostly the original minerals are hard to recognise but the main observable characteristic is the magnetic property of the rock. The volcanic andesites were intruded by light grey-grey diorite/ granodiorites. These are fine- to coarse-grained, porphyritic; comprising feldspar, quartz, biotite, and hornblende. The euhedral-subhedral crystal shape is slightly destroyed but no significant alteration is recognized.

RESULT OF INVESTIGATION
Alteration

Broad areas of pervasively altered country rock mark the occurrence of mineralization at Totopo West. There are at least three locations of large altered rock with various level of typical epithermal low-sulphidation system which are Bundulipu, Oletanggunga-Loba, and Solupite-Niwu, with the best geochemistry anomaly is Bundulipu as shown on Figures 4 and 5.

Bundulipu alteration intensities are weak to strong in a broad argillic alteration envelope and moderate to strong within a more confined mineralization zone. Alteration mineral assemblages comprise distal kaolinite, sericite, smectite-illite/smectite-chlorite changing to silica-quartz-illite-illite/smectite as thin zones surrounding the veins/vein zones. Alteration characterized by silica-quartz tends to have a better gold tenor than other alteration assemblages.

At the surface, protruding hill of Oletanggunga-Loba is characterized by a thick silica cap with vesicular texture and is recognized as an upper part of alteration system in low-sulphidation. Adjacent to the hill, trace of alteration mineral assemblages observed comprises illite-,illite/smectite-kaolinite-silica and closer to the vein/vein zone, a strong but very narrow silica alteration tends to occur.

At Solupite, exposures showing alteration are generally found closest to the Solupite

Figure 5. An example of multiple mineralization and alteration events in core (Dacosta, 2008).
The alteration mineral assemblages comprise illite, illite/smectite-kaolinite-silica, similar to those in Bundulipu and Oletanggunga areas.

Mineralization

Quartz vein and stockwork zones associated with broad quartz-clay alteration were emplaced soon after the Pliocene felsic volcanics. Accumulation of sinter boulder deposits occurring in the northwestern part of Totopo West are believed to be related to Late Pliocene-Pleistocene hydrothermal activity that introduced an extensive quartz-clay alteration and associated high-grade gold quartz-sulphide veining in felsic pyroclastics at the Bundulipu, Oletanggunga-Loba, and Solupite-Niwu.

At Bundulipu, the mineralization zones are veins/veinlets/stockworks of quartz-adularia-barite with pyrite, chalcopyrite, sphalerite, galena, and very fine-grained black sulphide filling fractures. Quartz sulphide veins are generally thin, up to a few cm wide, predominated by a simple geometry (planar) with a narrow silica replacement or phyllic alteration. Vein textures comprise simple banded, crustiform-colloform, cockade breccias and bladed that representing the boiling process.

Oletanggunga-Loba Quartz vein textures are mainly chaledonic and simple banded suggesting a low temperature in accordance with alteration assemblages. At depth (>200mdh), zone of strongly silica altered hydrothermally brecciated rock with cockade textures and disseminated pyrite-base metal assayed for 3 - 10g/t Au.

Some quartz veining at Solupite-Niwu are characterized by multiple banded and fine crystals with dogtooth textures, and returned high assay. It is believed, the Solupite-Niwu mineralization level is in-between Bundulipu and Oletanggunga-Loba.

The outline of the mineralization zone at the Totopo West veins exhibit various textures and mineral infill. Multiple stages of mineralization events are shown by cross-cutting relationships. The veins are usually brecciated and highly fractured. Figure 5 shows an example of mineralization and alteration cross-cutting relationship observed in core of Bundulipu.

Geochemistry and Geophysics Data

Soil sampling programme has been collected since the first discovery of Totopo Prospect both as a ridges and spurs and grid-soil sampling. At least two sampling procedures have been applied: auger sampling targeting B horizon and partial leach method. Levelling method using mean value of both sampling techniques is applied to analyze soil data. At Totopo West, anomalies of Au in soil clustered around the three areas, which is the best area at Bundulipu as shown in Figure 6.

Geophysics Induce Polarization Dipole Dipole (IPDD) survey resulted in two big clusters of high resistivity at the location known as Oletangungu-loba and Solupite-Niwu, and very narrow moderate resistivity at Bundulipu (Figure 7, Table 1). Chargeability survey yields two clusters of high chargeability at Bundulipu and Solupite-Niwu and moderate at Oletanggunga-loba. It appears here that geophysical survey results can aid the recognition of mineralization level. Wide high resistivity and moderate chargeability at Oletanggunga-loba may represent thick silica cap yet further down sulphide minerals. A narrow high chargeability and moderate resistivity may reflect concentration of mineralized body at Bundulipu.

Drilling Program

Scout and semi-infill drilling campaign are conducted at Totopo West in 2008. Of 24 drillholes, 15 were drilled at Bundulipu as
The Geology and Au-Mineralisation System in The Totopo West Prospect, Gorontalo, Indonesia (B. Budiman et al.)

Figure 6. Gold soil anomaly image of Bundulipu area at Totopo West.

Figure 7. Geophysical anomaly maps of the Totopo West Prospect. Note: high value is represented by red colour.

Table 1. Interpreted Mineralization Zone to the Geophysical Anomalies at Totopo West

<table>
<thead>
<tr>
<th>Location Name</th>
<th>Relative position to boiling zone</th>
<th>Resistivity</th>
<th>Chargeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oletanggungaloba</td>
<td>highest</td>
<td>Wide, High</td>
<td>Wide, Low</td>
</tr>
<tr>
<td>Solupite-Niwu</td>
<td>middle</td>
<td>Wide, High</td>
<td>Wide, High</td>
</tr>
<tr>
<td>Bundulipu</td>
<td>nearest</td>
<td>Very narrow, moderate</td>
<td>Narrow, high</td>
</tr>
</tbody>
</table>

the best project and remaining 9 holes are located at Oletanggungu-Loba and Solupite-Niwu as scout-drillholes.

At Bundulipu, a SSE trend fence drill programme was planned following the interpreted NE-ENE dilational structures as open space-infilled mineralization which was proven since those drillholes were successfully hit mineralization at depth over area about 500 m x 500 m.

The Bundulipu mineralization interpretation consists of parallel pinch and swell shaped zones in a dominant ENE-WSW direction with a minimum length of 600 m and width
varying from 1 - 30 m. The gold tenor of drill core samples is fairly high \((i.e. > 5.0 \, g/t \, Au)\), however, the high grades found are deep and the most significant zones as 7.8 m \(\geq 3.74 \, g/t \, Au\) from 258 mdh including 3 m \(\geq 8.76 \, g/t \, Au\) from 259 m and 13 m \(\geq 2.09 \, g/t \, Au\) from 183 mdh including 2 m \(\geq 6.95 \, g/t \, Au\) from 187 m could not be consider as bonanza (Figures 8 and 9).

A preliminary resource estimation of mineralization zone was calculated from NW-SE cross-sections using a sectional-polygon method. The calculation used a strike length of 400 m and a width of 54 m. Mineralization was conservatively inferred to be continuous down-dip to depths between 200 - 300 m from surface.

Additional assumptions and constraints adopted in the preliminary resource calculation are as follows:
- Cut off grade is 0.5 g/t Au with a maximum of 2 m waste allowed.
- Top cut value is 100 g/t Au.
- The maximum length interpolated in joining adjacent significant zones of mineralization is 50 m in both lateral and vertical extent, except where there is existing drill hole less than 100 m distance.
- In such case, then the maximum length of interpolation for both lateral and vertical extent is pegged at half the distance.
- Resource calculations involve only zones that can be projected with a fair degree of confidence. Mapped mineralized zones excluded in the calculation due to the absence of drill data are likely to upgrade the resource in the future.
- The average bulk density adopted was 2.5 t/m³.

On the basis of those parameters, an Inferred Mineral Resource estimate of 5.4 MT \(\geq 3 \, g/t \, Au\) for 500,000 oz Au at a 0.5g/t Au cut off was calculated, but this has not been developed in accordance with the JORC Code (2004).

![Figure 8. Drill hole locations and significant intercept highlights.](image-url)
CONCLUSIONS

The exploration programme at Totopo done by Avocet is considered as a continuance of well-reported previous exploration work at the area. A careful data re-evaluation and focussed exploration program at Totopo West of Totopo prospect, by carrying out detailed geophysics and geochemical survey methods directly followed by drilling programs and detailed logging of vein fabrics, are exploration approaches that are consistently applied that lead to definition of a gold deposit called Bundulipu.

Drilling programme at The Totopo West has not yet defined a bonanza zone at Bundulipu or fully tested the mineralization in the whole area but the exploration programme at Totopo West has proved the role of presumption NE-ENE structure-controlled mineralization and the position of boiling level of the epithermal system recognized by vein fabrics examination and prospect structure model, yet the end-result is still fairly unfavourable.

In prospect scale, the Totopo area is still far from exhaustively explored. A number of alteration and gold mineralization occurrences at Totopo prospect are still remain underexplored including the Bundulipu, Oletangguna-Loba, and Solupite-Niwu of Totopo West area.

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