The discovery and understanding of the Far Southeast copper – gold porphyry, Luzon, Philippines

Alina Gaibor (presenter), Peter Dunkley, Aaron Wehrle, Guillaume Lesage, Devin Den Boer, Froilan Conde

Contact:
Gold Fields Limited.
19th Floor, Lepanto Building, 8747 Paseo de Roxas, Makati City, 2600, Philippines
Phone: 63 917 5414557
Alina Gaibor: Alina.Gaibor@goldfields.com.ph
Abstract

The Far Southeast copper-gold porphyry deposit is concealed at depth beneath and adjacent to the historical Lepanto mine in the Cordillera Region of northern Luzon. The deposit is currently being explored by Far Southeast Gold Resources Inc. (FSGRI), a joint venture company of the Lepanto Consolidated Mining Company (LCMC) and Gold Fields Switzerland Holdings AG, a subsidiary of Gold Fields Ltd (Gold Fields).

The discovery of the deposit in 1980 presents a classic exploration story. In the 1970s the recognition of widespread mineralised diorite clasts in the pyroclastic cover sequence of the district led to the hypothesis that concealed porphyry systems could exist at depth. An IP survey conducted in 1979 delineated a chargeability anomaly which was then successfully drilled, with indications of porphyry style mineralisation being intersected in the second hole of the drilling campaign. The exploration that ensued however has involved a long and challenging sequence of drilling campaigns and related studies which have had to overcome logistical and technical complications on account of the considerable depth of the deposit. Economic cycles and fluctuating metal prices over the years have also played their part, affecting the resolve of any one company to continue with exploration and development plans over the long term required for such a large and ambitious project.

From 1980 to 1994 more than 100 drill holes were completed in several campaigns by LCMC and partners, the majority of which were collared from underground within the Lepanto mine directly above the deposit. At the end of this period of exploration a revised resource estimate was reported of 656.5mt @ 0.94g/t gold, 0.65% copper at a cut-off grade of 0.7% copper equivalent. Falling metal prices at the time were not however conducive to the project going forward.

No active exploration was undertaken on the deposit for the next 15 years, although a number of companies undertook due-diligence and conceptual studies on existing information.

In 2010 Gold Fields entered into an agreement with LCMC to take the project forward under the auspices of FSGRI. Subsequently a total of 98 holes with an aggregate of 102,339m were drilled from the 700-Level of the disused Lepanto mine, starting with two unsuccessful due diligence holes in 2010 followed by a major drilling campaign of 96 holes between early 2011 and mid-2013. This campaign comprised three separate phases, including an initial proof of concept phase, followed by a scoping study and lastly a prefeasibility study. An inferred resource was reported in September 2012 of 892mt @ 0.7g/t gold and 0.5% copper, equivalent to 19.8 moz gold and 4.6mt copper.

The recent (2010-13) exploration campaign has significantly advanced understanding of the deposit using a multidisciplinary approach that has required a strong team effort. Although drilling has underpinned this campaign, the deposit has been investigated at all levels, from the regional scale to more detailed investigations at the deposit scale and the microscopic scale, which combined have resulted in a more holistic model than existed previously and to a clearer understanding of the controls on mineralisation which contribute to increased confidence in the resource model.

Introduction

The Far Southeast copper-gold porphyry deposit occurs at depth beneath and adjacent to the historical Lepanto enargite mine, which is situated in the mining district of Mankayan in the mountainous Cordillera Region of northern Luzon. The district lies 250km north of the capital city of Manila and approximately 50km north of the provincial city of Baguio, which is the centre of another world-class gold mining district.

The Far Southeast (FSE) porphyry deposit is currently being explored by Far Southeast Gold Resources Inc. (FSGRI), which is a joint venture company between the Lepanto Consolidated Mining Company (LCMC) and Gold Fields Switzerland Holdings AG, a subsidiary of Gold Fields Ltd (Gold Fields).
History of exploration and discovery

Copper and gold were mined from enargite deposits of the district and traded with Chinese traders as early as the 14th Century. Attention was drawn to the district during Spanish colonial times because of the use of copper by the indigenous population. Hostilities towards outsiders precluded any organised development and it was not until 1864 that the first commercial-scale mining commenced at Lepanto by the Manila Cantabro-Filipino company. At least 1,100t of copper was produced from shallow workings in enargite orebodies over a 10-year period before operations ceased in 1874 on the death of the manager of the operation.

American prospectors began to investigate the area in the early 1900s and in 1936 a group pooled resources to form the Lepanto Consolidated Mining Company (LCMC). During the Second World War the Lepanto mine was managed by the Japanese company Mitsui, which produced 11,000t of copper in the early 1940s. After the war LCMC rehabilitated the mine and resumed mining in 1948. The Lepanto mine eventually ceased copper operations in 1996 after producing a total of 36.3mt of enargite ore, with an overall recovery of 0.74mt copper, 2.96 moz gold, and 12.64 moz silver.

Gold-bearing intermediate sulphidation epithermal quartz-carbonate veins have been worked for many years by artisanal miners in the Nayak area, situated a few kilometres south of the Lepanto mine. In 1991 LCMC began to explore the vein system through drilling campaigns underground from the Lepanto mine and eventually this led to the development of the Victoria gold mine which commenced production in March 1997. In the past 16 years of operation the Victoria mine has produced about 1.30 moz gold and 2.49 moz silver.

As early as the 1970s LCMC geologists recognised the occurrence of hydrothermally altered diorite clasts with porphyry style mineralisation dispersed throughout the district in young pyroclastic cover sequences. The pyroclastic deposits were later interpreted as the products of diatreme activity which led to speculation that porphyry mineralisation may have existed at depth beneath the enargite deposits and that the mineralised diorite clasts had been brought to the surface by phreatomagmatic explosive activity. Porphyry style alteration is also reported to have been encountered in the 1970s at Bulalacao to the south-east of the Lepanto mine while drilling for extensions to the enargite deposits. The core from these holes was not however thoroughly assayed at the time.
In 1975 the concealed Guinaoang porphyry deposit was discovered by the Mankayan Minerals Development Company Inc. a few kilometres to the south-east of the now known Far Southeast deposit. This spurred exploration for porphyry related mineralisation in the district.

LCMC’s initial area of interest for porphyry exploration was a forest reserve covering 80ha to the south-east of the company’s existing claims. In 1978 endorsement for a prospecting permit was given by the Mankayan Municipality and in the following year permits were approved by the Mines and Geoscience Bureau. In 1979 LCMC commissioned an IP survey over the forest area which delineated a chargeability anomaly measuring 1,400m by 300m to the east of the Tubo shaft of the Lepanto mine. The central part of the anomaly was tested by a drill hole in April 1980, drilled to a depth of 628m, but this did not encounter mineralisation. A second hole (S-80-2) drilled farther west in October 1980 to a depth of 1,116m intersected low-grade copper-gold mineralisation (0.16% copper, 0.305 g/t gold) in diorite over the bottom 200m of the hole, thus confirming that a porphyry deposit might in fact exist at depth. Surface drilling of the IP anomaly was however abandoned in the belief that the IP anomaly was related to shallow level argillic-pyrite alteration associated with enargite mineralisation.

Encouraged however by the mineralisation encountered in the bottom of the second drill hole LCMC decided to drill and further test the target from underground within the Lepanto mine. The first hole (U-80-23) was collared in December 1980 on the 900-Level and intersected 475m of mineralisation grading 0.46% copper and 0.41 g/t gold, with grades increasing with depth and continuing to the bottom of the hole. This is generally accepted as the discovery hole and was followed by an intense drill programme from the 700-Level that lasted through to 1987. The exact amount of drilling undertaken is uncertain because of conflicting reports. Concepcion and Cinco (1989) who were the LCMC geologists at the time reported a total of 75 holes amounting to an aggregate of 38,198m for resource drilling, as well as an additional 4,177m for other purposes. In addition, 7.65km of drives were developed on the 900 and 700 levels to accommodate the drill stations. At the end of this first campaign of drilling a resource of 356.6mt was declared with grades of 1.24 g/t gold and 0.73% copper at a 1.00% copper equivalent cut-off.

In 1987 Far Southeast Gold Resources Inc. (FSGRI) was organised as a joint venture company between LCMC and Galactic Resources Ltd to develop the FSE deposit. In the same year LCMC commissioned a feasibility study on the deposit.

In 1990 CRA Ltd acquired the interests of Galactic Resources in the joint venture and the feasibility study was also presented. Various contracts were entered into for infrastructure design, but in mid-1991 the financing negotiations ran into difficulties and development plans were curtailed. Despite the setback, FSGRI continued drilling between 1992 and 1994 with the objective of increasing the resource inventory. According to LCMC this brought the total number of drill holes to date to 114 for an aggregate of 52km; although other slightly higher numbers are reported by other sources. In late 1994 FSGRI commissioned consultants to update the resource model, which was estimated as 656.5mt @ 0.94g/t gold, 0.65% copper at a cut-off grade of 0.70% copper equivalent. Falling metal prices at the time were not however conducive to the project going forward.

No active exploration was undertaken on the deposit for the next 15 years, although several companies entered into negotiations and agreements with LCMC and undertook due-diligence and conceptual studies on existing information. Resolve by any one company to implement exploration programmes was impeded by varying factors, not least amongst these being the considerable depth of the porphyry system as well as metal prices.

In November 2009 Gold Fields expressed to LCMC an interest in the FSE deposit and undertook due diligence investigations in December 2009 and March 2010. Gold Fields’ due diligence and block model estimate concluded that FSE clearly represented an exceptional deposit in terms of tonnage, grade and down-hole continuity. Although the historical drilling was sufficient to model a significant high-grade inventory, the near-vertical orientation of the drilling was considered a risk with respect to the also near-vertical geological controls on mineralisation. In order to mitigate the risk of drilling bias and uncertainties in geological interpretation, a drilling programme of shallow-dipping holes was proposed and approved by the Gold Fields board. Final approval of the terms with LCMC was announced on September 20, 2010 with the execution of the FSE Option and shareholders agreement to take the project forward under the ownership and management of the joint venture company FSGRI. From mid-2010 until mid-2013 a total of 98 holes with an aggregate of 102,339m were drilled by Gold Fields from the 700-Level of the disused Lepanto mine, with the objective of delineating the porphyry system in preparation for pre-feasibility study. Although this period of exploration was largely focused on resource drilling, additional investigations were undertaken in order to understand the geological and structural context of the porphyry deposit. This included district-scale geological mapping, radiometric dating and structural, stratigraphical, geophysical and geotechnical investigations, as well as metallurgical testing.
Figure 2: Geological map of the Mankayan district showing the footprint of the FSE porphyry deposit, the high sulphidation enargite ore bodies of the Lepanto mine and the intermediate sulphidation veins of the Victoria – Tereza mine. Additional porphyry prospects referred to in the text are also shown

**District geology**

The geological succession of the Mankayan district consists principally of a basement of pre-Middle Miocene volcanic, volcaniclastic and intrusive rocks which are unconformably overlain by an extensive cover sequence of Late Pliocene-Pleistocene dacitic tuffs and breccias, the eruption of which was accompanied by the intrusion of diorite and andesite-dacite stocks and domes. The mineralisation of the district was related to the Plio-Pleistocene volcanism and is characterised by intermediate and high-sulphidation epithermal systems as well as copper-gold porphyries, including the FSE porphyry deposit itself.

The Late Eocene-basal Oligocene Lepanto volcanic unit forms a basement to the entire district and consists of a thick sequence of basaltic pillow lavas, dykes, hyaloclastites and related volcaniclastic rocks as well as minor rhyolite intercalations, dykes and sills. The basalts show geochemical affinities consistent with a marginal basin environment possibly transitional to primitive island arc. The Ballii volcaniclastic unit of Oligocene-Middle Miocene age unconformably overlies the Lepanto volcanic unit and comprises over 1,000m of very poorly sorted epiclastic andesitic breccias and conglomerates with subordinate volcanic sandstones. The environment of deposition is thought to be transitional from a terrestrial alluvial environment into a shallow marine fan environment with detritus having been derived from a tectonically active andesitic volcanic hinterland. A tonalite-diorite-gabbro complex of batholithic proportions intrudes the Lepanto volcanic unit along the western side of the district. This is known locally as the Bagon intrusion complex and forms part of the much larger Agno batholith that runs along the entire spine of the Cordillera of Northern Luzon.

The Late Pliocene to Pleistocene Imbanguila and Bato dacitic pyroclastic units form an extensive cover sequence over much of the district, in places reaching up to several hundred metres in thickness. Both units are similar, except the older Imbanguila unit pre-dates the mineralisation of the district and at many localities is strongly hydrothermally altered, whereas the younger Bato unit is generally unaffected by hydrothermal alteration. Both units consist of dacitic tuff-breccias and tuffs which show features consistent with emplacement by pyroclastic density currents and to a lesser extent air-fall, as well as reworking by debris-flow. They are interpreted as the products of phreatomagmatic eruptions from several different diatreme sources. The deposits contain sporadic but widespread diorite clasts with porphyry style mineralisation and hydrothermal alteration. Numerous intrusions of diorite and porphyritic andesite and dacite intrude the young pyroclastic cover sequences. Some of the dacites have almost pristine dome-like morphology and radiometric ages of less than a million years.
The structure of the district is dominated by a complex zone of north to north-westerly trending faults of the Abra River fault system, which is a major branch of the Philippine fault that runs along the length of the Cordillera of Northern Luzon. This system has undergone sinistral strike-slip movement since Miocene times and exerted controls on the sedimentation, volcanism and mineralisation of the region. The north-trending Mankayan fault is a major strand of the system and is the largest fault in the district. Important secondary faults splay from the main Mankayan fault and trend between north-west and west-northwest across the district. These secondary structures exerted a fundamental control on the epithermal mineralisation of the district and also on the emplacement of the FSE porphyry.

District-scale mineralisation

The Mankayan mineral district has a long history of copper, gold and silver production and over the past two decades has attracted considerable research interest with respect to the spatial and temporal association of epithermal and porphyry mineralised systems (Arribas et al., 1995; Hedenquist et al., 1998; Sajona et al., 2002; and Chang et al., 2011)

Three main styles of mineralisation occur, all of which were contemporaneous with the Plio-Pleistocene volcanism of the district. These include high-sulphidation epithermal mineralisation, characterised by fault-controlled enargite-luzonite copper-gold deposits of the Lepanto mine; fault-controlled intermediate-sulphidation epithermal carbonate-quartz gold-polymetallic veins of the Victoria-Teresa and Suyoc mines; and copper-gold porphyry systems, principally represented by the FSE deposit as well as several other prospects including Guinaoang, Buaki, Mutolinac, Bulalacao and Palidan.

Far Southeast deposit geology

The FSE porphyry lies immediately to the south-east of the enargite orebodies of the Lepanto mine but at a greater depth. The top of the porphyry mineralisation reaches to within about 550m of the surface; although the bulk of the mineralisation commences at around 1,000m from surface and extends to depths in excess of 1,800m and remains open.

The deposit straddles the east-west trending Imbanguala fault zone which is thought to have been the main structure controlling the emplacement of the intrusive porphyry complex and the mineralisation associated with it. The Imbanguala fault is a splay of the Mankayan fault and possibly represents a transfer structure within the overall
north-northwest-trending left-lateral strike-slip zone. It coincides with a strong east-west trending gravity gradient and is therefore considered to be a deep-rooted basement structure.

The FSE porphyry mineralisation is mainly hosted in the Imbanguila intrusion complex and surrounding basaltic country rocks of the Lepanto volcanic unit. The deposit is of Pleistocene age and probably formed during the initial stages of the Bato volcanic episode. Arribas et al. (1995) reported K-Ar radiometric ages from hydrothermal biotite in the range 1.41-1.45 Ma and from illite in the range 1.22-1.37 Ma.

The Lepanto volcanic unit adjacent to the intrusion complex comprises two main facies. These include basalts which are extensively pillowed and associated with hyloclastites and hyloclastite debris-flow breccias. The other facies is predominantly volcaniclastic, consisting of fine tuffaceous siltstones, sandstones and debris-flow breccias and tuff-breccias with basaltic and dacitic clasts and with intercalations of basalt.

The Imbanguila intrusion complex is composed of porphyritic dacite and porphyritic quartz diorite. Several different textural facies of each are apparent. The dacite forms a large body in the south and west of the complex. It is strongly porphyritic with prominent plagioclase, quartz and amphibole phenocrysts. Several different facies or phases are recognised on the basis of the proportion and size of quartz phenocrysts, which range up to about 10% by volume of the rock. In surface outcrop along the Imbanguila River the dacite contains abundant cognate xenoliths of basalt showing evidence of co-mingling of dacitic and basaltic magma. While basalts are not represented in the Pliocene-Pleistocene succession of the district the presence of the cognate xenoliths demonstrates that basaltic magma existed at depth at the time of porphyry formation.

The quartz diorite is a more homogenous body and generally contains up to 3% quartz phenocrysts, but locally increasing to as much as 10%. It is located between the dacite and the Lepanto volcanic unit on the eastern side of the complex and is host to the most intensive porphyry stockwork mineralisation. Contact relationships in drill core indicate that the diorite post-dates the main dacite. Dykes and inclined sheets of unaltered strongly porphyritic dacite cross-cut the complex and are assumed to have been intruded during the later stages of the Bato volcanic episode, but these are not volumetrically important.

Several pre- to post-mineralisation phreatic and phreatomagmatic breccia pipes cross-cut the porphyry intrusion complex. Four main breccia bodies have been delineated by drilling as well as numerous small bodies. One strongly altered breccia pipe cuts through the dacite. Another large vertical pipe-like body cuts through the centre of the mineralisation and contains abundant clasts of mineralised diorite and vein material. A third breccia occurs on the south side of the complex and contains abundant deformed, wispy shaped dacite clasts interpreted as original juvenile magmatic clasts that were still hot and plastic at the time of emplacement. The finer tuffisite facies within this breccia body exhibit stratification and cross-stratification and contains accretionary lapilli. The fourth breccia cuts through the Lepanto volcanic unit on the north-west side of the complex. It contains mineralised clasts, is largely hydrothermally unaltered and is considered to be a late feature.

Figure 4: 3D lithological model of the Far Southeast porphyry deposit, viewed from the north-east
Deposit mineralisation and hydrothermal alteration

Most of the FSE copper-gold mineralisation is hosted in the intrusion complex and to a lesser extent the basaltic country rocks of the Lepanto volcanic unit. The mineralisation is characterised by disseminated sulphides and multiple sulphide-bearing vein sets, both of which show strong spatial and temporal variations and close correlations with hydrothermal alteration style.

Early potassic alteration characterised by biotite-magnetite assemblages occurs at depth, predominantly in the quartz diorite and surrounding basaltic country rocks. This is overprinted by a sodic assemblage of sericite (paragonite)-chlorite-albite alteration (SCC2) which grades outwards into sericite (muscovite)-chlorite-illite alteration (SCC). The SCC2 alteration is associated with the most intense development of stockwork mineralisation and coincides closely with the best gold and copper grades. Phyllic alteration overprints SCC2 and SCC alteration and is characterised by sericite-quartz-anhydrite, with varying amounts of pyrophyllite in the upper part of the phyllic zone. The latter mineral indicates a transition to advanced argillic alteration at higher levels in the system closer to the enargite orebodies of the Lepanto mine. Phyllic alteration is also intensely developed in the central phreaticomagmatic breccia pipe. Propylitic alteration is outboard of the above mentioned alteration assemblages. Calc-silicate alteration consisting of diopside-garnet-epidote assemblages also occurs locally at depth in the basaltic rocks of the Lepanto volcanic unit close to intrusion contacts.

Late-stage fault-controlled argillic and advanced argillic alteration occurs in the upper part of the deposit and also penetrates deeply into the porphyry system along cross-cutting fault structures. Argillic alteration is characterised by smectite, illite, kaolinite and silica, whereas advanced argillic alteration is characterised by vuggy silica, alunite, kaolinite, dickite, diaspore and pyrophyllite. Anhydrite-pyrite veins containing enargite occur locally and typically have advanced-argillic alteration halos.

The highest gold and copper grades occur in the SCC2 alteration zone within the quartz diorite and are associated with the most intense development of quartz vein stockworks. The SCC2 alteration is related to the veining and overprints the earlier pervasive potassic alteration. The main sulphide minerals controlling gold and copper grade are bornite and chalcopyrite. Gold occurs as native gold and in tellurides which include calaverite, hessite, and petzite. Some gold grains are associated with palladium. Molybdenite occurs as an accessory mineral in quartz-anhydrite-pyrite-molybdenite veins. The highest molybdenum grades are observed on the edges of the higher grade gold-copper zone, dominantly in the phyllic alteration.

Figure 5: Vein examples from the FSE rock atlas. (A) and (B) drill core with stockwork veins of quartz-anhydrite (minor) carrying specularite-magnetite-chalcopyrite-bornite—pyrite in quartz diorite with strong pervasive SCC2 alteration and weak vein-controlled phyllic alteration overprint associated with cross-cutting anhydrite veins (FSU124048W1, 1254.7m; FSU113029, 1109.7m). (C) Close up view of (B). (D) Close up view of (B) showing a late anhydrite-chalcopyrite-pyrite-molybdenite veinlet cutting the quartz-specularite-magnetite-chalcopyrite veins.
Microfracture-controlled mineralisation which appears disseminated occurs in the upper part of the deposit. This is represented by assemblages of specularite-pyrite-chalcopyrite and pyrite-bornite-chalcocite, which occur respectively in the phyllic and in the argillic alteration zones.

Intermediate sulphidation epithermal veinlets characterised by quartz-carbonate-sphalerite-galena-chalcopyrite have been observed cross-cutting the porphyry mineralisation in rare examples in drill core. They are characterised by high silver values.

Six vein categories have been recognised as listed in table 1. Vein category names are based on the dominant minerals, although the presence of other accessory minerals is not precluded.

<table>
<thead>
<tr>
<th>Vein Type</th>
<th>Associated alteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz-anhydrite-magnetite-chalcopyrite-bornite</td>
<td>Potassic alteration</td>
</tr>
<tr>
<td>Lavender coloured quartz-bornite-chalcopyrite</td>
<td>SCC2 alteration</td>
</tr>
<tr>
<td>Quartz-specularite-magnetite-chalcopyrite</td>
<td>SCC2 alteration</td>
</tr>
<tr>
<td>Quartz-anhydrite-molybdenite-pyrite</td>
<td>Phyllic alteration</td>
</tr>
<tr>
<td>Anhydrite-specularite-chalcopyrite</td>
<td>Phyllic alteration</td>
</tr>
<tr>
<td>Anhydrite-pyrite-enargite</td>
<td>Advanced argillic alteration</td>
</tr>
</tbody>
</table>

Table 1: Vein types and related alteration

The higher copper and gold grades are associated with the early developed stockwork veins of lavender coloured quartz with bornite-chalcopyrite ± magnetite ± hematite which show a preferred west-northwest orientation parallel to the Imbanguila fault zone. Anhydrite is present in all vein types at different percentages, but is most abundant in late veins typically associated with phyllic to advanced argillic alteration. A shift in vein orientation is observed over time, from early lavender coloured quartz veins to late anhydrite veins with attitudes of 110°/90°N and 050°/76°N to 086°/76°N respectively.

Figure 6: Perspective view of gold-equivalent grade shells of the FSE porphyry deposit in relation to the historical workings of the Lepanto enargite mine. Drill hole traces from the 2011-13 drilling campaign shown in grey
Exploration of the deposit

Exploration of the FSE porphyry deposit has been drawn out over more than three decades. The initial discovery provides a classic exploration story from the recognition of widespread porphyry mineralised clasts within the pyroclastic cover of the district and the hypothesis that concealed porphyry systems possibly existed at depth, through to the successful drilling of an IP anomaly and discovery of the concealed porphyry early in the drilling campaign. The exploration that has ensued however has involved a long and challenging sequence of drilling campaigns and related studies which have seen companies come and go. There are various reasons why exploration of the deposit has been protracted. Not least amongst these is the considerable depth of the deposit and the technical and logistical complications this creates. Economic cycles and fluctuating metal prices over the years have also played their part, affecting the resolve of any one company to continue with exploration and development plans over the long term required for such a large and ambitious project.

Early drilling campaigns by LCMC: 1980-94

Drilling by LCMC and partners between 1980 and 1994 resulted in the first models of the deposit and initial resource estimates. More than 100 diamond drill holes were drilled in this period with the majority collared from underground directly above the deposit on the 700-Level (700m ASL) of the Lepanto mine, and to a lesser extent the 800 and 900 levels and a small number collared from surface. The drill spacing represents an approximate but irregular 80m to 100m grid. Despite the success of the early drilling, the data obtained has restricted application with respect to the current phase of resource assessment.

Underground access is restricted for most of the drill locations due to unsafe underground mine conditions which prevents collar position validation. Limited down-hole positional survey data was collected during the early drilling campaigns and given that much of the drilling was with NQ and BQ diameters and in some cases even AQ there is likely to have been significant hole deviation. These issues place some uncertainty on the positional accuracy of the logging observations and assays.

The sample representativeness of historical assay data is suboptimal. Most drill core was split and sampled in 5m intervals from HQ and NQ core sizes and diameters were often reduced to BQ and AQ with increasing depth in some of the higher grade mineralised zones. Only gold, copper and limited silver analyses were collected with no QA-QC information available. Sampling concerns associated with small sample diameters are compounded by the sub-vertical orientation of the drill core and the intersection angle with important steeply dipping structural features, including the high-grade lavender coloured quartz vein set, diorite intrusion contacts and faults, which together result in a lack of certainty in the historical geological interpretation, grade distribution and continuity between drill holes. Despite the shortcomings of the historical data Gold Fields has deemed it fit for use in inferred resource estimation and classification.

Most of the historical core is no longer available but that which is preserved has been re-logged during the current phase of exploration using the current Gold Fields geological legends and terminology.

Recent drilling campaigns by FSGRI: 2010-13

The recent underground drilling campaign was challenging on account of the considerable depth of the deposit, the high rock and water temperatures and the high humidity associated with a young and still cooling porphyry intrusive complex. Safety has been paramount, having up to nine drill machines with more than 60 people per shift working 700m below surface in disused mine workings. This called for added vigilance and enhanced safety measures which included the installation of efficient ventilation, monitoring of gas and temperature, the construction of refuge chambers and the maintenance of a second means of egress. The project registered approximately 3 million man-hours without a lost-time injury.

The underground drilling programme was undertaken using electric-hydraulic drill rigs capable of reaching depths of 1,000m with HQ and 2,000m with NQ core sizes. The total drill programme was completed in three separate phases, each with different specific objectives. These included an initial proof of concept phase, followed by a scoping study and lastly a pre-feasibility study. On completion of each phase a geological and grade model update was completed that fed into the next phase of drilling and mining studies. Currently a resource model update is underway that will be used as the input model for the pre-feasibility study (PFS) planned for 2014.
The proof of concept drilling programme was designed to validate Gold Field’s 2010 due diligence geological and grade models and to establish confidence in grade connectivity between the historical sub-vertical drill holes. It also resulted in a more meaningful understanding of the geology of the deposit with respect to rock types, the location of contacts and the impact of lithology and alteration on grade distribution. The drill programme consisted of a fan of drill holes, testing an area 1,300m horizontally and 1,000m vertically at the end of hole positions, and was drilled by eight machines located in cuddies on the 700-Level of the mine along the south-western side of the deposit (Figure 7). The longest hole during this phase was 1,901.6m reaching a depth of -762 mASL or approximately 2200m below surface. The geological and assay data from the proof of concept phase validated the 2010 due diligence model and indicated significant extensions to the mineralisation which remained open to the east, south-west and at depth.

The scoping study drilling programme commenced in August 2011 and was designed to reduce the proof of concept drill spacing in the mineralised zone from approximately 200m by 400m to 200m by 200m and define the limits to mineralisation in the east, south-west and at depth. This campaign was cut short however in October due to rapid flooding by stagnant water from the abandoned Lepanto mine, which forced the immediate evacuation of the drilling operations on the 700-Level and completely submerged the drill rigs with the drilling rods still down in the holes. The rigs were submerged for several months and were severely corroded when they were finally salvaged in early 2012.

Drilling for the pre-feasibility study commenced in March 2012, following pumping and rehabilitation of the 700-Level and the salvaging and refurbishment of some of the drilling rigs. This was designed mainly as an infill drill programme to increase resource classification confidence with the additional objectives of targeting the higher grade zones of mineralisation and to mitigate risk related to possible drill hole orientation induced bias. Given that the drill holes in the previous phases had all been drilled from the same eight cuddies on the south-western side of the deposit four new drill cuddies were developed to facilitate drilling from the southern side and north-western sides.

<table>
<thead>
<tr>
<th>Company</th>
<th>Location</th>
<th>Programme</th>
<th>No. of holes</th>
<th>Year</th>
<th>Meters Drilled</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCMC</td>
<td>Underground</td>
<td>Historical</td>
<td>106</td>
<td>1980-1994</td>
<td>57,681</td>
</tr>
<tr>
<td>LCMC</td>
<td>Surface</td>
<td>Historical</td>
<td>5</td>
<td></td>
<td>6,518</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td></td>
<td><strong>111</strong></td>
<td></td>
<td><strong>64,199</strong></td>
</tr>
<tr>
<td>FSGRI</td>
<td>Underground</td>
<td>Due Diligence</td>
<td>2</td>
<td>2010</td>
<td>433</td>
</tr>
<tr>
<td>FSGRI</td>
<td>Underground</td>
<td>Proof of Concept</td>
<td>19</td>
<td>2011</td>
<td>26,520</td>
</tr>
<tr>
<td>FSGRI</td>
<td>Underground</td>
<td>Scoping Study</td>
<td>14</td>
<td>2011-2012</td>
<td>14,214</td>
</tr>
<tr>
<td>FSGRI</td>
<td>Underground</td>
<td>Prefeasibility</td>
<td>63</td>
<td>2011-2013</td>
<td>61,172</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td></td>
<td></td>
<td><strong>98</strong></td>
<td></td>
<td><strong>102,339</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>209</strong></td>
<td></td>
<td><strong>166,538</strong></td>
</tr>
</tbody>
</table>

Table 2: Summary of drill phases
Data collection

Throughout the 2010-2013 exploration campaign a rigorous QA-QC system was developed and implemented for all aspects of data collection which included internal and external audits and reviews.

Down-hole surveys were conducted routinely using an electronic multi-shot (EMS) magnetic survey method with measurements taken every 30m in all drill holes. Given that some of the alteration assemblages are rich in magnetite it was decided to validate the data by resurveying many of the holes, initially using a surface reference gyroscopic survey tool on 72 holes and afterwards with a north-seeking gyroscopic tool on 50 holes. Apart from a few data outliers the three methods showed good repetition and increased confidence in the spatial location of drill holes and samples.

Core logging was undertaken using a digital data capture system which helped promote efficiency and consistency amongst the geological and geotechnical logging team, which at the project’s peak in activity consisted of 20 geologists. A comprehensive rock atlas and rock library was compiled and underpinned the logging system and database tables. The rock legend employed internationally recognised terminology and provided detailed descriptions and illustrations of all the lithologies and styles of alteration, mineralisation and structures encountered.

Magnetic susceptibility readings were taken at one metre intervals on all core. The identification of alteration mineralogy was performed on a daily basis using a portable infrared mineral analyser, which provided prompt feedback to the logging team, helping to hone skills in ocular mineral recognition. This was in turn backed-up by petrographic analysis of thin sections and polished sections augmented by X-ray diffraction analysis on selected samples.

Rockmass geotechnical logging was completed on all core for recovery, RQD, fracture frequency, estimated strength and discontinuity characteristics. Point load tests were completed on average at 5m intervals on more than 60% of the core. More than 95% of all drill core was successfully orientated. Digital photos of the core were analysed with Stereocore software which allowed the attitude of structures to be measured in a semi-automated manner. Acoustic Tele Viewer surveys were also completed in 45 drill holes and were used to identify and measure the orientation of structures.
Assays for multiple elements were performed on samples comprising 2.5m intervals of half core. Routine analyses were performed in a primary laboratory in Manila and umpire analyses undertaken at a reputable laboratory overseas. A strict QA-QC system was maintained which included regular audits of the laboratory by project staff. Comprehensive audits of the entire sampling and assaying process were undertaken annually by external consultant geochemists.

Mineral resources modelling

An Inferred Mineral Resource for the FSE deposit was declared in September 2012 which reported 891.7mt @ 0.7 g/t gold and 0.5% copper for 19.8 moz of gold and 4.45mt of copper. The resource is reported inside a mining constraint which assumes an eventual non-selective, bulk underground mining method as defined by scoping study modifying factors. The classification of inferred has been applied based on drill hole spacing, estimation quality, geological continuity and geological understanding of the deposit in early 2012 and is compliant with the SAMREC code (SAMREC, 2009). Significant improvement in geological understanding has been achieved since that time along with substantial additional drilling. This will result in a more robust and higher confidence resource estimate in the future, particularly with regards to the geological constraints on the distribution of the higher grade mineralisation.

The early 2012 geological interpretations of the FSE deposit were represented in an 8 km³ three-dimensional volume comprising lithological and alteration models. The models were constructed using Leapfrog® software utilizing drill hole logging and assay data, surface and underground mapping, and interpretation polylines. Approximately 70,000m of historical LCMC drill core logging in 126 drill holes and 40,000m of Gold Fields drill core logging in 34 drill holes were considered in the geological modelling process. Not all of these holes had assay data and as such the number of holes used in the grade estimation was less than those used in the geological model.

Twelve distinct rock types as logged were consolidated into five coherent and spatially distinct lithological groups for the purpose of geological modelling. From youngest to oldest these included the central phreatic-phreatomagmatic breccia pipe, the southern phreatomagmatic breccia body, the quartz diorite porphyry intrusion, the Imbanguila dacitic intrusion complex, and the Lepanto volcanic unit. Four alteration groups were created from the thirteen observed alteration types in order to simplify the volume models for broad grade distribution investigations. The four alteration groups included an upper clay zone, a phyllic zone, a chlorite zone and a potassic zone.

Although the lithological and alteration models gave satisfactory representation of the deposit geology they did not define stationary domains of copper-gold mineralisation in terms of grade distribution geostatistics. Investigation of the correlation of vein density with copper and gold grade iso-shells provided a necessary addition to the geological models. The geology models formed the basis for density estimations while the mineralisation estimation domains consisted of a high-grade gold iso-shell core (greater than 1 g/t gold) enveloped by a copper grade iso-shell (greater than 0.6% copper). These are in turn surrounded by a low grade copper-gold iso-shell.

The assay samples were composited into 5m lengths down hole and within domains for the purpose of geostatistical investigations, which included analysis of data clustering, grade top cuts, multivariate relationships between gold, copper, and silver, and univariate and multivariate variography for each element per domain. The anisotropy defined in the univariate variogram models was used as the basis for the orientation of the estimation search ellipsoids. Initial grade estimation was by ordinary co-kriging into 80 mE by 80 mN by 20m elevation panels and 20 mE by 20 mN by 10m elevation blocks. The final block model grade estimation was completed using the multivariate uniform conditioning process at the panel scale, with localised multivariate uniform conditioning at the block scale.

An external mining consultant prepared a preliminary mining outline for the FSE deposit, based on the Inferred Resource category grade estimation block model. The modifying factors such as recovery, TC/RC factors, infrastructure, operating and capital costs were based on the March 2012 FSE Scoping Study completed by Gold Fields. Based on the direct mining factors and modifying factors a break-even cut-off NSR of $US25/t was calculated.
Conclusion and lessons learnt

The discovery of the Far Southeast porphyry deposit presents a classic exploration story from the recognition of porphyry mineralised clasts in the pyroclastic cover sequences of the district, through the delineation of an IP anomaly, which quickly led to the discovery of the deeply concealed porphyry during a follow-up drilling programme. The exploration that ensued however has involved a long and challenging sequence of drilling campaigns and related studies which have seen companies come and go. There are various reasons why after so many years the deposit still remains incompletely explored. Not least amongst these is the considerable depth of the deposit and high geothermal gradients associated with it, and the technical and logistical challenges this creates. Economic cycles and fluctuating metal prices over the years have also played their part, affecting the
resolve of any one company to continue with exploration and development plans over the long term required for such a large and ambitious project.

The planning, execution, and management of such a significant and challenging drilling and resource development campaign, as that of the past three years, requires a well thought-out and consistent approach. Robust contracts and win-win style of contractor management is critical for positive relationships and mutual benefit. Appropriate infrastructure for both work and rest helps keep the workforce motivated and on task. Risks associated with working underground need to be thoroughly considered from a safety and productivity perspective. Effective and timely communication is essential to ensure such a large team is always aligned. While the approach needs to be consistent the ability to adapt to change is also important through such a long campaign as changing outside influences impact the project.

The recent (2010-13) exploration campaign has significantly advanced understanding of the deposit using a multi-disciplinary approach that has required a strong team effort. One of the factors that contributed to the success of the team has been an open management style which fostered the training of a team of young National geologists and their empowerment in all specialised aspects of the exploration programme. A second factor was the establishment of efficient procedures and data collection systems that are essential for managing the large amounts of drill core produced daily and the related data capture in a consistent, thorough and efficient manner.

A rigorous QA-QC system has been applied to all aspects of data collection and management during the 2010-13 exploration campaign. Due to less stringent procedures and lack of documentation generally applied by the industry in the past however, the utility of data from historical drilling programmes has its limitations.

Although drilling has underpinned this campaign, the deposit has been investigated at all scales, including regional-scale geological mapping, structural investigations and geophysical surveys through to more detailed investigations at the deposit scale and microscopic scale employing petrography, mineralogy, geochemistry, geochronology, metallurgical and alteration studies as well as detailed geotechnical and structural investigations of the drill core. These combined studies have resulted in a more holistic model than that previously established and to a clearer understanding of the controls on mineralisation which together contribute to increased confidence in the resource model.

Acknowledgements

We wish to thank all past and present members of the FSE geological and technical team for their dedication and hard work over the past three years. The technical success of the project can largely be attributed to this well-organised, motivated and spirited group. Thanks are also extended to the Management of Gold Fields and the Lepanto Consolidated Mining Company for their strong support and encouragement throughout the project and their permission to publish this work.

References


