Geology of the Sepon Copper and Gold Deposits, Laos

BounOum Bouttathep

MMG Limited, Sepon District, Savannakhet province, Lao PDR; e-mail: bbouttathep@mmg.com

ABSTRACT

The Sepon project area is located in south-central Laos and has a long history of artisanal panning, but hard rock gold potential was not recognized until 1990 when field reconnaissance identified high grade rock chip samples and widespread alteration. Large scale exploration commenced in 1993, leading to the discovery of the Nam Kok and Discovery deposits. Continued detailed work in the Sepon mineral district (SMD) has resulted in the discovery of seven additional gold ore-bodies totaling 64.74 Mt @ 2.0 g/t Au for 4.19 Moz Au, plus the Khanong (44 Mt @ 2.9 percent Cu); Thengkham South (25.85 Mt @ 1.24 percent Cu) and Thengkham North copper deposits (11 Mt @ 2.14 percent Cu).

The SMD is situated in the Sepon basin within the Truongson Fold Belt, an elongate NW trending belt of Paleozoic sedimentary and metamorphic rocks, which forms part of the Indochina terrane of SE Asia. The Sepon basin comprises Devonian to Carboniferous sedimentary rocks deposited during the formation of an E-W oriented pull-apart basin. These alternating sequences of calcareous shale, dolostone, limestone, sandstone, and siltstone underwent a major compressional event, likely associated with the Indosinian orogeny. The major basin forming structures were inverted and became conduits for mineralizing fluids. Intrusion of rhyodacite porphyry dikes post-dated late diagenesis but occurred before the conclusion of compressional tectonism.

The dominant style of mineralization in the SMD is micro-disseminated, sediment-hosted gold in structural, rheological and chemical traps. Gold mineralization is closely associated with decalcification of calcareous shale and irregularly distributed silica replacement (jasperoid) bodies. The geometries of the deposits are controlled by the interplay of shallow-dipping lithological contacts and high-angle faults, forming tabular to rod-like ore bodies. Gold mineralization is associated with elevated arsenic, antimony and locally thallium. It can be argued that the Sepon district is a zoned district-scale system associated with intrusion of the rhyodacite porphyry suite. In this model porphyry Mo-(Cu) systems are present at the core and mineralization zones outward through skarn and carbonate replacement Cu deposits to the Au-Ag dominated sediment-hosted deposits.

Gold mineralization in the Sepon deposits is similar in many respects to the sediment-hosted replacement style deposits known as the Carlin-type in the Great Basin, Nevada. Host rocks comprise mid-Paleozoic calcareous and carbonaceous sedimentary rocks; high-angle faults served as fluid conduits and are major ore controls; ore-bodies are generally characterized by the dissolution of carbonate minerals and the precipitation of silica (jasperoid); gold is generally ultra-fine and intimately associated with pyrite; and base metal levels are typically low. Significant differences between Sepon and the Great Basin Carlin-type deposits include the age of gold mineralization – Permian versus Late Eocene respectively, and the tectonic setting – compressive versus extensional respectively. Although the Sepon gold mineralization shares many similarities with the Carlin-type deposits, it also has unique features that set it apart from other sediment-hosted gold deposits.
characteristics with the Carlin-type of mineralization, it may be classified as “distal-disseminated Au-Ag” because of the association with a possible zoned, porphyry intrusive centered system.

**Key words:** Sepon, sediment-hosted Au, distal-disseminated, jasperoid, exploration

1 Introduction

The Sepon project comprises a 1247 km² contract area and is owned by Chinese domiciled MMG, which operates locally as Lane Xang Minerals Limited (LXML). Gold and copper deposits at Sepon contain over 4.4 Moz of gold and 2.0 Mt of contained copper. Seven gold and three copper deposits exist within a distance of 5 km and comprise the Sepon mineral district (SMD). The Sepon gold mine commenced operations in late 2002 and produced 165,000 oz of gold in its first year. Expansion of the gold plant and construction of the adjacent copper plant were completed in late 2004 and early 2005 respectively. Current gold resources stand at 78 Mt @ 1.7 g/t Au for 4.4 Moz Au, (0.5 g/t Au cut-off) while copper resources comprise 44 Mt @ 2.9 percent Cu for 1.23 Mt Cu at Khanong; 25Mt @ 1.3 percent Cu for 330Kt Cu at Thengkham South (1.0 percent Cu cut-off) and 29Mt @ 1.5 percent Cu for 430Kt Cu at Thengkham North(1.0 percent Cu cut-off).

The Sepon project is located 40 km north of the town of Sepon in the Savannakhet province of south-central Laos, at approximately 105°59’ east longitude and 16°58’ north latitude (Fig. 1). Laos is a landlocked country in central Indochina, sharing borders with Thailand, Myanmar, China, Vietnam, and Cambodia. The topography of the Sepon area is moderately undulating, at an elevation of around 250 m above sea level. Vegetation comprises secondary forest punctuated by rice paddies, slash and burn agriculture, and patches of primary rain forest. The area has a typical monsoonal climate with an annual rainfall of
2200 mm, and can be divided up into 3 seasons: a dry, cool period from October to February; a hot, humid period from March to June; and a rainy monsoon period from July to September.

Access to the project from the provincial center of Savannakhet is via a 3-hour drive on a sealed highway followed by a 1-hour drive on an all-weather, unsealed public access road. The company runs a 6-times-weekly, 90 minute charter flight to and from the capital, Vientiane. The project is located on the southern portion of the historically infamous Ho Chi Minh Trail, a major North Vietnamese supply line into southern Vietnam during the Vietnam War. As such, the area was heavily bombarded by U.S. forces trying to stem the flow of North Vietnamese troops and war machinery into the southern Vietnam’s theater. Effective safety systems developed for the clearance of residual ordinance contamination remain an ongoing part of daily operations.

2 Exploration History

2.1 Discovery of Sepon

Although the Sepon area had been sporadically worked by both local artisans and Soviet alluvial miners, no assessment of the hard rock potential of the area had ever been undertaken prior to the involvement of CRA/Rio Tinto Exploration in 1990 (Manini and Albert, 2003). Following the end of the cold war and the subsequent opening of new exploration and development frontiers, CRA Exploration made a strategic decision to expand its search into Laos (Manini et al., 2001). Very little was known at the time about the geology and mineral potential of the country, so a reconnaissance visit was made to assess the opportunities there. Following reviews of the geology, politics, skills base, infrastructure, and logistics of the country, three priority areas in southern and central Laos were identified for assessment. Of particular interest were the Nam Kok and Nam Sengi areas which had been the focus of Soviet alluvial mining between 1983 and 1985. Soviet reports and mapping indicated the presence of quartz stockworked, sub-volcanic intrusive complexes and gold mineralization in silicified and sericitized contact zones (Bakulin, 1985).

CRA Exploration geologists first visited the Sepon area in December 1990 (Gregory, 1991). Reconnaissance traverses verified the presence of altered porphyry intrusives and multi-phase stockwork veining as described in the Soviet reports. This, coupled with the presence of pannable gold and outstanding rock chip results (17 samples over 200 m averaging 18g/t Au) in strongly silicified sediments, highlighted district scale potential for intrusive related mineralization (Manini et al., 2001). A rapid review of the available Landsat TM imagery confirmed regional prospectivity and an application for a 5000 km² area was submitted to the Lao government. After a lengthy negotiation, exploration and development rights were granted to CRA under a Mineral Exploration and Production Agreement (MEPA) in 1993.

Following the grant of title in 1993, surface mapping and rock chip sampling generated immediate drill targets. On the Discovery prospect, a 700 m long boulder train of highly mineralized, silicified, and brecciated sediments on the south side of the Nam Kok river was delineated and subsequently drill tested. Drill holes eventually intersected in-situ silicified and mineralized calcareous shale, providing impetus for scaled up activities in the district.
Upon conclusion of the 1993 drilling program, systematic geological mapping and sampling were conducted, focused on delineating additional in-situ mineralization and enhancing the geological understanding of the immediate area. As a result, similar silicified sediment was discovered along 1500 m of strike immediately to the east of the Discovery prospect. Simultaneously, broader geological prospecting was carried out, identifying additional areas of gold mineralization at Vang Ngang and Namkok West, and copper-gold mineralization at Khanong on the flanks of the Padan porphyry intrusion (Fig. 2) (Manini et al., 2001). Mineralization in the Sepon area was identified as having affinities to the Carlin-type sediment hosted gold deposits of Nevada (Sillitoe, 1994).

By the end of the 1994 drilling campaign, potential for a +1 Moz resource at Discovery was confirmed. In addition, systematic mapping and sampling resulted in the recognition of six new sediment hosted gold targets and a second porphyry system with associated skarn and carbonate replacement copper mineralization at Thengkham (Fig. 2) (Manini et al., 2001). Regional exploration of the broader Sepon MEPA commenced in 1994 and programs comprising detailed regional stream sediment and rock geochemistry, mapping, airborne magnetic and radiometric surveys, and remote sensed Landsat and photo interpretation were completed over the entire 5000 km². Stream sediment geochemistry clearly outlined a standout, high-order, district-scale, multi-element geochemical signature in the Sepon mineral district, which has been the focus of gold and copper exploration since.

Between 1994 and 1999, drill delineation work by RioTinto continued on all of the newly discovered ore-bodies with 44,000 m of drilling completed. Oxiana acquired an 80 percent stake in the project in early 2000 with the Rio Tinto retaining a 20 percent holding. Upon finalization of the asset sale, Oxiana immediately commenced feasibility and environmental/social impact studies for a two stage development of the Sepon gold and copper projects (Manini and Albert, 2003). Following a 12 month construction period, the Sepon gold mine poured first gold in late 2002 and has been operating successfully since.

2.2 Ongoing Exploration

Exploration re-commenced in 2003 and additional resources were delineated at both Luang and Vang Ngang. Coupled with near-mine resource extensions and before depletion the gold resource base rose from 3.5 to 4.2 Moz in the first year of renewed exploration activity (Manini and Albert, 2003).

With detailed resource drilling, grade-control drilling, and the commencement of mining in 2003, understanding of the geological framework and controls on mineralization in the SMD was significantly upgraded. Enhanced geological understanding of the economic gold deposits is being used to generate new prospects in the SMD and a prospectivity matrix for prioritization of existing prospects has been developed. Five key exploration criteria common to all known ore bodies were identified: 1. ENE and/or WNW structures; 2. Rheological/chemical contrasts; 3. Presence of rhyodacite porphyry dykes and sills; 4. Presence of mapped jasperoid; and 5. Strong multi-element Au-As-Sb geochemical signature in soils (Smith, 2003). These key criteria were applied to the entire district and 36 priority targets identified.
Fig. 2 Summary geological map of the Sepon mineral district (main Fig.) and inset showing the location of the Au and Cu deposits with respect to the sub-economic porphyry stockwork systems and Padan and Thengkham. On main Fig. A-A’ Location of Discovery Colluvial cross section (Fig. 5); B-B’ Location of Nalou cross section (Fig. 6).

Exploration programs in late 2003 and 2004 have been designed primarily to test these 36 identified target areas. Several of the prospects have yielded high-grade drilling intercepts, most notably Nakachan and Phavat (Fig. 2). Many of the identified targets possess little or no surficial geochemical signature; however blankets of transported alluvium up to 10 m in thickness appear to be masking bedrock geochemical signatures. As a consequence, a district-wide regolith/porphyry map was produced based on air photos and field traverses, identifying areas that may be covered by transported alluvium. An extensive RAB
(Rotary Air Blade) drilling program has been planned in an effort to more effectively sample bedrock.

While exploration at Sepon has always utilized a wide spectrum of techniques and technologies, programs have always maintained a strong geological focus with an emphasis on basic prospecting, geological mapping, and drilling (Manini and Albert, 2003).

3 Geological Setting

3.1 Regional Setting

The SMD is located within the informally defined Sepon basin. The Sepon basin is situated within the Truongson belt which forms part of the Indochina terrane of Southeast Asia (Metcalfe, 1996). The Indochina terrane formed part of northern Gondwanaland during the Precambrian and may have rifted off in the Late Devonian. Late Paleozoic and Mesozoic faunas indicate amalgamation with Southern China during the Late Paleozoic (Metcalfe, 1996).

The Truongson belt extends in a NW orientation from central Vietnam to northern Laos and consists of a metamorphic complex (the Kontum block), with successor basins (including the Sepon basin) of poorly constrained age possibly ranging from Silurian to Permian (Lepvrier, 1997). Overlying the Paleozoic basins is the Mesozoic Khorat basin of Thailand and Laos.

The Sepon basin has an anomalous E-W character within the overall NW trend of the Truongson belt and the tectonic fabric of this part of South East Asia (Fig. 2). This has been interpreted to indicate development of the Sepon basin as a pull-apart basin in response to sinistral strike slip transpression on the Truongson Belt (Coller, 1999; Smith 2003). In this interpretation, near east-west faults represent basin forming normal faults and northwest oriented structures represent original transfer structures (Coller, 1999; Smith 2003).

The timing of events in and around the Sepon basin is poorly constrained. Limited paleontological data suggest sedimentation took place from Devonian to Early Permian (Oxiana Ltd., unpublished data), consistent with a Late Devonian age for the onset of extension. The timing of igneous activity in the basin is similarly poorly constrained. The metamorphic grade is sub-greenschist and away from discrete structures or high strain zones no penetrative fabrics are developed.

3.2 Stratigraphy of the Sepon basin

The stratigraphy of the Sepon basin has been studied in detail only in the vicinity of the mine area where detailed drilling has allowed a robust stratigraphic interpretation. Away from the mine area the general relationships appear to hold true, but generally scarce outcrop and lack of detailed drilling have prevented comprehensive development of a basin-wide scheme.

The Sepon mine area stratigraphy comprises eight major informal units (Highway formations to Phabing) with one unit (Nalou formation) comprising 3 informal members (Morris, 1997) (Fig. 2 and 3). Sepon Highway formation is a thin (<100 m) unit consisting of basement derived conglomerate, minor calcirudite, calcarenite and green claystone. This unit passes up to the >300 m thick, heavily bioturbated, fine quartz-lithic sandstone which dominates Upper Highway formation. Minor interbedded mudstone, siltstone and calcarenite exist throughout this formation. Upper Highway Formation passes conformably up to VangNgang formation which is >300 m thick and...
Fig. 3 Schematic stratigraphic column for the Sepon mine area, with thickness of black bars relative to the approximate Au endowment. Abbreviations as for Fig. 2.
KengKeuk Formation is the stratigraphically lowest carbonate dominated unit of the Sepon basin and is known from drilling in the mine area. It is <100 m thick and consists of dark, bedded, carbonaceous limestone and calcareous shale. KengKeuk Formation is conformably overlain by the dolomite dominated Nalou formation, which has been subdivided into 3 informal members. Members 1 and 3 consist of medium gray, bioclastic dolomite (and minor limestone) that are generally <30 m thick. These units bracket the light gray, laminated (+/- stromatolitic) dolomite and limestone of formation 5, member 2. Nalou Formation has a total thickness exceeding 120 m. Nalou Formation, member 3 has a gradational contact with the overlying dark gray to black, bedded, calcareous shale and limestone of the Discovery formation. The contact is gradational over approximately 10-20 m and is marked by decreasing bioclastic component up-section. Discovery Formation has a thickness exceeding 200 m and is characterized by a well-developed, bedding-sub-parallel lamination developed by concentration of residual carbonaceous matter along swarms of non-sutured pressure solution features. Kengkeuk, Nalou and Discovery Formations form the main carbonate package of the Sepon basin.

Discovery Formation passes conformably upward to Namkian formation which marks the return to siliciclastic sedimentation. Namkian Formation consists of laminated black to dark gray chert, pale colored pyritic siltstone-shale and lesser black shale with a total thickness of >600 m. The formation Discovery-Namkian contact is gradational with the lower ~10 m of formation Namkian consisting of interbedded black chert and calcareous shale. Phabing Formation is a poorly defined, laminated, calcareous and non-calcareous black shale with interbedded turbiditic calc-arenite unit that marks the top of the currently known stratigraphy.

3.3 Diagenesis

The Sepon basin carbonate sequence has a number of recognizable diagenetic stages that provide constraints on the timing of other events within the basin. The earliest recognizable diagenetic features are early diagenetic pyrite and two minor calcite vein stages that all pre-date the majority of bedding parallel pressure solution. Swarms of non-sutured, bedding-parallel, pressure solution features developed in the carbonaceous calcareous units, concentrating carbonaceous material and other non-calcareous components. Lesser bedding-parallel stylolites formed within the organic-poor carbonates of the Nalou formation.

A major, basin-wide dolomitization event occurred, primarily affecting the relatively organic-poor limestone of the Nalou formation. However it is also observed to affect the Discovery formation black calcareous shale, both at the lower contact with the Nalou formation and less commonly higher up in the Discovery formation. Dolomitization ranges from relatively fine-grained texture preservative to coarse-grained (+/-sparry) and texture destructive.

Cross-cutting bodies of vuggy, sparry dolomite are also present, which have been interpreted as reefs (Morris, 1997) although some may also represent cutting hydrothermal dolomite zones (Smith, 2003). Dolomitization post-dates much of the bedding-sub-parallel pressure solution of the carbonate sequence.
parallel pressure solution which, together with its relatively coarse grain size and occasional saddle form, is interpreted to indicate a late-diagenetic timing for most of the regional dolomitization (Smith, 2003). The dolomitization event fundamentally altered the rheology and chemistry of the Sepon basin, a factor that is interpreted to have been important in the subsequent development of the gold deposits (see discussion below).

### 3.4 Igneous Rocks

The Sepon basin sequence was intruded by a widespread quartz-rich dike set oriented along the dominant near east-west structural trends (Fig. 2). The dikes are locally referred to as rhyodacite porphyry (RDP) and generally have a relatively narrow range of phenocryst populations. Large (up to 1 cm) rounded and embayed quartz phenocrysts generally constitute 10-25 percent of the rock with the remainder comprising altered K-feldspar, plagioclase and <10 percent former mafic minerals. A strong, basin-wide phyllosilicate (sericite-illite), pyrite, +/- quartz alteration has affected all the dikes.

RDP intrusions do not have peperitic margins, and are universally later than late diagenetic dolomitization. The dikes have been affected by the same regional fault sets that dominate the structural fabric of the basin and most of the RDP-sediment contacts are marked by shears rather than intrusive contacts. Therefore it is interpreted that intrusion occurred after lithification and late diagenetic alteration of the sediments, but prior to conclusion of the major compressional event. The only other igneous rocks known in the Sepon basin are rare andesite dikes and conglomerate units within Formation 2 that contain andesite cobbles.

### 4 Gold Mineralization

The principal gold deposits in the Sepon district (Table 1) are hosted in carbonate rocks of the Discovery formation with lesser amounts in the Nalu and KengKeuk formations (Figs 2 and 3). The only economic deposit hosted within the siliciclastic dominated sequences is Vang Ngang, which is a minor component of the total gold endowment of the district (Table 1).

### 4.1 Mineralogy/Alteration

Ore within the Sepon sediment-hosted gold deposits is hosted predominantly by jasperoid and decalcified shale, with minor ore also present in RDP intrusions. Jasperoid typically hosts the highest grade ore and consists of massive to weakly banded, intensely silicified carbonate rock with 1 to 10 percent disseminated and fracture controlled pyrite (Fig. 4). Jasperoid ranges from massive to highly fractured and brecciated. Brecciated jasperoid is typically monolithic however rare examples of poly lithic jasperoid breccia have been noted. Vein and breccia cement is dominated by white to gray quartz with lesser dolomite and calcite (Fig. 4). Jasperoid mimics parent rock textures with jasperoid developed after calc-shale typically dark colored and massive to weakly banded. In contrast, jasperoid developed after dolomite is typically mottled gray to black and banded (Fig. 4).

Decalcified shale is similar in hand specimen to the unaltered calc-shale with “sanded” textures very rarely developed. Contacts between decalcified shale and unaltered calc-shale are typically gradational and can be highly irregular.

Variable degrees of alteration have resulted in zones of patchy jasperoid and decalcified shale at the centimeter to meter scale. A characteristic feature of these mixed
zones is their higher strain compared with adjacent host rocks. The decalcified material typically displays a conspicuous cleavage and small scale folds and shears. Early veins within jasperoid are in some cases faulted and folded (Fig. 4).

Pyrite is the dominant sulfide in the mineralized zones. However sphalerite, lesser galena and minor stibnite exist in some deposits (e.g., Nalou, Discovery Main) (Fig. 4). The base metal sulfides are associated with pyrite and typically form veins and fracture fill. The zones with elevated base metals are typically auriferous, although a few thin zones (<5 m) with percent levels of zinc and lead are known to be barren of gold. The sphalerite associated with gold mineralization is typically dark red in color whereas the gold-poor base metal zones generally have pale colored sphalerite.

Mineralization within decalcified shale zones (i.e. without jasperoid) is best developed in the Discovery West deposit, but is also present in other deposits (Fig. 4). In several deposits minor ore exists in calc-shale that is not obviously altered, retaining its calcareous component.

4.2 Geometry and Structural Associations

The gold deposits possess a range of geometries and some deposits include several different shapes within the same ore body. The typical geometries are:

Table 1 Total gold resources (pre-mining and current) for the Sepon mineral district at 0.5 g/t Au cutoff.

<table>
<thead>
<tr>
<th>Product</th>
<th>Tonnage (Mt)</th>
<th>Au (g/t)</th>
<th>Ag (g/t)</th>
<th>Au (Moz)</th>
<th>Ag (Moz)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OXIDE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEASURED</td>
<td>3.58</td>
<td>1.7</td>
<td>8</td>
<td>0.20</td>
<td>0.88</td>
</tr>
<tr>
<td>INDICATED</td>
<td>10.00</td>
<td>1.0</td>
<td>6</td>
<td>0.33</td>
<td>2.08</td>
</tr>
<tr>
<td>INFERRED</td>
<td>4.88</td>
<td>0.9</td>
<td>4</td>
<td>0.14</td>
<td>0.56</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>18.47</td>
<td>1.1</td>
<td>6</td>
<td>0.67</td>
<td>3.51</td>
</tr>
<tr>
<td><strong>PARTIAL OXIDE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEASURED</td>
<td>2.72</td>
<td>2.7</td>
<td>13</td>
<td>0.24</td>
<td>1.13</td>
</tr>
<tr>
<td>INDICATED</td>
<td>3.92</td>
<td>1.4</td>
<td>9</td>
<td>0.18</td>
<td>1.15</td>
</tr>
<tr>
<td>INFERRED</td>
<td>1.87</td>
<td>1.0</td>
<td>5</td>
<td>0.06</td>
<td>0.27</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>8.52</td>
<td>1.8</td>
<td>9</td>
<td>0.50</td>
<td>2.56</td>
</tr>
<tr>
<td><strong>PRIMARY</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEASURED</td>
<td>2.24</td>
<td>3.2</td>
<td>10</td>
<td>0.23</td>
<td>0.72</td>
</tr>
<tr>
<td>INDICATED</td>
<td>26.48</td>
<td>2.7</td>
<td>10</td>
<td>2.26</td>
<td>8.20</td>
</tr>
<tr>
<td>INFERRED</td>
<td>9.08</td>
<td>1.9</td>
<td>7</td>
<td>0.57</td>
<td>1.99</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>37.75</td>
<td>2.5</td>
<td>9</td>
<td>3.03</td>
<td>10.90</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>64.74</td>
<td>2.0</td>
<td>8</td>
<td>4.19</td>
<td>16.97</td>
</tr>
</tbody>
</table>

Sepon gold resources as at 30th June 2012.
• Shallow to moderate dipping sheets that may or may not be connected to steep faults – e.g. Discovery Colluvial, Discovery West, Discovery Main, Nalou (Fig. 5, Fig. 6, Fig. 7)

• Steep, fault-controlled, sheet-like bodies continuous in both strike and down dip directions – e.g. Discovery Colluvial (Fig. 5, Fig. 7)

• Strike continuous, dip-limited, “ribbon-like” bodies – e.g. Discovery Main, Nalou, Namkok East and West (Fig. 7)

All of these geometries relate in some way to the interaction between steep structures and a secondary shallow dipping control. None of the deposits have “pipe-like” steeply-plunging geometry, indicating that the intersections of steep faults are not a controlling factor in the formation of the Sepon ore bodies at the deposit-scale.

Several key fault associations are apparent in the Sepon gold systems. The Discovery West deposit is dominantly hosted within a WNW-striking, steep NNE-dipping normal fault whereas the Nalou-Namkok deposits appear to be associated with a WNW-striking, steep south-dipping strike-slip fault. The Discovery Main-Discovery Colluvial trend exists along a steep, ENE-striking fault that appears to have normal movement in the Discovery Main area and reverse movement in the Discovery Colluvial area (Fig. 5).

Fig. 4 Photos of Sepon Au mineralisation. A) Dark gray massive jasperoid developed after calcareous shale without significant textural modification. B) Dark gray quartz veined and brecciated jasperoid. C) Two examples of jasperoid illustrating the differences between jasperoid developed after dolomite (lower sample) and massive black jasperoid developed after calcareous shale. D) Mixed jasperoid (massive) and decalcified shale (thin domains with strong cleavage). Thin quartz-antine-sphalerite veins exist and have small scale fault offset. E) Mineralised decalcified shale samples at Discovery West ramp showing the Discovery West Fault with weathered decalcified shale in the fault zone and the adjacent mineralised transition between the Discovery and Namkian formations.
At Discovery Colluvial the south dipping fault shows an offset of the formation 5-formation 6 contact (and a lower RDP) that indicates approximately 40 m of apparent reverse movement (Fig. 5). Jasperoid hosted mineralization is developed both within the fault zone and at the calc-shale – dolomite contact in the hanging wall of the fault. No significant mineralization exists at the same contact on the footwall side of the fault. Mineralization is interpreted to have occurred during or after the reverse movement of the fault because a direct continuity exists between the fault-hosted and dolomite contact-hosted ore (Fig. 5). If substantial post mineralization fault offset had occurred, these two ore zones would be displaced along the fault.

All of the deposit scale structural associations (faults and folds) are also important regional orientations with major basin-wide structural patterns interpreted from mapping, aeromagnetics, aerial photography and satellite data mimicking the patterns observed in the deposits (Lane Xang Minerals Ltd., unpublished data) (Fig. 2). This is interpreted to indicate that the Sepon basin has undergone any major deformation event after mineralization.
The overall trend of the deposits is typically the same as trends in internal grade and thickness. High grade zones in Discovery West, Discovery Colluvial, Namkok and Discovery Main typically follow the overall trend of these deposits. In the Nalou deposit, however, the overall WNW trend of the deposit forms only one of two internal trends. Within the deposit the higher grade zones define separate ENE and WNW trends that exist in the hinge zone of folds with sub-vertical axes trending ENE and WNW.

**Fig. 6** Cross section through the Nalou deposit. On this section the deposit is concentrated on the dolomite-calcareous shale contact with lesser mineralisation developed on RDP contacts.

**Fig. 7** Schematic illustration of the geometry and location of the structure, stratigraphy and geological contacts. Csh = calcareous shale; dcsh = decalcified shale; DW = Discovery West, DC = Discovery Colluvial, DM = Discovery Main, NE = Namkok East, NW = Namkok West.
4.3 Location of Mineralization With Respect to Geological Contacts

There is a strong association between mineralization and the dolomite – calc-shale, RDP – dolomite/calc-shale and calc-shale – chert contacts (Fig. 3). The most important of these is the dolomite - calc-shale contact that exists close to the Nalou formation - Discovery formation stratigraphic contact (Figs. 5 and 6). This is a major control at Nalou, Discovery Colluvial, Discovery Main, Namkok West and Namkok East. Dolomitization within the upper part of the Discovery formation is evident at Discovery West and exists in the immediate footwall of the deposit. Mineralization associated with the dolomite – calc-shale contact is developed in both calc-shale and dolomite; however it is much more extensive in the calc-shale. Jasperoid and decalcified shale hosted ore zones typically extend for tens of meters above the contact into the calc-shale, but only several meters into the underlying dolomite. Gold grade is also controlled by host rock lithology with grades typically higher in the altered calc-shale than in the altered dolomite.

The RDP – dolomite and RDP – calc-shale contacts are lesser controls on orebody formation, but are important at Nalou, Discovery East and Discovery Main, with approximately 20 percent of the resource located along these contacts. The RDP contact controlled zones are characterized by strong shearing of the RDP and mineralized calc-shale. Although mineralization typically exists in both the calc-shale and the RDP, it is best developed in the calc-shale.

The third major geological contact to host ore is the calc-shale – chert (Discovery formation –Namkian formation contact. At Discovery West mineralization exists in the underlying calc-shale and in the stratigraphic transition zone between the Discovery and Namkian formations (Fig. 4).

5 Discussion

5.1 Timing of Gold Mineralization

- Several observations constrain the timing of gold mineralization in the Sepon deposits.
- Gold mineralization occurred after late diagenetic dolomitization
- Gold mineralization exists within altered RDP
- The structures that host gold deposits cross-cut the RDP dikes and locally host ore within the RDP
- In certain areas ENE and WNW faults are known to have undergone reverse and/or strike slip movement before or synchronous with development of jasperoid and gold mineralization
- Thickness and grade is in some cases controlled by ENE and WNW oriented fold hinges. Locally these folds have deformed the RDP dikes.
- The ore zones include small scale faults, folds and cleavage that developed after jasperoid and decalcification

Given these constraints, the Sepon gold deposits post date, or are broadly synchronous with, compressional movement on certain faults, fold development and RDP intrusion. The increased strain and development of small scale compressional structures within the ore zones indicate that compression continued after mineralization.

Our preferred timing is syntectonic development of the gold systems within faults and folds during basin inversion, which was
broadly synchronous with RDP intrusion. In this interpretation, gold mineralization developed within active folds and faults that were propagated or reactivated during basin shortening, and these structures continued to be active after initial alteration and mineralization, to develop the small scale structures in the ore zones. It is acknowledged that the timing of the small scale structures is not well constrained and could be unrelated to the folds and faults that control mineralization. If this is the case, the gold deposits could have formed at any time after development of the faults and folds. However this is considered less likely because it is interpreted that no major structural event has affected the basin post-mineralization (as discussed above).

5.2 District-wide Metallogenesis

In addition to the economic gold systems a number of other styles of mineralization exist in the Sepon district. Principal among these are the copper deposits at Khanong and Thengkham South (Fig. 2). Hypogene mineralization consists of massive sulfide-(hematite) and silica-sulfide-(hematite) replacement zones associated with skarn alteration of dolomite and locally siltstone. Prograde garnet-pyroxene skarn is overprinted by retrograde amphibole-chlorite-epidote-calcite-hematite-sulfide-magnetite skarn that grades into massive sulfide - (hematite) and silica-sulfide - (hematite) ore. The mineralization at both deposits is characterized by a Cu-Ag-Bi-(Au) association. At Phavat (Fig. 2), high sulfide ore is characterized by a strong Au-Cu-Ag-Bi association that is geochemically intermediate between the Cu-dominated and Au-dominated deposits.

The copper deposits are considered to be related to the nearby Padan and Thengkham porphyry stockwork systems. These porphyry stockwork systems consist of extensive quartz stockwork in host sediments and rhyodacite to quartz diorite porphyry. Extensive silicification and lesser potassic (Kfeldspar and biotite) alteration are known to be associated with the porphyry systems and may be equivalent to the prograde skarn developed in carbonate hosts. The porphyry systems are predominantly Mo systems with weakly elevated Cu and Bi. Sillitoe (1994) and Manini et al. (2001) have proposed that the Sepon district is zoned from the quartz stockwork porphyries at the core, outward through the Cu-rich skarn and replacement bodies, to the Au-Ag dominated sediment-hosted deposits.

5.3 Controls on Location of Gold Deposits

The gold deposits are controlled by both regional and local scale features, including the regional ENE and WNW to NW oriented steep faults. The intersections of the ENE and WNW structures with the more NW oriented segments may exert a regional-scale influence over the locations of deposits (Fig. 2).

The spatial association of the gold deposits with the magmatic-related Mo-Cu systems at Padan and Thengkham suggest the possibility of a genetic link and therefore location with respect to these systems should be important. However major gold deposits range from 100 m (Discovery Main) to 4 km away (Nalou) from known copper mineralization. Therefore proximity to porphyry stockwork or skarn occurrences is not a useful exploration criterion within the district.

Local controls are a combination of structural and chemical influences. The structural control consists of the interaction of steep faults and shallow dipping lithological units. The chemical control is related to the interaction of the ore fluids with carbonates, argillites, and silty claystones, and the resulting mineral assemblages.
contacts. Gold mineralization is hosted within the steep structures, predominantly in their hangingwalls along favorable contacts. The most important contact is the dolomite – calc-shale contact. This is interpreted to be a major control due to the rheological and chemical contrast it provides. It is interpreted that strain was concentrated along this contact during active deformation, thereby enhancing fluid flow. Gold deposition was favored in the calc-shale through pH and/or sulfidation reactions. Although pre-dating mineralization, the basin-wide, late-diagenetic dolomitization fundamentally changed the rheological and chemical composition of the basin, which influenced both fluid flow and gold deposition during the subsequent mineralizing events.

It is also inferred that fluid flow was controlled by the calc-shale – RDP contacts and the formation Discovery – formation Namkian contact at Discovery West. This contact may be an example of stratigraphically controlled fluid flow with the impermeable chert of formation Namkian channeling fluids into the reactive formation Discovery calc-shale.

6 Comparison to Carlin-type Gold Deposits

Carlin-type deposits in the Great Basin of the USA have yielded more than 70 Moz of gold in the past 40 years (Thompson, 2002), and this style of deposit has evolved into a major exploration target for mining companies worldwide due to the potential for large tonnage, high grades, and the amenability to open-pit mining. Numerous geologic models have been proposed to understand this style of mineralization and predict where the next Carlin-type deposit or district may be found. Although the Great Basin hosts the majority of Carlin-type deposits, deposits of significant size exist elsewhere, most notably in Iran (Zashuran), Indonesia (Mesel), and SE China (Lannigou, Jinfeng).

The gold deposits at Sepon were recognized to have characteristics of the sediment-hosted Carlin type very early in the exploration program (Sillitoe, 1994). Continued exploration at Sepon over the past 10 years and the advent of mining have provided further support for the Carlin-type deposit label, with the district being considered an example of distal magmatic related gold mineralization (Sillitoe, 2004). Although the deposits of Sepon and Carlin share many distinct characteristics, significant differences exist between the two mineral districts. A comparison of the principal characteristics is outlined below and summarized in Table 2.

6.1 Host Rocks

Gold deposits in both areas are spatially associated with a transitional zone between shallow-water platform sediments and deeper marine sediments. The key host rock lithologies in both cases are calcareous, carbonaceous, pyritic siltstones and shales, (Berger and Bagby, 1993; Smith, 2003). Dolomitic lithologies rarely host significant amounts of mineralization at Sepon, while at Carlin, ferroan carbonates are optimal hosts for generally narrow but very high-grade ore zones due to the availability of iron for the sulfidation of pyrite and precipitation of gold (Hofstra and Cline, 2000).

Some workers believe that a low permeability cap rock is a key element in the localization of ore deposits in the Great Basin because most deposits formed at or near contacts between lower plate carbonate units and overthrust siliciclastic units (i.e. Roberts Mountain allochthon). A low permeability cap may have forced fluids laterally away from conduits and into favorable, reactive, permeable
Table 2 Comparison and contrast of the major features of the Carlin-type deposits and the sediment-hosted Au deposits in the Sepon district.

<table>
<thead>
<tr>
<th></th>
<th>SEPON</th>
<th>GREAT BASIN CARLIN-TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tectonic Setting</strong></td>
<td>• Carbonate/siliciclastic basin</td>
<td>• Back-arc rifting and magmatism</td>
</tr>
<tr>
<td></td>
<td>• Major compressional event</td>
<td>• Deep crustal structural control</td>
</tr>
<tr>
<td></td>
<td>inverted basin-forming structures that control mineralization</td>
<td></td>
</tr>
<tr>
<td><strong>Key Host Rock Lithology</strong></td>
<td>• Calcareous, carbonaceous, nodular shale, rarely dolomitic</td>
<td>• Calcareous, carbonaceous, pyritic, finely laminated, siltstone/dolomitic limestone</td>
</tr>
<tr>
<td><strong>Age of Host Rocks</strong></td>
<td>• Mid-Paleozoic (Dev-Carb)</td>
<td>• Mid-Paleozoic (Dev)</td>
</tr>
<tr>
<td><strong>Intrusive Relationships</strong></td>
<td>• Intrusive rhyodacite porphyry, syn-tectonic, likely syn-mineral</td>
<td>• Some deposits within 2km of Mesozoic stocks and within 1km of the stock’s metamorphic aureole.</td>
</tr>
<tr>
<td></td>
<td>• Age date ~290±5 Ma (early Permian)</td>
<td>• Some deposits have syn-mineral Eocene dikes.</td>
</tr>
<tr>
<td></td>
<td>• Intimate spatial relationship of dykes with ore</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Intrusives rarely significantly mineralized</td>
<td></td>
</tr>
<tr>
<td><strong>High Angle Control</strong></td>
<td>• WNW and ENE striking faults serve as main conduits</td>
<td>• NNW, NW, and NE striking extensional faults serve as main conduits</td>
</tr>
<tr>
<td><strong>Low Angle Control</strong></td>
<td>• Rheological/chemical contrasts</td>
<td>• Fold noses/flanks</td>
</tr>
<tr>
<td></td>
<td>• Fold noses</td>
<td>• Sills/flows</td>
</tr>
<tr>
<td></td>
<td>• Bedding (formational contacts)</td>
<td>• Thrust faults</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Low-angle extensional faults</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Bedding (formational contacts)</td>
</tr>
<tr>
<td><strong>Hydrothermal Alteration and Zonation</strong></td>
<td>• Decarbonation – dissolution of carbonate minerals</td>
<td>• Decarbonation – dissolution of calcite and dolomite</td>
</tr>
<tr>
<td></td>
<td>• Silicification – replacement of carbonate (jasperoid)</td>
<td>• Silicification – replacement of carbonate (jasperoid)</td>
</tr>
<tr>
<td></td>
<td>• Argilization – replacement of silicate minerals, mainly in igneous rocks</td>
<td>• Argilization – replacement of silicate minerals, ore associated with illite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Calcite veins – present as halos to decarbonatized zones</td>
</tr>
<tr>
<td><strong>Style of Mineralization</strong></td>
<td>• Micro-disseminated, sediment-hosted, replacement style</td>
<td>• Micro-disseminated, sediment-hosted, replacement style</td>
</tr>
<tr>
<td></td>
<td>• Associated with carbonate dissolution and usually jasperoid formation</td>
<td>• Associated with carbonate dissolution, with or without silicification</td>
</tr>
<tr>
<td><strong>Gold Occurrence</strong></td>
<td>• Generally less than 11 microns as inclusions or solid solution in pyrite, with some in carbonates and silicates</td>
<td>• Submicron inclusions or solid solution in arsenian pyrite, arsenian marcasite, and arsenopyrite</td>
</tr>
<tr>
<td></td>
<td>• Au precipitation during sulfidation and decarbonization reactions</td>
<td>• Au precipitated primarily during sulfidation reactions</td>
</tr>
<tr>
<td><strong>Age of Mineralization</strong></td>
<td>• Poorly constrained - Permian (?)</td>
<td>• Late Eocene (~42-30 Ma)</td>
</tr>
<tr>
<td><strong>Orebody Geometry</strong></td>
<td>• Tabular stratiform bodies</td>
<td>• Tabular bodies</td>
</tr>
<tr>
<td></td>
<td>• Steep fault controlled bodies</td>
<td>• Pipe-like and podiform bodies</td>
</tr>
<tr>
<td></td>
<td>• Rod-like bodies</td>
<td></td>
</tr>
<tr>
<td>Vertical Range of Mineralization</td>
<td>• Untested, but &gt;150m</td>
<td>• Generally 100 to 500m, but can be &gt;1000m.</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>----------------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>Cap-rock</td>
<td>• Stratigraphically overlain by siliciclastic sequence (interbedded chert and siltstone)</td>
<td>• Structurally overlain by allochthonous eugeoclinal siliciclastics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Stratigraphically overlain by miogeoclinal siliciclastics</td>
</tr>
<tr>
<td>Geochemistry</td>
<td>• Low Au/Ag ratios, (~ 1:4)</td>
<td>• Au/Ag ratios generally &gt;2</td>
</tr>
<tr>
<td></td>
<td>• Moderate base metal levels (Cu+Pb+Zn = ~2700ppm)</td>
<td>• Low base metal levels (Cu+Pb+Zn generally &lt;300ppm)</td>
</tr>
<tr>
<td></td>
<td>• As = ~300ppm, Sb = ~140ppm</td>
<td>• Generally As &gt;500ppm, Hg &gt;1ppm, Sb &gt;50ppm</td>
</tr>
<tr>
<td></td>
<td>• Au+As+Sb+Tl+Te+Se+Hg±(Ag, Pb, Zn) association</td>
<td>• Au+As+Hg+Sb±(Ba, Tl, Te, W, Ag) association</td>
</tr>
<tr>
<td></td>
<td>• District-scale geochemical zoning prominent</td>
<td>• Geochemical zoning patterns generally not observed</td>
</tr>
<tr>
<td>Organic Carbon</td>
<td>• Black carbonaceous ore common in most deposits</td>
<td>• Black carbonaceous ore common</td>
</tr>
<tr>
<td></td>
<td>• Often found in anticlinal traps</td>
<td>• Introduced as liquid petroleum, subsequently matured</td>
</tr>
<tr>
<td></td>
<td>• No strong correlation with Au grades</td>
<td>• Often found in anticlinal traps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• No correlation with Au grades</td>
</tr>
<tr>
<td>Fluid Chemistry</td>
<td>• Poorly constrained</td>
<td>• Generally &lt;6 percent NaCl</td>
</tr>
<tr>
<td></td>
<td>• Slightly acid to neutral pH</td>
<td>• Generally &lt;4 mole percent CO₂</td>
</tr>
<tr>
<td></td>
<td>• CO₂-rich, H₂S-rich</td>
<td>• Generally pH 5 – 6</td>
</tr>
<tr>
<td></td>
<td>• Low-moderate salinity</td>
<td>• Generally &lt;0.4 mole percent CH₄</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Generally &gt;0.01 mole percent H₂S</td>
</tr>
<tr>
<td>Au Transport Mechanism</td>
<td>• Likely bisulfide</td>
<td>• Bisulfide</td>
</tr>
<tr>
<td>Temperature of Formation</td>
<td>• Poorly constrained</td>
<td>• Generally 150° - 250° C</td>
</tr>
<tr>
<td></td>
<td>• Likely low-moderate, ~200-300°C</td>
<td></td>
</tr>
<tr>
<td>Depth of Formation</td>
<td>• Poorly constrained</td>
<td>• Generally 2-4 km (?)</td>
</tr>
<tr>
<td>Deposit Size</td>
<td>• Generally &lt;1Moz (oxide), but sulfide potential essentially untested</td>
<td>• All ranges and &gt; 5 Moz</td>
</tr>
<tr>
<td>Grade</td>
<td>• 1.9 to 4.3 g/t Au (@ 0.5 g/t Au cut-off)</td>
<td>• 0.6 to 29 g/t Au</td>
</tr>
</tbody>
</table>

host rocks (Muntean, 2003). At Sepon, the cap rock comprises a thick sequence of interbedded non-calcareous shale, siltstone, and chert (Namkian formation) stratigraphically overlying favorable carbonate host rock units (formation Discovery). Only the Discovery West orebody is known to have formed along this contact, with most of the ore deposits instead formed at the calc-shale – dolomite rheological and chemical contact.

6.2 Hydrothermal Alteration

Sepon and Carlin have similar patterns and styles of hydrothermal alteration. In both areas, the main ore stage is dominated by carbonate dissolution, silica replacement of carbonate units, argillation of silicates, and 

เอกสารแนบไปคือสรุปข้อมูลของงานพัฒนาการณีที่ส่งเสริมการผลิตและใช้ประโยชน์ใน 

รายงานผลการวิจัยและพัฒนาการณีที่ส่งเสริมการผลิตและใช้ประโยชน์ใน
sulfidation of iron bearing minerals (Hofstra and Cline, 2000). However, at Sepon there is a dominance of silicification and jasperoid formation. In this respect Sepon is more akin to the smaller Alligator Ridge district in east-central Nevada (Nutt and Hofstra, 2003). The mineralizing/altering fluids at Carlin were moderately acidic (pH = 5), reduced fluids containing <6 wt percent NaCl equivalent, <4 mole percent CO₂, and >0.01 mole percent H₂S (Hofstra and Cline, 2000). At Sepon, the physiochemical composition of the fluids has not been studied extensively, but alteration assemblages and elemental associations suggest that the fluids were low to moderate temperature (~200-300°C), CO₂-rich, slightly acidic, H₂S-rich and low-moderate salinity (Smith, 2003).

6.3 Gold Mineralization

The style and mode of occurrence of gold mineralization at Sepon and Carlin are broadly similar. Both areas are characterized by micro-disseminated, carbonate-hosted, replacement styles of gold mineralization associated with the dissolution and, in some cases, the silicification of carbonate strata. Although some Carlin deposits contain jasperoid that is ore grade, in most Great Basin districts gold content of jasperoid is highly variable and commonly well below ore grade (Hofstra and Cline, 2000). This differs significantly from Sepon where the majority of the ore is hosted in jasperoid and a broad correlation between silicification and gold grades can be demonstrated.

At Carlin, native gold generally exists as submicron inclusions or as solid solution in arsenian pyrite, arsenian marcasite, and arsenopyrite, and commonly was precipitated in arsenic rich rims that enveloped pre-existing pyrite (Hofstra and Cline, 2000). Gold at Sepon ranges up to 11 μm in size and exists as inclusions within ultrafine pyrite. There is no evidence of arsenic rimming or discrete arsenic sulfide phases as seen in the Carlin deposits (Hoffman et al., 1995).

6.4 Geochemistry

The geochemical signatures of Sepon and Carlin are similar in a gross sense, but there are differences in the relative concentrations of the elements and geochemical zoning patterns. Both Sepon and Carlin have a strong Au-As-Sb-Hg elemental association, with significant associated Tl, Te, and Ag (Muntean, 2003). Base metal levels are significantly higher at Sepon, averaging 2700 ppm (Cu+Pb+Zn) while at Carlin, base metal levels are generally less than 300 ppm. At Sepon, the high Pb and Zn values may be the result of remobilization of early MVT style mineralization (Coote, 2004) while at Carlin, several deposits contain elevated Zn, thought to be the result of remobilized syn-sedimentary exhalative mineralization or Mesozoic intrusion-related mineralization (Emsbo et al., 1997; Muntean, 2003). Carlin deposits typically possess high gold to silver ratios (> 2:1) while at Sepon the gold to silver ratios are low, overall about 1:4, but vary significantly between deposits. Antimony levels are generally of similar tenor in both areas, but significantly higher levels of arsenic are found in the Carlin ores.

6.5 Organic Carbon

Sooty black carbonaceous ores are locally present at both Sepon and Carlin. In most deposits, the organic carbon in the ores is either indigenous to the host rock or was introduced as liquid petroleum and subsequently matured prior to gold mineralization (Morris, 1997; Hofstra and Cline, 2000). Hydrothermal activity is believed to have heated, crashed
matured, and remobilized by the organic carbon (Morris, 1997; Hausen and Park, 1986). In both areas, thermal maturity of the organic carbon progressively increases with proximity to the deposits and is potential vector to mineralization (Morris, 1997; Hofstra and Cline, 2000). In many of the Carlin deposits little, if any, gold is contained in the carbonaceous material (Berger and Bagby, 1993) and there is no consistent relationship between gold grades and the amount of carbon in the host rocks, indicating that carbon did not play a major role in gold precipitation (Hofstra and Cline, 2000). At Sepon, there appears to be a broad association between carbon rich rocks and highest gold grades, though a definitive correlation between gold grades and organic carbon content has not been established. At both Sepon and Carlin, conventional structural and stratigraphic hydrocarbon traps are considered to be important exploration targets.

### 6.6 Deposit Sizes and Grades

Carlin-type deposits of the Great Basin encompass a wide range of gold endowments with most in the range of 0.15 to 2.3 Moz, and some exceeding 5 Moz (Hofstra and Cline, 2000). At Sepon, the individual deposits are generally smaller than those in the Great Basin (Table 1). Average grades of the Carlin deposits range from 0.6 to 29 g/t Au (Hofstra and Cline, 2000) while at Sepon the grade range is much narrower and generally lower, from 1.2 to 4.3 g/t Au. The vertical extent of gold mineralization in the Carlin deposits generally ranges from 100 to 500 m, rarely exceeding 1000 m (Hofstra and Cline, 2000). At Sepon the vertical extent is known to be at least 150 m, however very little drilling has surpassed this depth, as was the case at Carlin in the early 1980’s. At Sepon it is likely that deposit sizes, and vertical extents will increase over time with additional drilling and eventual consideration of sulfide ores.

### 6.7 Structural Control, Basin Evolution and Timing of Mineralization

Gold bearing trends in the Great Basin appear to be first order structures near the rifted craton margin, implying a deep crustal control to the major mineralizing conduits (Thompson, 2002). These NNW and WNW trending Late Proterozoic basement structures likely had a strong influence on subsequent patterns of sedimentation, deformation, magmatism, and hydrothermal activity (Hofstra and Cline, 2000). In the Sepon basin, ENE and WNW oriented basin forming structures were inverted during compressional tectonic events, and are thought to be the controlling feeder structures of the Sepon ore bodies (Smith, 2003). At Sepon tectonically driven fluid flow during the compressional event, along with porphyry driven hydrothermal activity (with unknown amount of magmatic fluid input) are thought to have contributed to the development of the gold deposits (Smith, 2003).

The localization of ore bodies at both Carlin and Sepon is strongly influenced by the interplay of high-angle faults and low angle strata. Deposits in both areas contain elements of both fault-hosted and lithologically-controlled mineralization and are commonly found in low-angle structural traps – anticlines, domes, flat-lying dikes, and low angle faults (Smith, 2003; Muntean, 2003). Organic geochemical studies at several Carlin-type deposits indicate increased amounts of carbonaceous material in and around the ore-bodies, suggesting that the deposits are occurring in pre-existing hydrocarbon traps (Hofstra and Cline, 2000). Morris (1997) made similar observations in the Sepon District, suggesting that the structural
traps hosting gold mineralization had previously been petroleum reservoirs.

The Sepon and Great Basin host rocks have had quite different evolutionary paths since formation in the Paleozoic. The Great Basin has been subject to five documented compressional tectonic events of varying kinematics that have produced complex fault and fold arrays (Heitt et al., 2003 and references therein). Superimposed on this are two Tertiary extensional deformations that re-activated earlier structures (Heitt et al., 2003). The area also has a complicated igneous history with two significant Jurassic intrusive events and the important Eocene felsic intrusions (Emsbo et al., 2003 and references therein). The metallogenic history of the Carlin-type host rocks in north-central Nevada is also highly complex with Devonian, Late Jurassic, Cretaceous, Eocene and Miocene hydrothermal and mineralization events documented (Emsbo et al., 2003; Leach, 2004).

In contrast, fault arrays and fold patterns in the Sepon basin indicate a comparatively simple structural evolution, and only one significant igneous event has affected the basin. The metallogenic history is also less complex than the Great Basin with only minor Zn-Pb occurrences of possible Mississippi Valley Type.

There is general agreement that the Carlin-type deposits in the Great Basin formed long after the marine basins, post-dating much of the complicated tectonothermal history mentioned above, and were associated with Eocene extension and magmatism (Cline, 2004 and references therein). In contrast the Sepon deposits are interpreted to have formed during the Permian, much closer to the Devonian to Carboniferous age of the host succession.

6.8 Relationship to Intrusions

The Sepon district is zoned around the two porphyry stockwork systems at Padan and Thengkham. The possible continuum from Mo-Cu mineralized porphyries to Cu-Ag-Bi-(Au) skarn and massive sulfide, to Au-Ag-Sb-(As) sediment-hosted mineralization suggests upward and outward flow away from the intrusions. Based on metal zoning and geochemical patterns in the Sepon district, it is likely that the larger intrusive centers were broadly syn-mineral, providing the heat source and possibly magmatic fluids and other components of the gold deposits. In this sense the Sepon district is one of the districts that can be included in the “distal-disseminated” or “Carlin-like” class of deposits, seen by some as distinct from the “Carlin-type” (Seedorf, 1991; Seedorf and Barton, 2004; Sillitoe, 2004).

Many Carlin-type deposits and districts do not have this type of zoning, whereas the distal-disseminated class was conceived specifically to include those sediment-hosted deposits zoned around porphyry intrusive centers, and associated with skarns and/or polymetallic veins (Cox and Singer, 1992). However enticing this model is for Sepon it is noteworthy that direct paragenetic, isotopic or geochronological evidence for a magmatic link in the sediment-hosted gold deposits is currently lacking.

7 Conclusions

The discovery of Sepon is an example of exploration success utilizing traditional prospecting techniques and a geological focus. Like the Carlin deposits of the Great Basin, Sepon was discovered relatively recently due to the ultra-fine, encapsulated nature of the gold particles in altered sediments, easily missed during historical prospecting (Manini, et al., 2001; Maciulaitis, 2002).
Although Sepon was originally recognized as having affinities with the Carlin-type deposits, and subsequently shown to share many key characteristics, it could be classified as a “distal-disseminated” district, if the distinguishing criterion is proximity to mineralized porphyry intrusions.

Only the Carlin-type deposits have been demonstrated to attain “giant” status – individually greater than 5 Moz (Muntean, 2003) with the distal disseminated deposits more typically in the <1-5Moz range. Exploration activities in the Sepon district are at a very immature stage compared to the 40 years of work that has been carried out on these deposits in the Great Basin. The main focus in the initial 10-year exploration history of the Sepon district has been on proving up sufficient oxide reserves to justify the commencement of mining. Deeper drilling to more thoroughly assess the sulfide potential has only recently started. With continued exploration and drilling, current ore-bodies may be expanded and additional ore-bodies may be discovered, further enhancing the status of Sepon as a world-class mineral district.

Acknowledgements

Many geologists have contributed to the understanding, exploration and exploitation of the Sepon gold deposits and the contribution of all those involved over the long history of the project has been critical to the current understanding. Particular recognition is given to the contribution of Doug Morris to the development of the Sepon stratigraphy and other aspects of the district. The support of senior Oxiana Ltd and Lane Xang Minerals Ltd management for ongoing exploration and permission to publish is gratefully acknowledged. Thoughtful review by GSN reviewer Steven Weiss greatly improved the manuscript.

References


