CHAPTER 4: DEPOSIT GEOLOGY

4.1 INTRODUCTION

The SMD is a mineral district in SE Asia that hosts a variety of deposit types, ranging from: (1) intrusion centres containing porphyry style Mo (-Cu) mineralisation; (2) flanked by Cu (-Au) skarns with associated supergene copper, and; (3) adjacent to distal type sedimentary-rock hosted gold (SHGD). The principal aim of this Chapter is to document the geology and characteristics that control the formation of the SMD gold and copper deposits to provide a geological framework to constrain the paragenesis of the hypogene mineral assemblages that will be presented in Chapter 5.0.

The geological relationships presented in this Chapter for the SMD SHGD are first compiled from publications, previous studies and unpublished company reports by Sillitoe (1994a, b, 1995, 1998), Smith (2003), Manini et al. (2001), Smith et al. (2005) and Olberg et al. (2006), incorporating with the author’s own field research observations recorded during surface pit mapping and drill-core logging from the Nalou, Discovery West, Discovery Colluvial, Discovery Main and Discovery East gold deposits during 2004 and 2005. During this period, drill core logging along keys sections at each deposit was the main method used by the author to guide geological observations also at the Khanong and Thengkham South Cu deposits, Phavat Au-Cu deposit, Nakachan Au Prospect and Padan Mo (-Cu) Prospect, together with information from a publications by Loader (1999) and Cannell and Smith (2008) and reports for the copper deposits by Cannell (2005, 2008). The SMD stratigraphy revised by Feldman (2005) and Morris (2006) is used in this Chapter to describe the host-rock types and relationships observed in the SMD deposits. The local structural geology of the SMD deposits is based on previous reports by Marten (1998), Coller (1999), Smith (2003), Smith et al. (2005) and fieldwork observations by the author.

Three sub-sections will be presented in this Chapter, each describing in turn the geological setting of the following SMD mineral deposit types that are shown in Fig. 4.1.1:

1. SMD SHGD, including: (a) deposits dominantly hosting disseminated gold, namely the Nalou, Discovery West, Discovery Colluvial, Discovery Main, Discovery East, Namkok and Vang Ngang gold deposits, and (b) areas containing both disseminated gold and elevated amounts of associated base metals, namely Phavat (Au-Cu) Prospect and Nakachan (Au-Zn-Pb) Prospect (Section 4.2);
2. SMD copper deposits: skarn associated Cu-Au hypogene mineralisation and supergene Cu mineralisation at the Khanong and Thengkham copper deposits (Section 4.3), and;
3. SMD Porphyry Mo (-Cu) mineralisation: at Padan Prospect (Section 4.4).
Fig. 4.1.1. District-scale geology map of the Sepon Mineral District (SMD) showing the location of the main gold and copper deposits (provided courtesy of OZ Minerals Limited).
4.2 SMD SEDIMENTARY ROCK-HOSTED GOLD DEPOSITS

4.2.1 Introduction

The currently known sedimentary rock-hosted gold deposits (SHGD) in the SMD are predominantly located within the present day Sepon mining area (Fig. 4.1). Most of the known SHGD in the SMD are hosted in carbonate dominant rocks belonging to the Discovery Formation, especially at the Nalou and Discovery deposits, with lesser amounts also occurring in the Nalou and Kengkeuk Formations (Fig. 4.1). A small resource of gold at the Vang Ngang deposit occurs in a siliciclastic sequence belonging to the Nampa Formation (Fig. 4.1). Gold ores in the SMD SHGD occur mostly in decarbonatised shale and jasperoid with minor amounts along silicified fractures in RDP and dolomitised carbonate rocks (Smith et al., 2005).

Previous unpublished company reports by Sillitoe (1994a, b, 1995, 1998) and publications by Manini et al. (2001), Manini and Albert (2003); Smith et al. (2005) and Olberg et al. (2006) refer to the SMD SHGD as containing several geological characteristics that share similarities with the Carlin-type gold deposits in Nevada, USA. This section presents descriptions of the geological setting of the SMD SHGD, commencing with the Nalou gold deposit, then in turn the Discovery West, the Discovery Colluvial, the Discovery Main and East, the Namkok East and West, the Vang Ngang, the Phavat and the Nakachan gold deposits respectively (Fig. 4.1). A summary discussion of the similarities and differences between the SMD SHGD is provided in Section 4.10 and a comparison with other Carlin-type gold deposit examples will be presented in the discussion section of Chapter 8.0.

4.2.2 Nalou gold deposit

4.2.2.1 Location and background

The Nalou gold deposit is located towards the eastern end of the Sepon mining area at 603760E and 1874791N (UTM48), approximately one kilometre to the south-west of the Discovery West gold deposit (Figs. 4.1 and 4.2.1). Manini et al. (2001) reported that Nalou was discovered from the follow-up of soil geochemistry data containing coincident Au-As-Sb anomalies. During 1996, a one kilometre long E-W trending gold anomaly zone was confirmed via 1:500 scale mapping by LXML geologists who found cobbles of silicified decarbonatised shale and jasperoid in and around the margins of old bomb craters along the former Ho Chi Minh trail. West of Nalou, sub-crops of decarbonatised and silicified shale was also mapped, with rock chips sample results indicating 0.5 – 5.0 g/t Au. Subsequently, four scout diamond holes drilled at Nalou confirmed gold prospectivity with hole NLU002 intersecting 13m @ 2.2 g/t Au in dolomitised and silicified black shale at the contact with an underlying bioclastic dolomite (Fig. 4.2.2; Manini et al., 2001). Since 1997, a resource of 1.64 M oz Au contained in 30.24 Mt of ore averaging 1.19 g/t Au has been delineated at Nalou (Smith et al., 2005).
4.2.2.2 Geology and structure

Nodular decarbonatised dark grey-black calcarceous shale belonging to the Discovery Formation conformably overlies Nalou Formation variably dolomitised bioclastic limestone at the Nalou gold deposit (Manini et al., 2001; Smith et al., 2005). The Discovery Formation calcarceous shale at Nalou generally has beds dipping at 30° towards the SW (Fig. 4.2.2). Locally discordant and grossly sill-like bodies of rhyodacite porphyry intrude the sedimentary sequence at Nalou and are interpreted to have been emplaced along sub-vertical WNW-trending faults and bedding planes, in particular the geological contacts between the dolomite and calcarceous shale (Figs. 4.2.1 to 4.2.4; Smith et al., 2005).

The Nalou gold deposit occurs along the southern side of the WNW-trending Thengkham-Nalou-Namkok-Nampa Fault (TNNN) that is interpreted to be a strike-slip fault, dipping steeply to the SW towards the eastern end of this deposit (Fig. 4.2.3; Norris, 1999; Smith, 2003; Smith et al., 2005). Structural measurements by the author in the eastern section of the Nalou open pit confirmed that the TNNN Fault dips 65°–70° to the SW (i.e. towards 210°) and strikes WNW-ESE (Fig. 4.2.3). Non-mineralised fractures and joints occurring in RDP at the Nalou open pit also appear to record similar strike orientations to the TNNN Fault (Fig. 4.2.3; Appendix 4.1). In the central section of the Nalou deposit, the TNNN Fault is inferred to bend towards the west, especially where the intersection of steep NNW-trending strike-slip faults cross-cut the TNNN Fault (Smith, 2003). A small later-stage N-S striking reverse fault dipping 62–64° to the west (i.e. 275°) was observed cross-cutting a small WNW-trending anticline in the Nalou open pit (Figs. 4.2.3 and 4.2.4).

4.2.2.3 Surface mineralisation

Gold mineralisation at Nalou is mostly hosted by decarbonatised calcarceous shale and jasperoid, especially at rheological and contrasting chemical contacts between: (1) the Discovery Formation calcarceous shale and underlying Nalou Formation dolomite; (2) Discovery Formation calcarceous shale and RDP, and; (3) at the lower contact between RDP and Nalou Formation dolomite (Figs. 4.2.1 to 4.2.5; Smith, 2003; Smith et al., 2005). No visible gold was observed at Nalou, but gold is closely associated with ore types containing abundant finely disseminated pyrite (i.e. <0.5 mm diameter grains in ore samples, Figs. 4.2.4 and 4.2.5).

Structurally prepared sites, such as anticline and syncline hinge zones and also the limbs of associated folds typically contain high gold grades at this deposit (Figs. 4.2.2 to 4.2.5; Smith, 2003). Bedding measurements collected from gold mineralised Discovery Formation decarbonatised calcarceous shale along the limbs of small anticlines in the Nalou open-pit indicate WNW-trending anticlinal hinge zones (Fig. 4.2.3). Jasperoid-hosted gold also occurs towards and in the hinge zones of small folds at Nalou (Figs. 4.2.3 and 4.2.4). Smith et al. (2005) described the gold-bearing jasperoid ore zones at Nalou as exhibiting both sheet and ribbon-like geometries that may not be directly connected to steep faults (Fig. 4.2.2).
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Fig. 4.2.1. Geological map of the Nalou gold deposit, SMD. The locations of drill holes logged and sampled by the author during this project are represented by the black circles along section lines (black). Abbreviations: DIS FM = Discovery Formation: calcareous shale (CSH), NLU FM = Nalou Formation: bioclastic dolomite (DOL), KGK FM = Kengkeuk Formation: nodular calcareous argillite, RDP = rhyodacite-porphyry, TNNN Fault = Thengkham-Nalou-Namkok-Nampa Fault. Thick black lines represent faults and the red dashed line is the currently known economic gold ore zone (0.5 g/t cut off).

Fig. 4.2.2. Geological cross-section of the Nalou gold deposit along line 603550E (UTM48), the location of which is represented as a dark blue line in Fig. 4.2.1. Gold mineralisation occurs at the contacts between: (a) Discovery Formation calcareous shale in the hangingwall and Nalou Formation dolomite in the footwall, (b) Discovery Formation calcareous shale and RDP sills, and (c) Nalou Formation dolomite and RDP sills (modified after Smith et al., 2005).
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Fig. 4.2.3. Geological map of the eastern section of the open-pit at the Nalou gold deposit and plots of structural data collected by the author during 2004-2005. The map above shows the locations of structural measurements represented in plots A to D. Numbers 1 to 8 show the distribution of structural measurements, namely: 1 = Rose diagram for location A; 2 = Equal area net for location B; 3 = Rose diagram for location B; 4 = Equal area net for location B; 5 = Rose diagram for C; 6 = Equal area net for location C; 7 = Rose diagram for location D; 8 = Equal area net for location D; Abbreviations: calcareous shale (CSH); laterite (LAT); carbon-rich clay (CARB); jasperoid (JAS), rhyodacite-porphyry (RDP), and the Thengkham-Nalou-Namkok-Nampa Fault (TNNN). The inset map shows the location of the Nalou gold deposit in relation to the other Sepon gold deposits.
The overall WNW-trend of the Nalou gold deposit is reported by Smith (2003) to contain at least three ore zone orientations: (1) ENE-trending gold-bearing folds in the eastern sector of the deposit; (2) a WNW-trending gold-ore zone along the southern side of the TNNN Fault (Fig. 4.2.3), and; (3) WNW-trending gold-ore bearing folds towards the west section of the deposit (Figs. 4.2.3 and 4.2.4A-B). Examples of the Discovery Formation calcareous shale hosting high grade gold along a WNW-trending gold-ore at Nalou are shown in Figs. 4.2.4C-D.

Fig. 4.2.4. Photographs showing lithological and structural features of the Nalou gold deposit. (A) View towards the western end of the Nalou deposit open pit. Note the weathered rhyodacite porphyry (RDP) sill (tan) overlying carbonaceous Discovery Formation decarbonatised shale (CSH) containing disseminated pyrite ore with gold. (B) Westerly view of a small N-S striking reverse fault at Nalou. Note the displacement of the silicified calcareous shale, locally termed jasperoid (JAS). (C) View of contact between RDP and CSH shown in (A). (D) Dark grey dolomitised calcareous shale (Discovery Formation) with finely disseminated pyrite and later stage white calcite veins (CAL).
Drill core from the Nalou gold deposit indicates that the highest gold grades are best developed in zones exhibiting high deformation, such as fault zones and breccia zones that often occurred along rheological contacts (Fig. 4.2.5). Rubble breccia zones containing a framework of rounded and reworked clasts with a matrix fill of quartz and disseminated pyrite generally had high gold grades where as non-fractured or poorly fractured rocks generally contained very little gold mineralisation suggesting that structural deformation developed porosity to enable gold mineralising fluids to enter the host rocks at Nalou (Fig. 4.2.5).

![Diagram showing stratigraphic position of gold mineralisation in relation to structurally prepared rheological zones at the Nalou gold deposit.](image)

Fig. 4.2.5 Photographs and drill hole logging section along DDH NLU072 showing the stratigraphic position of gold mineralisation in relation to structurally prepared rheological zones at the Nalou gold deposit. (A) 4–50m: Non-decarbonised calcareous shale (CSH; 0–30m: < 0.05 g/t Au). Pink carbonate veins from 30 – 50m (< 0.3 g/t Au). (B) 50–68m: Decarbonised calcareous shale (CSH) with patchy dolomitisation, fracturing and minor gold. 68–70m: Fault zone with silicified (JAS) decarbonatised CSH (4-6 g/t Au). Dolomitised CSH cut by py-sp-gn veins @ 70.4 m, n-turn cut by Qtz-py+Au. (C) 80–96m: Section with mosaic to rubble breccia developed in dolomitised limestone (DOL) and cemented by quartz (JAS) and disseminated pyrite (main gold zone in this hole: >1–4.7 g/t Au). These observations are from the drill core logging of DDH NLU072 by the author during 2005. Structural abbreviations: FR = fractures, FZ = fault zone, MBX = mosaic breccia, RBX = rubble breccia, VN = vein.
Alteration towards gold mineralised zones at Nalou generally comprised (a) white to pink calcite veins in an interval of up to 50m thickness into the hangingwall sequence (Leach, 2005), (b) increasing dolomitisation towards the contact between the Discovery Formation calcareous shale and basal Nalou Formation bioclastic dolomite, and (c) increasing quartz (jasperoid) and disseminated pyrite in deformation zones containing fractures and breccia (Fig. 4.2.5). Black carbon-rich zones (>1m width) trending WNW were also observed in the Nalou open pit and generally occur along the silicified contacts between RDP and silicified Discovery Formation calcareous shale hosting gold mineralisation (Figs. 4.2.3 and 4.2.4).

Minor carbonate-hosted style Pb-Zn-Ag+Cu vein and fracture fill type mineralisation containing inter-grown dark brown resinous sphalerite, galena and coarse-grained pyrite hosted by brecciated dark grey Nalou Formation dolomitised bioclastic limestone was also observed in the footwall zone of the Nalou open pit (Figs. 4.2.6A-C). Veins containing sphalerite, galena and coarse pyrite cross-cutting footwall Nalou Formation dolomite are also present in drill core from Nalou hole NLU072 (Fig. 4.2.6B). Smith et al. (2005) reported that some zones containing elevated base metals at Nalou are auriferous, in particular when dark red-brown sphalerite is present. Late stage minor acicular and dendritic stibnite occurs mostly in carbonate veins that cut silicified and gold-mineralised decarbonatised calcareous shale and jasperoid at Nalou, especially along the limbs of a small WNW-trending anticlines (Fig. 4.2.6C).

![Fig. 4.2.6. Photographs showing examples of rock types containing mineralisation at the Nalou gold deposit.](image)

(A). Dolomitised and brecciated Discovery Formation calcareous shale (CSH) with a matrix fill of sphalerite (sp), minor galena (gn), euhedral pyrite cut by thin veins with quartz and traces of disseminated pyrite (i.e. contains 11 g/t Au, 415 g/t Ag, 2.2 % Pb and 22 % Zn). (B). Nalou Formation dolomitised bioclastic limestone (BDM) with a vein of sphalerite, galena and pyrite in a core sample from hole DDH NLU072 @ 70.4m depth containing: 2.7 % Zn, 5.7 % Pb, 1.2 % Cu, 500 g/t Ag and 2.2 g/t Au. (C). Silicified decarbonatised CSH and jasperoid (JAS) with acicular silver stibnite crystals in sample 603853 containing 0.3 % Sb and 3.2 g/t Au.
4.2.3 Discovery West gold deposit

4.2.3.1 Location and background

The Discovery West gold deposit (DSW) is located at 604455E and 1875685 (UTM48), approximately one kilometre northwest of the Nalou gold deposit (Figs. 4.1 and 4.3.1). Reconnaissance geological mapping and rock-chip sampling of a 300m x 300m area with a coincident Au-As-Sb soil anomaly during 1995 identified a narrow 600m long zone with gold mineralised jasperoid and decarbonatised shale occurring along a NW-trending contact with RDP (Fig. 4.3.1). Subsequently, a reconnaissance hole drilled through northerly dipping Nan Kian Formation siltstone with interbedded chert identified gold mineralisation hosted by the underlying Discovery Formation comprised of dark-grey decarbonatised shale with an intersection containing 8m @ 3.11 g/t Au from 17m, and 5.2m @ 3.8 g/t Au from 32m downhole depth. During 1996, a preliminary gold resource of 400,000 oz Au was confirmed at DSW from the drilling of 14 holes (Manini et al., 2001). On-going resource development drilling found 13.4 Mt ore averaging 2.2 g/t Au for a total of 947,800 oz Au (Smith et al., 2005).

4.2.3.2 Geology and structure

The basal stratigraphy at the DSW deposit consists of Nalou Formation bioclastic algal dolomite (Member 2) that grades upwards to bioclastic dolarenite (Member 3) and is conformably overlain by Discovery Formation carbonaceous, calcareous mudstone that grades upwards to the shallow NW-dipping Nam Kian Formation sequence of non-calcareous mudstone with interbeds of laminated chert (Morris, 1997, 2006; Figs. 4.3.1 to 4.3.4). The RDP sills range in thickness from >17m to over 70m and form the footwall to most of the gold mineralisation at this deposit. In the central part of the DSW deposit, RDP intrudes between Nalou Formation dolomite and Discovery Formation calcareous shale as a shallow NE-dipping sill (Manini et al., 2001; Figs. 4.3.1 and 4.3.2). The basal section of the Discovery Formation calcareous shale at DSW is also strongly dolomitised, vughy and grades upwards with weakly dolomitised intervals in the upper sections of this formation (Fig. 4.3.4; Smith et al., 2005).

The DSW deposit occurs along the eastern side of a WNW-striking normal fault known as the Discovery West Fault Zone (DWFZ) that steeply dips 70° to the NNE (Figs. 4.3.3 and 4.3.4). The bedding of the calcareous shale indicates NW-trending fold axes at DSW with beds dipping 34° towards 350 or 20° towards 280 (Fig. 4.3.3). Gold mineralisation at DSW mostly occurs as a sheet-like body in the hanging wall sequence along the DWFZ and also within the limbs and crest of a broad NW-trending anticline (Fig. 4.3.2; Smith et al., 2005). Structurally prepared sites, such as the DWFZ contact and the limbs of associated folds in the hangingwall sequence host the highest grades of gold currently known at this deposit (Figs. 4.3.2 and 4.3.4). Steep sub-parallel shears that induced fractures cutting RDP along the DWFZ also contain minor veins with sphalerite, galena, pyrite, quartz and traces of gold (Fig. 4.3.5).
Fig. 4.3.1. Geological map of the Discovery West gold deposit (DSW). The locations of drill holes logged and sampled during this project are represented by the black circles along section lines (blue). Abbreviations: chert (CHE), calcareous shale (CSH), dolomite (DOL), reef dolomite (RDM), limestone (LST), siltstone (SLT), jasperoid (JAS), rhyodacite-porphyry (RDP). Thick black lines represent faults.

Fig. 4.3.2. Geological cross-section of the DSW gold deposit looking east along line 604350mE. Gold mineralisation at this deposit mostly occurs in jasperoid (JAS) and decarbonatised Discovery Formation calcareous shale, in the hangingwall sequence above a RDP sill (section courtesy of LXML).
Fig. 4.3.3. Discovery west gold deposit geological mapping of the open-pit and plots of structural data collected during 2004 - 2005. This map shows the locations of structural measurements represented in structural plots A to C. Numbers 1 to 6 show the distribution of structural measurements, namely: 1 = Rose diagram for location A; 2 = Equal area net for location B; 3 = Rose diagram for location B; 4 = Equal area net for location B; 5 = Rose diagram for C; 6 = Equal area net for location C. Abbreviations: Chert (CHE); calcareous shale (CSH); dolomitised shale (DSH); decarbonatised calcareous shale (DCS); oxidised decarbonatised shale (OX DSC); jasperoid (JAS); rhyodacite-porphyry (RDP). The inset map shows the location of the Discovery West gold deposit (red area) in relation to the other Sepon gold deposits.
Fig. 4.3.4. Photographs showing lithological features of Discovery West gold deposit (DSW) rock type examples. (A). Westerly view of the open pit at this deposit showing the Discovery West fault zone (DWFZ) occurring along the contact between rhyodacite porphyry (RDP) and gold bearing decarbonatised calcareous shale (CSH) belonging to the Discovery Formation. Note that the hanging wall sequence consists of a transition zone of interbedded CSH (Discovery Formation) and thinly bedded chert (Nam Kian Formation) also containing minor amounts of gold hosted by the CSH interbeds. (B). Easterly view of the Discovery West gold deposit showing the thickness of oxidised decarbonatised CSH containing oxide gold (tan coloured area). (C). Close up view of the transition zone shown in (A) that contains of interbedded CSH (Discovery Formation) and thinly bedded chert (Nam Kian Formation). (D). Decarbonatised CSH with preservation of the original bedding (averaging >2 g/t Au). (E). Open pit outcrop example of a dolomitised basal section of the Discovery Formation at DSW showing the transition from weakly dolomitised CSH with primary bedding preservation (F), moderately dolomitised CSH with mosaic breccia (G), and a pervasive vugy solution collapse type dolomitisation (H) The blue arrow in (E) shows the direction of an inferred dolomitisation front from a strongly dolomitised basal vugy zone (G and H) to weak dolomitisation in the upper basal sections (F).
4.2.3.3 **Surface mineralisation**

Gold mineralisation occurring in the DSW open pit is: (a) not visible to the naked eye, (b) closely associated with anomalous As and Sb in the deposit soil profile, (c) associated with ore types containing fine-grained disseminated pyrite, and (d) occurring mostly in silicified decarbonatised calcareous shale and jasperoid ores, especially along the permeable contacts between: (i) Discovery Formation calcareous shale and RDP, and, (ii) Discovery Formation calcareous shale and Nalou Formation dolomite, but with only low gold grades generally occurring for a few meters into the underlying Nalou Formation dolomite (Figs. 4.3.2 to 4.3.5).

The best developed gold mineralised zones at DSW mostly occur in and along the hangingwall sequence to the NW-trending DWFZ for more than one km strike length (Fig. 4.3.1). Drill core from the DSW gold deposit indicates that the higher gold grades predominantly occur in zones exhibiting high structural deformation, in particular fault zones, breccia zones and adjacent fractured intervals (Fig. 4.3.5). The hangingwall sequence towards the rheological contact between the Discovery Formation calcareous shale and footwall RDP generally contain high gold grades in mosaic breccia and fractured intervals, with only minor gold occurring into the brecciated and fractured sections of the footwall RDP (Fig. 4.3.5). Deeper intervals of RDP only contained traces of gold mineralisation in fractured sections, but also hosted minor epigenetic base metal veins (<2 cm wide) containing sphalerite-galena-pyrite cut by later thin (< 0.5 cm wide) quartz veins with disseminated pyrite veins (Fig. 4.3.5).

Alteration surrounding the gold zones at DSW comprised: (a) minor patchy dolomitisation for up to 10m along rheological contacts between RDP and calcareous shale, (b) decalcification of calcareous shale for tens of meters into the Discovery Formation hangingwall sequence, close to the footwall RDP, (c) sericite overprinting the footwall RDP, and (d) disseminated pyrite and silicifaction (jasperoid) in the fractured sections of the hangingwall Discovery Formation calcareous shale (Fig. 4.3.5). Decalcification of calcareous shale belonging to the Discovery Formation is a pervasive alteration feature that can be observed in the open pit at this deposit (Fig. 4.3.4). Smith (2003) and Smith et al. (2005) reported that the contacts between unaltered calcareous shale and decarbonatised shale can be both gradational and irregular, resulting in the development of patchy zones of jasperoid and decarbonatised shales at DSW. Smith et al. (2005) also reported that gold-ore zones associated with jasperoid and decarbonatised shale at DSW generally contained high gold grades and also occur more extensively for tens of meters into the Discovery Formation calcareous shale hangingwall sequence from the underlying Nalou Formation dolomite contact. Gold is also reported in the minor decarbonatised shales interbeds that occur within a sedimentary transition zone between the Discovery Formation decarbonatised shale and the Nam Kian Formation sequence of non-calcareous mudstone with interbeds of laminated chert (Smith et al., 2005; Fig. 4.3.4).
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Fig. 4.3.5. Photographs and drill hole logging section along DDH DIS056 showing the stratigraphic position of gold mineralisation in relation to structurally prepared rheological zones at the Discovery West deposit (DSW).

(A) 4 – 33m: Nam Kian Formation chert (CHE), 33 – 42m: Clay transition zone between CHE (Nam Kian FM) and Discovery Formation calcareous shale (CSH), 42 – 43m: calcareous shale silicified (JAS),

(B) 59 – 126.4m: Sericite altered rhyodacite-porphyry (RDP), 68 – 70m: Rubble breccia in RDP with quartz-pyrite (disseminated +Au),

(C) At 120.3m: Py-gn-sp vein cutting RDP (syn-post RDP emplacement) and in-turn sheared with quartz-disseminated pyrite in fractures. (Drill core logging observations by the author during 2005). Abbreviations: FR = fracture, FZ = fault zone, MBX = mosaic breccia.


4.2.4 Discovery Colluvial gold deposit

4.2.4.1 Location and background

The Discovery Colluvial gold deposit (DSC) is located approximately 500m east of the DSW gold deposit at 606005 E and 1875930 N (UTM 48). This deposit mostly occurs along a high-angle NE–trending fault zone for more than one kilometre strike length (Figs. 4.1.1, 4.4.1). Initial reconnaissance rock chip sampling by CRA geologists during 1990 identified gold in eighteen jasperoid samples in a 200m x 20m area along the Namkok River, averaging >3.56 g/t Au and up to 55.91 g/t Au (Manini et al., 2001). Follow-up surface mapping and rock chip channel sampling along the Namkok River during 1993 identified boulders of silicified and brecciated sediments occurring over a strike length of more than 700m along the contact between RDP and calcareous shales at DSC (Manini et al., 2001; Manini and Albert, 2003; Fig. 4.4.1).

Preliminary diamond drilling at DSC during 1993 intersected in-situ gold mineralised and silicified calcareous shale overlying dolomite and altered RDP in holes DIS005, DIS008, and DIS009 at this deposit (Manini et al., 2001; Figs. 4.4.1 and 4.4.2). Sillitoe (1994) observed that the jasperoid hosted gold mineralisation at DSC exhibited some geological similarities with the Carlin-type sedimentary rock-hosted gold deposits in Nevada, USA. Subsequently, LXML geologists constructed a conceptual geological model to target SHGD mineralisation at DSC that incorporated shallow northerly dipping stratigraphy cross-cut by steeply dipping feeder structures, with jasperoid boulders being the surface expression of sub-vertical feeder structures (Manini et al., 2001; Fig. 4.4.2). Development drilling to date has established a resource of 2.94 Mt of ore averaging 2.87 g/t Au containing 271,000 oz Au (Smith et al., 2005).

4.2.4.2 Geology and structure

The hangingwall sequence at Discovery Colluvial consists of a basal shallow northerly dipping RDP sill (>100m thick) intruding Nalou Formation bioclastic dolomite (>50m thick) that is in turn overlain by dark-grey decarbonatised Discovery Formation calcareous shale (Figs. 4.4.2-4.4.6). The footwall sequence at DSC is similar to the hangingwall sequence, but differs slightly in that the Discovery Formation in the footwall consists of non-decarbonatised dark grey calcareous shale containing some brachiopod fossils within thin beds (<1 cm thick) dipping 15 to 25 degrees towards the NW (Figs. 4.4.2-4.4.4). No economically significant gold grades have been intersected to date in the footwall sequence of Discovery Formation non-decarbonatised calcareous shale at this deposit (Fig. 4.4.2). A later-stage non-mineralised dark green-brown fine-grained intermediate dike cuts both mineralised RDP and silicified Discovery Formation calcareous shale at DSC, as can be observed in drill hole DD93DIS001 (Fig. 4.4.6).
Fig. 4.4.1. Geological map showing the location of the Discovery Colluvial gold deposit (DSC). The locations of the five drill holes logged and sampled during this project are represented by the black circles along section lines (blue dashed lines). The thick black lines represent faults.

Fig. 4.4.2. Geological cross-section through the Discovery Colluvial deposit looking east along line 605500mE in Fig. 4.4.1. Gold mineralisation at this deposit mainly occurs in both jasperoid and decarbonatised Discovery Formation calcareous shale along a steep faulted contact between rhyodacite porphyry (RDP) in the hangingwall and Discovery Formation calcareous shale and the underlying Nalou Formation dolomite in the footwall sequence (section courtesy of OZ Minerals Limited).
4.2.4.3 Structure

The geometry of the DSC gold deposit is elongate-shaped, steeply dipping and predominantly occurs in the hangingwall sequence along the NE-SW trending Discovery Fault (Figs. 4.4.1 to 4.4.4). Structural measurements of the Discovery Fault from the NE end of the open pit indicate that the Discovery Fault strikes 050–230 (NE-SW) and dips 70° to the SE (Figs. 4.4.2 to 4.4.5). Smith (2003) and Smith et al. (2005) describe the Discovery Fault at DSC as being a high-angle fault with an a reverse movement, based on the interpreted displacement of the contact between the Discovery and Nalou Formations shown in Fig. 4.4.2. Non-mineralised joints in RDP strike WNW and dip shallowly to the SW at DSC, whilst pyrite mineralised veins were observed in RDP that strike E-W to WNW with moderate dips to the south (Figs. 4.4.4 and 4.4.5 respectively, Appendix 4.1).

Fig. 4.4.3. Photographs showing examples of Discovery Formation calcareous shale at the Discovery Colluvial deposit (DSC). (A). Northwest view of the Discovery Fault zone exposed in the DSC open pit. Note the faulted contacts between calcareous shale (CSH) in the footwall and rhyodacite porphyry (RDP) in the hangingwall. (B). Medium grey bedded nodular calcareous shale (CSH) at DSC. (C). Close up view of the calcareous shale shown in (B) containing brachiopod fossils adjacent to the coin shown.
Fig. 4.4.4 Geological map of the Discovery Colluvial gold deposit (DSC), at the open-pit and plots of structural data collected. This map shows the locations of structural measurements represented in structural plots A to D. Numbers 1 to 8 show the distribution of structural measurements, namely: 1 = Rose diagram for location A; 2 = Equal area net for location B; 3 = Rose diagram for location B; 4 = Equal area net for location B; 5 = Rose diagram for C; 6 = Equal area net for location C; 7 = Rose diagram for D; 8 = Equal area net for location D. **Abbreviations:**

- Calcareous shale (CSH)
- Manganese-rich clay (Mn CLY)
- Oxidised decarbonatised shale with Au (OX DCS)
- Jasperoid with Au (JAS Au)
- Rhyodacite-porphyry (RDP)

The inset map shows the location to the Discovery West gold deposit (red area) in relation to the other Sepon gold deposits.
4.2.4.4 Surface mineralisation

Gold mineralisation at DSC is: (1) associated with a coincident As-Sb±Tl soil anomaly overlying the deposit (Manini et al., 2001), (2) predominantly hosted by a hangingwall sequence of decarbonatised Discovery Formation calcareous shale that is strongly silicified (jasperoid), (3) occurring in a steely dipping sheet-like body along the strike length of the high-angle Discovery Fault for a distance of more than one kilometre (Figs. 4.4.1 and 4.4.2), and (4) closely associated with fine-grained disseminated pyrite in ores.

The brecciated and fractured sections of decarbonatised and silicified calcareous shale observed in drill core from DSC appear to contain high gold grades, especially where disseminated pyrite and quartz also occurs as matrix fill in the fractures (Fig. 4.4.3). Sericite alteration overprints RDP at DSC and the fractured and brecciated sections of RDP also contain thin quartz veins with disseminated pyrite cutting earlier base-metal veins (Fig. 4.4.6). High-angle NW-SE trending quartz+pyrite veins (>1 to <10 cm wide) containing minor galena, sphalerite and tetrahedrite mineralisation can be observed in the DSC open pit, which crosscuts calcareous shale and RDP in the hangingwall sequence at this deposit (Figs. 4.4.5). Veining also appears to intensify towards the contact with the Discovery fault zone at DSC where the weathering of exposed veins are oxidised and stained with malachite, and minor azurite can also be observed in the open pit (Fig. 4.4.5). Drill core from hole DIS001 also shows laminated base metal veins containing sphalerite-galena-pyrite occurring in a fault zone cutting RDP which are in-turn, cut by later white calcite-dolomite veins (Fig. 4.4.6).

Fig. 4.4.5. Photographs showing examples of weathered sulphide veins occurring in rhyodacite porphyry (RDP) at the Discovery Colluvial deposit (DSC). (A). View of the DSC open pit showing RDP (cream coloured, right) and black calcareous shale (CSH, left). (B). Jointed RDP with no sulphide veining. (C). RDP adjacent to the Discovery Fault Zone (DSW FZ) at DSC showing low-angle cross-cutting sulphide veins containing quartz-pyrite-galena-chalcopyrite-tetrahedrite. (D). Sulphide vein in RDP from (C) containing quartz (Qtz)-pyrite (py)-galena (gn)-chalcopyrite (cpy)-tetrahedrite (tet) with 0.8 g/t Au, 0.83% Cu and 6.2 % Pb (DSC Sample 5531416).
Fig. 4.4.6 Photographs and drill hole logging section along DDH DIS001 at the Discovery Colluvial deposit. Note the stratigraphic position of base metal mineralisation in relation to structurally prepared rheological zones and mafic dikes. (A). Interval from 4–92m depth (i) 4–24m: Clay after rhyodacite porphyry (RDP). 24–66m: Sericite altered RDP. 66 – 92m: Fractured RDP with Stage 3B veins (<1 to >5 cm wide) containing pyrite-galena-sphalerite-quartz. (B). 92–96m: Dolerite dyke (fine-grained) cuts mineralised fault zone in RDP. Minor pyrite occurs in this dyke, but is post RDP and base metal vein emplacement. (C). 96–102m: Interval with a laminated base metal vein comprising pyrite (py), galena (gn), sphalerite (sp) and quartz (qtz) in a fault zone cutting RDP (red boxed area, also shown in D). (D). Calcite veins (Cal) in-turn, cut earlier base metal veins. *Abbreviations: FR = fracture, FZ = fault zone, MBX = mosaic breccia, VN = veins. (Drill core logging observations by the author during 2005).*
4.2.5 Discovery Main and Discovery East gold deposits

4.2.5.1 Location and background

The Discovery Main (DSM) and Discovery East (DSE) gold deposits are centrally located at 607600 E and 1876220 N (UTM 48). Both of these deposits occur along the NE-trending Discovery Fault and are also located approximately 500 m to the NE of the Discovery Colluvial gold deposit (Figs. 4.1.1 and Fig. 4.5.1). These SHGD gold deposits were both originally grouped together with the Discovery Colluvial gold deposit and collectively known as the Discovery gold prospect prior to 1994 (Manini et al., 2001). During 1994, scout drilling of gold in soil anomalies at DSM confirmed the presence of gold by intersecting two mineralised calcareous shale intervals above a dolomite contact, containing 5.5m @ 3.2 g/t Au and 3.25m @ 13.94 g/t Au respectively in diamond drill hole DIS012 (Fig. 4.5.2; Manini et al., 2001). Infill drilling since 2001 has identified the continuation of significant gold resources between these deposits along strike of the NE-trending Discovery Fault, up to the contact with the NW trending Muang Luang Fault that cross-cuts the Discovery Fault in the east (Fig. 4.5.1). A resource of 8.79 Mt of ore averaging 2.87 g/t Au and containing 811,000 oz Au has been outlined at Discovery Main (Smith et al., 2005).

4.2.5.2 Geology and structure

The stratigraphy at both the DSM and DSE gold deposits is similar to those observed at Discovery Colluvial (DSC), comprising a basal shallow north-westerly dipping RDP sill (>100m thick) intruding Nalou Formation bioclastic dolomite that is directly overlain by Discovery Formation dark-grey decarbonatised calcareous shale that is in turn overlain by laminated non-calcareous shale with minor chert inter-beds that are interpreted to belong to the Nam Kian Formation (Figs. 4.5.2 and 4.5.3).

The DSM gold deposit has an elongate oval shape geometry that is approximately >1000m in length with the long axis predominantly occurring along the NE-trending Discovery Fault zone (Fig. 4.5.1). At the far NE end of this deposit, the Discovery Fault is interpreted to be cross-cut by the WNW-trending Muang Luang Fault which is an inferred normal fault that dips 60° to 70° to the NE (Fig. 4.5.1; Loader, 1999). The DSE gold deposit appears to be divided into two zones with a northern gold-ore zone occurring along the WNW-trend of the Muang Luang fault and the southern gold-ore zone occurring along an inferred NE-trending fault, sub-parallel to the Discovery fault zone (Fig. 4.5.1). Alternatively, geomorphological investigations reported in LXNL (2003) suggest that the DSE southern gold-ore zone may not be structurally controlled but located at the current position due to a large post-gold mineralisation land-slip that dislocated approximately half of the DSE northern gold-ore zone towards the south (Fig. 4.5.1).
4.2.5.3 **Surface mineralisation summary**

Gold mineralisation at both the DSM and DSE deposits is: (a) not visible, (b) inferred to be mainly micro-disseminated, (c) commonly associated with fine-grained pyrite ore types, and (d) occurs along permeable rheological contacts, in particular between the: (i) Discovery Formation calcareous shale and RDP sills, (ii) Discovery Formation calcareous shale and Nalou Formation dolomite, and (ii) faulted contacts between Discovery Formation calcareous shale and non-calcareous shale (Figs. 4.5.1 to 4.5.3). Minor base metals occurring as fracture fill and cross-cutting veins are present at the DSM deposit. Light green-yellow (iron-poor) sphalerite and minor galena were observed occurring in vughs and veins at DSM, especially in the basal sections of dolomitised Discovery Formation calcareous shale that directly overlies Nalou Formation bioclastic dolomite (Fig. 4.5.2). The fractured margins of a RDP sill intersected in drill hole DD94DIS012 at 60.2m depth contained small base metal veins (<1 cm wide) composed mainly of pyrite and quartz-carbonate with minor sphalerite and galena that show post-mineralisation offsets (Fig. 4.5.4). The presence of chalcopyrite associated with retrograde skarn mineralisation at DSE was also identified during 1994 in drill-hole DD94DIS023 that was targeted through the WNW-trending Muang Luang Fault (Figs. 4.5.2 and 4.5.3; Loader, 1999; Loader et al., 1999). The paragenesis of skarn assemblages occurring at DSE and also at other locations in the SMD is described in Chapter 5.0.

![Geological map showing the location of the Discovery Main (DSM) and East (DSE) gold deposits. The locations of drill holes logged and sampled during this project are represented by the black circles along section lines (blue). Diamond drill hole (DDH) numbers are prefixed with DIS.](image-url)
Fig. 4.5.2. Geological cross-section through the Discovery Main (DSM) deposit looking east along line 606800mE (Fig. 4.5.1). Gold mineralisation at this deposit mostly occurs in jasperoid (JAS) and decarbonatised Discovery Formation (DIS) calcareous shale along a contact between Nalou Formation (NLU) dolomite and rhyodacite porphyry (RDP) in the footwall and Discovery Formation calcareous shale in the hanging wall (section modified after Manini et al., 2001).

Fig. 4.5.3. Geological cross-section through the Discovery East DSE deposit looking east along line 607500m (Fig. 4.5.1). Gold mineralisation at this deposit occurs in jasperoid (JAS) along the rheological contact between decarbonatised Discovery Formation (DIS) calcareous shale (hangingwall) and rhyodacite porphyry (RDP, footwall). Retrograde skarn (SKN) alteration was also intersected along the Muang Luang fault (section modified after Manini et al., 2001).
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Fig. 4.5.4. Photographs showing hostrock lithology and mineralisation at the Discovery Main and East deposits. (A). Easterly view of the Discovery Main deposit (DSM) showing oxide gold ore mining from decarbonatised Discovery Formation calcareous shale (CSH) along a jasperoid contact (JSA) between CSH and rhyodacite porphyry (RDP). (B). Rhyodacite porphyry at DSM. A sample was collected from this site for U-Pb zircon dating (Sample PCDSM03007). (C). Jasperoid (strongly silicified calcareous shale surrounded by orang colluvium (CLV) at DSM. (D). Strongly dolomitised calcareous shale (CSH) with black carbon-rich (CARB) residues remaining in large vughs. (E). Dolomitised calcareous shale at DSM averaging 18.6 g/t Au, 2.1 % Cu, 2.2 % Pb and 3.7 % Zn (Sample 5548893). (F). Pale light-green sphalerite (sp) collected from DSM containing >60% and <0.2 ppm Au (Sample 5531423). (G). Prograde garnet skarn alteration (GAR) overprinted by retrograde veins containing chalcopyrite (cpy) and quartz (Qtz) in DDH DIS023, drilled through the Muang Luang fault at Discovery East (Sample at 131.5m depth with grades of 1.8 % Cu, 0.2 g/t Au). (H). Retrograde chlorite altered calcareous shale (CSH) from the Discovery East deposit with late stage pink calcite (CAL) veins in DDH DIS023 @ 117.8m and containing no Cu or Au.
4.2.6 Namkok West and Namkok East gold deposits

4.2.6.1 Location and background

The western sector of the Namkok area is located in a low lying area, approximately 500m east of the Nalou gold deposit (Figs 4.1.1 and 4.6.1). Laterite and oxide gold-ore types both occur at the Namkok West (NKW) and East (NKE) gold deposits located between 604500 to 606500 E and 1874000 N to 1874500 N (UTM 48). The Namkok River separates the overall Namkok gold resource into the western (NKW) and eastern (NKE) deposits (Fig. 4.6.1; Manini et al., 2001). During 1993 to 1994, geological mapping by LXML geologists identified a 1.5 km long east–west trending area along the contact with RDP containing sporadic jasperoid cobbles and boulders carrying up to 5 g/t Au. No in-situ mineralised host stratigraphy was identified during surface exploration stages, but textures observed in mineralised jasperoid samples collected at this prospect suggested silica replacement of both limestone and calcareous shale host-rock types (Manini et al., 2001).

Laterite and clay was intersected in three preliminary scout holes that were drilled along the western side of the Namkok River to test the potential for blind northerly dipping stratabound sedimentary rock-hosted gold mineralisation, resulting in 9.1m @ 10.35 g/t Au and 12.7m @ 4.5 g/t Au, from surface. During 1996–1997, follow-up drilling of 37 holes delineated a global low-grade residual oxide gold resource, containing approximately 400,000 oz Au for both the NKW and NKE gold deposits (Manini et al., 2001). Continued development drilling has established resources of: 4.24 Mt ore averaging 2.48 g/t Au containing 338,000 oz Au at NKW and 3.22 Mt ore averaging 1.19 g/t Au containing 123,000 oz Au for the NKE gold deposit (Smith et al., 2005).

4.2.6.2 Geology and structure

Both the NKW and NKE gold deposits occur along the WNW-trending strike of the Thengkham-Nalou-Namkok-Nampa (TNNN) fault that is interpreted by Smith et al. (2005) to be a steeply dipping strike-slip fault (Fig. 4.6.1). The TNNN fault is interpreted to change direction from a NW-trending fault between the Nalou and Namkok West gold deposits and then trends in a WNW-direction towards the eastern end of the Namkok East gold deposit (Figs. 4.1 and 4.6.1; Loader et al., 1999; Smith, 2003).

Four sedimentary formations are recognised in the Namkok area, which are divided by the E-W trending TNNN fault (Figs. 4.6.1 and 4.6.2). Along the southern side of the TNNN fault, Kengkeuk Formation laminated calcareous shale is overlain by Nalou Formation laminated dolomite. Both of these formations are gently folded and dip to the NW (Fig. 4.6.2). Along the northern side of the TNNN fault, Nalou Formation dolomite is overlain by Discovery Formation calcareous shale that dips shallowly to the NW (Fig. 4.6.2).
RDP in the Namkok area intrudes along the TNNN fault and also between the Nalou and Discovery Formations and also along the southern margins of the NKE deposit (Figs. 4.6.1 and 4.6.2). Geological mapping was not undertaken at this deposit as the open pit operations at this deposit had not commenced during the 2004 to 2005 fieldwork program for this project. Information about the NKW and NKE deposits was obtained from drill core.

4.2.6.3 Surface mineralisation

The laterite and oxide gold resource at Namkok West and East is outlined by a 1.5 km long E-W trending gold in-soil anomaly (Manini et al., 2001). Gold mineralisation at NKW is mostly oxide and predominantly hosted by ferruginous and manganiferous sections of the upper laterite profile overlying Kengkeuk Formation calcareous shale and RDP along the southern side of the WNW-trending TNNN fault (Fig. 4.6.1). Minor laterite gold mineralisation overlying Nalou Formation dolomite occurs along the northern side of the TNNS fault (Manini et al., 2001). At NKE, laterite gold mineralisation overlies Nalou Formation dolomite along the northern side of the TNNN fault, with minor laterite overlying Kengkeuk Formation calcareous shale and RDP along the southern side of the TNNN fault (Fig. 4.6.2, Manini et al., 2001).

![Geological map of the Namkok West (NKW) and East (NKE) gold deposits in the SMD. The locations of drill holes logged and sampled during this project are represented by the black circles along section lines (blue). The Tengkham-Naou-Namkok-Nampa Fault (TNNS) is represented by the thick WNW-trending black line.](image-url)
Fig. 4.6.2. Cross-sections looking east, showing the geology of the Namkok West (A) and Namkok East (B) gold deposits (courtesy of LXML). (C). Photograph of mottled laterite clay in drill hole NKK007 at the Namkok West deposit from 5 to 7.5m with minor jasperoid fragments (after carbonate) containing oxide gold grades ranging from >1 to 4.7 g/t Au. (D). Photograph of drill core from NKK007 showing the fractured contact between bioclastic dolomite (BDM) from 49.15 - 52.77m depth and rhyodacite porphyry (RDP) from 52.75 - 70.3m.
4.2.7 Vang Ngang gold deposit

4.2.7.1 Location and background

The Vang Ngang deposit (VNG) contains micro-disseminated SHGD mineralisation that is predominantly associated with a silica-pyrite mineralisation style and hosted by siliciclastic rocks (Sillitoe, 1998b; Smith et al., 2005). Vang Ngang comprises a East and West deposit, both centred at 607850 E and 1873500 N (UTM 48) and located approximately one kilometre south-east of the Namkok East gold deposit (Figs. 4.1.1 and 4.7.1). Reconnaissance mapping and shallow soil sampling by LXML geologists at Vang Ngang during 1994 defined a 1.5 km long x 0.4 km wide ENE-trending gold anomaly in laterite averaging 0.22 g/t Au (Bateman, 1999). Follow-up scout drilling at Vang Ngang discovered high-grade gold associated with abundant quartz and semi-massive pyrite that is locally referred to by LXML geologists as silica-pyrite mineralisation that occurs in steeply dipping faults at the contact between weakly hornfels-altered mudstone and interbedded bioclastic dolomite within the Nampa Formation (Fig. 4.7.2). Encouraging results were obtained in diamond drill hole VNG004 that intersected 10.9m @ 8.99 g/t Au (Loader et al., 1999). Subsequent exploration drilling by LXML was conducted at Vang Ngang from 2002 to 2003 to outline a measured and indicated resource of 1.01 Mt ore averaging 2.86 g/t Au containing 92,800 oz Au that was brought into production during December 2003 (Smith et al., 2005).
4.2.7.2  **Geology and structure**

Gold mineralisation at Vang Ngang West is mostly hosted by a steeply dipping siliciclastic sequence of sandstone and intercalated sandstone-mudstone units with minor limestone inter-beds interpreted to belong to the Nampa Formation (Figs. 4.7.1 and 4.7.3; Sillitoe, 1994b; Smith et al., 2005). The Vang Ngang Formation siltstone, sandstone and minor limestone units mainly occur at Vang Ngang East (Figs. 4.7.1 and 4.7.2). Andesite dominant conglomerates interpreted to belong to the Namphuc Volcanics were also intersected in drill holes VNG004, VNG042 and VNG043 at Vang Ngang East (Fig. 4.7.2). Later steeply dipping RDP dikes cut the sedimentary sequence at Vang Ngang East (Fig. 4.7.2). Smith (2004) noted that oxide and primary gold mineralisation at Vang Ngang West is predominantly occurring along disharmonic folded bedding with strikes ranging from 240-280 and dipping 50-60° to the NW. Fracture measurements recorded at the Vang Ngang West deposit by the author in Appendix 4.1 indicated two main sets; (1) NE-striking with steep NW dips that are parallel to sub-parallel to bedding measurement, and; (2) NW-striking. Near surface, the Vangngang West deposit occurs along two zones that dip 50-60° to the NW, but predominantly occurs as a ENE-striking elongate body >150 m long with >10m thickness at depth. Later NW-striking normal faults dipping 65-75 degrees to the SW with >5m displacements cut ENE-striking iron-oxide gossan zones that are exposed along the mine haulage road (Fig. 4.7.3).

![Fig. 4.7.2. Geological cross-section of the Vang Ngang East gold deposit looking west along section 608650E, showing the location of holes VNG004, -044 and -045 that intersected gold along a steeply dipping silica-pyrite mineralised zone (section courtesy of LXML).](image-url)
4.2.7.3 Surface mineralisation

Sillitoe (1998b) reported the following mineralisation observations at Vang Ngang:
(1) supergene derived oxide gold mineralisation ranges in depth from 15 to 90m and is mostly
controlled by both topography and the positions of steep primary mineralised zones,
(2) two main types of veinlets occur at Vang Ngang: (i) quartz-pyrite-base metal sulphide veins
(composed mostly of sphalerite and galena) and (ii) quartz-pyrite-base metal sulphides, and (3)
jasperoid development after limestone at Vang Ngang contains comb-textured quartz as
veinlets and cockades that contain high gold values ranging from <4 to >10 g/t Au.
Smith (2004) also noted that two main gold ore-types occur at Vang Ngang: (1) siliceous iron-
oxide gossan zones derived from silica-pyrite mineralisation, and; (2) limonitic clay-rich
sandstone derived from clay and pyrite altered sandstone (Fig. 4.7.3).

Fig. 4.7.3. Photographs showing lithology and mineralisation at the Vang Ngang (VNG) gold deposit. (A). Westerly
view of steep NW-dipping (NE-striking) interbedded sandstone and mudstone units (Nampa Formation) containing
oxide gold ore along the open pit access road at VNG. (B). An example of a post-gold mineralisation medium angled
NW-striking normal fault displacing steeply dipping NE-striking Nampa Formation sandstone and mudstone beds
hosting bedding parallel oxide gold ore (dark orange rocks) at VNG. (C). Photographs of vugly quartz (jasperoid)
from hole VNG004 @ 56.0m containing 9.3 g/t Au and 15 g/t Ag from the interval shown in (D). (D). Highly
fractured and oxidised section of Nampa Formation sedimentary rocks in hole VNG004 with 4.9m @ 16.6 g/t Au
from 55.6 to 60.4m. (E). Photographs of semi-massive pyrite and quartz with trace sphalerite occurring in an
interpreted fault zone in hole VNG004 @ 55.6m containing 0.45 g/t Au, 15 g/t Ag and 0.2% Zn. (F). Close up
photograph of semi-massive pyrite and quartz from the interval shown in (E).
4.2.8 Phavat Gold-Copper Prospects

4.2.8.1 Location and background

Both laterite-hosted gold and inferred skarn associated gold and copper mineralisation have been identified at the Phavat Prospects, in an area along the western slopes of Thengkham ridge, located approximately 10 km west of the LXML Sepon gold production plant (Figs. 4.1.1 and 4.8.1; Norris, 1999; LXML, 2003; LXML, 2006). LXML (2006) report that this area is currently divided into two prospects, namely: Phavat (VAT), located at UTM 595300mE, 1873600mN and Phavat North (PVN) at 596200mE, 1874100mN (Fig. 4.8.1).

Reconnaissance work by LXML during 1996 first recognised the gold potential of the Phavat Prospect area after finding high grade gold values in gossan, commonly >10 g/t and up to 132 g/t Au (Norris, 1999). Follow-up grid soil sampling identified a 1.5 km long x 0.5 km wide laterite gold prospect area averaging 0.22 g/t Au in soil samples (LXML, 2003). During 1996 to 2003, wide intervals of low-grade gold mineralisation ranging from 0.5 to 1.0 g/t Au were intersected from surface in most of the drill holes completed at Phavat, with exploration extending to Phavat North during 2005 (LXML, 2003; LXML, 2006). The resource size and grades for gold and associated copper at both prospects is not currently reported.

4.2.8.2 Geological setting

The current understanding of the geology and structural setting at the Phavat Prospect (VAT) is not well-constrained due to extensive soil and laterite cover masking much of the low-lying topography in the area. However, northerly dipping Nalou Formation laminated and bioclastic dolomite, and Kengkeuk Formation calcareous shale and jasperoid were reported by Norris (1999) and LXML (2003) to occur at depth in the VAT Prospect area along section lines 595200 mE and 595250 mE (Fig. 4.8.1). Both of these lithologies are intruded by RDP dykes (LXML, 2003). On-going surface mapping and drill-hole interpretations by LXML geologists have inferred that both steep NNE-trending and NW-trending faults occur in the VAT Prospect area and are inferred to be influencing the control of primary mineralisation associated with both skarn and silica-pyrite mineralisation types (Figs. 4.8.1 and 4.8.2; LXML, 2006).

LXML (2006) report that the Phavat North (PVN) Prospect area is underlain by a northerly moderate to shallow dipping sedimentary sequence comprising Nalou Formation dolomite overlain by Discovery Formation calcareous shale and in turn, Nam Kian Formation interbedded chert, siltstone and sandstone (Fig. 4.8.1). Both E-striking and NW-striking faults are reported to cut the formations at PVN and inturn, are intruded by steep and shallowly dipping RDP dykes (LXML, 2006). Gold at the PVN Prospect is reported by LXML (2006) to be mostly hosted along NW-trending faults and immediately adjacent to RDP dykes.
4.2.8.3 Mineralisation

The initial drilling program within the western sector of the Phavat Prospect during 1997 intersected Au-Cu mineralisation occurring in: (a) gossan that was interpreted to be after skarn associated quartz-pyrite mineralisation; (b) skarn mineral assemblages, and; (c) quartz-pyrite, including native copper and malachite intersected in 3 holes at this prospect (Figs. 4.8.1 and 4.8.2; LXML, 2003; LXML, 2006). Gold and copper mineralisation was observed in the Phavat Prospect drill hole VAT006, with intervals containing: (a) 37.7m @ 2.48 g/t Au from surface, and; (b) 10.9 m @ 0.86 % Cu from 15 – 25.9m down-hole depth (Figs. 4.8.1 and 4.8.2; Bateman, 1999). Both skarn and silica-pyrite mineralisation types occurring along the contacts between RDP and dolomite and also within RDP has been observed at the VAT Prospect by LXML geologists, especially in core from drill holes VAT001 and VAT006 along section lines 595200mE and 595350mE, respectively (Figs. 4.8.1 and 4.8.2). Drill core samples were collected for petrographic and geochemical studies for this project from these two holes at the VAT Prospect (Fig. 4.8.2).

Fig. 4.8.1. Geological map of the Phavat and Phavat North gold prospect areas in the SMD. The locations of drill holes logged and sampled by the author during this project are represented by the black circles along section lines (green). Thick black lines represent faults and the red dashed lines are the currently known economic gold ore zone (0.5 g/t cut off). Abbreviations: NKN = Nam Kian Formation: siltstone, shale, chert and limestone (LST), DIS FM = Discovery Formation: calcareous shale (CSH), NLU FM = Nalou Formation: bioclastic dolomite (DOL), KGK FM = Kengkeuk Formation: nodular calcareous argillite, UKN = Unknown: possibly the NKN or DIS Formation, RDP = rhyodacite-porphyry. KRT = Khorat Group: shale (Mesozoic).
At PVN, the best gold grades are reported to occur where the Nalou Formation dolomite and Discovery Formation calcareous shale contact has been intersected by RDP dikes (LXML, 2006). Other host rocks for gold mineralisation at this prospect include: (a) Nam Kian Formation siliciclastic rocks; (b) Discovery Formation calcareous shale, and; (c) the contact between the Discovery Formation and the Nam Kian Formation (LXML, 2006). The gold mineralisation at the Phavat North Prospect is also reported to be closely associated with: (a) decarbonisation, silicification, and dolomitisation of Discovery Formation calcareous shale, and; (b) pyrite-chalcopyrite-carbonate-sericite alteration, mostly along RDP dike margins (LXML, 2006).

Fig. 4.8.2. Photographs showing lithology and mineralisation at Phavat Prospect in drill holes VAT001 and VAT006. (A). Laminated quartz (qtz)-pyrite (py)-chalcopyrite (cpy) mineralisation occurring in a fault zone and comprising 1.4 g/t Au, 30 g/t Ag and 1.4 % Cu in DDH VAT001 @ 83.9m depth. (B). The main fault zone interval in DDH VAT001 containing pervasive quartz-pyrite-chalcopyrite mineralisation averaging 6m @ 1.9 g/t Au, 44.5 g/t Ag and 3.2 % Cu from 78-84m depth. (C). A breccia section in DDH VAT001 containing a matrix fill of quartz-pyrite-chalcopyrite with 2.5 g/t Au, 50 g/t Ag and 4.9 % Cu at 78.1m depth. (D). An interval of Nalou Formation bioclastic dolomite (BDM) in DDH VAT006 containing laminated quartz-pyrite-chalcopyrite from 146 to 148.4m. (E). Close up view of disharmonic folding in a laminated vein comprising quartz-pyrite-chalcopyrite averaging 2.7 g/t Au, 13 g/t Ag and 4.2 % Zn in DDH hole VAT006 @ 146.1m depth.
4.2.9 Nakachan Gold Prospect

4.2.9.1 Location and background

The Nakachan gold prospect area (NAK) is located at 584500 E and 1877250 N (UTM 48), approximately twenty kilometres west of the LXML Sepon gold plant (Figs. 4.1.1 and 4.9.1). LXML (2003) reports that Nakachan contains both: (1) near surface laterite-hosted gold and, (2) fault-controlled sedimentary rock-hosted high-grade primary gold mineralisation occurring in a quartz-pyrite dominant mineral assemblage with associated minor sphalerite and galena (Fig. 4.9.2). Reconnaissance stream sediment gold anomaly checking, grid soil sampling and follow-up mapping work conducted by RioTinto prior to 1999 confirmed the presence of laterite-hosted gold occurring in a >1 km long x 300m wide NW–trending gold in soil anomaly area at Nakachan. Exploration drilling in the Nakachan prospect area since 1999 confirmed the presence of high-grade gold mineralisation occurring with primary silica-pyrite mineralisation and base metals, mostly along NW–trending structures (LXML, 2003). The mineral resource size and gold grades occurring at Nakachan Prospect is not currently reported.

4.2.9.2 Geological setting

The understanding of the stratigraphy and structural setting of the Nakachan Prospect area is also not constrained due to extensive soil and laterite covering the area. Surface mapping and drill-hole interpretations by LXML geologists have inferred that NW-trending faults occur in the prospect area and may possibly be influencing the control of gold mineralisation associated with primary sulphide mineralisation along structural zones that are interpreted to be sub-parallel the NW–trending margins of the regional Truong Song fault zone (Figs. 4.1 and 4.9.1). Out crop mapping and drilling has established that calcareous shale, dolomite, limestone, chert and RDP underlie the laterite cover at the Nakachan Prospect. Narrow RDP dikes mapped at surface and intersected during drilling appear to be intruding along NW-trending fault zones (Fig. 4.9.1; LXML, 2003).

4.2.9.3 Surface mineralisation

The first scout diamond hole drilled at the Nakachan Prospect by RioTinto during 1999 intersected 12m @ 7.13 g/t Au in hole NAK001 (i.e. from 7.6 m depth onwards). This drill hole established that gold is predominantly associated with quartz-pyrite and minor base metals (sphalerite and galena) that mostly occurs along a NW–trending high-angle fault zone (Figs. 4.9.1 and 4.9.2; LXML, 2003). Samples of drill core observed from gold mineralised intervals at the Nakachan Prospect also contained early silica-pyrite mineralisation occurring in fractured and brecciated sections, especially along the rheological contacts between: (a) RDP and calcareous shale, and; (b) RDP and dolomite. In turn, later stage veins containing pyrite, dark-brown sphalerite and minor galena cut the earlier quartz-pyrite intervals (Fig. 4.9.2).
Chapter 4 – Deposit Geology

Fig 4.9.1 Geological map of the Nakachan Prospect area in the SMD (courtesy of LXML). The names of the geological formations at this prospect were not constrained during this study and therefore only the known rock types are shown on this map. The dashed black lines represent interpreted faults. The locations of drill holes logged and sampled by the author during this project are represented by the red circles along section line 584500mE (blue dashed line). Abbreviations: CHE = chert, CSH = calcareous shale, DOL = dolomite, LST = limestone, Qtz-py = quartz-pyrite (fault zone), RDP = rhyodacite-porphyry.

Fig. 4.9.2. Photographs showing lithology and mineralisation at Nakachan Prospect in drill holes NAK001 and NAK006. (A). Fault zone interval in diamond drill hole (DDH) NAK001 with a hangingwall section of massive pyrite and quartz containing 10.5m @ 10.5 g/t Au, 60.5 g/t Ag, 1.7 % Pb and 3.5 % Zn from 8.8 to 19.35m depth. Bioclastic dolomite (BDM) occurs in the footwall from 19.35m onwards. (B). Gold mineralised quartz (qtz)-pyrite (py)-sphalerite (sp) section in brecciated dolomite from DDH NAK001 containing 0.2m @ 21.6 g/t Au, 74 g/t Ag, 2.6 % Pb, 13.3 % Zn and <0.05 % Cu at 14.3m depth. (C). Gold mineralised quartz-pyrite section hosted by brecciated dolomite cut by veins with (py)-sphalerite (sp)-galena (gn) containing 8.3 g/t Au, 122 g/t Ag, 2.1 % Pb and 6.2 % Zn at 93.7m depth in DDH NAK006. (D). A vein with quartz (qtz)-sphalerite (sp)-pyrite (py)-galena (gn) cutting a dolomite host rock, containing 5.6 g/t Au, 39 g/t Ag, 1.1 % Pb, and 4.6 % Zn at 99m depth in DDH NAK006. (E). Rhyodacite porphyry cut by a quartz (qtz)-pyrite (py) containing 1.1 g/t Au, 29 g/t Ag, at 104.6m depth in DDH NAK006.
4.2.10 Discussion of SMD SHGD mineralisation

4.2.10.1 Introduction

The geological characteristics of the SMD SHGD investigated by the author during this study are herein discussed in order to summarise the geological controls involved with the genetic development of these deposits. Previous information about the similarities and differences between the SMD SHGD presented in this section is also sourced from Company reports by Sillitoe (Sillitoe, 1994a, b, 1995, 1998), Norris (1999) and LXML (2006) and also publications by Manini et al. (2001), Manini and Albert (2003), Smith et al. (2005) and Olberg et al. (2006). Table 4.1 provides a summary of the currently known principal geological features present in the SMD SHGD that are discussed in the sections to follow.

4.2.10.2 Host rocks

The majority of gold resources occurring in the SMD SHGD are reported to be hosted by the Devonian Discovery Formation that is comprised of carbonaceous calcareous shale, namely at the Discovery West, Colluvial, Main and East deposits (Discovery deposits) and also at the Nalou, Namkok East and Namkok West, Phavat North and Nakachan deposits (Fig. 4.1.1 and Table 4.1; Manini et al., 2001; Smith et al., 2005; LXML, 2006; Olberg et al., 2006). Minor amounts of gold are also hosted in the Devonian Nalou Formation dolomitised bioclastic limestone and Silurian-Devonian Kengkeuk Formation nodular calcareous shale at the Nalou, Namkok East and Namkok West and Phavat deposits (Fig. 4.1.1; Manini et al., 2001; Smith et al., 2005). A turbidite sequence of claystone with interbeds of dolomitised limestone belonging to the Ordovician-Silurian Nampa Formation is also known to host a small resource of gold at the Vang Ngang deposit (Fig. 4.1.1; Table 4.1; Smith et al., 2005). The fractured margins of Early Permian rhyodacite-porphyry (RDP) intrusions in the SMD can also contain some minor gold, in particular at the rheological contacts between (a) RDP and calcareous shale, and (b) RDP and dolomite, namely at the Nalou and at the Discovery deposits (Table 4.1). Overall, the SMD gold deposits occur in Palaeozoic rocks that range in age from Ordovician through to Early Permian with the majority of currently known gold resources hosted by Devonian rocks.

4.2.10.3 Structural controls on gold deposit geometries

Folds, faults and rheological contacts in the SMD are described as being integral structural components in the development of the SHGD deposit geometries (Sillitoe, 1994a, b, 1995; Manini et al. 2001, Smith 2003, Smith et al. 2005; Table 4.1). Smith et al. (2005) and Manini et al. (2001) reported at least three types of gold ore zone geometries observed to date in the SMD: (a) ribbon-like bodies that are strike continuous (e.g., at the Discovery Main, Nalou, Namkok East and Namkok West deposits), (b) moderate- to shallow-dipping sheets that are not necessarily always connected to faults (e.g. Discovery West, Discovery Colluvial, Discovery Main and Nalou), and (c) fault controlled steep sheet-like bodies (e.g. Discovery Colluvial; Fig. 4.10.1).
<table>
<thead>
<tr>
<th>SMD Sectors</th>
<th>Location (UTM 40)</th>
<th>Pre-mining Resource (g/0.5 g Au cut off)</th>
<th>Host Rocks (Au)</th>
<th>Intrusion Type and Age</th>
<th>Gold ore zone controls (structure and/or rheologic)</th>
<th>Alteration</th>
<th>Mineralisation (surface)</th>
<th>Mineralisation (open pits and drill core)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal to Padin and Khongor ruby placer (RPDP) intrusion sector</td>
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<tr>
<td>Discovery East (DSE) and Discovery Main (DSM)</td>
<td>607600 2E, 1867500 N</td>
<td>6.9 Mt @ 2.9 g Au</td>
<td>Naiman FM, Discovery FM, Naifu FM, RDP fractures</td>
<td>RDP 200 6 5 Ma</td>
<td>NE-trending Discovery Fault, steeply dipping to NE. Shallow NW-dipping sheet-like ore zone along the rheological contact between calcareous shale and dolomite, connected to the NE-trending Discovery Fault. Dolomitisation, decalcification, carbonisation, silicification, and pyritisation at both DSM and DSM. Including prograde skarn (garnet and porphyro) and retrograde skarn (chlore-aepitole carbonate) only at DSM. Au-Cu in gossan and iron oxide float along Khongor creek containing up to 4.4% Cu and 2.8 g Au (Minari et al., 2001).</td>
<td>Au in silicified boulders (pseudomorphs) in an area 300 m long x 20 m wide ranging 3.5 to 5.9 Au (Minari et al., 2001).</td>
<td>DSSM - Veins and breccia fills of pyrite-sphalerite-galena (early), veins and breccia fill of quartz (pseudomorph) and disseminated pyrite (late). DSE - prograde skarn (garnet and porphyro) cut by retrograde skarn (chlore-aepitole carbonate), in turn cut by later quartz and disseminated pyrite.</td>
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</tr>
<tr>
<td>Discovery Central (DCC)</td>
<td>606000 2E, 1867500 N</td>
<td>2.94 Mt @ 2.9 g Au</td>
<td>Discovery FM, Naifu FM, RDP fractures</td>
<td>RDP 200 6 5 Ma</td>
<td>NE-trending Discovery Fault, steeply dipping to SE. Shallow NW-dipping sheet-like ore zone along the rheological contact between calcareous shale and dolomite, connected to DCC. Dolomitisation, decalcification, carbonisation, silicification, and pyritisation. Au in silicified boulders (pseudomorphs) in an area 300 m long x 20 m wide ranging 3.5 to 5.9 Au (Minari et al., 2001).</td>
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<tr>
<td>Discovery West (DSW)</td>
<td>604495 E, 1867500 N</td>
<td>5.4 Mt @ 2.9 g Au</td>
<td>Naiman FM, Discovery FM, Naifu FM, RDP fractures</td>
<td>RDP 200 6 5 Ma</td>
<td>WNW-trending Discovery West Fault, steeply dipping to NE. Open and gently folded sheet-like ore zone along the rheological contact between calcareous shale and dolomite, connected to DWF. Dolomitisation, decalcification, carbonisation, silicification, and pyritisation. Au in silicified boulders (pseudomorphs) in an area 300 m long x 20 m wide ranging 3.5 to 5.9 Au (Minari et al., 2001).</td>
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<tr>
<td>Nansuk East (NHNE) and Namsuk West (NHNW)</td>
<td>604400 3E, 1867400 N</td>
<td>2.1 Mt @ 1.2 g Au</td>
<td>Discovery FM, Naifu FM, RDP fractures</td>
<td>No Data</td>
<td>WNW-trending fault (steep). Rhologial contacts between RDP and dolomite or calc-silicate skarn. Dolomitisation, decalcification, carbonisation, silicification, and pyritisation. Au in silicified boulders (pseudomorphs) in an area 300 m long x 20 m wide ranging 3.5 to 5.9 Au (Minari et al., 2001).</td>
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<tr>
<td>Naturo (NU)</td>
<td>603795 E, 1867400 N</td>
<td>302 Mt @ 1.68 g Au</td>
<td>Discovery FM, Naifu FM, RDP fractures</td>
<td>RDP 200 6 5 Ma</td>
<td>WNW-trending faults (steep). Gently folded ribbon-like ore zones, predominantly along the rheological contact between calcareous shale and dolomite. Dolomitisation, decalcification, carbonisation, silicification, and pyritisation. Au in silicified boulders (pseudomorphs) in an area 300 m long x 20 m wide ranging 3.5 to 5.9 Au (Minari et al., 2001).</td>
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<tr>
<td>Proximal to Thanglams ham ruby placer (RPDP) intrusion sector</td>
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<tr>
<td>Phravat North (PN)</td>
<td>596300 E, 1867400 N</td>
<td>Not reported</td>
<td>Discovery FM, Naifu FM, RDP fractures</td>
<td>No Data</td>
<td>NE- and NW-trending faults. Rheologial contacts between RDP and dolomite or calc-silicate skarn. NE- and NW-trending faults. Dolomitisation, decalcification, carbonisation, silicification, and pyritisation. Au-Cu in veins of gossans. NW-trending Au in soil anomaly, 1.5 km long x 0.5 km wide. Samples with 130 g Au and indications of copper identified.</td>
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<tr>
<td>Phravat (VT)</td>
<td>595300 E, 1867300 N</td>
<td>Not reported</td>
<td>Naiman FM, RDP fractures</td>
<td>No Data</td>
<td>RWP-trending faults. Rheologial contacts between RDP and dolomite or calc-silicate skarn. RWP-trending faults. Dolomitisation, decalcification, carbonisation, silicification, and pyritisation. Au-Cu in veins of gossans. NW-trending Au in soil anomaly, 1.5 km long x 0.5 km wide. Samples with 130 g Au and indications of copper identified.</td>
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<tr>
<td>Naksan in the Thanglams ham sector</td>
<td>564500 E, 1877200 N</td>
<td>Not reported</td>
<td>Discovery FM, Naifu FM, RDP fractures</td>
<td>RDP 200 6 5 Ma</td>
<td>NW-trending faults. Rheologial contacts between RDP and dolomite or calc-silicate skarn. Dolomitisation, decalcification, carbonisation, silicification, and pyritisation. Au in soil anomaly in NW-trending zone, 1 km long x 0.3 km wide.</td>
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</table>
Most of the SMD SHGD ore-zone geometries indicate that gold ore formation has undergone some involvement between steep and shallow dipping structures such as gentle dipping rheological contacts (Fig. 4.10.1, Smith et al., 2005). Smith et al. (2005) also report that at least two main fault trends are associated with gold ore zones in the SMD that include: (1) WNW-striking normal faults with steep dips (a) to the NNE (e.g., at Discovery West) or (b) to the south (e.g., Nalou) and, (2) steep ENE-striking faults with (a) normal movement (e.g., at Discovery Main) or (b) reverse movement (e.g., at Discovery Colluvial).

Fig. 4.10.1. Diagrammatic examples of gold ore zone geometries that have been observed in the SMD SHGD. The main controls in their formation comprise structure, stratigraphy and rheological contacts. (A). Geological cross-section through the Discovery Colluvial deposit looking east along line 605500mE. The two gold-ore zones shown in this cross-section are both closely associated with jasperoid (JAS) along shallow dipping sheets connected to steeply dipping faults. (B). Geological cross-section of the Nalou gold deposit along line 603550mE. A gently folded ribbon-like gold ore zone geometry is represented in this cross-section by jasperoid (JAS) along the rheological contact between brittle footwall Nalou Formation (NLU) dolomite and ductile hangingwall Discovery Formation (DIS) calcareous shale that is also closely linked to a fault zone.
4.2.10.4 Surface trace-element associations

Surface trace element indicators have aided exploration programs during the discovery of SHGD in the SMD through initial stream sediment surveys and subsequent follow-up soil, float rock and outcrop sampling geochemical programs over gold and copper anomaly areas (Table 4.10.1; Agnew, 1998; Norris, 1999; Loader et al., 2001; Manini et al., 2001; LXML, 2003; Smith et al., 2005). SHGD located adjacent to or proximal to the Padan RDP intrusion sector and also the Thengkham RDP intrusion sector were generally identified by (a) the presence of Au (+Cu-Bi) in gossan or ironstone float rocks in prospect areas (e.g., at Discovery East, Phavat and Phavat North) and also (b) gold in laterite soils ranging from <0.22 up to 1 g/t Au (e.g., at Vang Ngang, Phavat and Phavat North, Table 4.10.1).

Outbound of the Padan and Thengkhan RDP intrusion sectors, distally located SHGD occurring in the Palaeozoic sedimentary basin sequence commonly had (a) gold present within silicified rocks (jasperoid) in float samples or in outcrop ranging from <3.5 and up to 55.9 g/t Au (e.g., at Nalou, Namkok East, Namkok West and Discovery Colluvial) and also (b) coincident Au-As-Sb (+Pb-Zn) anomalies in soil containing up to 0.4 g/t Au (e.g., at Nalou and Discovery West, Table 4.10.1).

In general, the SHGD located proximal or adjacent to RDP intrusions in the Padan and Thenkham RDP sectors exhibit Au (+Cu-Bi) in float samples or gold in laterite, whilst the more distally located SHGD commonly contained gold in jasperoid float and also coincident Au-As-Sb (+Pb-Zn) in soils (Table 4.10.1).

4.2.10.5 Mineralisation characteristics

Smith et al. (2005) report that some of the earliest alteration features present in the SMD SHGD involved a basin wide dolomitisation of carbonate rocks, development of calcite veins and formation of diagenetic pyrite. District-scale dolomitisation is best preserved in the (a) Nalou Formation (bioclastic dolomite) at the Nalou and the Discovery gold deposits (Fig. 4.2.3, Section 4.2.2), and (b) the basal sections of the overlying Discovery Formation calcareous shale at the Discovery West gold deposit (Figs. 4.3.4-4.3.5, Section 4.2.2). Early diagenetic dolomitisation varies from fine-grained through to coarse-grained sparry types that are interpreted by Smith et al. (2005) to have pervasively altered the rheology and chemistry throughout the Sepon basin which also enabled the development of conducive brittle and ductile sites for later fault zones in the SMD, in particular between the Nalou and Discovery Formations, respectively.

Observations of outcrop, open pit exposures and drill core during this study suggest that post-diagenetic sulphide mineralisation styles associated with the SMD SHGD can be grouped into two main areas (a) mineralisation occurring proximal to RDP intrusion centres and (b) mineralisation distally located from RDP intrusion centres. The paragenesis of the
mineral assemblage of these two SMD SHGD styles will be described in Chapter 5.0 but, the main geological observations associated with mineralisation are summarised as follows:

**Distal SHGD mineralisation characteristics:**

- Both vein and breccia styles of sulphide mineralisation occurring in the SMD distal-type SHGD were mostly observed along faults and highly fracture rheological contacts.
- Jasperoid and decarbonatised shale are reported to host the majority of known oxide and hypogene gold in the distally located SMD SHGD at the Nalou, Namkok and Discovery deposits (Manini et al., 2001; Smith, 2003; Smith et al., 2005).
- Early base metal veins (<5 cm wide) and fault breccia containing low gold grades (<2 g/t Au) were observed in drill core and open pit exposures through the (a) Nalou Formation and basal sections of the Discovery Formation, comprising sphalerite-galena-pyrite at the Nalou and Discovery Main deposits (Fig. 4.2.6, Section 4.2.2), and (b) in RDP along faulted contacts between the Nalou or Discovery Formations, comprising galena-sphalerite-pyrite-tetrahedrite at the Discovery Colluvial and Discovery West deposits (Fig. 4.3.5, Section 4.2.3).
- Later stage acicular stibnite also fills fractures in silicified calcareous shale gold ores containing finely disseminated pyrite at the Nalou deposit (Fig. 4.2.6, Section 4.2.2).

**Proximal SHGD mineralisation characteristics:**

- Low grade gold (<3 g/t Au) commonly occurs in fault zone ore intervals containing abundant silica (quartz) and semi-massive pyrite with associated minor base metals in the proximal type SMD SHGD at the (a) Vang Ngang deposit, adjacent to the Padan RDP intrusion sector, and (b) at the Phavat and Phavat North deposits, along the western margins of the Thengkham RDP intrusion sector (Fig. 4.1, Section 4.1; Manini et al., 2001; Smith et al., 2005).
- Skarn altered intervals can also be observed along the eastern margins of the Discovery East SHDG in drill hole DIS023 through the NW-trending Muang Luang Fault adjacent to the Khanong copper deposit, comprising prograde garnet skarn cut by later retrograde stage veins containing quartz and pyrite with minor chalcopyrite (Fig. 4.5.4, Section 4.2.5). However, the bulk of the SHGD mineralisation at the Discovery East deposit occurs in disseminated pyrite type ores hosted by the Discovery Formation calcareous shale.
- SHGD in the Phavat Prospect area can contain at least three types of fault-controlled, gold-bearing mineralisation that occur: (a) commonly quartz and semi-massive pyrite intervals with minor chalcopyrite, (b) laminated quartz veins with massive pyrite and minor chalcopyrite, and (c) quartz and disseminated pyrite hosted by Discovery Formation calcareous shale (Fig. 4.8.2, Section 4.2.8; LXML, 2003; LXML, 2006).
In general, the proximal type SHGD in the SMD located adjacent to large RDP intrusion areas near the Padan or Thengkham sectors commonly contained fault-controlled, sulphide-mineralised intervals with low grade gold associated with (a) abundant silica (quartz) and semi-massive sulphide and minor base metals (e.g., Vang Ngang, Phavat and Phavat North) and can also have (b) retrograde skarn assemblages (e.g., Discovery East).

4.2.10.6 Summary

The following features observed in the SMD SHGD summarise the currently available preliminary surface information on the characteristic geological controls and timing of sulphide mineralisation in these deposits:

- Host rocks for both base and gold mineralisation in the SMD SHGD are: (1) Palaeozoic sedimentary rocks ranging in age from Ordovician through to Early Devonian with the majority of currently known gold resources hosted by the Devonian Discovery Formation, and (2) the faulted margins of rhyodacite-porphyry (RDP) dikes and sills in the Padan to Thengkham sector (Table 4.10.1).

- The SMD SHGD located proximal or adjacent to RDP intrusions in the Padan and Thenkham RDP sectors generally exhibit Au (+Cu-Bi) in float samples or gold in laterite, whilst the outwardly bound and distally located SHGD commonly contained coincident Au-As-Sb (+Pb-Zn) in soils and also gold in jasperoid float.

- Folds, faults and rheological contacts are described by Smith et al. (2005) as being integral structural components in the development of the SMD SHGD. They report that the main structural trends controlling and hosting gold mineralisation in the SMD SHGD are (1) WNW-striking normal faults with steep dips and, (2) steep ENE-striking faults with both normal and reverse movements.

- At least three types of gold ore zone geometries have been observed to date in the SMD by Smith et al. (2005): (a) ribbon-like bodies that are strike continuous, (b) moderate to shallow dipping sheets, not always connected to faults, and (c) fault-controlled, steep sheet-like bodies (Fig. 4.10.1).

- Both base metal and silica-pyrite veins were observed along faults and fractures cutting Ordovician to Devonian sedimentary rocks in the SMD. RDP dykes and sills occurring at the SMD SHGD that range in age between 280 ± 6 Ma to 290 ± 6 Ma are also cut by faults hosting both epigenetic base metal veins and silica (quartz)-semi massive pyrite associated with low-grade gold mineralisation, indicating that these types of mineralisation were formed syn- to post-Early Permian RDP emplacement in the SMD (Table 4.10.1).
4.3 SMD COPPER DEPOSITS

4.3.1 Introduction

Copper resources identified in the SMD include the Khanong, Thengkham South and Thengkham North deposits (Table 4.3.1) and copper prospects identified at Thengkham East and Pha Bing (Fig. 4.3.1.1). Publications by Loader (1999), Manini et al. (2001) and Cannell and Smith (2008) introduce the geological setting of the Khanong copper deposit and company reports by Norris (1999), Bateman (1999), Loader et al. (1999), LXML (2003) and Cannell (2006) briefly describe the geology of both the Khanong and Thengkham copper deposits. This section introduces the geological setting of the Khanong and Thengkham South copper deposits that were also included during this study to investigate the hypogene skarn mineral assemblages hosting copper with associated gold reporting in some of the drill-hole intervals.

![Fig. 4.3.1.1 Map showing the location of known copper resources and prospects in the SMD, including the location of the SMD SHGD (figure courtesy of Oxiana Limited, 2005, www.oxiana.com.au).](image)

Table 4.3.1. Sepon copper resources summary. The copper ore resource values tabulated below comprise the JORC-compliant inferred, indicated and measured resources published in Cannell and Smith (2008).

<table>
<thead>
<tr>
<th>Copper Resource Parameters</th>
<th>Khanong</th>
<th>Thengkham North</th>
<th>Thengkham South</th>
<th>Phabing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supergene Resource</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mt (ore)</td>
<td>25.5</td>
<td>10.4</td>
<td>10.7</td>
<td>2.0</td>
</tr>
<tr>
<td>% Cu</td>
<td>3.5</td>
<td>2.2</td>
<td>1.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Contained Cu (kt)</td>
<td>893</td>
<td>226</td>
<td>149</td>
<td>68</td>
</tr>
<tr>
<td><strong>Ore Type</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chalcolite</td>
<td>&gt;75%</td>
<td>&lt;50%</td>
<td>&lt;50%</td>
<td>None</td>
</tr>
<tr>
<td>Malachite</td>
<td>&lt;25%</td>
<td>&gt;50%</td>
<td>&gt;50%</td>
<td>100%</td>
</tr>
<tr>
<td>Primary (sulphide)</td>
<td>Minor: 130 kt Cu @ 1.2 % Cu</td>
<td>Minor</td>
<td>Minor</td>
<td>None</td>
</tr>
<tr>
<td><strong>Status</strong></td>
<td>Mining</td>
<td>Resource definition completed</td>
<td>Resource definition in progress</td>
<td>Resource definition in progress</td>
</tr>
</tbody>
</table>
4.3.2  Khanong copper deposit

4.3.2.1  Location and background

The centre of the Khanong copper deposit is located at 608000 E and 1875800 N (UTM 48) and is 500m south of the Discovery East gold deposit (Fig. 4.3.2.1). The Khanong deposit is at least 1.5 km long and 0.5 km wide and primarily consists of a copper resource dominantly within a supergene-enriched leached blanket of chalcocite clay with associated malachite, azurite, cuprite, native copper and proximal exotic copper wad (Fig. 4.3.2.1, Loader 1999; Manini et al., 2001; LXML, 2003; Smith et al., 2005; Sillitoe, 2006; Cannell 2006, 2008; Cannell and Smith, 2008). The initial discovery of the Khanong deposit was during reconnaissance surveys by LXML geologists prior to 1995 who reported an ironstone covered area containing up to 0.4% Cu and 2 g/t Au in samples collected from gossans (Manini et al., 2001). Subsequent exploration for porphyry and skarn related copper-gold targets at Khanong identified a NE-trending area (750 long x 400m wide) near the Mount Padan RDP intrusion, comprised of ferruginous soil and sporadic gossan containing open-ended multi-element anomalies with Cu-Au-Pb-Zn-Ag-Bi-As. Soil anomalies in the Khanong area also contain coincident trace-element patterns with Au-Cu-Bi and Cu-Zn-Pb-Ag and also a high uranium and low potassium and thorium radiometric signature (Loader, 1999; Manini et al., 2001).

A preliminary eight hole scout drilling program by LXML at Khanong during late 1995 intersected low-grade gold hosted by an ironstone cap containing <1.5 g/t Au overlying a high-grade copper mineralisation zone with >3.0 % Cu that is hosted by supergene derived chalcocite-bearing clay and minor basal hypogene skarn associated Cu-Au mineralisation in sulphides (Loader, 1999). During 1998 to 1999, a follow-up drilling program of 20 holes at Khanong established an inferred resource of 28 Mt @ 2.6% Cu (Manini et al., 2001). Since 2000, LXML has delineated a NE-trending inferred and indicated resource of 25.5 Mt @ 3.5 % Cu with 0.9 Mt of contained copper metal at Khanong (Table 4.3.1, Cannell and Smith, 2008).

4.3.2.2  Geology and structure

Early interpretations of the geology at the Khanong copper deposit are briefly described in publications by Loader (1999) and Manini et al. (2001). Geological investigations by the author at Khanong involved drill core logging and core sampling of hypogene ores containing gold, but no mapping was able to be conducted due to field investigations being completed prior to the start of open pit mining at this deposit during late 2005. Since the mining for copper ores commenced at Khanong, ongoing open pit geological mapping and resource drilling by LXML geologists has further refined the understanding of the geology at Khanong which is described as being structurally complex and also masked by supergene alteration of the primary host rocks (Cannell, 2006, 2008; Cannell and Smith, 2008). A brief description of the known geology at Khanong is provided in this section based on these reports.
The known copper resource at Khanong occurs in a NE-trending zone that is shown on the district-scale geology map to cover an area composed of (a) basal Nampa Formation siltstone, overlain by (b) the Vang Ngang Formation, comprising interbedded sandstone, claystone, mudstone and siliceous mudstone with minor chert and carbonate units, in turn overlain by (c) Kengkeuk Formation nodular calcareous shale, and (d) Nalou Formation bioclastic dolomite (Fig. 4.3.2.1). A disconformity contact between the Nampa Formation and Nalou Formation is also mapped through the middle of the Khanong deposit (Fig. 4.3.2.1).

The geology of the southern section of Khanong described by Cannell (2006) provides an insight into the stratigraphy hosting copper at this deposit, based on drill core observations. The basal rocks at Khanong south comprise Vang Ngang Formation light to medium grey-green non-metamorphosed interbedded sandstone and siltstone up to 100m thickness, overlain by Kengkeuk Formation purple to green-grey, non-metamorphosed, laminated soapy (illitic) claystone up to 100m thick. The Nalou Formation disconformably overlies the basal Kengkeuk Formation and comprises light to medium grey recrystallised limestone (marble) with variable thicknesses of up to 65m, with some sections containing retrograde skarn (semi-massive sulphide pyrite ± galena-chalcopyrite-sphalerite) and intercalated siltstone beds towards the lower sections. Undifferentiated light grey-orange laminated to massive bedded chert interbedded with hornfels-altered laminated, siltstone overlies the Nalou Formation. An RDP sill containing minor disseminated pyrite and trace molybdenite intrudes the upper sections of this sedimentary sequence (Cannell, 2006).
A large ENE-trending RDP intrusion is mapped to occur between the northern margins of the Khanong copper deposit and the southern margins of the Discovery East gold deposit (Fig. 4.3.2.1). The sedimentary sequence at the Khanong deposit is also known to be intruded by RDP dikes and sills (Figs. 4.3.2.1 and 4.3.2.2; Loader, 1999, Manini et al., 2001; Cannell, 2006). LA-ICPMS U-Pb dating of zircons from a RDP sill in Khanong drill hole KHN013 @ 78.5m depth during this study yielded an age of 283 ± 3 Ma and confirms a similar date to those also obtained from other RDP sills occurring in the SMD SHGD (Table 4.3.1).

The NE margin of the Khanong copper deposit is reported to be bound by the major NW-trending Muang Luang fault (MLFZ) that is interpreted to be a left lateral strike-slip fault dipping steeply to the NE and extends along strike from the Discovery East gold deposit through to the Padan Mo (±Cu) prospect (Fig. 4.3.2.1, Loader, 1999; Manini et al., 2001; Smith et al., 2005). At least three steeply dipping faults with NW-trending fault trends sub-parallel to the main MLFZ are described through the Khanong deposit by Loader (1999). The NW margins of Khanong were interpreted by Loader (1999) to be bound by a northerly dipping NE-trending right lateral strike-slip fault called the Khanong fault. Cannell (2006) reports that bedding measurements throughout the Khanong deposit indicate that sedimentary units strike towards the NE with variable moderate to steep dips towards the NW or the SE, suggesting that a NE-trending anticline may occur through the deposit area.

### 4.3.2.3 Mineralisation

At least three main groupings of copper mineralisation types are reported to occur in the Khanong copper deposit area, namely: (a) supergene, (b) exotic, and (c) hypogene, as summarised in Table 4.3.2 (Loader, 1999; Manini et al., 2001; Cannell, 2006, 2008; Cannell and Smith, 2008). Simplified schematic geology sections from Manini et al. (2001) show the main copper horizons at the Khanong deposit (Figs. 4.3.2.2 and 4.3.2.3).

<table>
<thead>
<tr>
<th>Style (in-situ)</th>
<th>Mineralisation Type</th>
<th>Geochemical signature</th>
<th>% of Cu resource</th>
<th>Average grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ironstone and limonite-clay</td>
<td>All elements elevated</td>
<td>7</td>
<td>0.6 % Cu, 0.6 g/t Au</td>
<td></td>
</tr>
<tr>
<td>Limonite-clay and ironstone with oxidised Cu minerals</td>
<td>Cu-Zn-Ag</td>
<td>15</td>
<td>8.8 % Cu, 45.7 g/t Ag, No Au</td>
<td></td>
</tr>
<tr>
<td>Partially oxidised chalcocite-clay</td>
<td>Cu-Ag</td>
<td>2</td>
<td>2.0 % Cu</td>
<td></td>
</tr>
<tr>
<td>Chalcocite-clay</td>
<td>Cu-Ag (±Bi)</td>
<td>68</td>
<td>4.9 % Cu, 16.9 g/t Ag, No Au</td>
<td></td>
</tr>
<tr>
<td>Mobilised exotic</td>
<td>Mn-oxide and Cu-Mn-wad clay</td>
<td>Cu-Mn-Au</td>
<td>4</td>
<td>1.4% Cu, 24.3 g/t Ag, 0.4 g/t Au</td>
</tr>
<tr>
<td>Hypogene</td>
<td>Skarn associated sulphide</td>
<td>Cu-Au-Ag-Bi</td>
<td>4</td>
<td>2.0 % Cu, 0.3 g/t Au</td>
</tr>
</tbody>
</table>

Table 4.3.2. Khanong copper deposit mineralisation types (adapted from Loader, 1999)
Fig. 4.3.2.2. Geological section through the Khanong copper deposit along line 608250E. (A). Ironstone cap (red). (B). Chalcocite dominant horizon (grey - main Cu ore zone). (C). Exotic copper wad (lime green). (D). Hypogene sulphide zone associated with retrograde skarn (dark green). This figure is modified from Manini et al. (2001).

Fig. 4.3.2.3. Geological section through the Khanong copper deposit along line 608500E. (A). Ironstone cap (red). (B). Chalcocite dominant horizon (grey - main Cu ore zone). (C). Hypogene sulphide zone associated with retrograde skarn (dark green). This figure also shows the location of drill hole KHN013 (modified from Manini et al., 2001).
Supergene type copper ores mostly occur in the hanging wall sequence at Khanong and broadly consist of at least four mineralised horizons, as described by Loader (1999) in the following order from the surface with increasing depth, namely (1) ironstone and limonite clay (oxidised cap rock horizon up to 20m thick, Fig. 4.3.2.4A-B), (2) limonite clay, with minor ironstone and copper oxide minerals (Fig. 4.3.2.4 C), (3) chalcocite clay and limonite clay (intermediate partial oxidation zone), and (4) chalcocite-clay (main supergene copper ore horizon, Table 4.3.2, Figs. 4.3.2.2 to 4.3.2.5).

Grey-black chalcocite-clay is the main copper resource at Khanong, comprising disseminated chalcocite within a matrix of kaolinite-sericite-quartz averaging 4.9% Cu, <17 g/t Ag and containing no significant Au (Table 4.3.2, Loader, 1999). Minor brecciated clasts and aggregates of hypogene semi-massive sulphide with quartz are reported by Loader (1999) to occur throughout the main chalcocite-clay copper ore horizon at Khanong. Sillitoe (2006) reports that significant amounts of chalcocite-enriched and oxidised copper ores at Khanong exhibit clastic origins that are possibly developed from the collapse of material over time into carbonate paleo-karst features during periods of acidic supergene solution generation and dissolution of the surrounding carbonate host rocks.

Exotic copper type mineralisation at Khanong comprises brown-black coloured (a) Cu-bearing manganese oxide (MnO) and (b) Cu-Mn-wad, with average grades of 1.4 % Cu, 24.3 g/t Ag and trace gold (Table 4.3.2). Both of these types of exotic mineralisation can have coatings of associated malachite, azurite, cuprite and native copper. This type of mineralisation is known to develop in a horizon of up to 25m thickness, usually towards the basal portions of the supergene zone, in karsted areas with Cu-rich ground water drainage (Figs. 4.3.2.2 to 4.2.3.5 and Table 4.3.1., Loader, 1999; Manini et al., 2001; Cannell and Smith, 2008).

The footwall mineralisation at Khanong is interpreted to be the precursor of the overlying supergene copper mineralisation derived from the in-situ leaching of Cu-bearing, skarn-associated hypogene sulphide mineralisation (Fig. 4.3.2.2, Norris, 1999; Loader, 1999, Manini et al., 2001; Smith et al. 2005; Sillitoe, 2006; Cannell, 2006, 2008). The Khanong hypogene ore types average 2 % Cu (Loader, 1999). Hypogene copper at Khanong occurs with massive, semi-massive and vein sulphide ore types comprised of (a) pyrite-chalcopyrite and (b) quartz-pyrite-chalcopyrite (Loader, 1999; Manini et al., 2001; Cromie et al., 2004; Smith et al., 2005; Cannell and Smith, 2008). Early prograde garnet-pyroxene skarn is overprinted by retrograde chlorite-epidote-calcite-hematite-sulphide skarn that is in turn cut by retrograde veins comprised of quartz-euhedral pyrite-chalcopyrite (Fig. 4.3.2.5, Cromie et al., 2004; Smith et al., 2005; Cannell and Smith, 2008). Minor chalcopyrite is interstitial to pyrite in the hypogene ores at Khanong (Loader, 1999; Cromie et al., 2007). Loader (1999) notes that pyrite in the upper sections of the Khanong hypogene zones can be replaced by supergene chalcocite. No visible gold is reported in any of the Khanong copper ore types.
Fig. 4.3.2.4: Photographs showing characteristics of supergene mineralisation at the Khanong copper deposit. (A). View of ironstone, limonite gossan and ferruginous soil covering the Khanong copper resource (pre-mining, 2004). (B). View towards the eastern end of the Khanong copper deposit open pit showing the upper ironstone zone (orange horizon), chalcocite-clay-copper (Cu) oxide horizon (green-grey zone) and chalcocite-clay main copper ore zone (grey area). (C). Close up view of grey chalcocite-clay copper ore from the area shown in (B). (D). Native copper sample collected from the copper-oxide zone represented in Fig. 4.3.2.2. (E). Prismatic crystals of dark red-brown cuprite collected from the copper oxide-zone in (B). (F). Botryoidal textured blue azurite sample with minor associated malachite (light green) from the copper oxide zone. (G). A polished slab showing the botryoidal textural characteristics of dark-green malachite from the copper oxide zone at Khanong.
Fig. 4.3.2.5. Photographs showing nature of supergene and skarn associated mineralisation along DDH KHN013 at the Khanong copper deposit. (A). Supergene copper interval from 67 to 70m depth with chalcocite clay (grey) ranging in grade from 2.2 to 10 % Cu. (B). High grade chalcocite-clay section at 68 m depth with 10 % Cu, 4.4 g/t Ag and <0.02 g/t Au. (C). Transition zone between the overlying supergene chalcocite-clay blanket containing copper and basal skarn (SKN) associated hypogene copper hosted in a dolomitised limestone (DLM) interval from 72.7 to 75.5m depth. (D). Close up view of retrograde skarn altered dolomitised limestone (DLM) with semi-massive pyrite (PY) containing 1 % Cu, 1.1 % Zn and no Au at 73.7m depth. (E). Skarn altered limestone - SKN (LST) with retrograde infiltration veins (Stage 2B), overprinting prograde garnet alteration (Stage 1) and retrograde chlorite-epidote alteration (Stage 2A) at 101 to 106.2m depth. (F). Close up view of a sample at 105m depth with pink Stage 1 prograde garnet (Gar) overprinted by Stage 2 retrograde chlorite-epidote (Chl-epi), in turn cut by Stage 2B veins comprising quartz (qtz)-calcite (cal)-pyrite (py)-sphalerite (sp). (G). Retrograde skarn altered limestone - SKN (LST) with pervasive Stage 2B alteration comprising quartz (qtz)-calcite (cal)-pyrite (py)-sphalerite (sp). (H). Close up view of a sample at 117m depth containing Stage 2B retrograde skarn alteration comprising quartz (qtz)-calcite (cal)-pyrite (py)-sphalerite (sp) overprinting Stage 2A chlorite-epidote alteration (green)
4.3.3 Thengkham South copper deposit

4.3.3.1 Location and background

The greater Thengkham copper resource area occurs along the margins of an ENE-trending ridge with quartz-stockwork veined RDP intruding a large-scale anticline of sedimentary rocks in an area that is 5 km long by 2 km wide located 596000E to 601000E and 1873500N to 1875500N (UTM 48, Figs. 4.3.1.1 and 4.3.3.1, LXML, 2003, Smith, 2004, Cannell, 2005; Cannell and Smith, 2008). The Sepon gold and copper production plant site is located approximately 9 km east of the centre of the Thengkham area (Smith, 2004; Cannell, 2005). Three main copper deposits are reported to collectively comprise the greater Thenkham copper resource area, namely Thengkham South. Thenkham North and Phabing (Fig. 4.3.3.1, LXML, 2003; Smith, 2004; Cannell, 2005; Cannell and Smith, 2008). This section only provides geological information about the Thengkham South copper deposit that was investigated by the author through drill core logging and sampling of sulphide ores intervals containing both copper and gold. The Thengkham South copper deposit is located between 597000E to 601000E and 1873500N to 1875500N (Figs. 4.3.3.1 and 4.3.3.2).

Fig. 4.3.3.1. Geological map of the greater Thengkham copper resource area, showing the locations of the Thengkham South, Thengkham North and Phabing copper deposits (green copper resource outlines) and the Phavat gold deposits (red dashed gold resource outlines). Abbreviations: NKM FM = Nam Kian Formation: interbedded shale and chert; NKM FM (black area) = Nam Kian undifferentiated shale and chert; DIS FM = Discovery Formation: calcareous shale (CSH); NLU FM = Nalou Formation: bioclastic dolomite (DOL); KGK FM = Kengkeuk Formation: nodular calcareous argillite; MEZ = Mesozoic: Khorat Basin sediments, RDP = rhyodacite-porphyry, Thick black lines represent faults.
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The initial discovery of copper potential in the greater Thengkham copper resource area was during a preliminary exploration program by LXML in 1995 which identified skarn-associated and supergene-enriched copper zones along the southern and northern flanks of the Thengkham ridge (Fig. 4.3.3.1). Elevated Mo and low gold and copper anomalism occurs in soils over stockwork centres associated with RDP and also red soils with high values of >1,000 ppm Cu occur in areas coincident with skarn and ironstone outcrops overlying altered calcareous sedimentary rocks at Thengkham (Norris, 1999). Strong Induced Polarisation (IP) charges are reported by Norris (1999) to occur over RDP rocks containing disseminated pyrite in the Thengkham area. Several small zones containing (a) sulphide skarn, (b) chalcocite-dominant sulphide bodies and (c) graphitic calcareous shales were also identified during CSAMT surveys at Thengkham (Norris, 1999).

Preliminary drilling during 1995 by LXML at Thengkham tested for porphyry-skarn related mineralisation which indicated the presence of gold poor molybdenum-copper mineralisation at this prospect. However, drill hole TKM002 intersected 15m @ 4.3 % Cu from 62m depth, confirming the presence of supergene copper occurring above skarn mineralisation in the Thengkham South prospect area (Manini et al., 2001). Further drilling by LXML from 1998 to 1999 outlined a preliminary resource of up to 400,000 tonnes of contained copper metal (ctm) hosted by massive sulphide and supergene ore types at Thengkham South (Manini et al., 2001). Resource drilling prior to mining is in progress by LXML at Thengkham South and has delineated an inferred supergene copper resource of 10.7 Mt. ore averaging 1.4 % Cu (149,000 t ctm) at 0.5 % Cu cut-off grade (Table 4.3.1; Cannell and Smith, 2008).

4.3.3.2 Geology and structure

The understanding of the geological setting in the Thengkham South Prospect area is not well-constrained due to extensive soil and scree cover in the prospect area. Company reports by LXML (2003), Smith (2004) and Cannell (2005) and a publication by Cannell and Smith (2008) provide insights into the geology of the Thengkham South prospect area through drill hole logging and mapping observations. The Thengkham South stratigraphy is reported to be complex and poorly understood (Smith, 2004). The Thengkham South copper resource is mostly located along the faulted southern margins of a large ENE-trending body of RDP (Figs. 4.3.3.1 and 4.3.3.2). Geological mapping by LXML geologists at Thengkham South since 2006 shows this body of RDP intruding a faulted stratigraphic sequence defined by a large anticline comprising the following oldest to youngest formations, commencing with the: (a) Kengkeuk Formation nodular calcareous shale, (b) Nalou Formation bioclastic dolomite, (c) Discovery Formation calcareous shale, and (d) Nam Kian Formation interbedded chert, siltstone and sandstone (Fig. 4.3.3.2). The Kengkeuk Formation is lower green-schist metamorphosed, is steeply dipping and occurs in the core of the anticline (Cannell and Smith, 2008).
Steep normal faults and strike-slip faults are reported as the dominant structures in the Thengkham copper resource area (Marten, 1998a, b, Coller, 1999, Norris, 1999, Smith 2004; Cannell and Smith, 2008). The earliest fault generation described at the Thengkham South deposit is the extension of the ENE-trending Thengkham-Nalou-Namkok-Nampa fault (TNNN) that is interpreted to continue from the Nalou gold deposit and is reported to have been observed in widely spaced drill holes in this prospect area (Fig. 4.3.3.2, Marten, 1998a, b, Coller, 1999, Norris, 1999, Smith 2004). The TNNN fault is described by Smith (2004) to dip moderately towards the north in the western sector of the Thengkham South prospect area then dips steeply towards the south in the eastern sector. Later stage strike slip faults with NW-trends are interpreted to cut earlier ENE-trending faults and divide the sedimentary package along the flanks of the Thengkham South prospect area into several blocks (Fig. 4.3.3.2; Smith, 2004; Cannell and Smith, 2008). The overall understanding of the structural setting, bedding orientations and stratigraphic contacts is currently not well constrained due to the paucity of available outcrop and drill core in the Thengkham South prospect area (Smith, 2004).

Fig. 4.3.3.2. Geological map of the Thengkham South copper deposit area, showing the location defined copper resources (green outlines). The western end of the Thengkham North copper prospect area is also shown (top left hand side of map, green copper resource outline) and also the outline of the Phavat gold deposits (red dashed gold resource outlines). The locations of drill holes logged and sampled by the author during this project are represented by the red circles along section lines (blue). **Abbreviations:** NKM FM = Nam Kian Formation: interbedded shale and chert; NKM FM (black area) = Nam Kian undifferentiated shale and chert; DIS FM = Discovery Formation: calcareous shale (CSH), NLU FM = Nalou Formation: bioclastic dolomite (DOL), KGK FM = Kengkeuk Formation: nodular calcareous argillite, RDP = rhyodacite-porphyry, Thick black lines represent faults.
4.3.3.3 Mineralisation

At least three main types of rocks are reported to host sulphide mineralisation in the Thengkham South area, namely (a) RDP dykes that are strongly altered by sericite and can also typically contain networks of quartz-veins with minor pyrite and chalcopyrite and traces of molybdenite (Figs. 4.3.3.3 and 4.3.3.4, LXML, 2003, Smith, 2004), (b) dolomite rocks that were originally bioclastic limestone and are similar to the Nalou Formation, that are altered by later retrograde skarn sulphide-bearing assemblages in some places (Smith, 2004), and (c) bedded black shale and calcareous shale containing pyrite, similar to the Kengkeuk Formation (Smith, 2004). The Nalou Formation dolomites and the Kengkeuk Formation are the main host-rocks to copper mineralisation at Thengkham South. Calcareous sediments adjacent to RDP are variably altered to prograde garnet skarn, where as non-calcareous sediments show signs of diopside and biotite hornfels alteration, both of which are over-printed by patchy chlorite dominant retrograde skarn (LXML, 2003, Smith, 2004; Cannell and Smith, 2008).

At least four broadly defined mineralisation types are reported to occur in the Thengkham South area: (1) disseminated low grade primary porphyry associated Cu-Mo mineralisation in stockwork veins; (2) prograde and retrograde skarn with disseminated to massive sulphides occurring in pods (Fig. 4.3.3.3); (3) overlying chalcocite clay occurring in lenses and pods (Fig. 4.3.3.3), and; (4) exotic Mn-Cu wad covering areas down slope of hydraulic gradients (Norris, 1999, Loader et al. 1999, Smith 2004; Cannell and Smith, 2008).

Massive sulphide mineralisation intersected along the TNNN fault zone at Thengkham South is up to 100m thick, contains between 0.5 to 1 % Cu and is inferred to be a proto-ore type for the development of supergene enriched copper mineralisation along structural zones at this deposit (Norris, 1999; Smith, 2004; Cannell and Smith, 2008). The overlying chalcocite zones are also reported to be controlled by RDP geometries, often forming troughs and pods (Cannell and Smith, 2008). Irregular karsts can also contain up to 50m thick breccia infill with associated exotic copper ore types containing up to 10 % Cu (Cannell and Smith, 2008).

Detailed paragenetic descriptions of the hypogene mineralisation observed at Thengkham South are presented in Chapter 5. However, at least five mineral assemblage paragenetic stages were observed by the author from the logging of Thengkham South drill core, as summarised below and in Fig. 4.3.3.5:

- Stage 1: Prograde garnet (grossular) alteration occurs mostly within carbonate intervals, with diopside and biotite hornfels alteration occurring in non-calcareous sedimentary rocks,
- Stage 2: Early retrograde base metal skarn, comprising at least two sub-stages:
  - Stage 2A: Strong retrograde chlorite-epidote alteration overprints Stage 1, and
  - Stage 2B: Infiltration veins with quartz-chlorite-epidote-pyrite
- Stage 3: Quartz infiltration veins with pyrite+chalcopyrite+hematite, overprints Stages 1 – 2:
- Stage 4: Carbonate infiltration vein development with two sub-stages, overprints Stages 1 -3:
  - Stage 4A: Early carbonate veins with quartz+pyrite, and;
  - Stage 4B: Late pink carbonate veins (no sulphides), overprinting all stages.
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Fig. 4.3.3.3. Cross-section line 597100mE showing copper mineralised intervals and skarn zones at the Thengkham South copper deposit (courtesy of LXML).

Fig. 4.3.3.4. Photographs showing nature of supergene, skarn and sulphide mineralisation at the Thengkham South copper deposit. (A). Red soil containing indications of copper along the flanks of skarn lithologies near rhyodacite porphyry intrusions (RDP) at the Thengkham South copper deposit. (B). Iron rich clays containing supergene copper mineralisation comprising chalcocite (grey) and copper oxides (green malachite) in drill hole TKM002 with the interval @ 68.4m containing 21.5 % Cu. (C). Prograde garnet skarn Dark orange-red-green prograde garnet skarn (Stage 1) cut by retrograde skarn veins containing milky white quartz veins (qtz) with associated chlorite (chl)-epidote (epi)-pyrite (py) in drill hole TKM047 from 100m to 104m depth. (D). Potassic altered RDP cut by milky white quartz stockwork veins with minor grey molybdenite in drill hole TKM022 from 45.8 to 48.5m depth.
Fig. 4.3.3.5. Photographs showing characteristics of skarn mineralisation and paragenetic Stages 1 to 4 observed in Thengkham South drill hole TKM035. (A). Pervasive tan-pink coloured prograde garnet skarn alteration (Stage 1) of calcareous shale from 53.5 to 58m depth. (B). Close up view of the Stage 1 prograde garnet skarn alteration shown in (A) at 54.8m depth. Note the minor light green chlorite-epidote alteration (Stage 2A) filling voids and rimming individual Stage 1 garnets. (C). Close up view of Stage 1 tan-pink coloured prograde garnet (gar) and Stage 2A light-green chlorite-epidote alteration cut by Stage 2B infiltration veins containing quartz (qtz)-chlorite (chl)-epidote (epi)-pyrite (py). Sample from 55.8m depth. (D). Hornfelsed calcareous shale (dark green-grey) with patchy Stage 1 prograde pink garnet (gar) alteration and Stage 2A light-green chlorite (chl)-epidote (epi) alteration, in turn cut by Stage 2B infiltration veins with (qtz)-chlorite (chl)-epidote (epi)-pyrite (py). Sample from 62.4m depth. (E). Interval of endo skarn altered rhyodacite porphyry (RDP) from 43.5 to 47.3m depth. (F). A close up view of endo skarn altered RDP cut retrograde skarn infiltration veins comprising Stage 3 quartz (qtz)-calcite (cal)-pyrite (py)-chalcopyrite (cpy)-hematite (hm), in turn cut by Stage 4 quartz (qtz)-calcite (cal)-pyrite (py). Sample at 47.0m depth.
4.3.4 Padan Prospect (Cu-Mo)

4.3.4.1 Location and Background

The Padan Cu-Mo Prospect area occurs along an ENE-trending ridge at Mount Padan located between 609000E to 611000E and 1875000N to 1876000N (UTM 48). The Khanong copper deposit is located one kilometre west of the Padan Prospect (Figs. 4.3.4.1 and 4.3.4.2). Exploration by LXML geologists in 1994 identified a 2 km long x 1km wide area with a coincident Cu-Mo soil anomaly that also has RDP and silicified sedimentary float rocks containing quartz stockwork veins with traces of molybdenite (Norris, 1999). Two drill holes have been completed at Padan Prospect to date, namely PDN001 and PDN002 (Fig. 4.3.4.1).

During 1995, diamond hole PDN001 was drilled at the centre of the Padan Cu-Mo anomaly to test the tenor for Cu-Mo-Au mineralisation of an inferred porphyry stock (Fig. 4.3.4.1, Norris, 1999). No significant results were obtained, with PDN001 intersecting a highly silicified sandstone, siltstone and shale sequence with quartz stockwork veins containing sub-economic traces of chalcopyrite and molybdenite at depth. Follow-up exploration during 1999, involving an interpretation of radiometric data by LXML geologists, identified an E-W trending alteration zone occurring at the Padan Prospect (i.e. 1.5 km long x <1 km wide) containing a radiometric K-U-Th low area, inferred to be a leached zone, and a high potassium zone towards the middle of the prospect area (Norris, 1999; Manini et al., 2001).
The second Padan Prospect diamond drill hole PDN002 was completed by LXML in 1999 to test for a chalcocite enrichment blanket in an area containing (a) strong Mo and low Cu levels in soil and (b) outcrops of quartz stockwork veined sandstone. No significant mineralisation was intersected in PDN002 and a chalcocite blanket was not identified. Only minor molybdenite was observed in PDN002, which also contained a similar altered sequence to PDN001 (Fig. 4.3.4.3, Norris, 1999). Drill core logging and sampling of the hypogene sulphides for mineral paragenesis investigations to determine if gold occurs at this prospect was the primary methods of study conducted by the author from both PDN001 and PDN002.

4.3.4.2 Geology and structure

The stratigraphy and structural setting at the Padan Prospect is not well-constrained due to a current paucity of drill holes in the area and also a lack of rock exposures masked by a predominance of soil cover at this prospect. The district-scale SMD geology map shows NW-trending faults dissecting a sedimentary sequence comprised of (a) basal Houay Bang Formation calcilutite and sandstone, overlain by (b) Nampa Formation siltstone and, in turn overlain by (c) the Vang Ngang Formation, comprising interbedded sandstone, claystone, mudstone with minor chert and carbonate units (Fig. 4.3.4.1). Reports of intensely silicified and stock-worked veined sandstone with interbedded laminated siltstone and shale, inferred to belong to the Houay Bang Formation were initially observed at surface by LXML geologists during reconnaissance mapping and confirmed by subsequent drilling at the Padan Prospect (Fig. 4.3.4.1; Norris, 1999). A WNW-trending body of rhyodacite porphyry (RDP) is shown as intruding the sedimentary sequence near drill hole PDN002 at Padan. RDP has not been reported to crop out at surface to-date, but was confirmed when it was intersected in hole PDN002 at 172m depth (Fig. 4.3.4.3). The NW-trending Muang Luang fault is also interpreted to cut RDP in the Padan prospect area (Fig. 4.3.4.1, Norris, 1999).

Fig. 4.3.4.2. Easterly view towards Mt Padan (horizon) and the Padan Cu-Mo Prospect area in the SMD. The Discovery Colluvial gold deposit open pit (left) and the LXML Sepon gold and copper mining operations production area (right) are shown in the foreground.
4.3.4.3 Mineralisation

Reports for drill holes PDN001 (LXML, 1995) and PDN002 (LXML, 1999) together with the author’s drill hole logging currently provide the only known information about the rock-types, alteration and mineralisation occurring below surface at Padan prospect (Appendix 4.2). Drill hole PDN001 intersected a weakly mineralised Mo-Cu zone in a 25 meter interval from 171.8 to 196.9m down-hole depth, containing quartz-chlorite-sulphide tectonic breccia composed of dismembered quartz veins and stockwork veined laminated sandstone, siltstone and shale clasts in a matrix of quartz-chlorite-pyrite with minor chalcopyrite and molybdenite. Sulphide mineralisation intersected in PDN001 is considered to be weakly Mo mineralised, ranging from >40 ppm Mo to 1020 ppm Mo, with low copper tenor from <0.19 % to 0.48 % Cu and poor gold grades <0.03 ppm Au throughout this hole (LXML, 1995; Appendix 4.2A).

Drill-hole PDN002 intersected minor amounts of sub-economic molybdenite and chalcopyrite that mostly occurs along the margins or in the central zones of quartz veins, commencing from 110m depth to 313.7m (Fig. 4.3.4.3; LXML, 1999). Mineralised intervals in PDN002 generally contained (a) molybdenite ranging from >5 ppm Mo and up to 945 ppm Mo, (b) low copper values from <0.11 to 0.15 and (c) poor gold grades <0.06 ppm Au (LXML, 1999; Appendix 4.2B).

Detailed mineral assemblage paragenesis descriptions for the Padan prospect area will be presented in Chapter 5.0. At least four mineral assemblage paragenetic stages were observed during this study from the author’s drill core logging of Padan hole PDN002, comprising:

**Stage 1:** Potassium feldspar (K-spar) alteration of RDP

**Stage 2:** Sericite-chlorite alteration overprints altered RDP

**Stage 3:** Retrograde infiltration veins cut altered RDP (4 sub-stages):

- **Stage 3A:** Early quartz veins with K-spar alteration along vein margins,
- **Stage 3B:** Quartz-euhedral pyrite veins,
- **Stage 3C:** Quartz-chlorite-epidote-molybdenite-chalcopyrite-hematite
- **Stage 3D:** Late quartz-carbonate-veins, and

**Stage 4:** Massive quartz veins (Fig. 4.3.4.3).
Fig. 4.3.4.3. Textural features, including characteristics of alteration and mineralisation along drill hole PDN002 at the Padan Prospect. 

(A). Photograph of drill core from hole PDN002 showing massive Stage 4 quartz (QTZ) veins (white) pervasively replacing RDP that is altered by Stage 2 sercite-chlorite in an interval from 170 to 173 m depth. 

(B). Photograph of drill core sample PDN0021700 from hole PDN002 @ 170.0 m depth showing Stage 4 massive quartz (QTZ) with minor fractures filled by iron oxides (red-brown). 

(C). Photograph of RDP in drill core from hole PDN002 between 220 to 223m depth at Padan Prospect. The rhyodacite porphyry (RDP) shown is altered by Stage 2 cream to pale-green coloured sercite (ser) and trace lime-green chlorite (chl), in turn cut by Stage 3 quartz veins. 

(D). Photograph of drill core sample PDN0022036 showing Stage 2 sercite-chlorite altered (ser-chl) RDP cut by (i) Stage 3B veins with quartz (QTZ) and euhedral pyrite (>2 mm diameter), in turn crushed and filled by (ii) Stage 3C quartz (qtz)-pyrite (py)-chalcopyrite (cpy)-molybdenite (mo) along a vein. 

(E). Photograph of RDP in drill core from hole PDN002 between 292 to 296m depth at Padan Prospect. Note, the RDP shown is altered by light brown-red coloured Stage 1 potassium feldspar (K-spar). Stage 3A quartz veins (white) also cut RDP in this interval. 

(F). Photograph of Padan Prospect drill core sample PDN0022846 from hole PDN002 @ 284.6 m. The potassium altered (K-spar) RDP shown in this sample contains rounded quartz phenocrysts (white). Linear-type Stage 3C quartz veins (qtz) cut the RDP shown and comprise minor brass coloured pyrite (py), chalcopyrite (cpy) and dark-grey molybdenite (mo), including traces of chlorite and hematite.
4.3.5 Discussion of the SMD copper deposits geology and mineralisation

4.3.5.1 Introduction

The geological characteristics of the SMD copper deposit investigated by the author during this study are herein discussed in order to summarise the geological and mineralisation controls involved with the development of the Khanong and Thengkham South copper deposits and also the Padan (Cu-Mo) Prospect. Previous information about the similarities and differences between the SMD copper deposits presented in this section is also sourced from publications by Loader (1999), Manini et al. (2001), Smith et al. (2005) and Cannell and Smith (2008) and Company reports by Norris (1999), Bateman (1999), Loader et al. (1999), LXML (2003) and Cannell (2006, 2008). Table 4.3.3 provides a summary of the known geological features present in the SMD copper deposits that are discussed in the sections to follow.

4.3.5.2 Host rocks

The hypogene and supergene copper resources occurring in the SMD copper deposits are reported to be predominantly hosted by calcareous rock types, mainly the Devonian Nalou Formation dolomitised bioclastic limestone and the Silurian-Devonian Kengkeuk Formation nodular calcareous shale at both the Khanong and Thengkham South copper deposits (Fig. 4.3.1 and Table 4.3.3; Loader, 1999; Manini et al., 2001; Smith et al., 2005; Cannell and Smith, 2008). Minor amounts of hypogene and supergene copper are also hosted in the Devonian Discovery Formation calcareous shale at the Thengkham South copper deposit (Norris, 1999; Cannell, 2006, 2008). Traces of hypogene copper mineralisation at Padan Prospect mainly occurs in rhyodacite porphyry (RDP) hosting retrograde veins comprising quartz-chlorite-chalcopyrite-molybdenite-hematite (Table 4.3.3, Fig., 4.3.1). The U-Pb zircon age of the RDP intrusions at the SMD copper deposits ranges from $283 \pm 3$ Ma at Khanong to $287.8 \pm 2.5$ Ma at both Thengkham South and Padan (Table 4.3.3).

4.3.5.3 Structural controls

Both the Khanong and Thengkham South copper deposits and also the Padan (Cu-Mo) Prospect are either bound or occur adjacent to major strike-slip faults (Table 4.3.3.; Loader, 1999; Cannell, 2006, 2008; Cannell and Smith, 2008). The NW-trending Muang fault is a steep NE-dipping left lateral strike-slip fault that cuts the stratigraphy at the Padan Prospect and also bounds the northern margins of the Khanong deposit. The Khanong fault is a steeply dipping right lateral strike-slip ENE-trending fault with that bounds the SE margins of the Khanong copper deposit. A similar steeply dipping ENE-trending right-lateral strike slip fault locally named at the Thengkham-Nalou-Namkok-Nampa (TNNN) cuts through the stratigraphy hosting the Thengkham South copper deposit along the southern limb of a broad ENE-trending anticline (Table 4.3.3.).
## Table 4.3.3. Comparison of geological and mineralisation characteristics of the SMD copper deposits

<table>
<thead>
<tr>
<th>Location (UTM 48)</th>
<th>Thengkham South Cu Deposit</th>
<th>Khanong Cu Deposit</th>
<th>Padan Cu-Mo Prospect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>598000 E; 1874000 N</td>
<td>608000 E; 1875800 N</td>
<td>610500 E; 1875500 N</td>
</tr>
<tr>
<td>Host rocks</td>
<td>Nalou FM and Kengkeuk FM (major); Discovery FM (minor); RDP fractures (trace)</td>
<td>Nalou FM and Kengkeuk FM (major); Discovery FM (minor); RDP fractures (trace)</td>
<td>RDP (major); Nampa FM and Vang Ngang FM (trace)</td>
</tr>
<tr>
<td>Intrusion type &amp; age</td>
<td>RDP: 287.8 ± 2.5 Ma</td>
<td>RDP: 283.0 ± 3.0 Ma</td>
<td>RDP: 287.0 ± 2.0 Ma</td>
</tr>
<tr>
<td>Structural controls</td>
<td>The deposit occurs along the southern flanks of a broad ENE-trending anticline. The ENE-trending Thengkham-Nalou-Namkok-Nampa (TNNN) fault is steeply dipping and cuts the southern margins of this anticline. In turn, later NW-trending faults cut all earlier structures.</td>
<td>The Muang Luang Fault, a steeply dipping NW-trending left lateral strike slip fault bounds the deposit northern margin. The Khanong Fault, a right-lateral strike-slip fault bounds the deposit SE margin.</td>
<td>The Muang Luang Fault, a steeply dipping NW-trending left lateral strike slip fault cuts the stratigraphy in the prospect area</td>
</tr>
<tr>
<td>Supergene Cu ore zone geometry</td>
<td>Four irregular bodies with a combined strike of 2000m long x 100m wide x 50m thick (Cannell and Smith, 2008)</td>
<td>Sheet 1500m long x 500m wide x 50m thick (Cannell and Smith, 2008)</td>
<td>Not identified to date</td>
</tr>
<tr>
<td>Geochemistry (surface)</td>
<td>Elevated Mo and low Au and copper anomaly occurs in soils over stockwork centres associated with RDP. Red soils with high values of &gt;1,000 ppm Cu also occur in areas coincident with skarn and ironstone outcrops overlying altered calcareous sedimentary rocks.</td>
<td>Gossan and iron stone float along Khanong creek contained up to 0.4% Cu and 2 g/t Au (Manini et al. 2001). Soil anomalies can have coincident trace-element patterns with Au-Cu-Bi or Cu-Zn-Pb-Ag</td>
<td>Coincident Cu-Mo soil anomaly occurs in a 2 km x 1km area that also comprised surface float samples with quartz stockwork veins containing traces of molybdenite.</td>
</tr>
<tr>
<td>Alteration (host rock)</td>
<td>Prograde garnet skarn with associated minor pyroxene-potassium feldspar alteration of carbonate rocks and hornfels alteration of siltstone (Stage 1). Retrograde chlorite-epidote (Stage 2A) over prints Stage 1.</td>
<td>Prograde garnet skarn with associated minor pyroxene-potassium feldspar alteration of carbonate rocks and hornfels alteration of siltstone (Stage 1).</td>
<td>Prograde potassium feldspar (K-spar) alteration of RDP (Stage 1). Retrograde sericite-chlorite alteration (Stage 2A) overprints Stage 1.</td>
</tr>
<tr>
<td>Hypogene mineralisation (drill core)</td>
<td>Retrograde infiltration veins, comprising: Stage 2B quartz-chlorite-epidote-pyrite, Stage 2C (not observed), Stage 3 quartz-pyrite-chalcopyrite-bornite-molybdenite-hematite, Stage 4 quartz-pyrite, Stage 5 calcite</td>
<td>Retrograde infiltration veins, comprising: Stage 2B quartz-chlorite-epidote-pyrite, Stage 2C sphalerite-galena, Stage 3 quartz-pyrite-chalcopyrite-molybdenite, Stage 4 (not observed), Stage 5 calcite-quartz-fluorite</td>
<td>Retrograde infiltration veins, comprising: Stage 2B (not observed), Stage 3A quartz-potassium feldspar, Stage 3B quartz-pyrite, Stage 3C quartz-chlorite-epidote-molybdenite-chalcopyrite-hematite, Stage 3D quartz-carbonate, Stage 4 massive quartz</td>
</tr>
<tr>
<td>Supergene mineralisation (open pits and core)</td>
<td>Chalcocite, malachite, azurite, cuprite, native copper</td>
<td>Chalcocite, malachite, azurite, cuprite, native copper</td>
<td>Not identified to date</td>
</tr>
</tbody>
</table>
4.3.5.4  Surface trace-element associations

Surface trace element indicators have also aided exploration programs during the discovery of the SMD copper deposits via the initial stream sediment surveys and subsequent follow-up red soil, float rock and outcrop sampling geochemical programs Table 4.3.3.; Agnew, 1998; Norris, 1999; Loader, 1999; Loader et al., 2001; Manini et al., 2001; Smith et al., 2005; Cannell and Smith, 2008). The Padan (Cu-Mo) Prospect was identified by a combination of red soil mapping, delineation of coincident Cu-Mo in red soils and the presence of surface float rock containing quartz stockwork veins with traces of molybdenite (Norris, 1999). The SMD copper deposits located adjacent to or proximal to the Padan RDP intrusion sector and also the Thengkham RDP intrusion sector were mainly identified by (a) the presence of Au or Cu in gossan or ironstone float rocks at both the Khanong and Thengkham South copper deposits (Norris, 1999; Loader, 1999; Manini et al., 2001; LXML, 2003). Gossan and ironstone float along Khanong creek contained up to 0.4 % Cu and 2 g/t Au (Manini et al., 2001). Soil surveys at the Khanong deposit identified coincident trace element patterns comprising Cu-Au-Bi or Cu-Zn-Pb-Ag (Table 4.3.3; Manini et al., 2001). More than 1000ppm Cu can occur in the red soils at the Thengkham South deposit (Norris, 1999).

4.3.5.5  Alteration

Alteration of the RDP host rocks at the Padan Prospect, centrally located at the Padan intrusion sector, predominantly comprise early prograde potassium feldspar alteration (Stage 1). Later retrograde sericite-chlorite alteration (Stage 2A) in turn overprints earlier Stage 1 alteration of the RDP host rocks at Padan (Table 4.3.3). The Khanong and Thengkham copper deposits located adjacent to or proximal to the Padan RDP intrusion sector and also the Thengkham RDP intrusion sector, respectively differ in that they both contain early prograde garnet skarn alteration (Stage 1) with associated pyroxene and biotite alteration of carbonate host rocks, including hornfels in siltstones. In turn, retrograde chlorite-epidote alteration (Stage 2B) overprints the Stage 1 alteration at both the Khanong and Thengkham South deposits (Table 4.3.3).

4.3.5.6  Mineralisation characteristics

Hypogene mineralisation is predominantly confined to the infiltration vein generations at Khanong, Thengkham South and Padan (Table 4.3.3.). The infiltration vein assemblages at the centrally situated Padan Prospect consist of at least 5 stages, namely Stage 3 (A to D) and Stage 4 that overprint alteration Stages 1 to 2A. In turn, the Padan vein assemblages comprise: Stage 3A quartz-potassium feldspar, Stage 3B quartz-pyrite, Stage 3C quartz-chlorite-epidote-molybdenite-chalcopyrite-hematite, Stage 3D quartz-calcite and Stage 4 massive quartz.
The Khanong and Thengkham South deposits share similarities with the five retrograde hypogene infiltration vein stages observed at Padan, but differ slightly in that they also contain minor sphalerite, galena and fluorite (Table 4.3.3). In turn, the combined retrograde infiltration veins at Khanong and Thengkham South comprise Stage 2B quartz-chlorite-epidote-pyrite, Stage 2C sphalerite-galena, Stage 3 quartz-chlorite-epidote-molybdenite-chalcopyrite-hematite, Stage 4 quartz-pyrite and Stage 5 quartz-calcite-fluorite. Both Loader (1999) and Cannell and Smith (2008) report that the hypogene mineralisation at the Khanong and Thengkham copper deposits is both spatially and temporally associated with the intrusion of RDP and also suggest that hypogene mineralisation provides a potential source of metals for the supergene copper zones that overlie these deposits.

The complex interplay between carbonate host rocks, retrograde skarn sulphide mineralisation, hydrology and weathering is described as contributing towards the development of the supergene copper zones at these deposits (Loader, 1999; Cannell and Smith, 2008). At the Khanong deposit, supergene copper is predominantly associated with a chalcocite blanket (>75 % of the Cu resource) and the remainder occurs with basal exotic copper ores comprising malachite, azurite and cuprite (Tables 4.3.1 and 4.3.3; Loader, 1999; Cannell and Smith, 2008). Pods of chalcocite (50 % of the copper resource) and exotic copper ores are described for the supergene ore zones at Thengkham South (Tables 4.3.1 and 4.3.3; Cannell and Smith, 2008).

4.3.5.7 Summary

The following features observed in the SMD copper deposits summarise the currently available surface information on the geological and mineralisation characteristics:

- Host rocks for copper mineralisation in the SMD are predominantly of the Devonian Nalou Formation dolomitised bioclastic limestone and Kengkeuk Formation calcareous shale (Table 4.3.3). The faulted margins of rhyodacite porphyry (RDP) also host some copper.
- Potential surface indicators towards supergene copper include, Au and/or Cu anomalous gossanous or lateritic iron stones, red soils with coincident anomalous Cu-Au-Bi or Cu-Zn-Pb-Ag and surface float rocks containing traces of molybdenite in quartz stockwork veins.
- Copper deposits and prospects are commonly bound or occur adjacent to major NW-trending and/or ENE-trending strike-slip faults (Table 4.3.3).
- Prograde garnet-pyroxene-biotite skarn alteration occurring proximal to RDP intrusions, commonly precedes retrograde skarn stage copper-bearing infiltration veins (Table 4.3.3).
- Hypogene copper mineralisation at Padan, Khanong and Thengkham is predominantly associated with retrograde skarn infiltration veins with quartz-chlorite-epidote-chalcopyrite.
- Supergene copper mineralisation mainly comprises of chalcocite ores and minor exotic copper ores (malachite, azurite, cuprite, native copper) that commonly form as flat to gently dipping blankets or pods that directly overlie hypogene copper zones.
(2) SMD Stage 3C comprises chalcopyrite with inclusions of low-grade gold ranging from 0.06 to 0.9 ppm Au that was observed in both the SMD central porphyry and proximal skarn deposit settings, but the distal SMD SHGD settings contained Cu-Sb-As bearing sulphosalts (Fig. 5.7.1). The SMD Stage 3C has been constrained through the Re-Os dating of SMD Stage 3C molybdenite to be syn- to late RDP emplacement (Section 5.8).

(3) SMD Stage 4 represents the main high-grade gold phase in the SMD, comprising pyrite with high-grades of gold ranging from >1 and up to 293 ppm Au concentrated along (i) the growth rims of pyrite cores that fill fractures cutting SMD Stage 3 sulphides in the SMD SHGD (Section 5.2.5) or (ii) associated with rough textured pyrite cutting SKN Stage 3C assemblages in the SMD copper deposits (Section 5.3.5).

(4) The SMD Stage 5 vein assemblage consisting of calcite-quartz-fluorite observed in the proximal copper skarn deposits is interpreted to be similar in mineral assemblage and timing to the distal SHGD assemblage of calcite-quartz-stibnite-dolomite (Fig. 5.7.1).

Fig. 5.7.2. A summary diagram for SMD Stages 1 to 5 showing the main mineral assemblages hosting gold-bearing sulphides and their associated gold grades as determined by LA-ICPMS analyses during this study. *Abbreviations used:* DSE = Discovery East, DSM = Discovery Main, KHN = Khanong, NLU = Nalou, PDN = Padan, TKM = Thengkham South, Vat = Phavat, SHGD = sedimentary-hosted gold deposit, Au = gold, Bn = bornite, Cal = calcite, Chl = chlorite, Cpy = chalcopyrite, Cu = copper, Dol = dolomite, Epi = epidote, Fl = fluorite, Hem = hematite, Mo = molybdenite, Py = pyrite, Qtz = quartz, Sb = stibnite, Ser = sercite, Sp = sphalerite.