J. Myanmar Acad. Arts Sci. 2018 **Vol. XVI. No. 5**

NATURE AND CHARACTERISTICS OF GOLD MINERALIZATION AT MODI TAUNG GOLD DEPOSIT, YAMETHIN TOWNSHIP, MANDALAY REGION*

Kyaw Linn Zaw[1], Ohn Thwin[2], Thet Paing Kyaw Win[3]

Abstract

The ModiTaung area is located 370 km to the north of Yangon. The segment of gold mineralization is of interest as it is the first reported gold deposits of slate-hosted mesothermal quartz-gold veins (orogenic gold deposit) in Myanmar. This slate belt consists of the argillaceous rocks namely Mergui Group (Late Palaeozoic age) and which is largely intruded by many plutons. The deposit is hosted within three major vein systems. They are made up of several veins which are spatially grouped into their respective systems. Vein textures are mostly of three types; book-and-ribbon texture, laminated to stylolitic texture and massive texture. Mineralized shear veins tend to follow three trends within brittle-ductile regimes and occur at the centre of the shear zone (C vein) or oblique to the shear zone boundary. Book and ribbon vein textures provide evidence that mineralization took place during D_2 within NNE trending shear zones.

Pyrite chemistry indicates two main episodes of gold mineralization: syngenetic gold precipitation in Py1 and an epigenetic gold mineralization in Py2 and Py3. Py1 is interpreted to be of syngenetic/diagenetic origin because of its higher Ag, Ni, V contents and the ratio Au/Ag is less than 1. Py2 and Py3 are of hydrothermal origin as they have low levels of Ni, V, and Ag with Co/Ni ratio and Au/Ag more than 1. Evidence of pulsed hydrothermal mineralizing fluids is also consistent with the presence of cobalt and nickel zoned micro-bands in the pyrite structure.gold in Py1 could have been remobilized by circulation of later magmatic and metamorphic fluids and concentrated elsewhere enhancing the gold content in later generations of pyrite (Py2 and Py3).

Keywords: *Mineralization, ModiTaung, Orogenic, pyrite chemistry, shear veins*

1. Assistant Lecturer, Department of Geology, Hinthada University
2. Professor (Retired), Department of Geology, University of Yangon
3. Lecturer, Department of Geology, Hinthada University

* Best Paper Award winning Paper in Geology, (2017)

Introduction

The ModiTaung area is located in central Myanmar, 150 km to the southeast from Mandalay and 370 km to the north from Yangon. The maximum elevation of the area is 1200m on the upland escarpment that divides the central plain and Paunglaung River valley. The area coverage of the area is the approximately 6105 acres (24.71 sq. km). Location map of approximate coverage of study area is shown in figure 1.

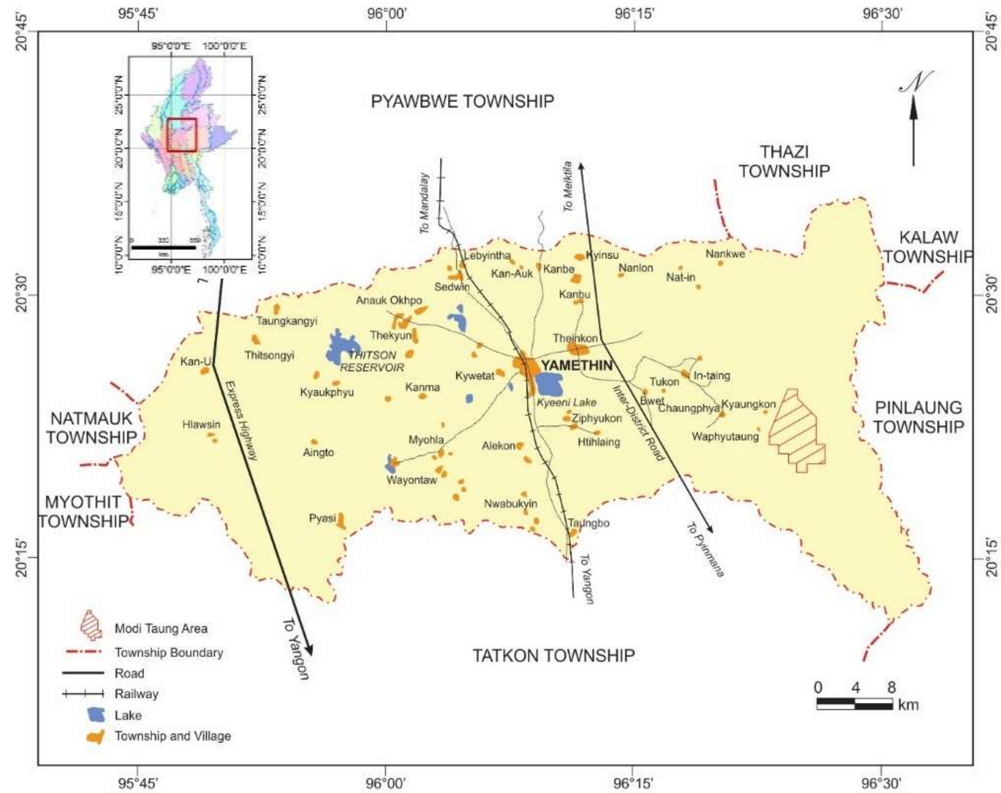


Figure 1. Location Map of the Study area

Deposit geology of the study area

The ModiTaung gold deposit is hosted in the sedimentary units of the Mergui Group, which itself is situated in the eastern extremity of the MMB. The Mergui Group is composed of two dominant sedimentary facies associations. A lower sequence is made up of massive to bedded shale, sandstone, rare limestone and channel fill pebbly wackes (Mitchell et al., 2004). The upper units of the Mergui Group include several polymict conglomerate units which occasionally host marine fossils (Mitchell et al., 2004). In ModiTaung area, there are two formations, Kogwe Mudstone and Poklokkale Pebbly Wackestone. The Kogwe Mudstone mainly consists of massive to laminated and locally calcareous mudstone and siltstone interbeddedquartzose sandstone which generally dips to northeast beneath Poklokkale Pebble Wacke. In the lower part, the Kogwe Mudstone includes channel-fill disorganized conglomerates with rafts of mudstones. It passes up transitionally into the Poklokkale Pebbly Wacke. This pebbly quartz wackes and pebbly mudstones or diamictites are interbedded with massive and laminated mudstones and siltstones, phyllite (Figure 2 A).The deposit geological map produced from field observations is shown in figure 2 B.

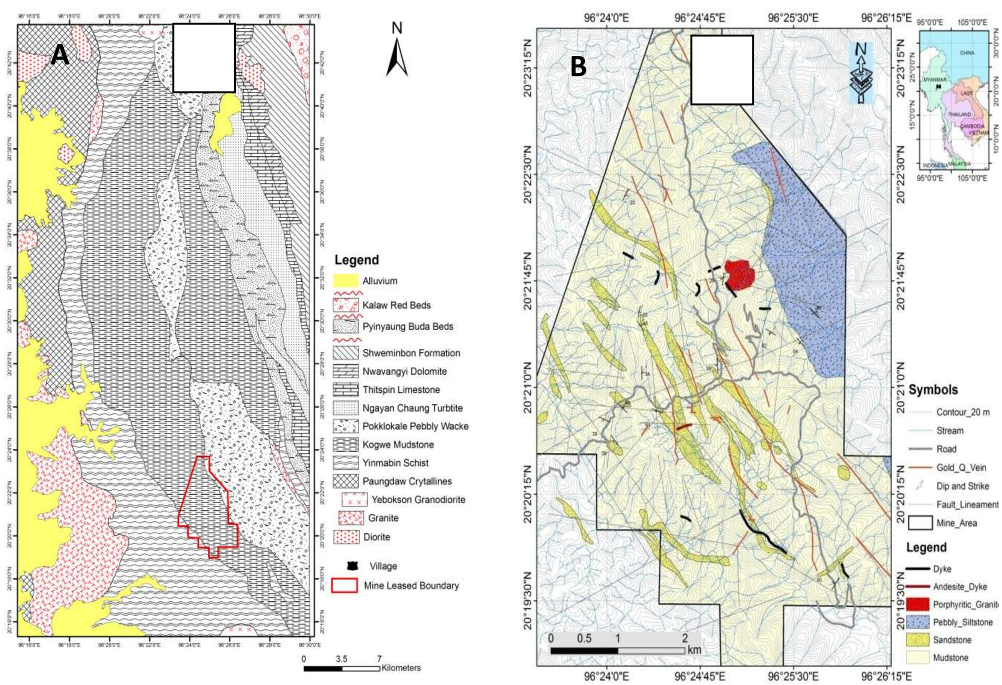


Figure 2.A. Geological Map around ModiTaung Area.
B. Deposit geological map of the Modi-Momi area.

Pebbly siltstone unit

The oldest stratigraphic unit exposed in the ModiTaung lease area is a pebbly siltstone which crops out in the eastern extremity of the lease area. The siltstone is characterized by occasional sub-centimetre scale lithic clasts which are supported by a weakly banded quartz dominated silty matrix (Figure 3). Clasts are polymict and range in shape from rounded to sub-angular. Some clasts display flattened edges; however, the term pebbly siltstone is preferred to tillite as no additional evidence of glacial input has been observed. No fossils were observed in the field, however Mitchell et al. (2004) noted the occurrence of Lower Permian fossils within the unit.

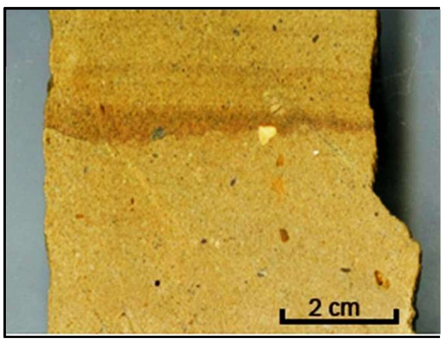


Figure 3.A. Pebbly siltstone exhibiting weak bedding textures and polymict lithic fragments. **B.** Outcrop of pebbly siltstone displaying load casts of sub-metre scale boulders.

Mudstone unit

Two mudstone units were observed in the ModiTaung lease area. The older unit is exposed in both the east and west of the study area where it conformably overlies the pebbly siltstone unit (Figure 4). This mudstone has an estimated thickness of ~ 40 m. The younger mudstone crops out throughout the central region of the lease area where it overlies a slate unit. This second mudstone is the youngest sedimentary unit exposed within the area. The thickness of this unit is unknown as it appears to have been thickened by east-west shortening of the strata. Pyrite is rarely observed and pyrite crystals never exceed 1 mm. In outcrops proximal to ore, the mudstone can be pervasively bleached and occasionally cut by carbonate veinlets; where present the veinlets broadly follow cleavage and cut bedding at a high angle.

Mudstone outcrops more distal to mineralization do not display these characteristics and are largely unaltered.

Figure 4:A. Outcrop nature of mudstone showing a tendency to break along bedding planes. **B.** Outcrop of mudstone near guest house

Sandstone unit

Sandstone is exposed in several regions in the ModiTaung lease area. However, regional folding has caused one unit to cropout in multiple locations and overrepresented the unit. Sandstone conformably overlies the older shale unit. The sandstone is weakly bedded to massive and is quartz dominated although rare magnetite is also present (Figure 5). The sandstone is medium-grained and highly silicified in all outcrops. This sandstone unit hosts gold mineralization in the Shwesin vein system and is overlain by slate which hosts gold mineralization in the Htongyi vein system.

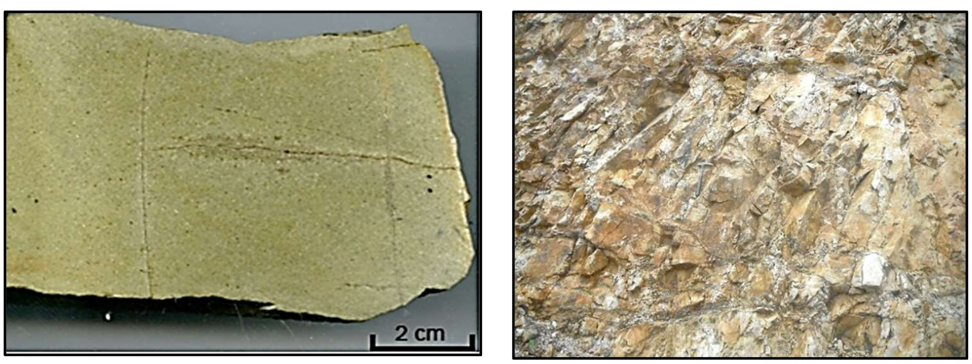


Figure 5.A. Sandstone sample showing well sorted massive texture, S_2 can be seen (vertical) in this sample. **B.** Outcrop of highly silicified sandstone.

Slate unit

Slate crops out in two parallel narrow NNW trending bands, and these conformably overlie the sandstone unit previously mentioned and is in turn overlain by the younger mudstone unit. The slate is moderately foliated, generally cut by carbonate veinlets and displays a pervasively bleached texture (Figure 6).

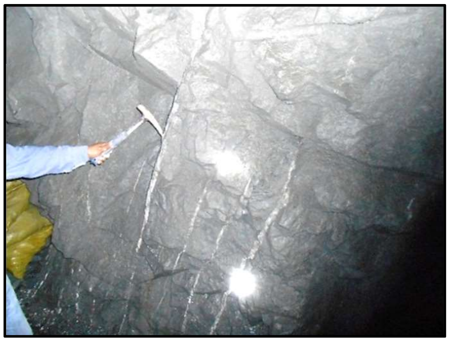


Figure 6.A. Outcrop nature of Slate showing a pyrite bearing carbonate vein cutting a smaller quartz vein. **B.** Bleached texture and a series of veinlets.

Mineralized vein system in the study area

The ModiTaung gold deposit is hosted within three major vein systems. From east to west these are: Htongyi, Sakhangyi and Shwesin. Htongyi and Shwesin are made up of several veins which are spatially grouped into their respective system (Figure 7 A). The three vein systems generally strike NNE, however the veins converge in the north and south of the lease area and little is known about them outside this zone. Veins in the east of the lease area dip steeply to the west, while veins in the west dip steeply to the east. This observation suggests that the veins have the same origin and that a major fluid conduit existed in the middle of the lease area (Figure 7 B).

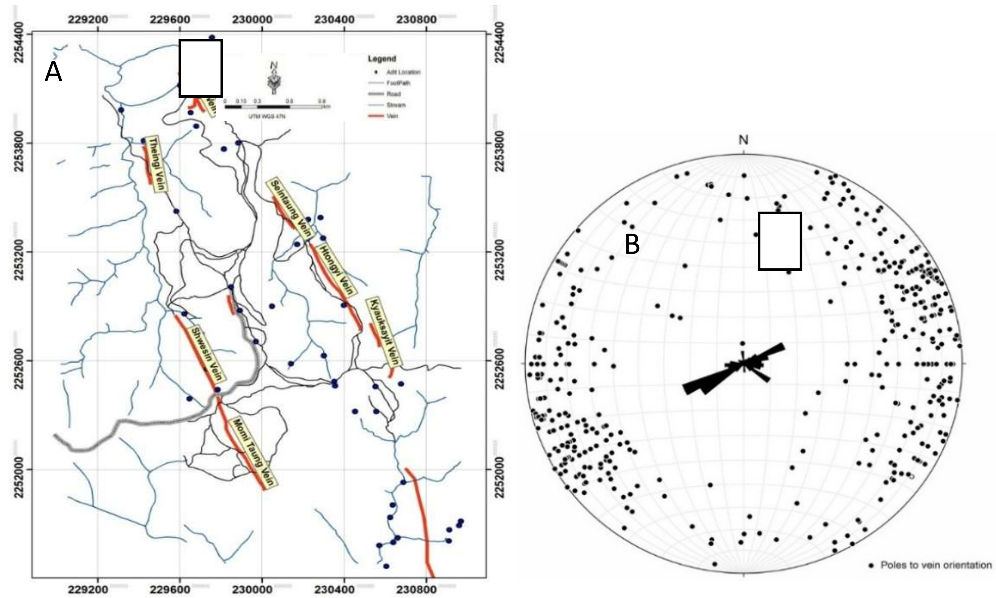


Figure 7.A. Location of three major veins system at ModiTaung area.**B.**Stereonet of poles to vein orientation demonstrating that the veins dominantly dip steeply to the northeast and southwest.

Channel sample across veins in adits assay up to 300 ppm Au; these high values tend to be in shallower obviously oxidized veins but value up to 100 ppm over 1 m occur beneath the oxidized zone. There is locally extreme variation in assays (3 to 300 ppm Au) across a single vein in channel samples less than a metre apart. Local veins segments with cm-scale parallel bands are containing coarse visible gold implying the existence of ore shoots, but the geometry of, or contours on, possible shoots are so far not known.

In the oxidize zone, which is up to 80 m thick, wall rock alteration is unimpressive, although mudstone slivers in book-and-ribbon textured veins are weakly or strongly altered to chlorite or chlorite and pyrite. Sandstones adjacent to veins are commonly silicified and sometimes bleached through supergene oxidation of pyrite and consequent kaolinization, with iron or manganese strains. Beneath the oxidized zone, phyllite within 5 to 10 m of veins shows abundant chlorite together with pyrite in fractures, and sandstones are grey-green, indicating chlorite or sericite and chlorite occurs as selvedges on quartz veins. It is uncertain whether the chlorite is similarly abundant further away from the veins.

The mineralization reaches a maximum elevation of 1326 m in the Sakhangyi vein system. The maximum depth explored thus far is 845 m in the Htongyi vein system. Vein width varies with elevation and ranges between centimetre and metre scale. The thickest veins tend to occur between ~ 1000m and 1200 m elevation and are part of the Htongyi vein system.

Nature of gold-bearing quartz veins

The book and ribbon, laminated, stylolaminated textures are typical of shear veins in mesothermal deposits (Figure 8). These textures are generally considered to result from repeated fracturing and quartz deposition during shear movement parallel or sub-parallel to the shear zone (Figure 9). If the country rock is mudstone, it is generally strongly foliated, chlorite altered, may contain pyrite and may be partly silicified. The quartz rich zone may be made up of an amalgamation of many quartz veins where the country rock slivers have variable separation widths or contain only very thin parallel slivers or exhibit stylolitic lines parallel to the vein boundary (Figure 10). The stylolitic laminations attest to high-pressure solution after vein formation.

The laminated veins are occasionally folded. Elsewhere the quartz is more massive with no or minor remnant country rock. The progression from a central zone of massive quartz to stylolaminated to an outer zone of book and ribbon structure is common and may result from progressive silicification during each quartz depositional event which gradually replaces the country rock. Pyrite patches varying from disseminated pyrite to almost 100% pyrite and pyrite-chlorite to chlorite foliated mudstone occur occasionally and are generally distributed along zones parallel to the laminations. The replacement of country rock fragments can often be defined by the clear quartz ghost-like patches containing alteration pyrite (Figure 11).

Figure 8.A. Book and ribbon texture in shear quartz vein. The dark patches are remnant mudstone of country rock. (Htongyi).**B.** Laminated quartz shear vein.

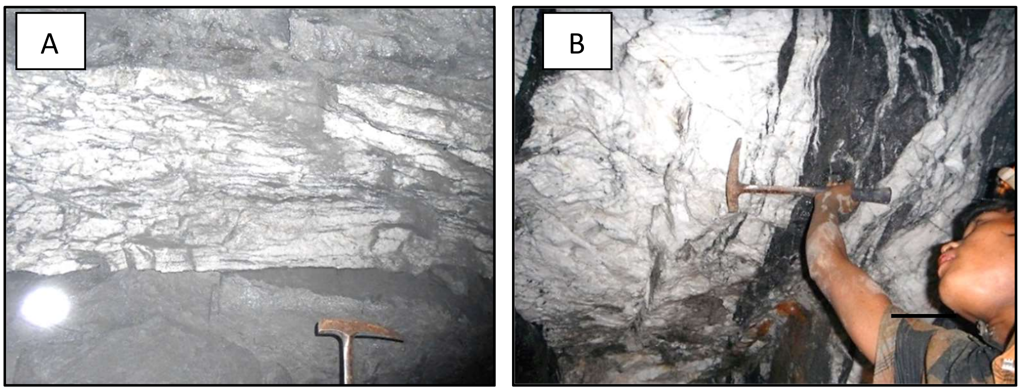


Figure 9.A. Stylolaminated quartz shear vein formed by high pressure and dissolution of country rock after vein formation. **B.** Massive quartz vein.

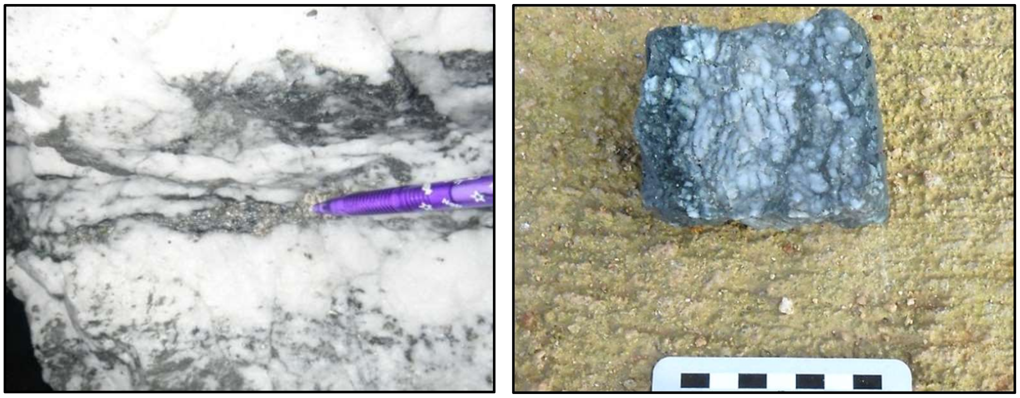


Figure 10. A. Book and ribbon structure. **B.** Laminated structure. **C.** Stylolaminated structure with pyrite patches. **D.** Brecciated structure.

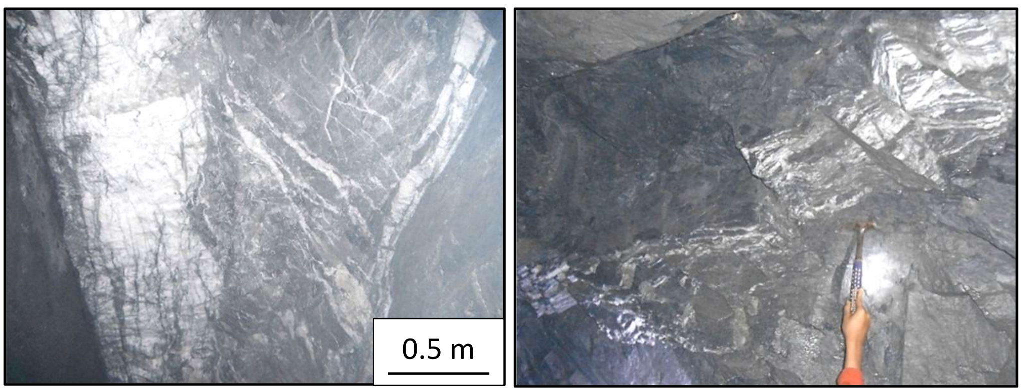


Figure 11.A. Complex shear vein with mudstone locally filling fractures in quartz. **B.** Ladder vein cross-cutting laminated quartz.

Slickensides commonly occur on discrete surfaces of individual quartz veins and adjacent country rock and are typically oblique with steep southerly plunge. Minor offset of shear veins and rock slivers along faults occur occasionally and the faults may offset the boundary shears or many appear to join them (Figure 11). The apparent joining of the two faults may be due to the late reactivation of the main boundary shear.

Shear veins tend to follow three trends within brittle-ductile regimes and occur at the centre of the shear zone (C vein) or oblique to the shear zone boundary (P and R veins in figure 12). The R (Reidel) is related to brittle fracture whilst the P (Pressure) vein is related to ductile fracture. All veins have the same sense of displacement as the main shear zone and may open at the same time such that related quartz vein deposition will show no crosscutting relationship. Overlapping of *en echelon* P oblique shear veins show the same sense of steeping (Figure 13). Right steeping indicates right lateral displacement and left steeping indicates left lateral displacement. In *en echelon* R shear veins the sense of overlapping will be opposite i.e. left steeping indicates right lateral movement. The three shear veins should theoretically trend within 30° of each other (i.e. 15° either side of the C vein). The various shear may open allowing for quartz deposition at different places and times. The compressional mineralization structure followed to the P shear direction (ENE-WSW) and vein trend tend to be (NNW-SSE) direction.

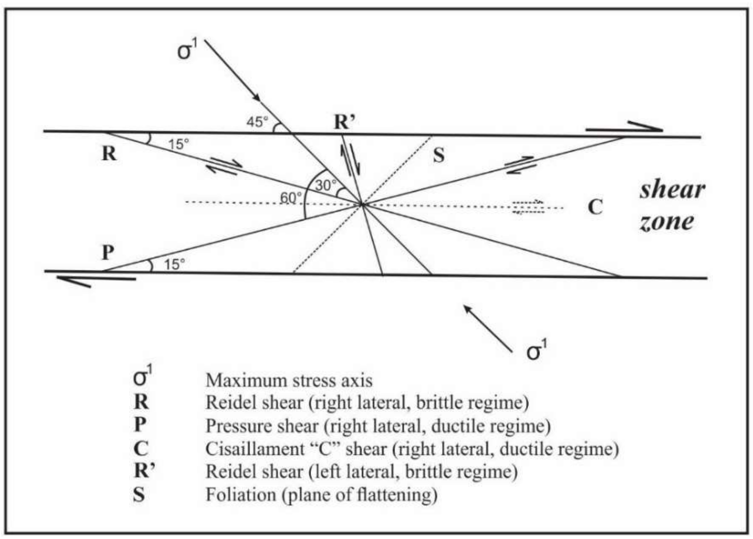


Figure 12. Theoretical geometry of shears within a right lateral, brittle-ductile, shear regime. A degree of extension may occur in all directions (Source, Worsley, 2001)

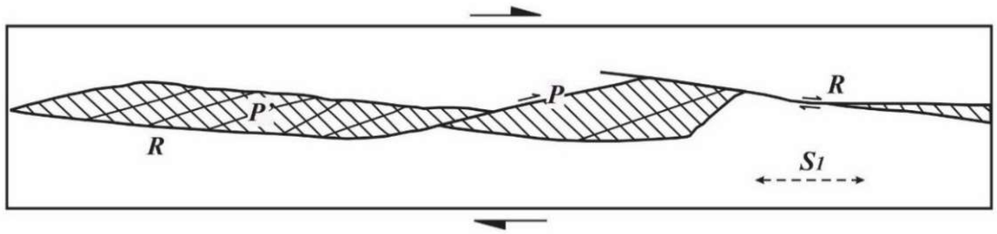


Figure 13. Tchalenko Shear box experiment. Diagram shows structures formed in clay in a direct shear test in shear box. P- pressure shear, R- Reidel shear, hatchings= particle orientation in zone of compression, white area= particle in initial fabric attitude (S1). (Source: Tchalenko, 1968)

Evidence for repeated ductile-brittle movement within the main shear zones includes local folding of laminations, foliated mudstone within fractures of the quartz veins, folded veins, possible ladder vein formation and multiple vein formation. If the main shear zone is developed within mudstone, there appears to be a tendency to develop more complex quartz vein arrays (possible jogs) whilst planar, simple quartz veins are developed in sandstone and at sandstone-mudstone boundaries.

Mineralization

Free visible gold can be observed in samples which exceed ~ 60 ppm Au. At lower grades microscopic gold occurs in fractures within pyrite and between the crystal boundaries of pyrite. Pyrite is the dominant sulphide mineral and shows at least three distinct forms. As yet it is unknown whether Au is preferentially associated with one particular pyrite generation. Galena was only observed in the Htongyi and Sakhangyi vein systems and shows a moderate correlation with high grade Au mineralization. No correlation between galena and Au was determined where Au grades are less than 100 ppm. Sphalerite and chalcopyrite are both rare in the ModiTaung gold deposit and dominantly occur within the Htongyi vein system. Sphalerite and chalcopyrite generally occur together. Both show multiple crystal textures which may indicate that they were emplaced via multiple mineralizing events (Figure 14). Quartz and calcite are the dominant gangue minerals, as would be expected in a vein type deposit. Carbonate accounts for less than 15 % of vein minerals which is consistent with the orogenic gold deposit model (Groves et al., 1998). Alteration minerals include graphite, sericite and chlorite. These form the dark bands in the book and ribbon zones of the Htongyi and Sakhangyi vein systems. The alteration minerals are likely to be the products of hydrothermal alteration of wall-rock lithics set in the veins during syn-shear veining.

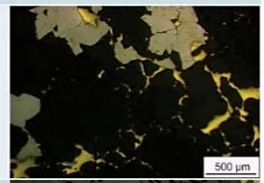
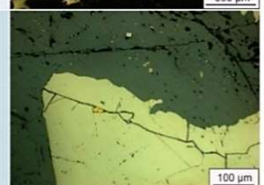
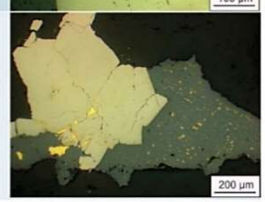
Vein System	Ore Minerals (● =major, □ = minor, ⬠ = trace)						
	Pyrite	Chalcop yrite	Sphaler ite	Galena	Gold	Gold Occurrence	
Shwesin	●	⬠	⬠	⬠	□	Gold (10-1000 µm) is infilled along quartz fractures	
Sakhangyi	●	⬠	□	⬠	⬠	Gold (<10 µm) is infilled along pyrite fractures and inclusions in sphalerite	
Htongyi	●	⬠	●	□	□	Gold (<100 µm) occur in fine-grained gangue materials (mainly quartz)	

Figure 14. The presence of sulphide minerals at representative vein systems.

Pyrite Chemistry

Pyrite samples analyzed from samples show similar textural and chemical aspects (Figure 15). Both these samples show an inner core pyrite Py1 with similar elevated levels of Sb, Bi, Cr, Ba, Mn, As and Au which are depleted in the outer euhedral pyrite Py2. The elevated As and Au in Py1 suggests that this pyrite is likely of diagenetic type from a depositional sedimentary source and that this Py1 has been remobilized by later metamorphic-magmatic fluids to form Py2 with lower concentrations of Py1 elements. The chemical signature of the inner pyrite core is closer in similarity to Py2. It is therefore suggested that this samples inner core is in fact a metamorphic type pyrite Py2. This pyrite has then been overgrown by hydrothermal pyrite associated with the quartz veining event and been enriched in Au and other elements such as Ni and As. Py3 has increased levels in all trace elements compared to the other pyrite types. The increased Au suggests that the pyrite has formed from an enriched hydrothermal source that formed after peak metamorphism. A summary of the pyrite samples analyzed and the pyrite types is supplied in Table 1.

Table1. Sumary comparison of sample numbers and their pyrite types with relavant element levels in ppm. Py1, Py2, and Py3.

Pyrite type	Au (ppm)	Ag (ppm)	As (ppm)	Ni (ppm)	V (ppm)
Py1	0.85	1.92	2681.80	306.45	4.98
Py2	0.77	0.77	1991.32	308.95	1.70
Py1	0.17	12.12	1103.59	145.47	-
Py2	0.052	3.33	760.91	156.09	-
Py2	0.041	0.44	51.82	15.50	2.62
Py3	0.33	0.81	1257.71	183.13	0.50

Study of the pyrite chemistry indicates two main episodes of Au mineralization: 1) syngenetic Au precipitation in Py1 and an epigenetic Au mineralization which also contributed to the formation of free gold in Py2 and Py3. Py1 is interpreted to be of syngenetic/diagenetic origin because of its higher Ag, Ni, V contents and the ratio Au/Ag is less than 1. Py2 and Py3 are of hydrothermal origin as they have low levels of Ni, V, and Ag with Co/Ni ratio and Au/Ag more than 1. Evidence of pulsed hydrothermal mineralizing fluids is also consistent with the presence of cobalt and nickel zoned micro-bands in the pyrite structure.

Au in Py1 could have been remobilized by circulation of later magmatic and metamorphic fluids and concentrated elsewhere enhancing the gold content in later generations of pyrite (Py2 and Py3). This interpretation is supported by the occurrence of pyritic slaty mudstone and the effect of low grade metamorphism with the capacity to mobilize sulphur and iron from early pyrite to form later hydrothermal pyrite (Large et al., 2007).

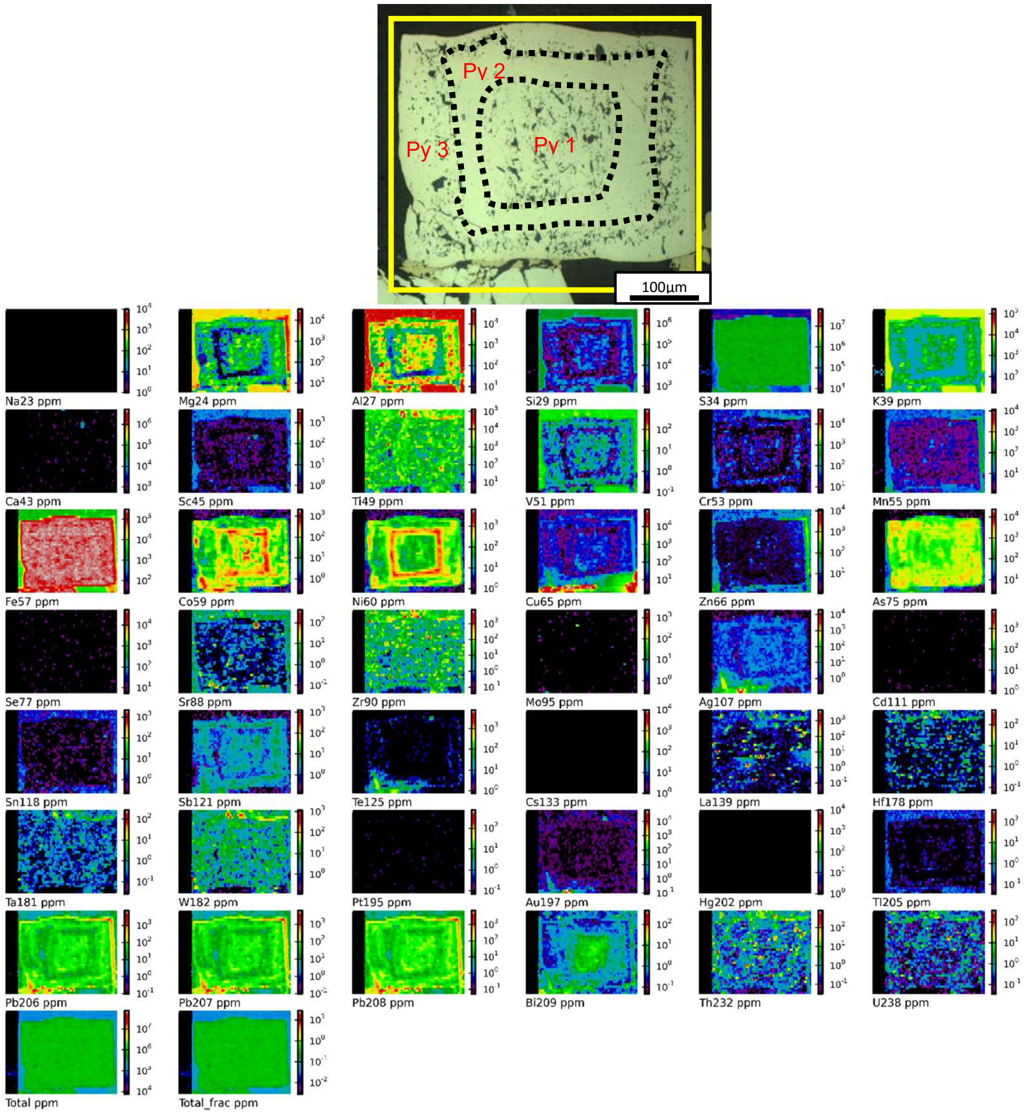


Figure 15.Pyrite map showing zoned pyrite euhedral grain comprising three pyrite generations. Pyrite 1 is enriched in V, Mg, Al, Bi, Sb, relative to pyrite 2 and 3. Gold inclusion is spotted from the rim of pyrite 3.

Conclusion and Discussion

The ModiTaung area is located in central Myanmar, 370 km to the north of Yangon, There are two formations, Kogwe Mudstone and Poklokkale Pebbly Wackestone.The sedimentary sequence has been intruded by at least three generations of igneous rocks.

The study area has been subjected to at least two deformation events as evidenced by S_1 and S_2 cleavages. S_1 is likely to represent the closure of the basin in which the sediments were deposited via east/west compression. The subduction related closure of the Paleotethys is likely to be the cause of D_1 as interpreted from S_1 cleavage. S_2 occurs almost at right angles to S_1 and suggests northeast/southwest compression. These two deformation events have led to the complex refolded fold geometry displayed in the host rocks of the area. Book and ribbon vein textures provide evidence that mineralization took place during D_2 within NNE trending shear zones and fault structures (Figure 16).

Pyrite is the dominant sulphide mineral and shows at least three distinct forms.Au is preferentially associated with one particular pyrite generation. Sphalerite and galena shows multiple crystal textures which may indicate that they were emplaced via multiple mineralizing events. The alteration minerals are likely to be the products of hydrothermal alteration of wall-rock lithics set in the veins during syn-shear veining.

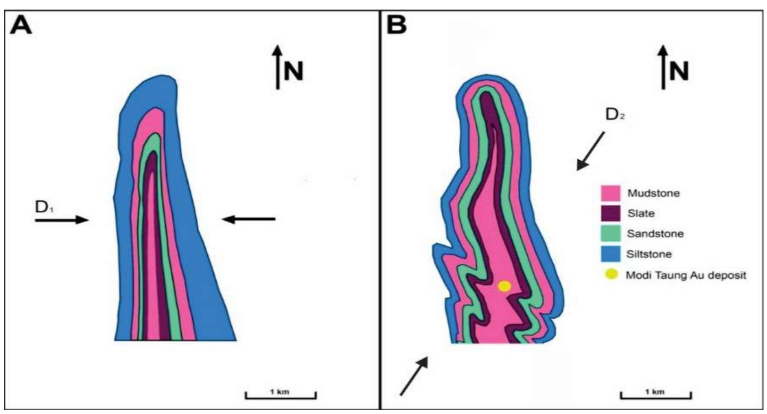


Figure 16.A. Inferred principal stress direction for the generation of S_1 cleavage. D_1 is shown as a major east-west compressional event resulting in north-south folds. **B**. Inferred principal stress direction for the generation of S_2 cleavage. D_2 is dominantly NNE-SSW compressional event resulting in a second generation of folds.

Acknowledgements

The authors wish to express their gratitude to DrTheingiKyaw, Professor and Head of Department of Geology, Hinthada University for her permission and valuable administrative support. We also wish to express our thank U SoeHtunShein (Chairman, National Prosperity Company), U TunAungSoe (Managing Director, and U ThihaZaw Lynn (Former Managing Director, NPGPG) for their invaluable help.

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