Geological and Geochemical Characteristics of the Pac Lang Gold Deposits, Northeastern Vietnam and Their Potential Prospects

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Abstract

The Song Hien Rift basin, located in northeast Vietnam, has been identified as an important region for gold deposits, including the Pac Lang deposit. Several methods like petrographic observations, elemental analyses, and geochemical elements and vertical zoning models of primary halo have been used to describe geological characteristic of this deposit. The investigation focused on examining the geological events that occurred both before and after the formation of the ore. The use of ICP-MS analysis and element concentration contrast enabled an effective assessment of the relative degrees of denudation that occurred at the Pac Lang deposit. The findings of this study were consistent with prior research on ore deposit geology, geochemical primary-halo, and examination of geochemical indicator zoning patterns for gold ore bodies. The study's application of singularity analysis for evaluating the degree of denudation provides important geological information that can aid in data interpretation. The results of the study can also have significant reference value in furthering our understanding of the post-ore deformation of deposits and in the investigation of unknown orebodies in northeast Vietnam. There indicate that, the research's findings suggest that the use of singularity analysis to evaluate the degree of denudation is a valuable tool for exploring potential gold deposits and enhancing our knowledge of gold deposit geology in northeast Vietnam. Overall, this study contributes to the existing body of knowledge on gold deposits in the Song Hien Rift basin and can serve as a useful reference for future research in the area.

Keywords: *geology, geochemistry, Pac Lang gold deposit, Vietnam*

1. Introduction

Gold, with its captivating allure and enduring value, has fascinated humanity for centuries. From ancient civilizations to modern-day societies, this precious metal has played a significant role in shaping economies, cultures, and even has a big influence for mankind development. Understanding the origin and formation of gold deposits has been a subject of intense scientific investigation, with researchers striving to unravel the intricate processes that lead to their creation. One aspect that has recently garnered attention is the denudation of gold deposits, which refers to the erosion and stripping away of overlying rocks and sediments, ultimately exposing the concealed gold beneath.

The denudation of gold deposits is a complex phenomenon that involves the interplay of various geological, geochemical, and environmental factors. Over geological timescales, tectonic forces, such as uplift and subsidence, along with climatic changes and erosion, act as powerful agents in unearthing these hidden treasures. These processes not only reveal the underlying gold deposits but also influence their distribution, concentration, and potential economic feasibility. In recent times, the identification of industrial metal ore deposits on a global scale has brought to light an interesting trend wherein new deposits tend to be concentrated in well-established ore regions, while concealed ore deposits are often discovered within extensively researched mineralization areas. This observation underscores the importance of conducting comprehensive investigations, surveys, and explorations into geological features that lie deeply buried. Following the formation of ore deposits, they frequently undergo alteration processes induced by geological activities occurring within or above the Earth's crust, as well as through interactions among different components of the lithosphere. These processes play a critical role in determining the positioning and subsequent preservation of the ores. Among these processes, denudation emerges as a significant factor influencing alteration (Zhai et al., 2000). For example, in the case of a vertical metal hydrothermal mineralization system, the altered mineralization zones situated in the upper portion of the sediment are prone to weathering and denudation, while the ore sources located in the lower sections of the sediments are more likely to be safeguarded (Zhai, 1999). In order to evaluate the rate of sediment denudation, identify undiscovered ore deposits, investigate geochemical peculiarities, and facilitate mineral exploration, quantitative assessments of ore denudation depth are commonly employed (Li et al., 2006; Liu and Ma, 2007).

2. Geological background

2.1. Regional geology

Northeastern Vietnam is home to a significant large-scale gold-polymetallic concentration area in the country. Up to this point, approximately 50 gold deposits and occurrences have been discovered in this region (Tri and Khuc, 2011). However,

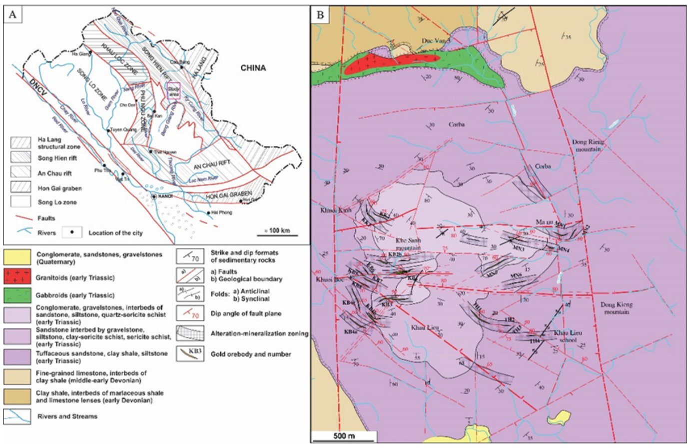

Fig. 1. A – Tectonic map of Northeast Vietnam and location of the study area (Dovjikov et al., 1965);
B – Geology and mineral map of the Pac Lang gold deposit (Hoang Van Quang et al., 1997)

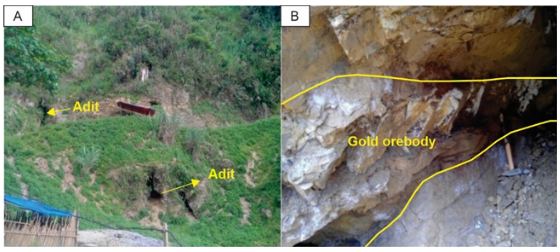

Fig. 2. Gold ore bodies in the Khuoi Boc (PL.3009) (A) and Khuoi Kinh (PL.3003) (B) areas exist in the form of veins (photo from Nguyen Van Dat et.al., 2017)

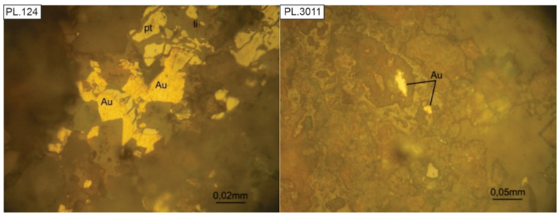

Fig. 3. Native gold concentrates in small nests, pseudomorph irregular shapes while being intercalated with pyrite. Moreover, it undergoes limonite alteration, as observed in samples PL.124 and PL.3011 (after Le Thanh Huong, 2017 in Nguyen Van Dat (2017))

certain deposits that share a similar metallogenic background and are influenced by comparable ore-controlling conditions (e.g., anticline and fault compound) exhibit distinctive characteristics in terms of exposed orebodies, deposit scale, and the intensity of geochemical anomalies associated with mineralization. While the diverse range of ore-forming processes may give rise to various mineralization products, denudation likely plays a pivotal role in responding to post-ore alteration is running simultaneously with gold precipitation during the hydrothermal circulation of the ore forming fluids.

The Pac Lang gold deposit is located at the western edge of the Song Hien zone, adjacent to the Bac Thai convexity complex (Fig. 1A). It is characterized by a deep depression that originated during the Middle Paleozoic and experienced significant tectonic activity in the Permian-Triassic period. As a result, the Mesozoic overlap may be associated with the intracontinental rift, which is connected to the late Permian-early Triassic mantle upwelling. The area primarily consists of terrigenous or terrigenous intercalated tufogen sedimentary rocks belonging to the Song Hien formation. In the northern region, there are additional carbonate and terrigenous sedimentary formations known as the Na Quan and Mia Le formations (Fig. 1B; Hoang Van Quang et al., 1997).

In the study area, there is a intrusive magmatic body in the form of vein belts, measuring 1200m in length and 100–200m in width (Fig. 1B). This body exhibits contrasting compositions, consisting of gabbrodiabase and granite porphyry, and is located along the sub-latitude fault in close proximity to the provincial road DT209.

The Song Hien formation, consisting of tufogen terrigenous sedimentary rocks, contains ores of interest. The potential source of these ores could be associated with the magmatic rocks found in the Cao Bang complex. These magmatic rocks exhibit a mafic to sub-alkaline acid composition and are characterized by copper magma eruptions, which differ from the formations found in the Song Hien formation.

The northwest-southeast and sub-latitude fault systems play a crucial role in creating fractured and compressed zones that host gold mineralization. Additionally, the sub-meridian faults are post-generation systems that cause shear and displacement of the ore mineralization controlling structures.

2.2. Characteristics of the Pac Lang gold deposits

2.2.1. Features of ore veins and gold orebodies

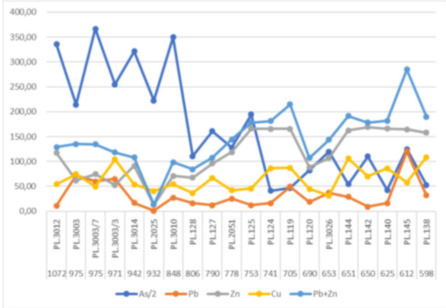

Fig. 4. Correlation relationship between the elemental content of As, Cu, Pb, and Zn and the ore-forming depth (due to the relatively large elemental content of As, As/2 is used here)

Tab. 1. Distribution order by the lithological structure of the Pac Lang gold deposit

Distribution location	Distribution order by the lithological structure	Mineral symbiotic complex	Distribution location
The upper part	Felzit, siltstone, sandstone, gravel of the Song Hien Formation. Mahogany brown siltstone, thick layer, quartz-sericite slab, black clay.	Quartz-gold-poor sulfide (pyrite, galenite, sphalerite, chalcopyrite). Large grain pyrite sulfide.	In the ranges of IV, III, II, I, Khuoi Boc, Khuoi Kinh, Mo Coi hill, and the Manu longwall route. These areas create a rather highly-distributed area by the stratigraphic structure
The lower part	Graphitized black shale, blue-gray quartzite, with dark siltstone.	Quartz-pyrite (with chalcopyrite, galenite-sphalerite-gold. Medium-grained pyrite, small-grained sulfide minerals.	The lower part of the Manu mining area

In the research area, gold ore bodies have various forms, including simple veins, complex veins, vein systems, lens-shaped bodies, stockwork bodies, and ore shoots.

In the sublatitude direction, ore bodies exhibit complex structures. When observing the ore body along its strike, simple vein segments with consistent thickness, dip angles, and relatively stable altered wall rocks become apparent. Additionally, several sections of the ore body branch out along the same orientation but at varying dip angles or perpendicular orientations, creating branching patterns that can resemble tree branches or cluster-like formations, sometimes similar to horse-tail shapes.

The ore body displays zonation, often with gold-containing quartz veins. The zonation within the ore body progresses as follows: In the center lies a core of quartz, usually containing gold sulfides, surrounded by phyllites and sericite, infiltrated by sulfides. Beyond the core is the primary rock, heavily fractured and fissured, with some sections cross-cut by quartz veins, and with boundaries not always distinctly defined, occasionally existing only within the walls or pillars of the ore body, with some sulfide infiltration. The outermost part of the ore body consists of less altered primary rock.

In the northwest-southeast direction, gold ore bodies are oriented with strike and dip values of approximately 40–60/220–240. These ore bodies commonly take the form of quartz-veins containing gold, exhibiting either simple structures or elongated lenses. The vein structures are relatively straightforward, with thickness ranging from 0.1 to 0.5m, and the elongated lenses extend for 5–40m with a thickness of 0.1–0.5m. The surrounding rocks show less alteration, and the gold content in these veins is generally quite low.

In the northeast-southwest direction, gold ore bodies are oriented with strike and dip values of approximately 300–310/40–80. These ore bodies frequently occur as vein systems or lens systems. The veins or lenses have a small thickness, ranging from 0.1 to 0.2m, spaced at intervals of 1–2m, and running parallel to each other, with observable lengths varying from 5 to 20m.

Furthermore, at the intersections of various fracture systems, rocks experience thrust folding and intense fracturing, leading to the formation of ore nests. These ore shoots typically bulge in the middle and taper towards both ends, with an average length of about 25m and some bulging areas extending up to 20m. These ore nests have a strike direction of 130° and a dip angle of 65°; a typical example of such ore nests is found in the I, II, III, IV areas.

2.2.2. Structural and textural gold ores

At the Pac Lang gold mine, a variety of ore structures are encountered, encompassing disseminated, veinlet, infiltration, pseudobedding, breccia, and banded structures.

Disseminated structures are observed within quartz veins with minimal fracturing, displaying a firm, milky-white color, and containing minute proportions of pyrite and limonite minerals. This type of structure is characteristic of ore shoots and quartz lens formations, which exhibit low and highly variable gold content.

The veinlet infiltration structure is a distinctive feature of gold–quartz–polymetallic sulfide ore. Sulfide veins are unevenly distributed within the quartz background, with veinlet sizes ranging from a few mm to 20mm.

Breccia and banded structures are commonly found in numerous ore bodies. In these structures, quartz, pyrite, and other fractured minerals form brecciated slates that are cemented by subsequent generations of quartz and pyrite.

Additionally, pseudobedding, foliation, and mesh-like structures are present in certain areas of high-grade gold ore bodies and in generations containing low-grade mineralization.

The typical ore textures in the mining area encompass euhedral, semi- euhedral, and anhedral textures, which are characteristic of minerals such as pyrite and sphalerite. Anhe-

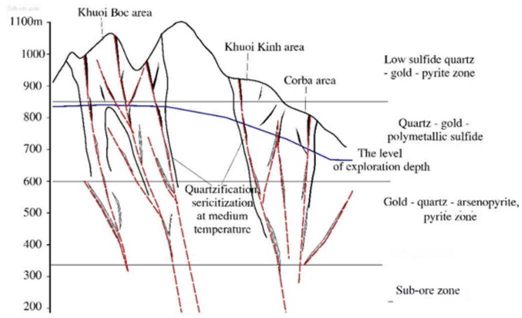

Fig. 5. Model of gold – quartz – sulfide ore zoning according to the depth of the Pac Lang gold deposit (Nguyen Van Dat et al., 2017)

dral textures are distinctive of galena; erosion features typify pyrite in the initial stage; and bone-shaped textures form due to the replacement of pyrite by limonite and goethite during oxidation processes.

3. Materials and methods

3.1. Analytical methods

Geochemical samples are collected from cross-sections of the ore body, typically selected to adequately represent the targeted region or ore body classification under investigation. The selection of sampling locations may be informed by existing geochemical data or a meticulously devised research plan. Subsequently, 70 geochemical samples undergo comprehensive analysis utilizing ICP-MS for the quantification of 17 elemental components, mineralogical examination, and handheld Xmet device measurements. The resulting analytical data is then synthesized and meticulously processed to facilitate the evaluation denudation of ore mineralization. This assessment is based on the vertical geochemical zoning characteristics of ore-forming elements, particularly pertaining to denudation depth.

3.2. Assessment of ore body's size, morphology, and localization

Based on research documents on thickness, the length in the strike direction, and the height in the dip direction of ore bodies in hundreds of hydrothermal deposits of tungsten, fluorite, molybdenum, gold, copper, tin, and uranium in the world. Lir (1984) established the correlation between the length in the strike direction (l) with the height in the dip direction (h) of the hydrothermal ore bodies and calculated the coefficient (k) of these parameters by the following formula:

$$k = h/l \qquad (1)$$

According to the formula (1), the coefficient k = 0.6 for the vein-type gold ore. From the strike direction dimensions of the gold ore bodies in the 03 study areas, it is possible to calculate the relative existence depth of the gold ore bodies. However, due to the discontinuous characteristics and low stability of gold ores, it is necessary to evaluate the overall ore zone to have an accurate assessment of the ore existence depth.

3.3. Assessment of the denudation rate

The vertical alteration in ore deposition conditions is one of the most important causes leading to the formation of mineral formations with different compositions.

One of the methods to assess the distribution depth of gold ore bodies is to calculate the vertical distribution of ore-forming elements, thereby calculating the ore body's denudation coefficient by the formula proposed by Beus and Grigoryan (1977) as follows:

$$K_z = \frac{Ag \times Pb \times Zn}{Cu \times Co \times Bi} \qquad (2)$$

In which: K_z is the denudation coefficient; Ag, Pb, Zn, Cu, Co, Bi are elemental contents of Ag, Pb, Zn, Cu, Co, and Bi (ppm); Kz < 0.1 under the ore-forming zone; $0.1 \le K_z \le 10{,}000$ in the ore-forming zone; $K_z > 10{,}000$ on the ore-forming zone.

4. Results and Discussion

3.1. Geochemical singularities

3.1.1. Correlation between elemental contents and ore formation depth

The results of the ICP-MS analysis of 70 ore samples in cross-section from the top of the Khuoi Boc peak in the Khuoi Kinh area to the lower longwall floors in the Manu area, as well as comparisons of the contents of some key elements and the sampling height, allow for the construction of a graph showing the relationship between the elemental content and ore formation depth (Figure 4).

On the Figure 4, the contrast in elemental content values can be seen at the position of the sample PL.128, which was collected from a longwall at an elevation of about 800–850m.

As can be seen that from the position of the sample PL.128 to the positions of the higher sampling locations, the As content increases significantly, whereas, the content of Cu, Zn, and Pb elements is much lower. From the position of the sample PL.128 to the lower sampling locations, the As content decreases remarkably along with the steady increase of Cu, Zn, and Pb.

This is the elemental geochemical characteristic of two different mineralization zones when the upper zone is characterized by arsenopyrite and pyrite minerals, the lower zone is characterized by an increase in polymetallic minerals such as galenite, sphalerite, and chalcopyrite, etc.

In the Pac Lang gold deposit, the elevation range of +800m to +850m marks the dividing line between the two main mineralization zones.

3.1.2. Ore zoning features

Vertical zoning: Based on actual observation and synthesis of gold ore documents of the Pac Lang deposit, the main ore zoning features are shown as follows. The upper part is the large size quartz veins that are poor in sulfide ore and contains gold in their mineral pillars; the middle part is hydrothermal quartz veins without ore and their local mineral pillars con-

Tab. 2. Range of ore-forming depth of gold ore bodies in the Pac Lang gold deposit

No.	Area	Ore body	Depth of the ore body's denudation surface (m)	Controlled ore-forming depth (m)	Forecasted ore-forming depth (m) (-50m)	Range of ore formation depth
1	Khuoi Kinh	KK1	1030	816	766	264
2		KK2	1068	902	852	216
3	Khuoi Boc	KB1	1083	878	828	255
4		KB2	1089	934	884	205
5		KB3	1060	807	757	303
6		KB4a	1015	758	708	307
7		KB4b	1008	777	727	281
8		KB4c	960	831	781	179
9		KB5	842	808	758	84
10		KB6	882	769	719	163
11		KB7	920	807	757	163
12		KB8	920	796	746	174
13	Manu	MN1	662	581	531	131
14		MN2	705	586	536	169
15		MN3	764	594	544	220
16		MN4	664	537	487	177
17		MN5	774	529	479	295
18		MN6	742	612	562	180
19	School	TH1	852	706	656	196
20		TH2	743	662	612	131
21		TH3	751	637	587	164
22		TH4	651	516	466	185
Average			**872.05**	**720.14**	**670.14**	**201.91**
Range of ore-forming depth of the ore field						**623**

Tab. 3. The height in the dip direction of the gold ore bodies of the Pac Lang gold deposit (Lir, 1984)

No.	Area	Ore bodies	Length in the strike direction (m)	Height in the dip direction (m)
1	Khuoi Kinh	KK1	182.8	109.68
2		KK2	143.6	86.16
3	Khuoi Boc	KB1	194.5	116.70
4		KB2	143.2	85.92
5		KB3	255.1	153.06
6		KB4a	142.7	85.62
7		KB4b	143.3	85.98
8		KB4c	206.3	123.78
9		KB5	81.0	48.60
10		KB6	82.9	49.74
11		KB7	110.3	66.18
12		KB8	106.5	63.90
13	Manu	MN1	132.0	79.20
14		MN2	112.5	67.50
15		MN3	168.9	101.34
16		MN4	81.5	48.90
17		MN5	230.0	138.00
18		MN6	163.3	97.98
19	School	TH1	207.2	124.32
20		TH2	89.0	53.40
21		TH3	87.0	52.20
22		TH4	161.7	97.02
Average			**146.60**	**87.96**

Tab. 4. Existence depth of the gold ores in the Pac Lang gold deposit by the ore body shape (Bogaski, 1982)

No.	Area	Ore bodies	Length in the strike direction (m)	Height in the dip direction (m)	Order No.	Existence depth
1	Khuoi Kinh	KK1	182.80	109.68	2	219.36
2		KK2	143.60	86.16	2	172.32
3	Khuoi Boc	KB1	194.50	116.70	2	233.40
4		KB2	143.20	85.92	2	171.84
5		KB3	255.10	153.06	2	306.12
6		KB4a	142.70	85.62	2	171.24
7		KB4b	143.30	85.98	2	171.96
8		KB4c	206.30	123.78	2	247.56
9		KB5	81.00	48.60	2	97.20
10		KB6	82.90	49.74	2	99.48
11		KB7	110.30	66.18	2	132.36
12		KB8	106.50	63.90	2	127.80
13	Manu	MN1	132.00	79.20	2	158.40
14		MN2	112.50	67.50	2	135.00
15		MN3	168.90	101.34	2	202.68
16		MN4	81.50	48.90	2	97.80
17		MN5	230.00	138.00	2	276.00
18		MN6	163.30	97.98	2	195.96
19	School	TH1	207.20	124.32	2	248.64
20		TH2	89.00	53.40	2	106.80
21		TH3	87.00	52.20	2	104.40
22		TH4	161.70	97.02	2	194.04
Average			**146.60**	**87.96**	2	**175.93**

Tab. 5. Calculation of denudation coefficient by the formula proposed by Beus and Grigoryan (1977) based on the sample ICP-MS analysis results in the whole Pac Lang gold deposit

No.	Sample No.	Analysis results (ppm)						Denudation coefficient K_z
		Ag	Pb	Zn	Cu	Co	Bi	
1	PL.119	0.38	49.04	165.70	87.16	48.49	0.92	0.79
2	PL.120	0.37	18.93	88.14	44.60	10.64	1.74	0.74
3	PL.123	0.45	29.39	50.85	42.85	19.94	0.95	0.83
4	PL.124	0.53	16.04	165.38	86.04	14.54	1.81	0.62
5	PL.125	0.48	12.26	166.17	45.79	21.96	0.84	1.17
6	PL.127	0.42	11.94	95.70	66.96	10.76	0.61	1.08
7	PL.128	0.71	16.39	67.63	36.73	10.46	0.64	3.22
8	PL.129	0.48	21.33	342.51	50.33	23.98	0.92	3.18
9	PL.138	1.46	31.74	158.06	108.66	23.15	2.41	1.21
10	PL.140	0.70	16.08	165.79	86.14	14.22	1.24	1.24
11	PL.142	3.04	8.87	169.14	70.07	20.84	0.69	4.53
12	PL.144	1.27	28.92	162.34	106.22	23.51	3.02	0.79
13	PL.145	0.46	120.43	164.48	57.84	24.74	3.66	1.74
14	PL.2025	0.84	1.09	12.74	40.61	5.49	0.55	0.10
15	PL.2051	0.60	25.34	118.96	41.92	16.55	0.78	3.35
16	PL.3003	0.74	132.68	122.14	74.54	9.92	2.80	5.80
17	PL.3003/1	0.65	47.54	192.28	73.81	17.94	2.69	1.66
18	PL.3003/3	0.84	115.20	102.97	103.88	29.20	1.59	2.07
19	PL.3003/5	0.88	207.25	117.09	39.55	19.40	0.66	42.30
20	PL.3003/7	2.34	59.66	114.67	49.66	23.40	1.16	11.85
21	PL.3003/9	0.97	149.81	190.67	77.42	29.34	0.80	15.15
22	PL.3003/11	0.67	100.76	218.02	56.71	20.24	0.96	13.37
23	PL.3009	2.33	42.36	178.33	65.53	10.96	0.71	34.33
24	PL.3010	4.58	27.32	71.02	54.38	10.65	0.99	15.56
25	PL.3012	1.05	11.32	117.48	54.43	12.91	0.50	3.95
26	PL.3014	1.03	16.92	91.17	53.94	11.23	0.85	3.07
27	PL.3026	0.83	36.79	106.98	31.59	7.02	1.11	13.30
Average		**1.08**	**50.20**	**137.64**	**63.24**	**18.20**	**1.32**	
K_z of the whole gold deposit		**4.91**						
The average value of ore gold samples		**1.41**	**78.97**	**135.24**	**61.29**	**16.85**	**1.24**	
Average K_z of ore gold samples		**11.78**						

tain sulfide-poor gold, and the lower part is quartz-pyrite veins containing gold in the graphite black shale. The distribution order of the lithographic structure can be divided into different zones as shown in Table 1.

Based on the ore zoning features and actual survey results, the author has built a cross-sectional model of the gold–quartz–sulfide ore zoning at the Pac Lang gold deposit (Figure 5).

Horizontal zoning: On the map, the Pac Lang gold deposit's region shows the horizontal zoning of the ore very well. This region can be separated into two primary ore zones, the polymetallic gold–quartz–sulfide ore zone, and the gold–quartz–pyrite ore zone, running from the northeast to the southwest.

The polymetallic gold–quartz–sulfide ore zone, which is found mainly in the Manu and Corba areas, forms a strip about 500–600m wide and extends from the northwest to the southeast;.

The gold–quartz–pyrite ore zone, which is distributed along the high mountain peaks from Khuoi Kinh and Khuoi Boc areas down to the School area, forms a strip many kilometers wide and stretches from the northwest to the southeast.

3.2. Prospective deep-buried mineral predictions

3.2.1. The ore-forming depth

It is feasible to determine the range of ore-forming depth for each ore body and the entire gold deposit by examining the depth of the ore body's denudation surface (the elevation of the outcrop) and the controlled ore-forming depth. Table 2 lists the results of the calculations for the range of formation depths of ore bodies.

The above-mentioned calculation results show that the development depth of the ore bodies at the Pac Lang gold deposit is relatively deep, the ore bodies are controlled and exploited to a relatively large depth from 84m to 307m, with an average of 201. 91m. The range of ore-forming depths of the whole gold deposit is 623m, indicating that the ore formation in the area has a high capacity to existing at depth. Furthermore, it is predicted that ore can develop to a depth of >450m.

3.2.2. The ore body's morphology and size

According to Lir (1984), the ratio between the height of the ore bodies in the dip direction and the length in the strike direction of the hydrothermal gold ore bodies has the coefficient k = 0.6. Based on the collected results on the length along the strike direction and the size of the ore bodies, and the formula (1), it is possible to calculate the distribution height of the ore bodies in the dip direction as shown in Table 3.

Tab. 3. The height in the dip direction of the gold ore bodies of the Pac Lang gold deposit (Lir, 1984)

On the other hand, according to Bogaski (1982), all 243 hydrothermal ore deposits in southern Siberia have a height in the dip direction equal to the length in the strike direction of the ore bodies. This finding is true for all three vertical forms of ore body existence, namely, single, intermittent, and stepwise.

Field survey results show that most of the gold ore bodies in the Pac Lang gold deposit are in the form of veins, sockets, cylinders, and intermittent lenses. Therefore, it is assumed here that the gold ore bodies have the existence number of 2 orders.

Then, regarding the existence form of hydrothermal ore bodies, the calculation results of the relative depths of gold ore bodies in the Pac Lang gold deposit are shown in Table 4.

The calculation results indicate that the ore bodies in the gold deposit have relatively high development prospects,

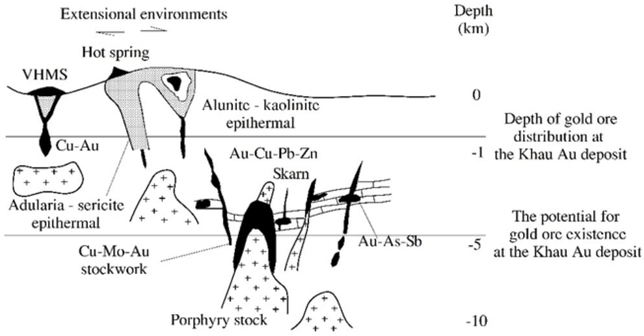

Fig. 6. The distribution model of original gold deposits by depth (Groves et al., 1998)

reaching 175.93m on average. Some ore bodies have a depth of 200–300m such as KK1, KB1, KB3, KB4c, MN3, and TH1.

3.2.3. The characteristics of the denudation rate

The change in vertical ore deposition conditions is one of the most important causes leading to the mineral formations with different compositions. The calculation of the denudation coefficient K_z by the formula (1) can assess the possibility of the existence of ore bodies deep-seated in the study area. Based on the ICP-MS analysis results of 27 samples at the Pac Lang gold deposit, the calculation results of the denudation coefficient K_z are shown in Table 5.

Calculation results of K_z by the formula (2) for the Pac Lang gold deposit show that the average K_z value of the whole gold deposit is 4.91 and of the ore samples are 11.78, all in the range from 0.1 to 10,000. No K_z value is less than 0.1 (below the value showing the ores or the ore bodies here have been completely denudated/eroded).

In general, the K_z value of the Pac Lang gold deposit is relatively low. Some areas with a low denudation rate include Khuoi Boc, Khuoi Kinh, and Mo Coi hill (Table 5), where the typical ore type is low-sulfide gold–quartz–pyrite, so the existence possibility of deep ore mineralization in these areas is still very promising.

The areas of Manu and School have a lower value of denudation coefficient, so the denudation rate is higher. These are also areas with low terrains and their typical ore type is gold–quartz–polymetallic sulfide. In these areas, the ore bodies of the sulfide-poor gold–quartz–pyrite ore zone have basically been completely denudated, and therefore, these areas have little potential for deep ore mineralization.

Evaluation of the ore body denudation depth: The ore formation distribution characteristics in ore-forming models indicate that the medium to low-temperature hydrothermal gold ore is formed at medium depth, with the depth fluctuating from about 800–1000m (Groves et al., 1998).

The study results on the ore mineralization characteristics, hydrothermal changes, and zoning features show that the gold–quartz–sulfide ore mineralization of the Pac Lang gold deposit is consistent with the distribution model of gold mines by depth mentioned by Groves et al. 1998) (Figure 6).

According to this model, the gold ore in the Pac Lang gold deposit is distributed at a depth of 0.5–1.2km and has a denudation rate of about 200–350m. Thus, based on the above-mentioned distribution model, it can be seen that the Pac Lang gold deposit has the ability to exist very deep and can go down to a depth of -5km.

5. Conclusion

Based on trace element geochemistry and assessment of the denudation rate of the Pac Lang gold deposit, the following conclusions can be made:

The ore mineralization at the Pac Lang gold deposit can be classified into three main zones: The gold–quartz–pyrite–poor sulfide zone; the gold–quartz–polymetallic sulfide zone, and the gold–quartz–arsenopyrite and pyrite zone.

The calculation results indicate that the depth range of gold ore formation in the deposit is approximately 623m. Based on the morphology of gold ore bodies and the average size of ore bodies in the Pac Lang gold deposit, the forecasted existence depth is estimated to be around 175.93m.

The denudation coefficient K_z for the gold ore in the deposit is calculated to be 11.78. This denudation coefficient suggests a moderate to strong denudation rate and places the deposit in the ore-forming zone, with the denudation depth estimated to be around 200–350m.

The study suggests the possibility of hidden gold ore deposits at even greater depths, potentially reaching depths of up to -5km.

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