Ore Mineral Exploration At Sungai Paguh Area, West Sumatra

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Abstract—Indonesia is a tectonic and volcanic area where valuable minerals can be formed. This paper perform research and study of ore minerals, objected for feasibility of mining purposes. Ore minerals are explored in mountainous regions: Sumatra, Java, and East Nusa Tenggara. The ore mineral in Bukit Barisan, West Sumatra attracts exploration activities, including the Sungai Pagu area. The method of exploration activities are carried out both traditionally (community mining) and those using standard mining machinery and equipment. This area has ore metal content which needs to be further explored to ensure that the area, grade, and distribution are quite economically feasible. From the mining geology survey of the area, rocks samples have been analysed. Using Atomic Absorption Spectroscopy (AAS) analysis, it is obtained an average primary gold content below 0.01 ppm. However, the lithological conditions resulting from petrographic analysis have made it possible to find gold and other heavy metals. At least sediment deposits show high gold content. In the mean time, mining exploration and activities must still comply with laws and regulations, especially concerning environmental issues.

Index Terms—Atomic Absorption Spectroscopy, environment, exploration, geology survey, heavy metals, mining, ore minerals, Petrography.

1. INTRODUCTION
West Sumatra is one of the provinces which has a potential ore mineral resource. It is interesting to explore and perform research for mining purposes. According to information from the West Sumatra Local Government (2018), South Solok Regency has the biggest gold potential in West Sumatra. At the moment, South Solok is estimated to have gold reserves of 749 kg and an indicated potential resource of 1,068,000 tons [1]. This is a quite significant potential if businessmen are interested to perform mining and contribute to regional original revenue. It can be used further for regional development and improving the welfare of the community in South Solok Regency. Based on general knowledge, ore minerals could be found a lot in volcanic mountain area, where evolved magma has become close to granitic type. Sumatra as one of active volcanic island has a potential resource of ore minerals, interesting to be studied and searched for mining purposes. This paper discusses stages in exploration of West Sumatra ore minerals and provides result of lab analysis of rocks samples taken from the area. A company has an interest in exploring ore minerals in the Sungai Pagu area, South Solok Regency, West Sumatra. By complying with government regulations, this company has a Mining Business License (IUP). Based on the IUP, the company is allowed to explore primary ore minerals. This paper analyzes data in information derived from the research on ore mineral exploration that has been carried out in the permitted area. It outlines the results and geologically analyzes the steps that need to be done next.

2. METHODOLOGY
By knowing the geology of Sungai Pagu area, Solok Regency, West Sumatra that has ore mineral resources, it is important to conduct research and studies on ore minerals in this area for mining purposes. In general, many ore minerals are found in areas where magma has been erupted to the surface of the earth. With the process of evolution of magma throughout geological history, the magma from basaltic origin will experience evolution into granitic. With the character of the metal and minerals that are contained in magma and formed when there is a freezing, will change. In the type of basaltic magma that has evolved to become granitic, it can form minerals and metals containing ores, so the minerals formed become ore minerals.
By understanding the composition of volcanic rocks in Sumatra, research and study have been carried out by taking 20 rock samples for Atomic Absorption Spectroscopy (AAS) and Petrographic analysis in early October of 2019. Figure 1 shows location map of rock samples taken during the survey. AAS analysis in particular can detect levels of valuable elements in these rocks. While petrographic analysis can find out the mineral composition and rock name. Using these two lab analyzes and understanding the regional geology of Sungai Pagu study area, an understanding of the ore mineral potential of the area can be obtained. Furthermore, by knowing the type of rock, heavy metal content and the geological conditions of the area they can be utilized for the next step of the plan and the mining potential of the area. By taking further steps namely shallow drilling, it can be seen the condition of rocks and mineral deposits below the surface of the ore. With this step it is expected to know more about the technical and economic feasibility of the area for mining.

2.1 Regional Geology
Regionally the geology of the area around West Sumatra is formed by a number of rock formations. The composition of rock formations in the study area in order from young to old is as follows [2] [3]:

1. River Alluvium (Qal), in the form of gravel sand and fragments of igneous rock, sedimentary rocks and metamorphic rocks along the floodplain, deposited around the river.
2. Siguntur Formation (Ps), in the form of solid and slightly altered quartzite, shale, solid and slightly crystallized siltstone. There is also slate as an intercalation in quartzite, phyllite and chert. Estimated thickness is of 2000 m. These rocks are Jurassic age.
3. Members of the Slate Siguntur Formation (Rls), in the form of slate, marbled shales with chert insertion, crystallized shale radiolarite and a thin layer of greywacke that is metamorphosed. The rocks are of Triassic–Jurassic age.
4. Barisan Formation (Pb) in the form of phyllite with mica, sericite, chlorite and quartz compositions. There are also slate, limestone, hornstone and greywacke meta. There are quartz veins from magmatic sulfide. Estimated thickness is of 3500m. These rocks are of Carbon to Permian age.
5. Barisan Formation limestone members (Pbl), limestone embroidered, covered and solid with color of light gray to dark gray. It is aged of Carbon to Permian.
6. Intrusion Igneous Rocks:
Granodiorite (Tgdr); Composition of hornblende granite to granodiorite.

Granite Rocks (Kgr); the composition ranges from arrangement between granodiorite to granite, dark blue with pseudo-green gray mafic mineral spots.

Granite (Jgr); light blue to pseudo dark red with spots greenish mafic mineral.

These rocks break through paleozoic and mesozoic rocks so it is assumed that these rocks are Cretaceous.

Figure 1: Location map of rocks samples taken during the field survey in October 2019

In this area, geological structures are complex. Both the folds and the faults on this area have a general northwest-southeast direction. The tilt angle of the pre-Tertiary rock layer or Tertiary rock near the fault area is usually large. The direction of the anticline and syncline of Tertiary rocks is almost similar to the direction of the pre-Tertiary rock fold that is inhaling. The main fault on this area is part of the Sumatran fault in the form of a sliding fault and some normal faults going northwest-southeast. The main fault is related to the formation of descending blocks such as Danau Atas and Danau Bawah, the Muaralabuh and Semurup valleys, Kerinci mountain activities and hot springs.

2.2 Ore Mineral

It is important to perform study, research and exploration of mineral deposit especially for mining purposes. According to Earth Science Australia (ESA) mineral deposits have been described and classified [4]. Based on a number of factors the ore mineral and deposits could be classified, those are host rocks i.e. the rocks which enclose or contain the deposit, minerals or metals component, the shape or size of the deposit, and the original source of the deposit in correlation with the geological processes which combined to form the deposit. Based on these features, ESA describes physical description and classifies the deposits. One of the group unit in the classification is Epigenetic. It is named to be epigenetic if a mineral deposit formed much later than the rocks which enclose it. ESA classifies Epigenetic to some units called: Porphyry, Skarn, Vein, Mississippi Valley, Volcanic Massive Sulphide Rocks (VMSR), Sedimentary Massive Sulphide Rocks (SMSR), Magmatic-layered mafic intrusion, and Placer.

2.3 Ore Mineral Exploration

In general, two types of ore deposits could be explored. Those are grouped into primary and secondary deposits. Government Mining Ministry may apply specified primary deposit type for mining companies who are interested in exploration and mining activity. From the above ESA classification it is interested to explore heavy metals in primary deposits. Using ESA’s classification, the ore mineral found in research location of Sungai Pagu area belongs to Vein. It is identified from the geological survey that Vein is found in Sungai Pagu and surrounding area, South Solok region. Genetically in particular, Vein is formed beginning by intrusion of hydrothermal fluid cracking or inserting of rock along a fracture or fault zone, in a depth of ranging from surface to several kilometers subsurface. The rock may have lithified to become solid but brittle, creating open spaces when it cracks. Hydrothermal solutions flows to fill the fracture and fault zones. By freezing the solutions then deposit or precipitate the ore and gangue minerals within the cracks and open spaces. Therefore, the vein should be younger than the rocks where vein inrupted. As a fracture filling deposit, vein usually have very narrow form in a great depth and wide lateral extent. It can be grouped into: 1. Hypothermal - Cu (Au), 2. Mesothermal - Cu-Pb-Zn-Ag-Au, and 3. Epithermal - Au-Ag (-Hg)The research was started by geological mapping of area around Sungai Pagu of South Solok Regency. Figure 2 shows location and geological map of the area. Rocks samples taken from survey locations have been analyzed for AAS (Atomic Absorption Spectroscopy) and Petrography.

Figure 2: Survey Location and Geological Map of Sungai Pagu area, South Solok Regency, West Sumatra
3. RESULTS AND DISCUSSION

3.1 Lab Analysis
Based on the analysis of AAS Lab, the following data are obtained:

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample ID</th>
<th>Au (ppm)</th>
<th>Ag (ppm)</th>
<th>As (ppm)</th>
<th>Cu (ppm)</th>
<th>Pb (ppm)</th>
<th>Zn (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>STOPSITE 2.1</td>
<td>&lt;0.01</td>
<td>&lt;0.5</td>
<td>6</td>
<td>8</td>
<td>21</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>STOPSITE 3.2</td>
<td>&lt;0.01</td>
<td>&lt;0.5</td>
<td>36</td>
<td>9</td>
<td>&lt;5</td>
<td>28</td>
</tr>
<tr>
<td>3</td>
<td>STOPSITE 8B</td>
<td>&lt;0.01</td>
<td>&lt;0.5</td>
<td>2</td>
<td>9</td>
<td>9</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>STOPSITE 9</td>
<td>&lt;0.01</td>
<td>&lt;0.5</td>
<td>2</td>
<td>4</td>
<td>&lt;5</td>
<td>19</td>
</tr>
<tr>
<td>5</td>
<td>LP-4</td>
<td>&lt;0.01</td>
<td>&lt;0.5</td>
<td>2</td>
<td>28</td>
<td>&lt;5</td>
<td>21</td>
</tr>
<tr>
<td>6</td>
<td>LP-06</td>
<td>&lt;0.01</td>
<td>&lt;0.5</td>
<td>&lt;2</td>
<td>2</td>
<td>&lt;5</td>
<td>25</td>
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<tr>
<td>7</td>
<td>LP-7.1</td>
<td>&lt;0.01</td>
<td>&lt;0.5</td>
<td>&lt;2</td>
<td>3</td>
<td>&lt;5</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>LP-10</td>
<td>&lt;0.01</td>
<td>&lt;0.5</td>
<td>3</td>
<td>7</td>
<td>&lt;5</td>
<td>28</td>
</tr>
<tr>
<td>9</td>
<td>SUNGAI ILS.</td>
<td>0.04</td>
<td>&lt;0.5</td>
<td>39</td>
<td>42</td>
<td>7</td>
<td>79</td>
</tr>
<tr>
<td>10</td>
<td>SUNGAI 2</td>
<td>0.51</td>
<td>&lt;0.5</td>
<td>2</td>
<td>264</td>
<td>&lt;5</td>
<td>17</td>
</tr>
</tbody>
</table>

While Petrographic analysis on 10 (ten) rock samples obtained the following data:

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample Location</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FILIT 8B</td>
<td>PHYLLITE (Ealle, 2015) [5]</td>
</tr>
<tr>
<td>2</td>
<td>LP 6</td>
<td>Alteration Zone: PHYLIC</td>
</tr>
<tr>
<td>3</td>
<td>LP 7.1</td>
<td>QUARTZITE (Ealle, 2015) [5]</td>
</tr>
<tr>
<td>4</td>
<td>LP 7.2</td>
<td>SERPENTINITE (Schoenherr, 2017) [15]</td>
</tr>
<tr>
<td>5</td>
<td>LP 10</td>
<td>SERPENTINITE (Schoenherr, 2017) [15]</td>
</tr>
<tr>
<td>6</td>
<td>STOPSITE 3.1</td>
<td>META-QUARTZ WACKE (Hudson Institute of Mineralogy, 2019) [7]</td>
</tr>
<tr>
<td>7</td>
<td>STOPSITE 8A</td>
<td>QUARTZOLITE (British Geological Survey, 2016) [8]</td>
</tr>
<tr>
<td>8</td>
<td>STOPSITE 8B</td>
<td>QUARTZOLITE (British Geological Survey, 2016) [8]</td>
</tr>
<tr>
<td>9</td>
<td>STOPSITE 9</td>
<td>Zona Alterasi: OUTER PROPYLLITE</td>
</tr>
<tr>
<td>10</td>
<td>SUNGAI ILS.</td>
<td>QUARTZOLITE (British Geological Survey, 2016) [8]</td>
</tr>
</tbody>
</table>

3.2 Discussion
Based on the results of petrographic and AAS analysis, it can be analyzed possible genesis of various rocks in the area. Geological survey found that basic rocks in the area are sedimentary and volcanic rocks of sandstone, limestone and shale. However, with tectonic and volcanic activities resulting intrusion of magma to form igneous rocks of granodiorite, the basic rocks have been affected to result in producing metamorphic rocks as well as metasediment rocks. Those are phyllite, interfingerling with slate (Figure 3), quartzite, and metasediment rocks from sandstone and limestone. Continuous volcanic activity may result in magma evolution to produce hydrothermal activity to produce quartz veins (Figure 4), filling the cracks, fractures, and fault planes as a results of previous tectonic and volcanic activities.

Phyllite is defined as a metamorphic rock that is foliated. It is created from slate that could further metamorphosed to form very fine grained white mica having a preferred orientation (Marshak, 2016) [9]. Mottana et al (1978) argued that phyllite is primarily composed of quartz, sericite mica, and chlorite [10]. Meanwhile King (2019) [11] pursues that phyllite as a very common metamorphic rock, could be found in many areas of the world. It was composed mainly of clay minerals in a semi-random orientation and generated from a fine-grained sedimentary rock such as shale or mudstone. Phyllite is formed when sedimentary rocks are buried and subjected to enough heat, directed pressure, and chemical activity to make the clay mineral grains compressed to cause parallel alignment. The heat and directed pressure of regional metamorphism then make the composition is mildly altered. It is then transforming the clay mineral grains into chlorite or a mica mineral. These activity and process happened at almost always convergent plate boundary environments involving continental lithosphere.

As shown in petrographic analysis, in the geological area of Sungai Pagu is also found a rock sample of quartzolite. According to Lishmund (1974) [14] and Schoenherr (2017) [15], it is known that quartzolite and silexite is generated to form intrusive igneous rock, where the mineral quartz component is more than 90% of the rock's felsic mineral content, and also having feldspar at up to 10%. Quartzolite could also formed like magma intrusion as dykes, sills, veins, bosses and segregation masses [15]. Meanwhile, in the
survey area is also found Serpentinite. Schoenherr (2017) [15] argues that the name of serpentinite has similar rock texture to that of the skin of a snake. It is composed of one or more serpentine group minerals. Minerals in serpentinite group are light to dark green color, rich in magnesium and water, greasy looking and slippery feeling. They are formed by serpentinization, i.e. a geological low-temperature metamorphic process involving heat and water in which low-silica mafic and ultramafic rocks are oxidized and hydrolyzed with water into serpentinite. The field survey also found and sampled a rock named quartzite. It is a non-foliated metamorphic rock which is hard and was originally pure quartz sandstone [10][17]. It is known that quartzite is originated from sandstone that is converted into metamorphic rock through pressure and heating usually related to tectonic compression within orogenic belts. From the field survey, it is also identified possible hydrothermal alteration in the rocks of the area. The petrographic analysis found rock alterations: phyllic and propylitic alterations. According to Yant (2009)[16], hydrothermal alteration zone in a permeable rock that has been affected by circulation of hydrothermal fluids could cause phyllic alteration. It is characterised by the association of quartz, sericite, and pyrite, occurs at high temperatures and moderately acidic (low pH) conditions. Meanwhile, propylitic alteration is also identified in the petrographic analysis. Lithologically, propylitic alteration is mineral rock composition that change chemically altering biotite or amphibole within the rock groundmass. In general, it is a chemical alteration of a rock, caused by iron and magnesium bearing hydrothermal fluids. Taylor (2009)[17] found that the alteration typically results in epidote–chlorite–albite alteration and veining or fracture filling with the mineral assemblage along with pyrite. The alteration happens causing by hot fluids that have a high sodium ion composition. This is typically a result of fluids that have lost potassium ions in potassic alteration and gained sodium ions. It is known that the alteration occurs due to hot fluids that have a high sodium ion composition. This is typically a result of fluids that have lost potassium ions in potassic alteration and gained sodium ions.

3.3 Geological Modeling
According to regional conditions, the above analysis, field survey data and the results of the AAS and Petrographic analysis, the geological rock genesis and mineral deposits of this region were formed in the following sequence (Figure 5):

1. Based on bedrock such as sandstone, claystone, and peat, then there will be an uplift that forms the geological structures of folds, faults and fractures.
2. Geological activity continues with intrusion and eruption of magma that forms granodiorite igneous rocks, where the pressure and heat from magma bursts can cause metamorphism from low to high levels.
3. Due to high pressure and temperature, eruption of magma causes changes in texture and composition of bedrock (sandstone, claystone, peat) to form metasedimentary rocks (Slate, Meta Quartz Wacke) or up to metamorphic (Phyllite, Serpentinite).
4. The activity of magma continues with the formation of quartz veins by the genetic mechanism that can be characterized as Epigenetic type. The breakthrough of the fluid that forms the quartz vein also affects the cracks in the fractures and fault plains where the quartz vein fills and freezes in it.
5. Quartz vein-forming fluid is interpreted to be part of the evolution of the final stage of magma which in addition to forming quartz minerals and hydrothermal alteration, also carries heavy metals and forms mineral deposits and ore minerals.

It can be viewed in Figure 5 that uplifting of basic rocks by magma intrusion forms granodiorite that followed by hydrothermal intrusion generating quartz vein and forming ore mineral containing heavy metals.
CONCLUSION
From the results of the study of data and information and scientific analysis of the results of the field survey can be concluded as follows: Sungai Pagu and its surrounding area are geologically identified as having ore deposit and mineral potential both in primary and secondary deposits. Field surveys that have been carried out in the field have collected data and information to strengthen the evidence and basis for geological scientific analysis for further steps. Data from the AAS and petrographic analysis of samples from the field provide strong enough evidence to explore ore mineral mining in the area.

To add data and information in making decisions, a shallow drill bor survey can be carried out, especially for the analysis of ore content in fresh rock samples (less weathered) from below the surface.

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