"EL TORO" GOLD MINE (PERU): GEOLOGICAL FEATURES AND PERSPECTIVES

Introduction. The northern segment of Peru hosts an extensive variety of polymetallic resources, genetically related to evolution of the Andean tectonics, highlighting the ore deposits with gold mineralization (Au-Cu porphyries, Au-Ag epithermal, the gold deposits related to batholithic and metamorphic complexes, etc.). Such a geological peculiarity is shown in the review of the national gold production (2016) which localized mainly in following regions: La Libertad (28.7%), Cajamarca (23.6%), Madre de Dios (11.6%), Arequipa (10.9%), Ayacucho (7.6%), Puno (6.7%) and others (10.9%). The first and second ones are located in the northern segment of region and both amount to more than 50% of national production. El Toro gold deposit belongs to the group of mines that are distributed in the La Libertad region and they can be geologically treated as an epithermal deposit of epizonal nature that is specially related to a subvolcanic intrusion. It is localized in the clastic sediments of the Chimu Formation (Lower Cretaceous), in the structural association with overthrusts, high bedding faults and narrow folds.

Regional geological context. The oldest rocks formations are represented by sediments of Permo-Triassic age that expose to NE of San Marcos city and occupy the area of approximately 1 km². Nevertheless, their greater development has been distinguished in adjacent zones. Above these deposits Mesozoic rocks are exposed which are followed by Cenozoic unconformity cover comprising of effusive rocks. At the upper section thin lacustrine and fluvialoglaciers deposits of quaternary age are exposed. The Mesozoic clastic sediments are generally continental (fluvial and deltaic), especially in eastern part where they are thin and increase in thickness westward [2]. Sandstones and quartzite of platform basin are interbedded with limestones and shales of Santa formation, some levels of paraglauconites. These deposits are continued by shales, sandstones and quartzite of Carhuez formation, ending at the top with a predominance of quartzite of Farnat formation. This suggests that basin sector was subjected to the subsidence movements which are separated from Maranon geanticlinal of the western basin. It is evident that the basin was related to a shallow sea during Goyllarquisquiza group deposition [7], where a constant exchange of water gave rise to the intensively oxygenated zones. As it was sinking, it was being filled with clastic materials, so that the same levels were maintained. Therefore, the clastic sedimentation area had a long period of apparent stability with constant movement, as a result, there was sediments accumulation about 2,000 m [11].

The plutonic bodies do not crop out, but some stocks, sills and dikes cut volcanic and sedimentary rocks. The deepest intrusive bodies are generally represented by diorites, tonalites and granodiorites, constituting coastal batholith prolongation. The hypabyssal bodies mostly occur as andesitic and dactic porphyries that arise indistinctly within the area, often confined to the metalliciferous minerals. The dispersed outcrops in the area allow investigating a relation between them. The studies performed in the neighboring areas confirm that the intrusive unit has a following paragenetic relationship: diorite-granodiorite-tonalite-porphyry-dacite-andesite-granites. Granodiorites, dactites and porphyritic dactites act on Calipuy group (fig. 1), emphasizing that diorites appear to still intrude to San Pablo volcanic unit [12].

Tectonically there is evidence of four deformation stages that began in late Cretaceous and continued during Cenozoic, all of which corresponding to Andean cycle movements. Approximately, at Upper Jurassic, Peruvian occidental basin and Maranon geanticlinal began to form. Probably distension forces influenced the development of two great elements: a graben (west) and a horsts (east) [12].

Naturally, the sedimentation began to accumulate in the basin continuously and it, in turn, was slowly subsiding. Between Aptian and early Albian, the marine transgression advanced towards the Maranon geanticlinal, completely covering the basin during the interval between Albian and Senonian. A thicker calcareous cover left in the basin lithological changes that correspond to the basin-platform slope change. At the end of the cycle of sea sedimentation in Senonian, when the sea covered Andes mountain ridge and the Amazon basin part in early Santonian, the basin and Maranon geanticlinal were affected by episregenetic movements, raising large regions of the basin and platform, thus initiating a clastic accumulation in lower parts (Chota formation) [3]. The second Andean cycle movement is the main movement in this zone. Early Tertiary is characterized by high compression forces, originated in vectors from southwest that pushed a sedimentary prism towards northeast, intensely folding the sediments in the basin sector and

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producing an overthrust on its eastern side that occurred after Chota formation deposition. As a result of this movement, a massif emerged to relatively moderate heights, without becoming true mountains, but with enough of a topographic contrast and was subjected to an intense erosion, whose removed materials were deposited discordantly in the lower part of the folded series, recognized as Huaylas formation [12].

The third deforming movement probably began at early Tertiary and continued until middle Tertiary, after a post-tectonic Calipuy group volcanic accumulation, developing structures with the same direction as the second movement. Regionally, it seems that the greatest volcanic rocks accumulation occurred in western part of the basin, where the first levels were interbedded with lenticular conglomerates [4]. Generally, this deposition was sub-
aerial, reaching thickness that exceeds 2,000 m. The third deformation movement was also characterized by compression. It affected the volcanic series with the incipient folding produced for the block faults, the upper undulating structures reached heights above their original positions, being therefore subjected to prolonged interval erosion, which resulted in a peneplanation, developing an erosion surface called the "Puna" surface.

The fourth movement was epigenetic and resulted in the elevation of the Andean region to present levels. These deformation phases are evidenced by discordances, folds and other structures regionally, it looks like the tectonic movements in some sectors have been more intense than in others. Main structures in the study area are directly related to the second Andean cycle movement, which clearly defined two structural provinces: a province of folds and an overthrust province [6].

**El Toro gold deposit.** El Toro is an epithermal gold deposit with an epizonal structure being hosted in the clastic sediments of lower Cretaceous (Chimu Formation). The ore deposit is located in La Libertad Region in northern Peru. Spatially it is configured as elongated geometry that aligns with the Andes mountain ridges; geomorphologically it is a 1.0 x 1.5 km dome structure (fig. 2), the axis of the dome is formed by a subvolcanic intrusion of dacite / andesite composition (20-18 My). The basement deposit is represented by pelitic rocks, slate, shales and carbonaceous slimes of Chicama Formation. They are underlain by clastic sequences of Goyllarisquizga Group conformed to quartz and laminar sandstones. Locally, four tectonic events (ET) are recognized: ET-2 (overthrust faults), ET-4 (NW-SE faults), ET-5 (high angle NW-SE faults) and ET-6 (annular faults). The mineralization occurs in oxides that constitutes 80% of current mineral resources and is related to sedimentary rocks, tectonic breccia, hydrothermal breccia, collapse breccia and oxidized dacite blocks; while sulfides and mixed materials are restricted to dacite/andesite bodies [10].

![Fig. 2. El Toro gold mine panoramic view, Huamachuco district](image1.png)

El Toro ore deposit structural specificities were interpreted and recorded in general plane (fig. 3) representing most mapped elements, which were later classified as tectonic events (ET). Criteria for this grouping are: geometric elements, faults mechanics, kinematic interpretation, mineral association and tectonic material characteristics. All of this is based on tectonic environments reconstruction and geological history of the Andes. Therefore, lithological units arrangement, mineral zones, rock competence and other geological variables will have an intrinsic relationship with conjugate dynamics of these planar elements.

![Fig 3. El Toro geologic map, Huamachuco district](image2.png)
The rocks arrangement is in relation to the structural framework. There are: ET-2 (overthrust faults that make tectonic windows), ET-4 (steeply dipping faults with associated gold mineralization), ET-5 (post-mineralization faults of NW-SE strike and E dip to E). The last one corresponds to higher levels of Andean tectonics, geographically limiting this sector and forming prominent cliffs. For example, these faults control the east and west flanks of El Toro ore deposit and generate tectonic breccia of considerable thickness. Finally, ET-6 demarcates igneous intrusions in collapse calderas which have an annular appearance with vertical and horizontal displacement (associated with transfer faults) [5]. They break the deposit and form the current structure (fig. 4).

Geological interpretation involved design and digitalization of six cross sections and three longitudinal sections (L. Central, LNE +100 and LNE -100). These sections have the separation of 100 meters between them (fig. 5), comprising an approximate area of 350,000 m². The modeling contemplates 3D detail of all geological variables mapped (faults and lithology). Figure 6 is a hypothetical regional model.

The resources estimation results are summarized in Technical Report 43-101 (NI 43-101 Resources Technical Report, El Toro gold project) [8]. They are shown in table 1 and based on information of RC-DDH historic drilling campaigns, production drill holes, trench samples, mining banks and the mineralized zone model.
Fig. 6. Hypothetical model regional, Huamachuco district

Table 1

<table>
<thead>
<tr>
<th>Category</th>
<th>Tonnage</th>
<th>Au (g/t)</th>
<th>Au (Ounces)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured</td>
<td>5,660,000</td>
<td>0.36</td>
<td>65,000</td>
</tr>
<tr>
<td>Indicated</td>
<td>19,060,000</td>
<td>0.45</td>
<td>276,000</td>
</tr>
<tr>
<td>Measured + Indicated</td>
<td>24,720,000</td>
<td>0.43</td>
<td>340,000</td>
</tr>
<tr>
<td>Inferred</td>
<td>25,460,000</td>
<td>0.49</td>
<td>398,000</td>
</tr>
</tbody>
</table>

Cut off: 0.16 g/t Au;
Estimate resources without dilution;
Mineral resources restricted to an open pit with value of 1,265 $/Oz

Based on the compilation, validation and interpretation of RC and DDH drilling (16,000 m approx.), access and open pit development, transversal and longitudinal sections are used to define a geo-structural model that is an important support for developing an aggressive DDH and RC drilling Program (10,000 m of DDH drill and 15,000 m of RCD drill). The details are shown in fig. 8.

The main objectives of 2016-2017 Drilling program are: (1) to define areas of condemnation to develop operational infrastructures; and (2) to increase mineral resources. Exploratory campaign 2106-2017 has good expectations, some results of this exploratory campaign are show in fig. 9 (PE16-TO-DH0017 and PE17-TO-DH0024), where breccia and oxidized zones are observed.

Fig. 8. Drilling campaign 2016-2017 (DDH and RCH), El Toro gold mine
Regional exploratory expectations. The configuration and the establishment of Peruvian deposits interrelate with the Andean mountain ridge course, defining twenty-four metallogenic belts [1]. The deposits of the northern Peru are mostly auriferous, including a great variety of mining occurrences, exhibiting from deep systems to apical levels, directly associated with intrusives or being housed in secondary structures.

Specifically, "XX metallogenic belt" (Cu-Mo-Au porphyry, Pb-Cu-Zn-Ag skarn and polymetallic deposits related to intrusives Miocene), is formed by tectonic activity during upper Mesozoic to Cenozoic, which is associated with intensive igneous Miocene activity. It contributed to ore generation and formation of big gold deposits.

According to projection and based on the interpretation and correlation of structural styles, lithological domains, mineral occurrences configuration of approximately 1,500 km² was limited. This preliminary interpretation is also based on analogical correlation with other mining districts with contemporary genesis and resources that would surpass in global thirty million gold ounces globally and consequently, it means increase in exploratory potential of resources in this region (fig. 10). It has been established by preliminary assessment that preponderant control mineralization is structural, with four regional tectonic events, which configure not only mineral occurrence but also geographic peculiarities. These traits are good exploration guides [9].
ЗОЛОТОРУДНЕ РОДОВИЩЕ "ЕЛЬ ТОРО" (ПЕРУ): ГЕОЛОГІЧНА ХАРАКТЕРИСТИКА І ПЕРСПЕКТИВИ

Епітермальне родовище золота Ель-Торо локалізоване в осадових породах північної криї (формація Chimu), у регіоні La Libertad в північній частині Перу, характеризується епіклональною будовою. Рудний район El Toro-Altagracia, до якого приурочено родовище, витягнуто навколо субвулканічного ядра. Родовище приурочено до купольоподібної структури розміром 1,0 х 1,5 км, ядро купола представлене субвулканічною інтурузією дацит-андезитового складу, віком 18–20 млн років. Вмістовими породами є гравій, сланці, мел, хребтові осяги, які відшаровуються оковками мінералізації.

За результатами оцінювання розрізних запасів (за нормативи NI 43-101, 2014 р.) розраховані запаси золота родовища становлять 65 000 унцій; попередньо розраховані запаси – 27 600 унцій, прогнозирються запаси – 398 000 унцій.

На основі інтерпретації та кореляції структур, литології цео i підбічних рудних родовищ виділено новий рудний район El Toro-Altagracia площею близько 1500 км², аналігічний за генезисом і ресурсами золота іншим відомим у регіоні золоторудним районам. Їх залишки можуть перешкоджати на 30–60 млн унцій золота.

Ключова слова: епітермальне родовище золота, мінералізація осадових відкладів, рудний район, литологічна і структурна інтерпретація, геологічне моделювання 3D.

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Эпительмальное родовище золота Эль-Торо локализовано в осадочных породах нижней крий (формация Чиму), в регионе La Libertad в северной части Перу, характеризуется епиклинообразной структурой. Рудный район El Toro-Altagracia, в который приурочено месторождение, вытянут в северо-северо-западном направлении, согласно простиранию горных пород Анд, более чем на 100 км при ширине 25–30 км. Месторождение приурочено к купольообразной структуре размером 1,0 х 1,5 км, ядро купола представлено субвулканической интрузией дацит-андезитового состава, возрастом 18–20 млн лет. Вмещающими породами являются песчаники, сланцы, хрусталь, формации Чима, которые подшерохованы напластованими песчаниками Серии Гойларскуиага. Выделяются четыре тектонических фазы (ET): ET-2 (формирование надвигов), ET-4 (субвулканическая интрузия) и ET-5 (клинообразные разломы). Месторождение представлено преимущественно оксидами (до 80%), связано с осадочными породами, тектоническими, частью миnergализованными брекчиями, окисленными дацитами, в последних развивается также сульфидная и смешанная минерализация.

По результатам оценочных работ (отчет NI 43-101, 2014 г.) разведанные запасы золота месторождения составляют 65 000 унций; предварительно разведанные запасы – 27 600 унций, прогнозные запасы – 398 000 унций.

На основе интерпретации и корреляции структур, литологии этого и подобных рудных месторождений выделен новый рудный район El Toro-Altagracia площадью около 1500 км², аналогичный по генезису и ресурсам золота другим известным в регионе золоторудным районам. Из общих ресурсов превышает 36 млн унций золота.

Ключевые слова: эпительмальное месторождение золота, минерализация осадочных отложений, рудный район, литологическая и структурная интерпретация, геологическое моделирование 3D.