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Notes on Economic Geology studies in Peru

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ABSTRACT

A review of ore deposit studies as published in the journal Economic Geology illustrates the amount and character of geosciences being conducted in Peru. A comparison is made with the number of ore deposit publications in both the Boletín and congress abstracts of the Sociedad Geológica del Perú. Many social-political-economic factors contribute to the major periods of research that are herein termed Formative, National, and Privatized.

RESUMEN

Una revisión de estudios de yacimientos minerales publicados en la revista "Economic Geology" ilustra la cantidad y el carácter de los estudios geológicos realizados en el Perú. Se hace una comparación con el número de publicaciones acerca de depósitos minerales en forma tanto de resúmenes de congresos, como de artículos del Boletín de la Sociedad Geológica del Perú. Son muchos los factores socio-político-económicos que contribuyeron y siguen contribuyendo a los principales períodos de investigación científica denominados aquí como Formativo, Nacional y Privatizado.

Palabras claves: Peru, Economic Geology, ore deposits.

1. Summary of Peru Economic Geology studies

This short summary gives the history of Peruvian mineral deposits as represented in the journal Economic Geology. Publications in the Society of Economic Geologists place the country's mining into a global context. The journal was started in 1910, and has become the world's leading venue for the dissemination of scientific information about ore deposits. Throughout much of the 1910's through 1920's the journal mainly reported on the Bolivian tin deposits when covering South America mining. A notable exception to this focus on tin came with Lindgren and Bastin's 1922 paper on the Branden Mine (El Teniente) in Chile. The first paper covering a deposit in Peru did not appear until 1932 with McKinstry and Noble's work on Casapalca mines. Subsequently a short flurry of Peru papers emerged: Lindgren (1935) on Colquijirca; McKinstry (1936) on Colquijirca; and Graton and Bowditch (1936) on Cerro de Pasco. The first mention of Chuquicamata of Chile did not appear until the paper by Lopez (1939). The first 30 years of Economic Geology mainly covered deposits in North America.

During the 1940's World War II certainly inhibited geological investigations of Peruvian deposits. Several more studies of the Bolivian tin mines were published in the 1940's, but the first post-war publication on a Peru mine did not come until the 1949 paper by Kruger and Lacy on the geophysical expression of Cerro de Pasco.

During the 1950's several major studies on Peru mineral districts were advanced. The next publications came with Johnson (1955) on the Atacocha deposit and Simmons (1955) on the Chilete district, both of which were supported by the United States Geological Survey (USGS). Another noteworthy early study backed by the USGS was by Yates et al. (1951) in the Huancavelica mercury district, although this was not published with Economic Geology. Lewis (1956), in another USGS backed program, gave the excellent report on the Quiruvilca district, presenting for one of the first times a detailed vein map of a Peruvian polymetallic district. These post-war studies by the USGS were joint efforts with the then Geological Institute of Peru,

which is now called INGEMMET. Nagell (1957, 1960) reported on the nature of anhydrite at Morococha (Cerro de Pasco Corp). In the first deposit origin and isotopic regional survey, Kulp et al. (1957), from the Lamont Geological Observatory, Palisades, New York, paper titled "Lead isotope compositions of Peruvian galenas" begins what could be called the analytical era in Economic Geology. While only covering four deposits from central Peru, the study results mark the base metal mines as having a magmatic fluid source. Most of what has been published on Peruvian ore deposits in the formative years of mineralization research, particularly the papers in the Sociedad Geológica del Perú (SGP) conferences, comes from geologists working for the Cerro de Pasco Company. This company sponsored public release of mine information and remained important up to the time of nationalization in January, 1974. From the beginning of the SGP Peruvian Geological Congress in 1956, short papers or notes ("Resúmenes Extendidos") on ore deposits greatly outnumbered full papers in either Economic Geology or the Boletín de la Sociedad Geológica del Perú, a pattern that continues to today. Also noteworthy is Ward's (1959) paper on Yauricocha describing a carbonate replacement deposit.

The first truly regional summary did not appear until Petersen's 1965 summary about the mineral deposits of central Peru. In 1968 Laughlin et al. Economic Geology paper gave the first K-Ar dates in Peru, which covered Toquepala and Michiquillay. The Toquepala mine was operated by the Southern Peru Copper Corporation, a company founded in 1952. Also in 1968, Lyon's paper on the Carahuacra mine illustrates the continued focus on the most easily accessed mineral district in central Peru. By this point political conditions in Peru were destabilized; meanwhile Economic Geology continues publishing the occasional article on Bolivian tin deposits, which had seen an uptick in prices during the 1970's.

Entering the 1970's the Economic Geology journal is realizing pedigree of the brand, which only increased for the last few decades, effectively raising the bar for any report on Peruvian geology to be communicated. This has essentially meant to be included required more expensive analytical methods, the data tables being justification of discourse about mineralization. Most poignant of the cultural shift in Economic Geology is the inclusion in the early 1970's mass spectrometer data such as oxygen and sulphur isotopes to characterize ore deposits. With the government coup in 1968 by General Velasco Alvarado, an event that strongly offset the advantages of jetliner transportation due to the sharp curtailment of foreign investment in Peru, scientific research in Peru was limited. In 1974, the next paper in Economic Geology, once again returning to mines along the Carreterra Central, was with Rye and Sawkins' reporting on stable isotopes of the Casapalca base metal veins. In the same year, Goodell and Petersen's report on Julcani metal ratios finally brought into the discourse an outlier ore deposit, expanding awareness that there was more to Peru than Morococha and Cerro de Pasco. Again, stable isotopes form the justification of communication, with yet another exotic location in Peru at Pasto Bueno being reported upon by Landis and Rye (1974). In the latter half of the 1970's Economic Geology started publishing few special editions dedicated to a region or deposit type, typically both. The 1977 volume 6 on the Andes delivered a record seven papers on Peruvian ore deposits. Once again the topics return to central Peru with Cerro de Pasco (Einaudi, 1977; Silberman and Noble, 1977) and Casapalca (Wu and Peterson, 1977), but now adding a second paper on Julcani (Petersen et al., 1977), the first paper on Raul Contestable (Ripley and Ohmoto, 1977), and a paper on the Finlandia vein in the Colqui district (Kamilli and Ohmoto, H., 1977). Birnie and Peterson (1977) described the veins of the Huachocolpa district.

Beginning in 1980, Peru entered the unfortunate decade of terrorist led rebellion, and select ore deposit studies continued through this difficult time. Agar (1981) reported on copper mineralization along Rio Pisco. In 1982, the scientific communication by Schwartz on La Granja porphyry marked the first time the geology of copper project instead of an operating mine was reported upon. Clark et al. (1983) provided the first Peruvian tin deposit Economic Geology paper after 60 plus years of scattered papers on Bolivia tin. Julcani was yet again revisited by Scherkenbach and Noble in 1984. Noble had a long productive relationship with the owner/operator of Julcani, Compañía de Minas Buenaventura, which resulted in several publications on this district and central Peru (Silberman and Noble, 1977; Noble and McKee, 1982; Noble et al. 1984; Shelnutt and Noble, 1984; McKee and Noble, 1986; Alvarez and Noble, 1988). Campbell et al. (1984) reported on oxygen isotopes from the San Cristobal mine. The Huanzala mine brought attention to manto-style mineralization the paper by Imai et al. (1985). Vidal (1987) was the first to publish in Economic Geology about a volcanic massive sulfide type deposit in Peru. The Leonila-Garciela district (Perubar zinc mine) was first placed into production for zinc in 1959 after three decades of researchers driving by it on their way up to Cerro de Pasco. Also in 1987, Bartos, representing the company ASARCO, published the second Economic Geology paper on Quiruvilca, coming 31 years later from the work by Lewis. Soler and Bonhomme (1988) was the first non-deposit specific more regional paper describing magmatic timing.

Volume 85 (7), 1990 of Economic Geology published a special edition featuring the deposits of Peru (Petersen et al., 1990a), giving 21 papers. Many of these for the first time covered other deposit types, like orogenic gold at Pataz (Schreiber et al., 1990) and low-sulfidation systems at Orcopampa (Gibson et al., 1990; Petersen et al., 1990b, 1990c) and Arcata (Candiotti de los Ríos et al., 1990). Fontboté and Gorzawski (1990) gave the first Mississippi Valley type deposit paper on San Vicente, covering an operation that had some 29 years of production. Also appearing in this 1990 addition were papers by Bartos, Bussell et al. on Uchucchacua, Clark et al. on geochronology, Farrar et al. dating the Choquene district; lead isotope data reported by Gunnesch et al., MacFarlane et al., and Mukasa and Vidal; and Noble and Vidal's geochemistry of Huancavelica mercury district. In addition, and more importantly, the Fujimori regime initiation of privatization in 1993-1995 began the current economic boom in Peru, and with an attendant lag time, a marked increase in the number of publications covering Peruvian ore deposits.

Many factors contribute to this, including decline of mining in the United States due to increased environmental regulations and deposit depletions. The 1990's saw the new kids on the block with global miners Newmont and Barrick operating in Peru. The attendant research-to-publication lag time meant very few publications for most of the 1990's. Nonetheless, Buenaventura's support research at Julcani saw Deen et al. (1994) publication and Orcopampa was again published upon in 1995 by Gibson. Gold in Peru lead the way in the industry from 1994 to 2001 and yet Economic Geology only published only 4 articles on Peru during this time. This included Spangenberg et al. (1999) on San Vicente Mississippi Valley type deposit, and the three studies listed below. The end of the 1990's integrated many studies into regional summaries on mineralization and metallogeny reported in Benavides-Cáceres (1999), Noble and McKee (1999), and Petersen (1999).

Post-2002, with greatly increased base metal prices, copper and silver took over from the now somewhat exhausted gold exploration industry. The rate of publication on Peru deposits did not significantly pick up. In part, this perhaps reflects space availability from displacement by prolific Australian-based studies, and preferences of the journal editors. It could also reflect a lack of industry support for publishing results, or lack of motivation by geologists working in Peru to go through the difficult hurdles to publish in Economic Geology. Throughout this decade the number of deposit related extended abstracts in the SGP Peruvian Geological Congress flourished. Kontak and Clark (2002) presented the second study on southern Peru tin mineralization. Perello et al. (2003) covered a widespread of porphyry-skarn systems in the Andahuaylas-Yauri belts. Also in 2004 Haeberlin et al. gave detailed geochronology results on the Pataz orogenic gold veins. Clark and Kontak (2004) study on the Antaula center came from even more off the beaten track covering a Fe-Ti-P oxide melt related small deposit with nelsonite (ilmenite and apatite rock). Then Love et al. (2004) and Redwood (2004) gave the first Economic Geology paper on the massive Zn-Cu skarn deposit of Antamina. SEG published Special Volume No. 11 on Andean Metallogeny, which included eight papers on Peru. Other noteworthy papers in this edition was by Gustafson et al. (2004), Petersen et al. (2004), Noble et al., (2004) Vidal et al. (2004). My own study, Wise (2005) on Castrovirreyna polymetallic district was published after a six year delay from conducting the field work in 1999. Quang et al. (2003, 2005) papers on the southern Peru Paleocene copper belt addressed uplift and erosion of the porphyries. 2006 continued the trend of increased Peru papers with De Haller et al. (2006; 2009) on Raul Contestable and Echavarria et al. describing the Caylloma vein in southern Peru. Maher and Larson (2007) paper on Coroccohuayco and Tintaya reported on copper isotopes and fractionation of the porphyry-skarn system. After a long period of little new reported work on Cerro de Pasco, Baumgartner et al. (2008; 2009) improved the geochronology along with geochemical and mineral zonation characterization of the deposit. Basuki et al. (2008) covered the second MVT locality in northern Peru at the Bongara project. Wagner et al. (2009) paper on the San Rafael Sn-Cu deposit gave stable isotope data. Finally, Bendezú and Fontboté (2009) upgraded the geological description of Colquijirca. The Accha nonsufide zinc project was described by Boni et al. (2009). The 2000-2009 period saw a total of 16 papers.

In 2010, Yanacocha is featured twice in Economic Geology, first by Teal and Benavides, and then by Longo et al. based on his dissertation work. Sillitoe and Mortensen (2010) reported on geochronology of the Quellaveco porphyry project. Maher (2010) gave his definitive paper on Coroccohuayco deposit. Chen (2010), also reporting on his 2008 doctoral study, wrote on the Marcona IOCG deposits. Winter et al. (2010) likewise published on his 2008 dissertation covering the VMS mineralization at Tambo Grande. Simmons et al. (2013) reported regional geochronology data on the Paleocene southern Peru copper belt. In the Andahuaylas-Yauri batholith, the Yanque prospect non-sulfide zinc-lead was documented by Mondillo et al. (2014). Catchpole et al. (2015) provide new mineralogy and geochronology to the Morococha district. Chelle-Michou et al. (2015) report on high-resolution geochronology of Coroccohuayco deposit, miss-correlating the mineralization to the Incaic orogeny [phase]. Rottier et al. (2016) worked on the trace element signatures during mineral replacements at Cerro de Pasco. These last six years has seen numerous results coming from approximately eleven dissertations on Peru deposits completed over the last ten years.

The total number of papers covering Peru ore deposits in Economic Geology is at 99, whereas the SGP Boletín has 84, and abstracts in Peruvian Geological Congress proceedings number at 187. While the latter two venues nearly match and double, respectively, the number of papers in Economic Geology, their quality and amount of data reported is far lower. The above described studies plot in Fig. 1 in somewhat apparent disarray, but generally show a trend of increasing studies, and clusters of more intense reporting with intervening lulls that become better illustrated in the histogram shown in Figure 2. I would propose terminology describing the Peruvian ore deposit reported studies as Formative, National, and Privatized periods. Cerro de Pasco and Yanacocha have the greatest number of papers, each standing at seven journal articles. Orcopampa, Julcani, and San Vicente follow with five papers each.

N. Discussion and Conclusions

A general acceleration in the number of publications reported in Economic Geology can be appreciated for the latter half of the 20th century continuing until this day. In contrast, the number of published upon ore deposits in the Boletín de la Sociedad Geológica del Perú is compared through time with those of Economic Geology in Fig. 1. There is a trend here in which the SGP should take note, the long and gradual decline of publishing on Peru's ore deposits.

The number of Peru mines being published upon in country is also not totally accounted for by the Boletín; much of this literature can also be found in the Boletín del Cuerpo de Ingenieros de Minas del Perú. Since the founding of the Universidad Nacional de Ingenieria (UNI) in 1876

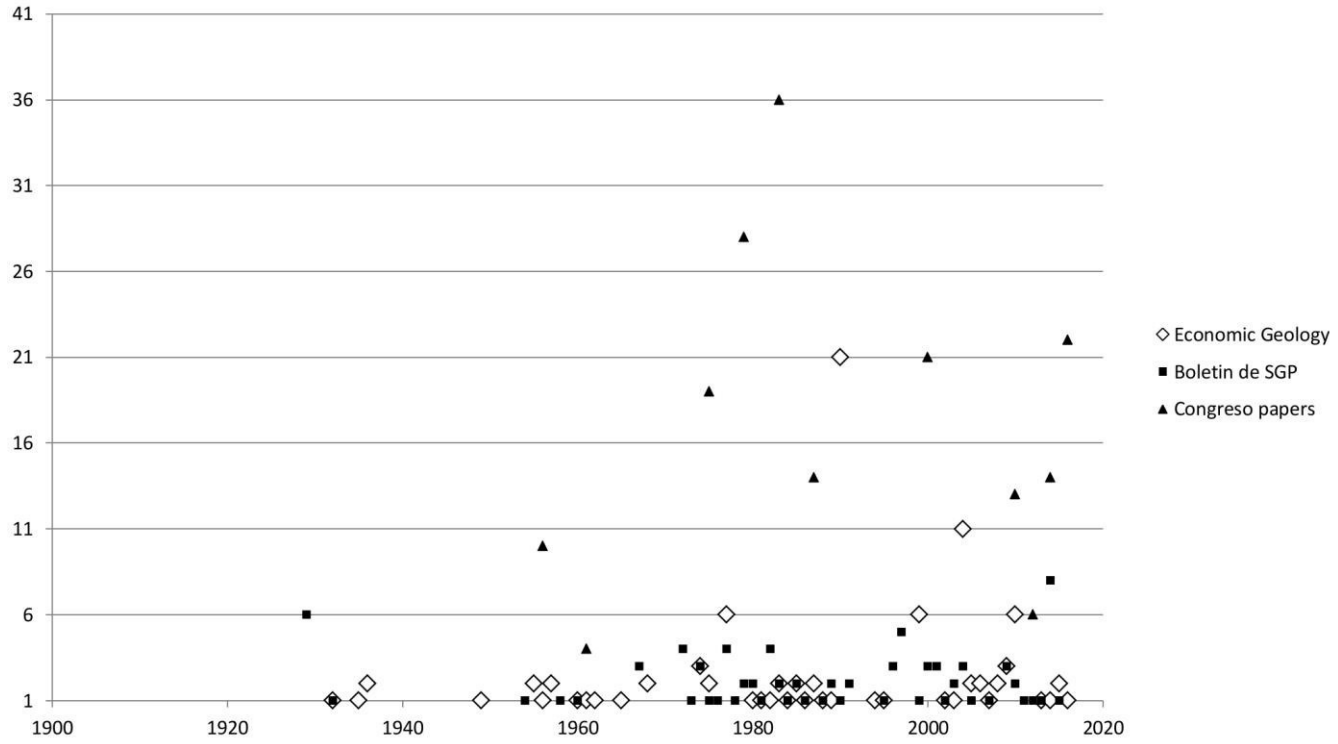

Figure 1. *Graph showing comparing the number of deposit publications in Peru by Economic Geology, the Boletín de la Sociedad Geológica del Perú, and the SGP Peruvian Geological Congress (Y axis) versus the year (X axis).*

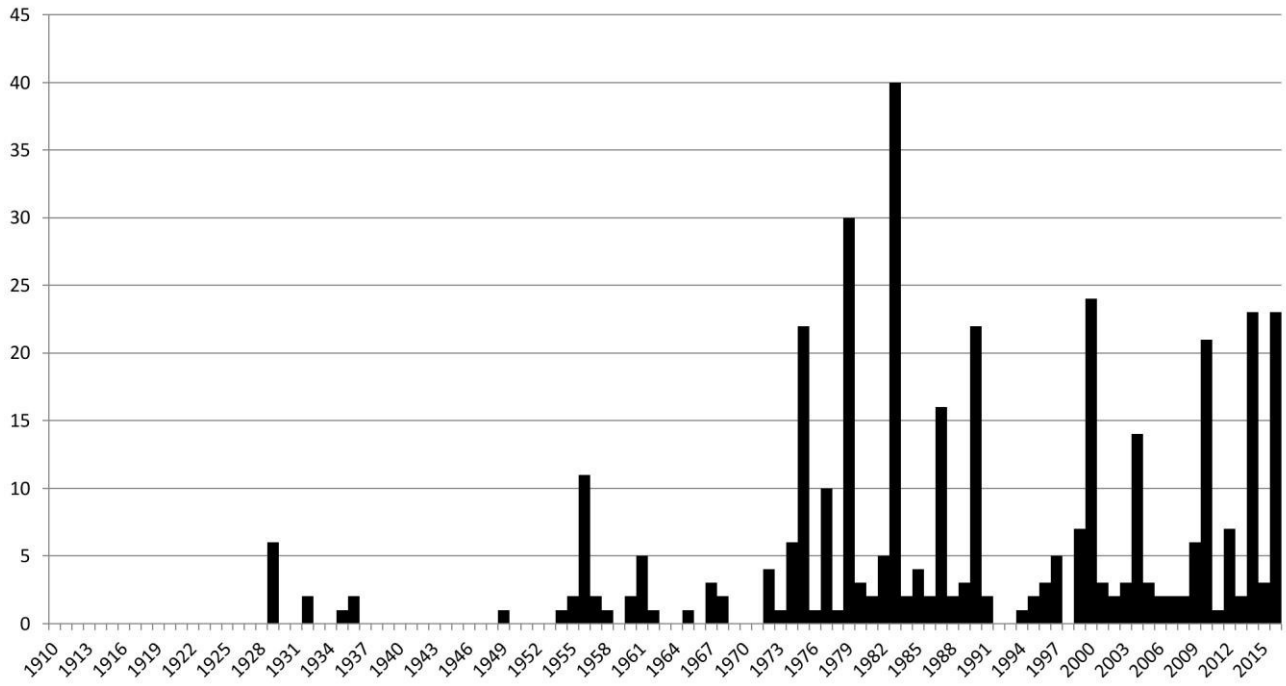

Figure 2*. Combined histogram showing SEG and SGP publications on Peru ore deposits (X axis = years). From 1910 to 1970 could be called the Formative period, 1970 to 1994 the National period, and 1994 to present the Privatized period. Years with greater magnitude of studies corresponds to SGP Peruvian Geological Congresses and timing of SEG special publications.*

Peru has had a steady professional support network for mining practices. Following the economic revival of the last decade and a half, undergraduate enrolment in geological and mining degrees in Peruvian universities has reached staggering proportions. The number of students certainly outnumbers the number of operating mines, leading to a situation of crisis between quantity versus quality in the education institutions.

The summary of Economic Geology papers on Peru should not be taken as the only measure of contribution to world geology, in fact, several early hallmark papers were done on regional geology in American Journal of Science, Bulletin of the Geological Society of America, Earth and Planetary Science Letters, and American Association of Petroleum Geologists Bulletin, amongst others. In the national stage, the role of the Peruvian Geological Congresses has been a dominant factor in the venues for deposit related studies, which continues to this day with mining related theme sessions capturing the greatest audiences. Other Peru deposit descriptions can be found in Chemical Geology, Geology, Journal of Geochemical Exploration, Mineralium Deposita, and Ore Geology Reviews.

Economic Geology has evolved in character, following trends, and restricting or delaying others, through tradition and vision of its editors. Really, the first 70 years of the journal contributed very little in the way of detailed geological maps or figures. The improvement of graphics with more sophisticated software and computing capabilities, and printing technology, has changed how geology is presented and thereby the nature of discourse describing mineral deposits. The publication has no mandate for equal representation of regions, countries, or deposit types, instead content is more haphazard depending on the interests of investigators and window of opportunity for accessing deposits.

The rate of economic geology studies in Peru has several contributing factors, with the arrival of economic airfares being important for access of the country by foreign investigators. Also clearly studies of ore deposits and reporting of them in Economic Geology has a relationship with macro political-economic conditions of Peru and the world. The role of computers, internet, corporate governance, federal transparency, arrival of the information age, and university pressure on publication quantities likewise is expressed in the dramatic increase in reporting on Peruvian metal deposits.

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