Presence of two Phanerozoic IOCG belts in México: geological framework and general characteristics.

R. Corona-Esquivel.
Instituto de Geología, UNAM, Ciudad Universitaria, México D.F., México.

J. Tritlla & G. Levresse.
Programa de Geofluidos, Centro de Geociencias, UNAM, Querétaro, México.

F. Henríquez.
Departamento de Ingeniería en Minas, Universidad de Santiago de Chile, Chile.

ABSTRACT: In Mexico, very recently some iron-rich ore bodies were re-classified as belonging to the IOCG type deposits. Their disposition is roughly parallel to the Pacific Coast, but mimic the disposition of Chilean deposits into two distinctive Belts: (1) an older, Mesozoic belt located near the Pacific border, constituted by magnetite-rich bodies with Cu-Au accumulation; (2) a Tertiary belt, located inland Mexico, grossly parallel to the Mesozoic belt, made up by magnetite-haematite or haematite-rich deposits, with many similarities with the Kiruna (Sweden) or El Laco (Chile) types.

KEYWORDS: IOCG deposits, Mesozoic belt, Tertiary Belt, Fe deposits, Cu-Au deposits, Mexico.

1 INTRODUCTION

Iron oxide–copper–gold deposits (IOCG) have been recently recognized as a new type of mineral deposits with high economic interest (Hitzman, 2000). These deposits are mainly composed by magnetite and/or haematite, with variable amounts of Au, Cu, REE, U, Co, Ni, As, Mo, W and Te. Yet, this typology is still controversial, as the geological settings and the source of metals and fluids is not still well constrained due mainly to their occurrence in highly deformed Proterozoic belts or in smaller deposits of Phanerozoic age where geological controls are usually difficult to ascertain.

Usually, this type of deposits are thought to be related with large scale faults and develop intense Na–Ca (albite–actinolite) or potassic (K-feldspar or biotite) alteration zones. IOCG deposits are usually located in continental or cratonic margins during the Proterozoic whereas the Phanerozoic deposits appear primarily related with continental arc ambients as well as extensional environments along subduction-related margins (Hitzman, 2000).

Although iron deposits with problematic affiliation are known in Mexico for quite a long time (Van Allen, 1978; Lyons, 1988; Corona-Equivel, 2000), the presence of IOCG deposits in Mexico was only very recently formally recognized by Tritlla *et al.* (2003).

2 IOCG DEPOSITS IN NORTH AMERICA.

In North America (US and Mexico), iron-oxide rich deposits are widespread and located mainly in a belt parallel to the Pacific border of the continent. These deposits share an association with saline fluids, voluminous alkaline (Na and/or K -rich) alterations, low sulphur contents and variable enrichments in REE, Cu, Au, Ag, Co and U (Barton *et al.*, 2000).

3 IOCG DEPOSITS IN MÉXICO.

In Mexico, this disposition is reproduced but, as in the Chilean deposits, two distinctive sub-belts can be recognized: (1) an older, Mesozoic belt located near the Pacific border, constituted by magnetite-rich bodies usually with several mineralized bodies within a discrete zone (Tritlla *et al.*, 2003); (2) a Tertiary belt, located inland Mexico, grossly parallel to the Mesozoic belt, made up by magnetite-haematite or haematite-rich deposits of tertiary age, with many similarities with the Kiruna (Sweden) or El Laco (Chile) types (Corona-Esquivel, 2000).

Traditionally, magnetite-dominated Mesozoic deposits have been classified mainly as skarns (Peña Colorada, El Encino, El Encino, Aquila, Las Truchas). However, our revision indicates that truly skarns (Cerro Nahuatl) coexist with well characterized IOCG's (Peña Colorada, Tritlla *et al.*, 2003) in similar geological scenarios. This coexistence has been already recognized in other IOCG provinces worldwide (*i.e.*, Ossa Morena Zone, Spain; Tornos & Casquet, 2005).

Tertiary deposits (La Perla, Chihuaha; Cerro de Mercado, Durango), on the contrary, were proposed to form after the upflow of iron rich magmas (Van Allen, 1978; Lyons, 1988), based mainly on textural evidences and field relationships. This origin has been recently claimed after their comparison with El Laco deposit (Corona-Esquivel *et al.*, 2007a and 2007b).

3.1 *Pacific Coast (Mesozoic) belt.*

This IOCG belt is defined by deposits located, from South to North, within the Guerrero, Michoacán (Aquila, Las Truchas), Jalisco (El Encino, Chanquehahuil) and Colima (Peña Colorada, Las Pesadas) States (Corona-Esquivel, 2000; 2007b; Tritlla *et al.*, 2003) as well as in the Baja California Peninsula (Alisitos Belt, López *et al.*, 2006). These deposits are mainly composed by magnetite, with minor quantities of sulphides (chalcopyrite, pyrite, pyrrhotite) and fluorapatite. They have been mined exclusively for iron ore, where no real exploration has been performed to look for other substances.

3.1.1 Peña Colorada (Colima).

The iron ore bodies are hosted by the middle Cretaceous Tepalcatepec formation, that is represented in the mine by a sequence of sedimentary units (lower clays and marls unit; limestone unit) with an overlying volcaniclastic unit, both of Albian age, and an upper conglomerate formation of Cenomanian age (Corona-Esquivel 2000). The lower clay and marl unit is locally intruded in the mine area by a granodiorite and by an aplite dike complex.

The Peña Colorada iron deposit is made up by three different mineralized bodies: (1) an upper massive magnetite body, up to 20 meters thick, sub-concordant with the regional stratification, that contains decimetric to metric fragments of an older garnet-bearing rock (grossular-andradite) completely replaced by plumose K-feldspar; (2) a lower disseminated magnetite body, also sub-concordant with the regional stratification, with a maximum thickness of 150 meters and made up by pyrite-magnetite-pyroxene rhythmic alternations with poiquilitic K-feldspar crystals, forming a sub-concordant mass resembling an episyenite *sensu.lato*, that has been mistaken with an endoskarn by Zurcher *et al.* (2001); and (3) a mineralized polymictic breccia, with evidences of hydraulic fracturing, with an overall diatreme morphology, cutting the whole sequence and the other ore bodies at Peña Colorada (Tritlla *et al.*, 2003). The diatreme includes xenoliths of a rock made up by the intergrowth of centimetric, squeletic to euhedral magnetite, pyroxene and apatite crystals, floating in a groundmass of minute magnetite crystals.

The disposition of the different mineralized bodies, their textural characteristics and the difference in ages among them suggest that the Peña Colorada iron deposit formed due to recurrent mineralizing events in a discrete cortical volume and within a relatively wide time lapse (>4 Ma; Tritlla *et al.*, 2003).

3.1.2 Alisitos Belt (Baja California Norte).

The Alisitos Belt represents the prolongation of the Mexican Pacific Coast IOCG Belt into the Baja California Peninsula, that broke up and separated during the Miocene.

Among the other deposits in mainland Mexico, the Alisitos Lower Cretaceous Arc in Baja California Norte stands out due to the presence of comparable magnetite-bearing IOCG deposits with economic concentrations of Cu and Au, now under exploration by Cardero Resource Corporation.

Ore deposits appear enclosed within the Alisitos Group, of Aptian-Albian Age, composed by a sequence of volcaniclastic andesitic to dacitic flows and a intermediate to mafic volcaniclastics and tuffs (López *et al.*, 2006). This sequence is intruded by a granodioritic pluton and a swarm of felsic dikes. This geological scenario is comparable with the local geology found to enclose mainland IOCG deposits.

Alteration around the ore bodies is widespread. This consists in a sequence of sodic (albite) to calcic-sodic (scapolite, actinolite, magnetite, albite), potassic (K-feldspar, biotite), tourmalinization (quartz, tourmaline), albitization (albite, calcite). Cu mineralization appears related with both potassic and tourmaline alterations (chalcopyrite), with formation of bornite-chalcocite rims around chalcopyrite during the last alteration phase (albite-calcite).

3.2 *Meseta (Tertiary) Belt.*

This IOCG belt is defined by deposits located in the Mexican Central Meseta, at the states of Durango (Cerro de Mercado; Lyons, 1988; Corona-Esquivel *et al,* 2007a), Coahuila (Hércules; Corona-Esquivel, 2000) and Chihuahua (La Perla; Van Allen, 1978; Corona-Esquivel *et al.*, 2007c). These ore deposits are located at the contact between the Sierra Madre Occidental volcanic province, one of the world's largest accumulations of felsic volcanic rocks at W, and the Laramide thrust and fold belt, at E, constituted by Mesozoic sedimentary materials.

These deposits are mainly composed by magnetite, martite and haematite (Cerro de Mercado) or dominant haematite (Hércules, La Perla), with minor quantities of fluorapatite, and both the presence of abundant haematite, their textures coupled with episodes of argillic alteration suggest that they formed in more surficial conditions than their older (Mesozoic) counterparts. They have been also mined exclusively for iron ore, where no real exploration has been performed to look for other substances.

As Cerro de Mercado is the more studied and representative deposit of this kind, we are going to base this discussion mainly on this location, although this is extensible to La Perla and Hércules ore deposits.

3.2.1 *Cerro de Mercado (Durango).*

Cerro de Mercado ore deposit is located in the City of Durango (Durango State, Mexico). Lyons (1998) and Labarthe *et al*. (1990) indicate that this deposit is located within the Chupaderos Caldera, a large rhyolitic volcanic center of Oligocene age (30.8-30.1 Ma, Swanson *et al.* 1978). The caldera consists of a series of units, beginning ash-flow tuffs (Aguila Formation) that filled the caldera. The last volcanic Cacaria Formation (rhyolitic domes, intrusions, and airfall tuffs) host the iron-rich bodies of Cerro de Mercado (Lyons, 1988).

The iron masses appear as massive lenses and breccias within the upper Members of the Cacaria Formation (Lyons 1988). At the present time, the mine workings allow to see that the emplacement of the deposit is controlled by the intersection of two faults of N-S and NE-SW directions that also host part of the breccia ore bodies. The massive bodies were conformable with the surrounding rhyolitic rocks, even though in some places they clearly cut and are cut by silicate-altered rocks. Elsewhere within the Chupaderos caldera, other iron oxide deposits occur within the same general stratigraphic interval and have been correlated by Lyons (1988) as part of the "Mercado Iron Member" of the Cacaria Formation. Megaw & Barton (1999), based upon Lyons (*in op cit*) comments and their own field observations, that some of the other occurrences represent distinct centers of iron oxide mineralization and thus may not be strictly correlated with the deposit at Cerro de Mercado. The different ore bodies present a fairly simple mineralogy, made up by magnetite, haematite, martite after magnetite, pyroxene and apatite with minor quartz and clays, and is surrounded by an aureole of argillic alteration (Megaw & Barton, 1999).

Two different origins have been proposed for this deposit. Lyons (1988) and Corona-Esquivel (2007a), among others, suggest an iron oxide-rich igneous melt that separated from a parental "oxide magma" in close relationship with the extrusion of silicic magmas, in a similar way as in El Laco deposit (Naslund *et al*., 2002). Others Labarthe-Hernandez *et al.*, 1987; Barton & Johnson 1996), suggested a combination of the replacement of older volcanic rocks by massive oxide bodies where hydrothermal fluids vented onto the surface.

4 DISCUSSION AND CONCLUSIONS

All these deposits clearly present characteristics that can be found in other IOCG type deposits worldwide. It is noticeable that, as in Chilean deposits, two different IOCG belts can also be distinguished in Mexico not only separated by their age and relative position, but also by their characteristics.

The deposits located within the Pacific Belt present characteristics of a deeper system with clear metasomatic bodies, no extrusive textures and, in Peña Colorada, episodes of reworking due to the formation of late explosive diatremes. These deposits just started very recently to be considered as possible targets for Cu-Au resources. The ages found by Tritlla *et al.* (2003) suggest some sort or relationship with scarce mafic intrusive bodies of the same age.

The deposits that form the Meseta Belt represent a more “surficial”, distal and younger equivalents of the Pacific Belt. Indeed, these Tertiary deposits present characteristics that suggest their formation in or near the surface, in close relationship with the latest magmatic pulses of the Sierra Madre Occidental Volcanic Province. No other commodities but iron have been found so far related with this ore deposits. This can be due to their “surficial” character, perhaps representing the apical part of an evolving IOCG system, where other metals than iron could be found accumulated in deeper parts of the feeder structures.

ACKNOWLEDGEMENTS

We would like to acknowledge Consorcio Minero Benito Juárez-Peña Colorada S.A. de C.V. and Grupo Acerero del Norte (GAN) and specially Ingenieros Roberto Villalobos Zavala José de la Luz Portugal, Juana Meza, Manuel López, Jesús Manuel Bueno-Rocha and Oswaldo Delgado for the permission, help and the geological discussions.

This work has been financed by the UNAM PAPIIT projects IN-123202-2 and IN115706-3

REFERENCES

Barton, M.D.; Johnson, D.A. and Zurcher, L. (2000). Phanerozoic Iron-Oxide (-REE-Cu-Au-U) Systems in Southwestern North America and Their Origins. In M.D. Roberts and M.C. Fairclough (ed.): *Fe-oxide-Cu-Au Deposits: A discussion of critical issues and current developments, EGRU Contribution* 58, James Cook University, p. 5-11.

Corona-Esquivel, R. 2000 Geología regional y modelo genético de los yacimientos de hierro de la porción suroccidental de México. *Instituto de Geologia, UNAM. Non published PhD. thesis.* 171 pp.

Corona-Esquivel, R.; Tapia-Zúñiga, C.; Henríquez, F.; Tritlla, J.; Morales-Isunza, A.; Levresse, G. y Peres-Flores, E. (2007a). Geología y mineralización del yacimiento de hierro de Cerro de Mercado, Durango, In: K. Clarck y G.A. Salas-Pizá (eds.): *Geologia Económica de México. In press.*

Corona-Esquivel R.; Tritlla, J.; Henríquez F.; Morales-Isunza, A.; Portugal, J.L.;Nava-Pérez, L. (2007b). Geología y mineralización del Yacimiento Peña Colorada, Colima, In: K. Clarck y G.A. Salas-Pizá (eds.): *Geologia Económica de México. In press.*

Corona-Esquivel, R.; Escudero-Chávez, M.; Henríquez, F.; Tritlla, J.; Morales-Isunza, A.; Ramírez Lara, M.A.; Rodríguez Elizarrarás, S.; Camprubi, A. (2007c). Geología y Mineralización del yacimiento de hierro La Perla, Chihuahua, In: K. Clarck y G.A. Salas-Pizá (eds.): *Geologia Económica de México. In press.*

Hitzman, M.W. (2000). *Iron oxide–Cu–Au deposits. What, where, when and why. In: Hydrothermal Iron Oxide–Copper–Gold and related deposits: A Global Perspective* (T.M. Porter, ed.), pp. 9–25. AustralianMineral Foundation, Adelaide.

López, G.; Gutiérrez, R.; Cheol-Shin, H.; Hitzman, M. and Curi, M. (2006). Alteration and mineralization San Fernando IOCG Prospect. Cardero Resource Corp., *Power Point presentation at www.cardero.com.*

Megaw, P.K.M. and Barton, M.D. (1999). The Geology and Minerals of Cerro de Mercado, Durango, Mexico. *Rocks & Minerals,* Vol. 74(1), pp. 20-29.

Naslund, H.R.; Henríquez, F.; Nyström, J.O.; Vivallo, W. and Dobbs, M. (2002). Magmatic iron ores and associated mineralization: examples from the Chilean High Andes and Coastal Cordillera. In Porter T.M. (Ed.), *Hydrothermal Iron Oxide Copper-Gold & Related Deposits: A Global Perspective,* Vol. 2, pp 207-226.

Tornos, F. and Casquet, C. (2005). A new scenario for related IOCG and Ni-(Cu) mineralization: the relationship with giant mid crustal mafic sills, Variscan Iberian Massif. *Terra Nova* 17, pp 236-241.

Tritlla, J.; Camprubí, A.; Centeno, E.; Corona-Esquivel, R.; Iriondo, A.; Sánchez-Martínez. S.; Gasca-Durán, A.; Cienfuegos-Alvarado, E. y Morales-Puente, P. (2003). Estructura y Edad del depósito de Peña Colorada (Colima). *Revista Mexicana de Ciencias Geológicas,* vol. 20, nº 3, pp 182-201.

Van Allen, B.R. (1978).Hydrothermal iron ore and related alterations in volcanic rocks of La Perla, Chihuahua, México. *M.A. Thesis, University of Texas Austin. 131 pp., unpubl.*

Zücher et al (2001).- Paragenesis, elemental distribution and stable isotopes at the Peña Colorada iron skarn, Colima, México. *Econ.Geol*. 96: 535-557.