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The Challenge (Goldcorp Inc.): prospección aurífera vía Internet. Aplicación del modelo de zona de cizalla aurífera a la mina Red Lake (Ontario, Canadá)

R. Oyarzun[(1)], P. Castiñeiras[(2)], I. López[(3)], I. Blanco[(1)] y R. Herrera[(3)]

(1) Departamento de Cristalografía y Mineralogía. Facultad de Ciencias Geológicas. Universidad Complutense. 28040 Madrid. España.

(2) Department of Geological Sciences. University of Colorado at Boulder. Campus Box 399, Boulder, CO 80309-0399.

(3) Escuela Superior de Ciencias Experimentales y Tecnología. Universidad Rey Juan Carlos.
Tulipán s/n, 28933 Móstoles (Madrid), España.

RESUMEN

En marzo del 2000 la compañía canadiense Goldcorp Inc. invitó a geólogos de todo el mundo a presentar propuestas de exploración para su propiedad minera en Ontario *(Red Lake mine)*. El concurso fue denominado *"The Challenge"*. Las propuestas tenían que: ser concisas, identificar objetivos específicos, estar sustentadas por un razonamiento geológico apropiado, y ser enviadas vía *e-mail* en inglés. Las propuestas podían ser presentadas por individuos o equipos. La información geológica sobre la propiedad minera se hizo disponible en formato digital (CD-ROM), y fue suplementada con información adicional en la página *web* habilitada por la compañía a tal efecto (http://www.goldcorpchallenge.com/challenge. homepage_static.html). Un equipo de la Universidad Complutense de Madrid formado por un profesor y alumnos de una asignatura del programa de doctorado se registró en *The Challenge* (junto con otros 1400 participantes), y la propuesta de exploración que elaboraron consiguió uno de los premios de semifinalistas. En este trabajo se muestra el desarrollo de dicha propuesta. Esta estuvo basada en la aplicación del modelo de zona de cizalla aurífera a una mineralización compleja bajo el punto de vista tectónico y metamórfico, emplazada en un cinturón de rocas verdes del Arqueozoico.

Palabras clave: Canadá, exploración aurífera, modelo, Red Lake, zona de cizalla

The Challenge (Goldcorp Inc.): Gold exploration via Internet. Application of the gold shear-zone model to the Red Lake property (Ontario, Canadá)

ABSTRACT

In March 2000 Goldcorp Inc. invited contestants from all over the world to submit exploration proposals for its Red Lake Mine Property. The contest was named The Challenge*. Each Proposal had to be: concise, identify specific targets, be supported by appropriate geological reasoning, and be submitted by* e-mail *in the English language. Proposals could be submitted by individuals or by teams. Geological information about the Property was available by CD-Rom and supplemented with additional information on the web site (http://www.goldcorpchallenge.com/challenge.homepage_static.html). A team from the University of Madrid (U. Complutense; a lecturer and a group of PhD. students) registered in* The Challenge *(among 1400 on-line prospectors), and the proposal was awarded one of the semifinalist prizes. In this paper we show the proposal, which was based on the application of the gold shear zone model to a mineralization hosted by a highly deformed sequence belonging to a greenstone belt of Archaean age.*

Key words: Canada, golg exploration, model, Red Lake, shear zone

Introducción

En marzo del año 2000 la compañía minera canadiense Goldcorp Inc. propuso una de las ideas más notables que ha habido en el mundo de la exploración de yacimientos metálicos. A través de Internet propuso un concurso de ideas de prospección aurífera para aumentar las reservas auríferas de su yacimiento Red Lake (Ontario, Canadá). En este concurso (*"The Challenge"*: El Desafío), podían participar individuos, grupos, compañías, o instituciones. A tal efecto, y he aquí una de las grandes ideas de la Goldcorp, la compañía puso a disposición de los participantes toda su base de datos geológicos del yacimiento Red Lake, así como una substancial información concerniente a la geología regional en la que se insertaban la mineralización de la Red Lake y otras del mismo tipo. Estas mineralizaciones son del tipo zona de cizalla aurífera, y están emplazadas en rocas del Arqueozoico incluyendo, komatiitas, peridotitas, basaltos, andesitas, riolitas, BIF, metasedimentos, granitos, etc.

Hacia finales de Julio del 2000 la página *web* del *Challenge* había sido visitada más de 475.000 veces. En el concurso se registraron más de 1400 prospectores *"on-line"* representando a 51 países. Los premios totales del concurso alcanzaban la cifra de US$ 500.000 en total, repartidos en 25 premios de US$ 10.000 para cada equipo semifinalista, y el resto para los tres finalistas. Por otra parte, en Febrero del 2000 comenzaba la asignatura de doctorado de *"Exploración de Yacimientos Minerales: el Papel del Geólogo"* (Facultad de Ciencias Geológicas, Universidad Complutense, Madrid). Dado que el profesor de la asignatura (R.O.) sabía de este concurso internacional, le propuso a los alumnos participar, como trabajo práctico (aparte de las clases teóricas), en *"The Challenge"*. A esta iniciativa se apuntaron inicialmente P. Castiñeiras, I. López, R. Artigas, I. Blanco, R. Herrera, P. López-Arce, y J. Martín. En una segunda fase continuaron P. Castiñeiras, I. López, I. Blanco, y R. Herrera (los que en la actualidad se desempeñan como profesores ayudantes en otras universidades o se encuentran como becarios postdoctorales en otros países). En Julio del 2000 se entregó el primer documento a la Goldcorp, y en Noviembre de 2000, un segundo *dossier*. Como resultado de estos trabajos el equipo de la Universidad Complutense consiguió uno de los premios de semifinalista, junto a geólogos de Australia, Canadá, Rusia, y USA.

A continuación mostramos el modelo de exploración tal como se presentó a la compañía Goldcorp. Por esta razón, y para mantener una fidelidad con el trabajo original hemos preferido mantener el texto en inglés.

Regional geology

The Red Lake District is entirely underlain by Archaean rocks of the Superior of the Canadian Shield (Fig. 1). These fall into four categories which are generally distinguished by the subprovinces in which they occur (Menard, 2000):

- *The Uchi Subprovince:* which contains the northeast-trending Red Lake and Birch-Confederation Lake greenstone belts, where the bulk of the exploration and mining activity has taken place;
- *The English River Subprovince:* south of the Uchi Subprovince, which are predominantly sedimentary and minor intrusive rocks similar to those in the Quetico Subprovince; and the Berens River Subprovince.
- *The Berens River Subprovince:* north of the Uchi Subprovince, and the *Sachigo Subprovince,* north of the Berens River Subprovince. Both of these subprovinces consist of relatively small, isolated greenstone belts surrounded by extensive granitic and gneissic units.

The Uchi Subprovince metavolcanic rocks (text from Menard, 2000) can be subdivided into assemblages with ages ranging from the youngest the Confederation Assemblage 2730 to 2800 Ma through the Bruce Channel and Woman Assemblages 2800 to

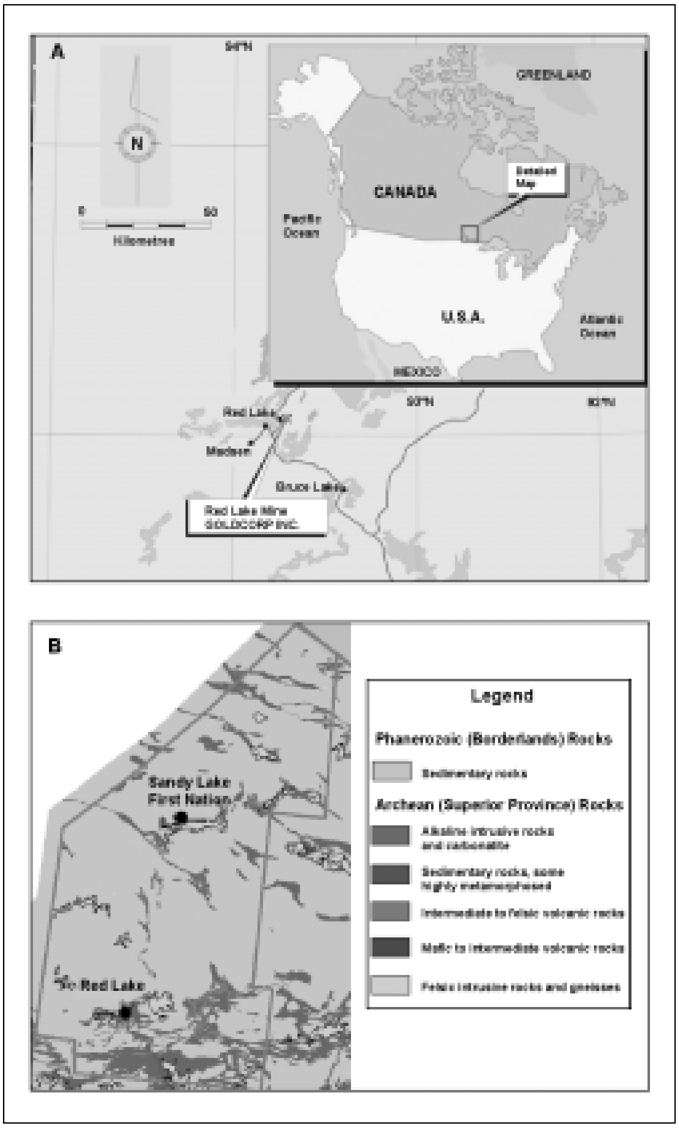

Fig. 1. A) Mapa de ubicación y B) geología regional (modificado de Menard, 2000)
Fig. 1. A) Location map and B) regional geology (after Menard, 2000)

2900 Ma to the Balmer and Ball Assemblage 2900 to 3000 Ma. The Balmer Assemblage rocks form the core of the Red Lake Greenstone belt and host several of the largest and most prolific gold mines. Small mafic to ultramafic plutonic rocks cut all the assemblages. The Balmer consists of basaltic tholeiite and komatiite flows with intercalated magnetite-quartz iron formation. Felsic pyroclastic rocks occur as comparatively thin units. Balmer Assemblage rocks are the oldest with ages 2958 to 2992 Ma. The Ball Assemblage, located in the northwestern corner of the Red Lake Belt, is slightly younger with ages 2940 to 2925 Ma in the upper part of the assemblage. The main mass of the Ball Assemblage is composed of calc-alkalic mafic flows and intermediate to felsic calc-alkalic flows and tuffs. Well preserved stromatolitic dolomitic rocks are found in the upper part of the Ball Assemblage in Ball and Todd Townships. The Bruce Channel Assemblage is poorly exposed in the eastern part of the belt. It is composed of basaltic flows capped by minor felsic pyroclastic rocks with a common age of 2894 Ma and clastic and iron formation metasediments. Woman Assemblage rocks are restricted to 2830 Ma felsic rocks in the central part of McKenzie Island. The Confederation Assemblage is found on the northern and southern flanks of the Red Lake Belt. The rocks are predominantly calk-alkalic with substantial amounts of felsic pyroclastic deposits that can be correlated stratigraphically with similar rocks in the Birch-Uchi Greenstone belt. The relationships between these assemblages are still under study. Gold has been produced from greenstone belts of the Uchi, Berens River and Sachigo Subprovinces while iron and base metals have been produced from the Uchi Subprovince. Due to the isolated nature of the northern greenstone belts only high value commodities such as gold were explored for in the past. Gold mining has taken place at two isolated deposits in the northern greenstone belts. Gold, iron and base metal occurrences have been reported from many parts of the District. Rare metal pegmatites are found along the southern boundary of the Uchi Subprovince and along the boundary between the Berens River and Sachigo Subprovinces. The locations of main shear zones in the area are displayed in figure 2.

Local geology

The geology of the Red Lake mine (3,797,000 oz Au; 1999 reserves) is characterized by a complex sequence of ultramafic, mafic, and felsic volcanic rocks, dioritic rocks, and metasediments including BIF facies (Goldcorp Inc., 2000). The ultramafic rocks consist of

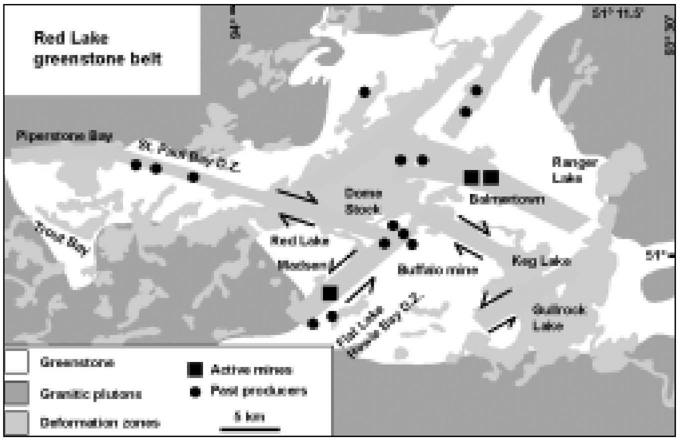

Fig. 2. Zonas de cizalla regionales (modificado de Menard, 2000)
Fig. 2. Main regional shear zones (after Menard, 2000)

peridotitic komatiite, basaltic komatiite, and peridotite. The mafic rocks are represented by Fe-tholeiitic basalts (the so-called 'andesite'). Other volcanic facies include rhyolites. The 'stratified' sequence is completed by metasediments. Other rocks include the so-called Campbell diorite. These rocks have been folded, metamorphosed, hydrothermally altered, and sheared (Figs. 3 and 4).

Structural setting of the mineralization

The Red Lake Shear Zone (RLSZ)

As shown in the first report (Oyarzun *et al*., 2000), the 3D distribution of shear bands allows definition of a major shear zone (Red Lake Shear Zone: RLSZ), which

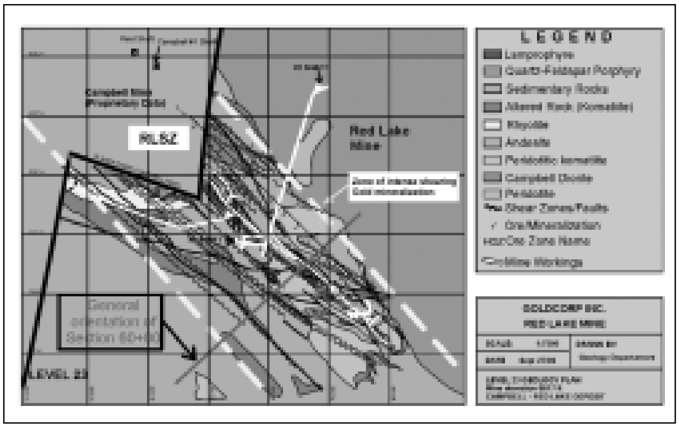

Fig. 3. Nivel 23 de la mina Red Lake: ZCRL: Zona de Cizalla Red Lake propuesta
Fig. 3. Red Lake mine, level 23. RLSZ: Red Lake shear zone as proposed in the report

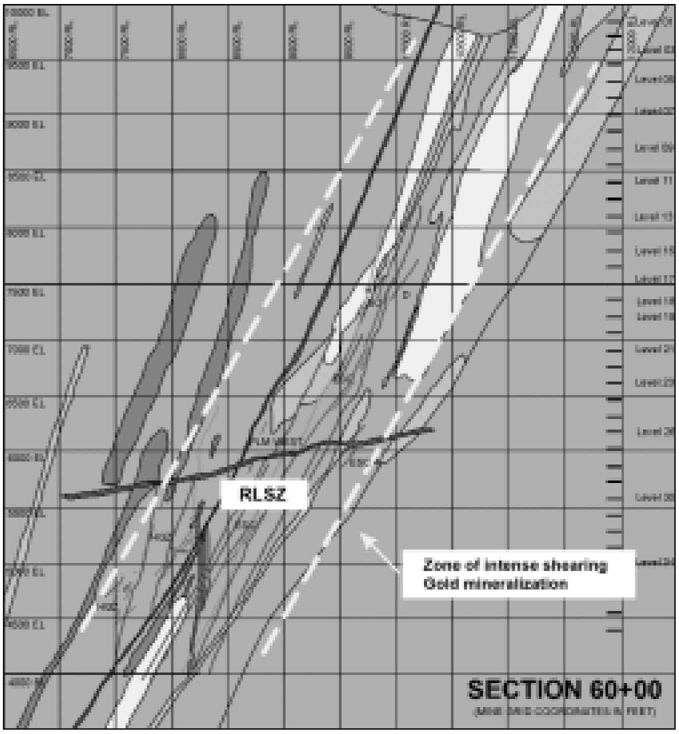

Fig. 4. La ZCRL en la sección 60+00, ver figura 3 para su localización
Fig. 4. The RLSZ along section 60+00, see figure 3 for location

hosts the different ore bodies (Figs. 3 and 4). The existence of such a shear zone is also recognized by the SRK (1999) report. Folds, foliation, shear zones, and the ore bodies strike NW and dip to the SW. The foliation dips 65-85° to the SW. The ore bodies dip 50-70° to the SW.

Timing of deformation and metamorphism: key elements for the exploration model

An early interpretation of deformational and metamorphic events in the Red Lake zone suggested the following sequence of metamorphic and deformational episodes (Menard, 2000):

M1-D1: Isoclinal folding; widespread early carbonate alteration; variable biotite and chlorite alteration (M1 or M2?); granitic batholiths; 2740-2720 Ma.

M2-D2: Peak metamorphism at edges of belt; vertical folding; K, SiO_2, and sulfide mobilization; amphibolite facies at edge of belt; mobility of gold in Balmertown; granitic batholiths and dioritic stocks; 2720-2715 Ma.

M3-D3: Mylonitic deformation; retrograde greenschist facies metamorphism; alteration to chlorite + epidote + anthophyllite + carbonate; small gold deposits in diorite stocks; granitic batholiths; 2700 Ma.

M4-D4: Brittle deformation; minor thin carbonate veins; 2680-2650 Ma?

However, as discussed in the initial report (Oyarzun *et al.*, 2000), a key element of the problem is the timing of the different episodes. For instance, what happens if shearing (mylonitic deformation) does not belong to D3 (as suggested by Menard, 2000) but to D2? This is not just an 'academic' question but clearly an 'economic' one, as the implications are of paramount importance as far as exploration is concerned. To this respect we would like to highlight the remarkable coincidence between the following structural trends, all of them NW trending (see next box):

NW trending structural elements

Fold axes (D2) (main component)
Foliation (S2)
Shear zones + orebodies

Can this be regarded as a mere coincidence? If three major structural trends are similar and coincide 'in space' they may coincide 'in time' as well. In our view this is not only likely but highly probable in the Red Lake-Campbell realm. If 'simplicity' ruled geological processes in the district ('complexity' often arises from geological interpretations), then we may explain the three structural trends in terms of a 'single' tectonic episode (see next box):

- NE-SW shortening, i.e., σ_1 oriented along this direction, being normal to the S2 foliation (flattening) and fold axial planes. A main stress of such a type could have also induced the development of reverse, district-scale shearing (Red Lake Shear Zone: RLSZ). **See figure 5**.
- This interpretation is supported by the geometric relationships between the dip of foliation and shear zones in the Red Lake mine, the former being steeper (65-85º SW) than the latter (50-70º SW).
- Additionally, the reverse movement along the shear zone is also supported by the stepping (upward descending) of individual orebodies.

Although we have no first hand structural observations of the deposit, we nevertheless suggest that the ore bodies most probably accommodate within dilatancy zones in either D- (main displacement shears, parallel to the main shear zone, e.g., Guha *et al.*, 1983) or slightly oblique P-type shears. This interpretation is based in the roughly parallel character displayed by the mineralized bodies with respect to the structural attitude of the RLSZ.

A high-angle reverse shear zone, but left- or right-lateral?

Regarding the left- (as suggested by SRK Consulting Engineers, 1999) or right-lateral character of the RLSZ

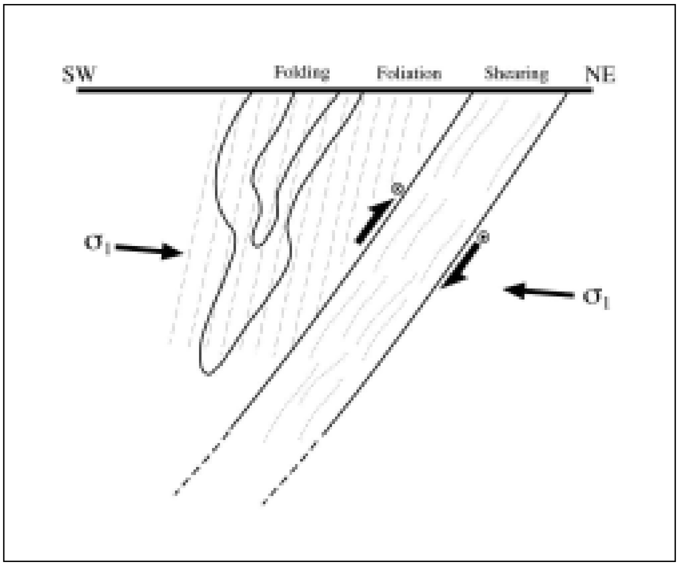

Fig. 5. Esquema que muestra las relaciones entre plegamiento, foliación, y cizallamiento durante el episodio de acortamiento cortical NE-SO

Fig. 5. Sketch depicting relationships between between folding, foliation, and shearing during the episode of NE-SW crustal shortening

(as suggested in our first report; Oyarzun *et al*., 2000), we keep on thinking that a dextral behavior is most probable. The SRK report does not indicate why the movement should be left-lateral, and refer to it as *"deduced from independent lines of evidence"*. Our conclusion is, on the contrary, supported by 'direct' evidence, i.e., the spatial arrangement of ore bodies (stepping to the right), which suggests right-lateral movement. The Hodgson (1989) paper on the structure of shear-related vein-type gold deposits, is illustrative enough of how the spatial distribution of ore bodies (Madsen mine, Ontario; stepping of ore bodies) can help to elucidate the sense of movement along a shear zone (Fig. 6).

Let us observe now the structural arrangement of ore bodies in the Red Lake mine, which suggests reverse (upward descending steps) (A), and right lateral movement (B) along the RLSZ (Fig. 7). In the Madsen mine (Fig. 6) the 'steps' (oblique shear veins) descend to the left (i.e., left-lateral), on the contrary, in the Red Lake mine (Fig. 7) they descend to the right (i.e., right-lateral) (B).

As far as exploration is concerned our general interpretation (high-angle reverse-oblique shear zone) indicates that further ore bodies can be found downward along the shear zone. This conclusion is not only based on structural evidence but also on the timing and nature of metamorphic facies as we will see in the next section.

Metamorphism, granitoids, and shear zones (or why "high-grade" ore zones can be found in the amphibolite facies): putting everything together

General background

- *On the finding of the high-grade zone in the Red Lake mine*

  "On march 29, 1995, Goldcorp Inc. announced the discovery of a new high-grade gold zone at the bottom of its Red Lake mine... The discovery of Goldocorp's High Grade Zone (HGZ) defied historical wisdom that suggested only lower grade disseminated-sulphide type ore could be found in the amphibolite facies metamorphic rocks at depth" (Goldcorp Inc. *"the Challenge"*, Red Lake Mine Geology; PDF document; 2000).
- *On "who cares about theories" (the empiricist approach)*

  "This process is exemplified by the story of the huge copper-zinc ore body at Timmins, Ontario. There was a large geophysical conductive area, a feature that could indicate the presence of ore minerals, near the end of the Timmins air-strip. Everybody knew about it, but because it didn't fit with a prevailing theory it was not considered important. Then the Texas Gulf Sulphur Company came along, following the empirical approach, and drilled anyway, and found the Kidd Creek ore body, one of the richest ever discovered in North America, setting off a major claim stacking rush and a stock market boom." (Gold !!! and other metals: how they are found and mined; J.B. Gammon, 1988).

In a way, the finding of the HGZ can be somehow ascribed to the concept of *"who cares about theories" ... or, historical 'wisdom' ...* (let us drill the amphibolite facies anyway !!!). However, we will show that the-

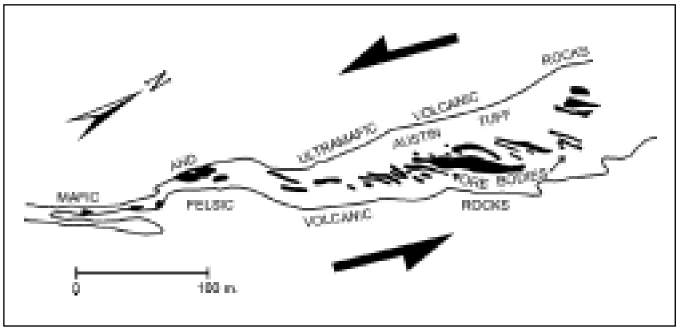

Fig. 6. Mapa geológico de la mina Madsen en el que se muestra los filones oblicuos asociados a la zona de cizalla (Hodgson, 1987)

Fig. 6. Geologic map of the Madsen mine showing oblique shear veins (Hodgson, 1987)

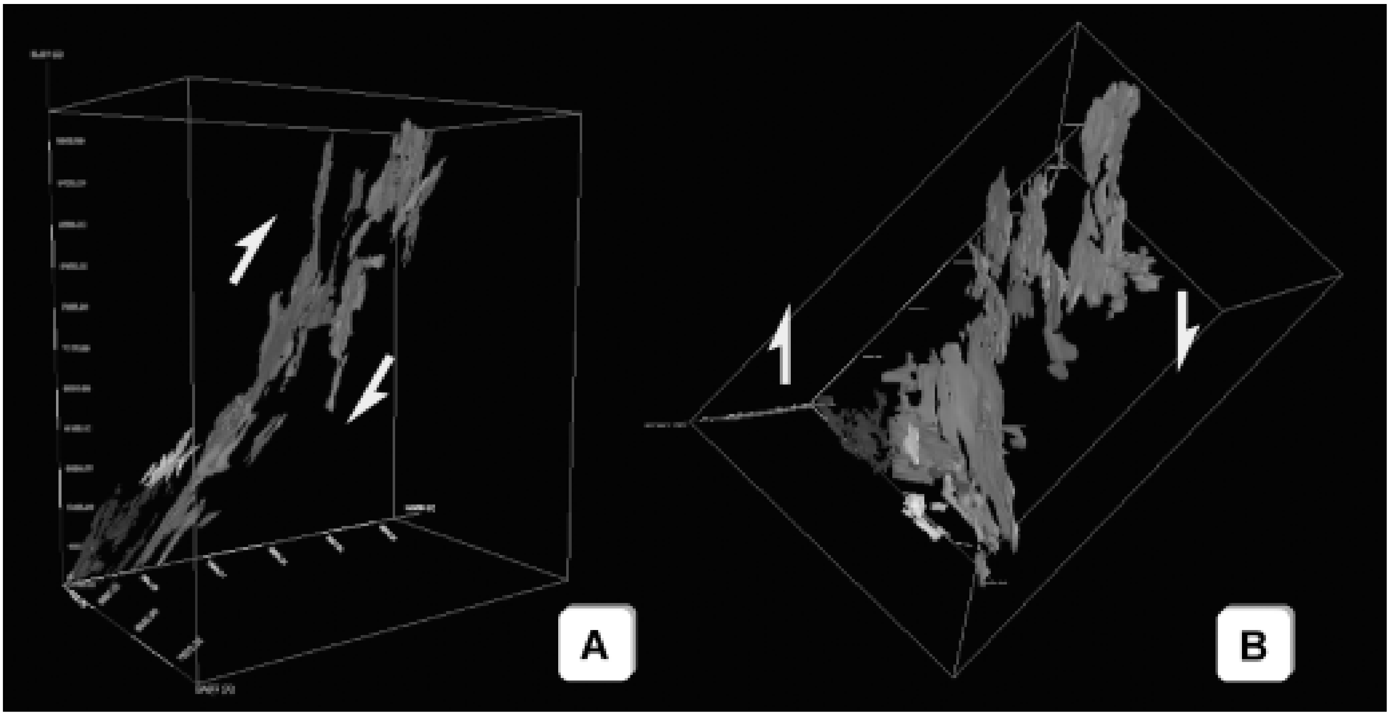

Fig. 7. La mina Red Lake. Distribución espacial (3D) de los cuerpos mineralizados en la que se observa el fenómeno de "stepping". A: vista desde el NO. B: mirando hacia abajo. Las flechas indican el movimiento combinado inverso-dextral de la zona de cizalla sugerido en el modelo

Fig. 7. Red Lake mine. 3D spatial distribution of ore bodies indicating stepping. A: looking NW, B: looking downwards. Arrows indicate the suggested combined, reverse (A) and right lateral (B) movement of the shear zone

ory and practice may not be in disagreement in the Red Lake case.

On why the understanding of a metamorphic episode can be so important

A highly relevant factor regarding gold deposition in the Red Lake deposit is the peak of metamorphic conditions (M2, amphibolite facies) and coeval granitoid emplacement. As noted by Menard (2000), the pattern of M2 suggests that it is an 'unusual contact metamorphism effect'.

Both the ratio Fe/(Fe+Mg) and the Ca content decrease to the rim of garnets during progressive metamorphism. As far as calcium is concerned, this is clasically interpreted in terms of the reaction between garnet and plagioclase during decompression (Spear *et al.*, 1990), the former becoming progressively Ca (XGrs)-depleted toward its rim, and the latter becoming An-rich. However, in the M2 case we have a reverse behavior, with Ca (XGrs) increasing to the rim (Fig. 8). This indicates the opposite, i.e., the reaction has taken place under increasing P conditions (Spear *et al.*, 1990). Thus, perhaps we are not dealing with 'contact metamorphism' but with a rather different phenomenon described elsewhere in the world (e.g., Bosost in the central Pyrenees; Nahuelbuta Mountains, southern central Chile; Winkler, 1965; Oyarzun, 1982). A thermal surge (e.g., induced by the emplacement of granitoid bodies) can generate an anomalous geothermal gradient. In turn, this can induce the anomalous passage from greenschist to amphibolite facies if the emplacement of granitoids occurs during ongoing regional metamorphism and deformation. A perfect example of this setting is provided by the 'anomalous' amphibolite facies displayed by the Lower Paleozoic metapelites of the Colcura Unit (Nahuelbuta Complex; southern central Chile; Oyarzun, 1982; Oyarzun *et al.*, 1986) around the granitoid facies of the Hercynian Nahuelbuta Central Pluton. Thus, we propose the following alternative explanation for the Red Lake realm (see next box):

- The amphibolite facies is 'granitoid-related' (thermal front, anomalous geothermal gradient; see figure 9).
- It follows that hydrothermal circulation and gold deposition during the development of the amphibolite facies may be also 'granitoid-related', which should not be surprising.

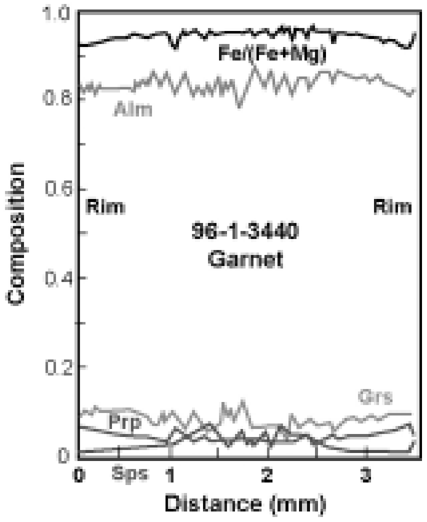

Fig. 8. Zonado composicional del granate (Menard, 2000). El incremento de XGr hacia el borde sugiere un incremento de presión durante el crecimiento del granate, fenómeno inusual en una aureola de metamorfismo de contacto
Fig. 8. Compositional zoning of the garnet (Menard, 2000). The general increase of XGr towards the rim may suggest increasing pressure during garnet growth, which would be unusual in a contact metamorphic aureole

When metamorphism and deformation meet: answering some key questions

It is important at this point to highlight another relevant factor regarding gold mineralization in the Red Lake mine. As noted by SRK (1999), there is an undisputable spatial association between ductile shear zones and areas of abundant colloform carbonate-quartz veining (brittle deformation). Furthermore, SRK regards this correlation as *"an amazing natural coincidence"*. On the other hand, Penczack (1999) (*in*: SRK report) argued that this is a case of ductile-on-brittle overprinting phenomena. Alternatively, geological considerations (metamorphic facies) rule out that the RLSZ can be ascribed to the brittle-ductile transition. Thus, the observation from Penczack may be the key for the understanding of deformation and mineralization in the Red Lake mine. However, although the brittle-on-ductile overprinting is a rather common and easy to explain phenomenon, the ductile-on-brittle overprinting can be far more complicated to explain (e.g., Davis and Reynolds, 1996), but, is it really 'that complicated to explain' in the RLSZ case?

The main question relates to how can a zone of brittle deformation be subjected to ductile conditions. Not a problem really in the RLSZ case, in fact we only need two basic elements: heat and fluids (e.g., Scholz, 1990). This is the time to return to our 'metamorphic story'. It has been widely acknowledged by most geologists that have worked in the Red Lake mine that the history of the RLSZ is complex and polyphase. We must consider three key elements for the understanding of this history (see next box):

- Deformation ('our' D2 episode: folding and shearing).
- Metamorphism (the M2 episode: greenschist to amphibolite facies).
- Granitoid intrusions.

If high-grade mineralization coincides in time with the peak of D2-M2, and the amphibolite facies developed in response to an anomalous thermal gradient (granitoid-related), then it follows that (see next box):

- Formation of the High Grade Zone (HGZ) occurred during the advanced stages of D2-M2.
- The HGZ developed 'in depth', and related to the deeper (and 'hotter') amphibolite facies.
- The anomalous thermal gradient not only generated the amphibolite facies but also induced ductile-on-brittle phenomena within the RLSZ (**see next box**).

- The passage from brittle to ductile conditions occurs at aprox. 300ºC. This passage is given by the T value at which quartz begins to behave plastically. For granitic (or compositionally equivalent materials) this temperature can effectively be regarded as the brittle-ductile transition boundary.
- However, if the initial mineralogy of a rock consists mainly of plagioclase-pyroxene-olivine (basalts) or pyroxene-olivine (komatiites), then ductile conditions are reached at higher temperatures. For example, plagioclase will become plastic at aprox. 450ºC, pyroxene at 550ºC, and olivine at 650ºC (Kusznir and Park, 1987).
- Thus, to reach mylonitic conditions in mafic-ultramafic materials, higher temperatures are required, i.e., at least 450ºC for basalts and 550ºC for komatiites.
- It follows that greenschist facies was the prerequisite to reach mylonitic conditions in the basalts, and amphibolite facies to reach plasticity in the komatiitic rocks → late, ductile-on-brittle overprinting.
- **Last but not least**, at high temperatures gold can extracted from arsenopyrite (**see Appendix**), a common gold precursor. Thus, it is in this high-T environment (amphibolite facies) that gold can be put into solution, precipitate, and generate new ore bodies (e.g., the HGZ). See figure 10.

Solving the puzzle

We may have solved most of the puzzle. By early M2-D2 time we have a shear zone (RLSZ) undergoing brittle deformation; as the thermal gradient increases, part of the deformed rocks hosted by RLSZ start mylonitization processes (ductile-on-brittle phenomena); at 450ºC plagioclase becomes plastic, therefore basalts can reach mylonitization; at 550ºC, pyroxene becomes plastic, so komatiites may undergo mylonitization as well. To achieve temperatures within such a range, the metamorphism has to go beyond the greenschist facies. We know also that granitoid intrusions did take place during M2, thus these intrusions may have been the heat engine to trigger amphibolite facies (Fig. 9).

Why this discussion is so important?

- Because equivalent conditions (amphibolite facies) are met beneath the spatial position of the HGZ, along the RLSZ ... and ...
- ‘Equivalent conditions’ indicate that ‘other’ (new) ore bodies may be there awaiting discovery.

A combined, theoretical and empirical approach

↓

And so, everything fits:
Deeper environments → granitoid intrusions → higher temperatures → amphibolite facies + ductile-on-brittle phenomena → gold put into solution → gold deposition

↓

FORMATION OF HGZ-TYPE ORE BODIES

Schematic sequence of processes during D2-M2 leading to formation of the HGZ

NE-SW crustal shortening; initiation of folding and fracturing

↓

Mostly brittle deformation in the early stages of the RLSZ.
At ~ 300ºC the felsic rocks start mylonitization

↓

Greenschist facies, beginning of generalized ductile-on-brittle phenomena along the RLSZ; at ~ 450ºC the basaltic rocks start mylonitization

↓

The intrusion of granitoids further elevates the regional geothermal gradient allowing passage into the amphibolite facies. This is better observed in the deeper sectors of the RLSZ (Fig. 10)
Ore deposition leading to formation of the HGZ begins

↓

At T > 550ºC the komatiitic rocks undergo mylonitization;
ductile-on brittle processes completed.
The HGZ completes its shaping

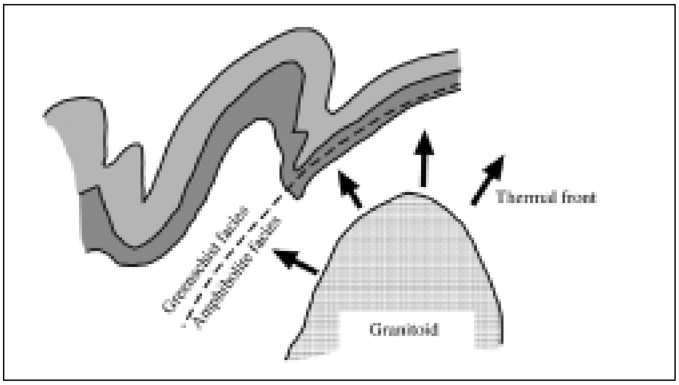

Fig. 9. Esquema que muestra la probable relación entre el emplazamiento del granitoide y el metamorfismo
Fig. 9. Idealized sketch depicting probable relationships between granitoid emplacement and metamorphism

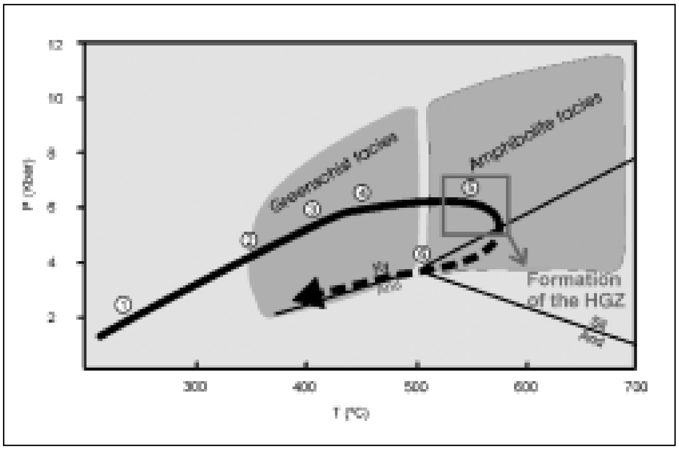

Fig. 10. Trayectoria P-T sugerida para M2 y otros fenómenos asociados. 1: Inicio de la deformación (D2); fracturación frágil a lo largo de ZCRL; 2: Inicio de la formación de las facies de esquistos verdes. 3: La intrusión de granitoides induce un gradiente térmico anómalo que permite el desarrollo de una trayectoria PT en el sentido de las agujas del reloj. 4: Inicio de la deformación dúctil en las rocas máficas (la plagioclasa se vuelve plástica). 5: M2 alcanza las condiciones de pico metamórfico (facies de anfibolitas); fenómenos del tipo dúctil-frágil en la ZCRL (el piroxeno se vuelve plástico; las komatiitas sufren milonitización); formación de la Zona de Alto Grado (ZAG). 6: Posible evolución PT durante los estadios finales de D2-M2
Fig. 10. Suggested P-T path for M2 and other time-related phenomena. 1: Onset of deformation (D2); brittle fracturing along the RLSZ. 2: Onset of greenschist facies. 3: Intrusion of granitoids induces an anomalous thermal gradient allowing continued clockwise P-T path. 4: Onset of ductile deformation in mafic rocks (plagioclase becomes plastic). 5: M2 reaches peak conditions (amphibolite facies); peak of ductile-on-brittle phenomena along the RLSZ (pyroxene becomes plastic; komatiites undergo mylonitization); formation of the High Grade Zone (HGZ). 6: Possible P-T evolution during the wanning stages of D2-M2

Target definition and location

The Red Lake mine is well known from Level 34 upwards, however, as far as exploration is concerned, it is precisely below Level 34 where a new high-grade zone can be found. The reasons have been already discussed:

- The ore bodies are hosted by a reverse oblique shear zone (RLSZ).
- The ore bodies define a stepping-type structural arrangement.
- Therefore, the next 'step' must be below Level 34.
- This zone (below Level 34) most probably display equivalent characteristics to those that are met in the vicinity of the HGZ.

It follows that:

- Below Level 34 a new ore body (here named as **HGZ-N**) should be found (Figs. 11 and 12).
- The **HGZ-N** should be laterally and vertically displaced with respect to the HGZ.
- The lateral displacement is southward directed.
- The vertical displacement is downwards (along dip of the RLSZ).

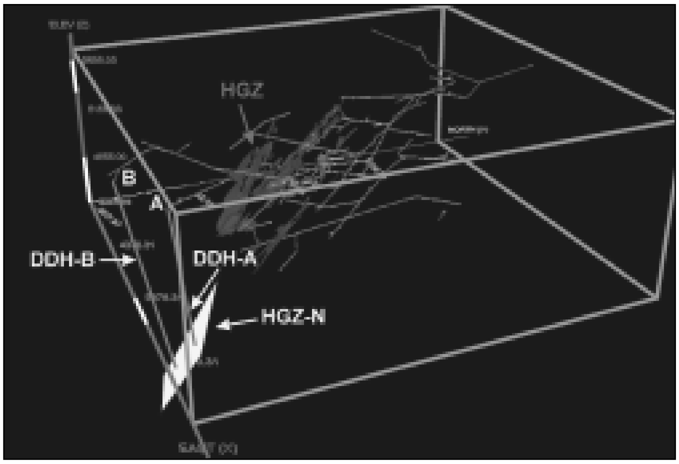

Fig. 12. Definición tridimensional del objetivo (ZAG-N, en amarillo). Red de galerías: nivel 34. A y B: sitios sugeridos para iniciar la perforación de los sondeos DDH-A y DDH-B para cortar a ZAG-N
Fig. 12. 3D definition of target (HGZ-N, yellow). Gallery network: level 34. A and B: suggested sites to drill DDH-A and DDH-B in order to intersect HGZ-N

A model for regional exploration of HGZ-type deep seated targets

As discussed in this report, we have found clear indications that a direct relationship can be established between the structural setting, amphibolite facies, granitoid intrusions, and the existence of HGZ-type ore bodies along shear zones. This allows definition of a model not only empirical, but also genetic for the finding of HGZ-type ore bodies. The following schematic figure (not to scale) (Fig. 13) displays the main elements of this exploration model, which we believe can be successfully applied to other greenstone belts in the region of Ontario.

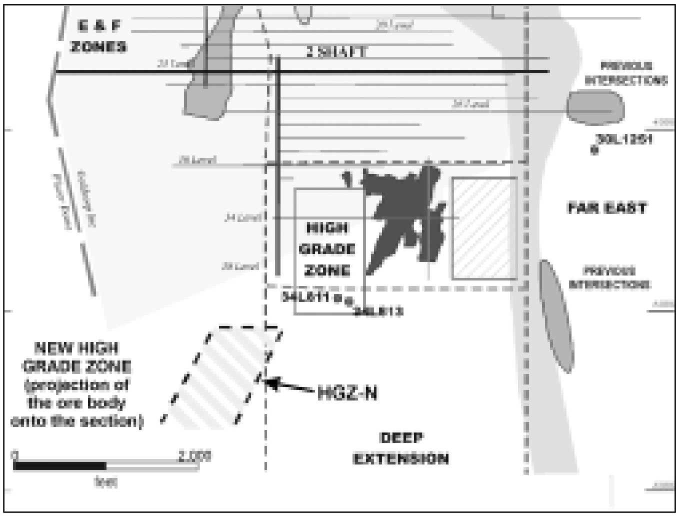

Fig. 11. Sección longitudinal esquemática de la mina Red Lake en la que se muestra las áreas de exploración (29 de Junio de 2000; Goldcorp Inc.). Hemos añadido a la sección la localización de la zona propuesta de alto grado (ZAG-N)
Fig. 11. Schematic longitudinal section, Red Lake mine, showing areas of exploration, June 29, 2000 (Goldcorp Inc.). We have added to the section the location of our HGZ-N

Conclusions

We suggest that alteration-mineralization occurred along two main episodes: 1) early alteration ('regional alteration') and mineralization. As suggested by Penczak and Mason (1999) the deposits of the district may be a case of metamorphosed early epithermal gold mineralization and massive sulphides. This is in agreement with what we called in our initial report (Oyarzun *et al.*, 2000) the 'regional alteration' episode (Fig. 14). Thus, this early gold+sulphide mineralization could be regarded as a 'precursor' for the later, main gold mineralization episode; 2) a main alteration ('local alteration') - mineralization episode, characterized by folding, shearing, and metamorphism (M2, amphibolite facies). Auriferous arsenopyrite (e.g., formed during the early episode, see above) subjected to high-T conditions (amphibolite facies) will liberate gold (e.g., Clark, 1960; Arehart *et al.*, 1993). A process of such a kind will be enhanced by the brittle behavior of sulphides during ongoing deformation (D2 event). This episode of mineralization was accompanied by acid alteration involving bleaching, quartz-sericite

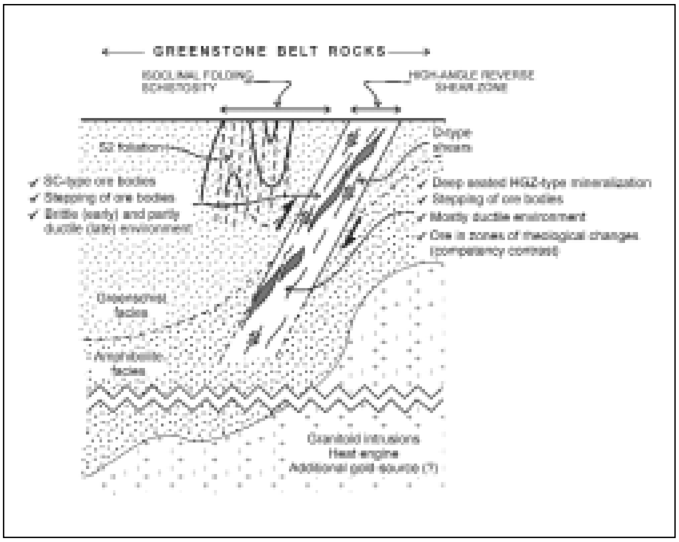

Fig. 13. Modelo de exploración regional
Fig. 13. Regional exploration model

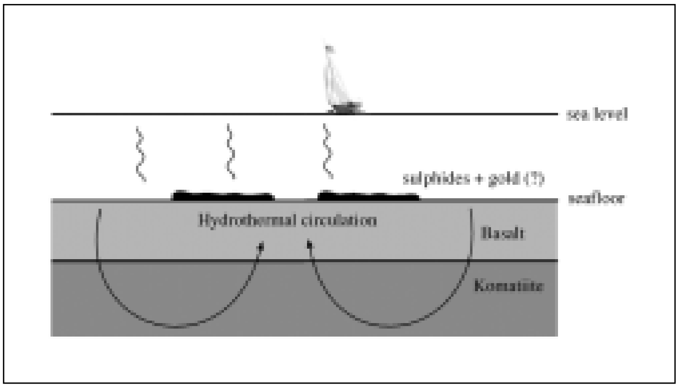

Fig. 14. Diagrama esquemático que muestra las probables relaciones entre vulcanismo, circulación hidrotermal, alteración (clorita-carbonatos) y mineralización temprana
Fig. 14. Schematic diagram showing probable relationships between volcanism, hydrothermal circulation, alteration (e.g., chlorite, carbonates), and early mineralization

alteration, silicification, overprinting the early assemblages (Goldcorp Inc, 2000). Note that this alteration did not necessarily develop in the epizonal environment, because equivalent facies can be found in deeper suites (e.g., Hemley *et al.*, 1980), such as at Las Cuevas (Almadén district, Spain), a shear zone related mercury deposit of Hercynian age (Higueras *et al.*, 1999).

An additional gold source may have been provided by the intrusions of granitoids that took place during D2-M2. In such a case, the presence of granitoid intrusions may be essential in any attempt to define regional targets (apart from the other considerations already discussed along the report). To this respect it is interesting to quote a report from Murgor Resources Inc. on its Mink Lake and Birch Lake properties: *"The gold showings are related to large regional structures as well as to alteration zones associated with granitic intrusives.*

Acknowledgements

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