The Benefits of Incorporating Admixtures into Mine Paste Backfill

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ABSTRACT

The benefits of incorporating chemical admixtures into mine paste fill designs are numerous and cost effective, especially when incorporating metrics such as energy- and cement consumption, reduced dewatering costs, reduced downtime and pipe blockages as well as reduced plant maintenance costs into the equation. The addition of admixtures is a tool to optimize the backfill product in order to have a direct feedback on the backfill quality and numerous operating cost centres. Using admixtures provides the paste fill engineer with a tool to adjust and modify many variables of the paste mix. The following variables can be modified in order to obtain a cost performing backfill paste: enhanced rheological behaviour (better thixotropic profile, improved slump, better pumpeability), reduced water content, reduced cement content or change of cement type, increased solid content, improved compressive strength and improved cure time. An adjustment to any of the mix design variables can result in significant improvements of the paste cost-performance and reduction in overall operational expenses. Test results have proven that the addition of a single admixture at relatively low dosage of 1% to 3% by weight of cement can have powerful effects in modifying the parameters listed above. A prerequisite for good results is a good understanding about the mineralogy and granulometry of the ore host and therefore the source of the tailing material which leads to a customized adjustment of the used admixture in any given paste backfill operation. This paper outlines results from different mine backfill pastes and how to come up with the right admixture choice.

INTRODUCTION

The number of mine paste fill operations is increasing globally, backed by increased environmental concerns of above ground storage of fined grained mine waste as well as by the utilization of modern and cost efficient paste backfill plants. The motivations for using admixtures in paste backfill are manyfold, including the increasing cost component over recent years due to higher binder consumption in addition to increasing equipment costs. Reducing binder consumption is hence the foremost motivating factor to assess the use of chemical admixtures in a backfill operation. The characteristics of the backfill material are as diverse as the nature of the ore deposits themselves, leading to a strong diversity of the paste mix for each single paste backfill operation. This diversity has in turn a very strong influence on the choice of the right admixture which is the main topic of this paper. Recent research and on site mine trials have shown, that the approach: “one product fits all” is wrong when it comes to paste backfill admixtures. By choosing the right type of admixture, it is possible to greatly influence the rheological properties of the paste and hence optimize the cost and performance of the mix.

ORIGIN OF THE PASTE – IT DOES MATTER…

Ore deposits are formed by different physical and chemical processes in the earth crusts from its origin through to its deformation history. These processes are the defining steps for the formation of the specific characteristics of each deposit type. A paste derived from a copper gold skarn that might have a relatively coarse ore mineral composition and a chemistry dominated by the calcareous environment it was formed in, will react very differently to a given admixture than deposits formed in an epithermal setting were the ore needs to be finely ground due to the possible refractory nature of the metals of interest and the completely different chemical composition of the alteration regime. Such mineralogical and geochemical differences influence success or failure of a chosen admixture and therefore each case needs to be assessed carefully in order to come up with the best suited admixture. Onsite mine trials as well as lab trials with paste material from different mine sites all around the globe have shown that pastes derived from different generic types of ore deposits respond differently to different admixtures. The following generic types of deposits have been assessed so far, where underground paste fill applies:

- Polymetallic VMS (Volcanogenic Massive Sulfides) deposits
- Polymetallic SEDEX (Sedimentary Exhalatives) deposits
- Orogenic, greenstone hosted gold deposits
- Epithermal silver and polymetallic deposits
- Copper-Gold Skarn deposits

These different ore deposit types include the vast majority of the worlds cut and fill and long-hole stoping and fill operations where cemented paste backfill is usually utilized. The goal of this work was to identify which chemical admixture interacts best with the granulometry and mineralogy of the different pastes as well as the binders used in order to achieve the maximum plasticizing effect which is key to optimizing the cost performance of a given paste mix as outlined below. The key characteristics of the five tested generic ore deposit types shall be discussed briefly, giving priority to the parameters that are likely to affect the admixture performance in pastes. An overview of the generic deposit types is given in figure 1.

Polymetallic VMS (Volcanogenic Massive Sulfides) Deposits

VMS deposits are formed on and below the sea-floor along ocean ridges where oceanic plates diverge. VMS deposits are a major source for lead, zinc and silver. Leaching of the mafic or felsic host rocks by circulating seawater, powered by the magmatic heat source, leads to a distinct mineralization and alteration pattern including intense chlorite alteration as well as the formation of other phyllosilicates such as sericite, biotite and others. Calcite and quartz are a common part of the ore composition. Mineralogy is usually relatively coarse (>90 microns).

SEDEX (Sedimentary Exhalatives) Deposits

SEDEX deposits are similar to VMS deposits in terms of the metal mix but a direct link to a magmatic source is generally missing. The alteration regime is less pronounced than with VMS deposits and distinct clay horizons are common (Goodfellow et al., 1993). Extensive zones of silicification may be present (Moore et al., 1986) In terms of the grain size, SEDEX deposits are generally finer grained than VMS deposits and barite can be closely associated with the ore (Robb, 2005)

Orogenic, Greenstone Hosted Gold Lodes

Orogenic, greenstone hosted gold deposits are a major source of gold. Despite being located in a variety of host rocks ranging from felsic to mafic composition, from sedimentary to plutonic rocks (Hagemann and Cassidy 2000), the mineralogy is dominated by quartz and in some cases calcite that hosts the gold and other minor by products in form of distinct veins. Alteration is present and can compose of intense chloritization and carbonation, sericite, biotite or strong hematization. Grainsize can vary strongly from sub 50 microns to well above 100 micron size.

Epithermal Deposits

Epithermal deposits are a major source for silver, gold and many additional by products. Acidic fluids are capable of leaching most of the major elements from the host volcanic rocks (Robb 2005). Mineralogy is usually complex, originating from hydrothermal fluids derived from a magmatic or meteoric source including alunite, kaolinite, sericite and potassic overprints (Arribas et al. 1995). Grain size varies strongly depending on the refractory nature of the metals of interest.

Skarn Deposits

Skarn type deposits are a major source for copper and gold as well as zinc, lead and other by-products. Skarn mineralogy can be described as complex including distinct alteration zonation depending where the skarn was formed. Common is a mineral paragenesis of calc-silicate minerals within the intrusive rocks or adjacent sedimentary packages. Frequent alteration minerals include garnet, pyroxene, amphibole and epidote (Einaudi et al, 1982). Also biotite and quartz is common. Grainsize is usually relatively coarse.

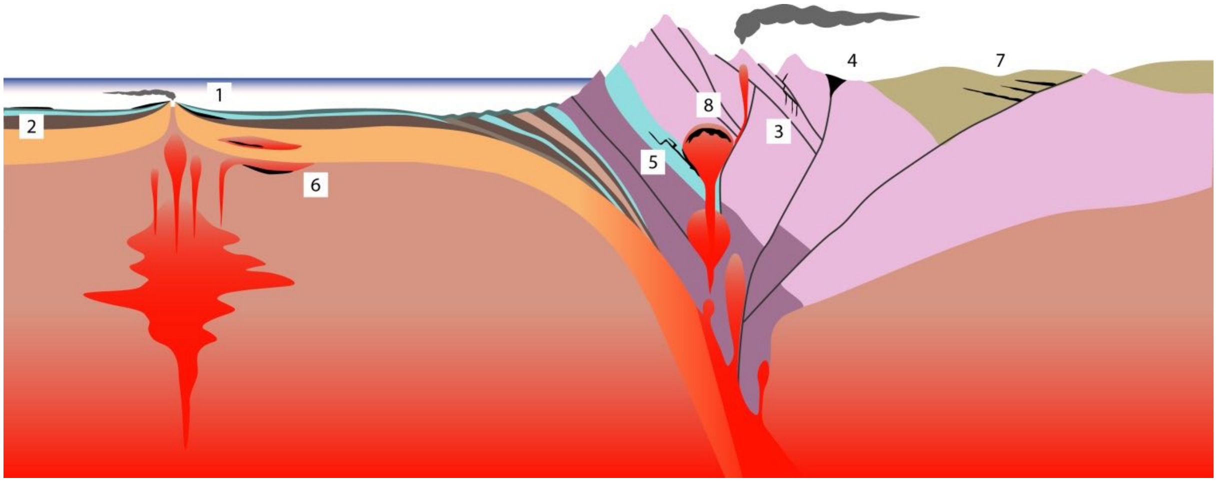

Figure 1. Schematic profile through the earth's crust and upper mantle with location of most common ore deposits: 1) VMS 2) SEDEX 3) Orogenic Gold 4) Epithermal 5) Skarn 6) Layered intrusions 7) Sedimentary hosted (MVT) 8) Porphyry

HOW TO CHOOSE THE RIGHT ADMIXTURE

The idea behind the use of admixture in mine backfill operations is their ability to plasticise the paste backfill mix and hence to reduce the water content of the paste by keeping the workability. This principle is the core behind standard concrete technology and describes the strong effect of a reduced water-binder ratio on the final strength of the concrete (figure 2) which has been known for over 100 years (D.A. Abrams 1918). Most recent types of “superplastizisers” are based on polycarboxylate ethers (PCE’s). As described by Giraudeau et al. 2009, the effectiveness of the PCE’s on cement pastes is based on negatively charged polycarboxylate backbone chains that interact with the positively charged cement particles. At the same time, these backbone chains are creating a steric repulsion effect that disperses the cement particles from each other.

But what is actually influencing the rheological behaviour of concrete? Grain size plays an important role as Van der Waals, electrostatic forces (surface charge), viscous drag, inertia and gravity play its role differently at different grain sizes (Giraudeau et al. 2009). This fact is particularly important when dealing with fine grained mine waste where fines play a vital role due to the large surface area available for particle interaction. Like in concrete, where a certain yield stress has to be overcome to make a concrete flow, the very same is true for a backfill paste. Finding the right “dispersant” at the right dosage in order to maximise water-binder ratio reduction, to minimize cement consumption for a specific strength requirement, is the main goal to achieve.

As well as this theory is understood for concrete, it is not the case for a highly complex paste mixes. Compared to a concrete, a cemented paste contains too little cement (usually between 3-8% of the total weight) in order for the admixture to just interact with the cement particles. A useful admixture needs to interact with all or at least a certain percentage of the total fines portion of a paste in order to be of sufficient use at economic dosages.

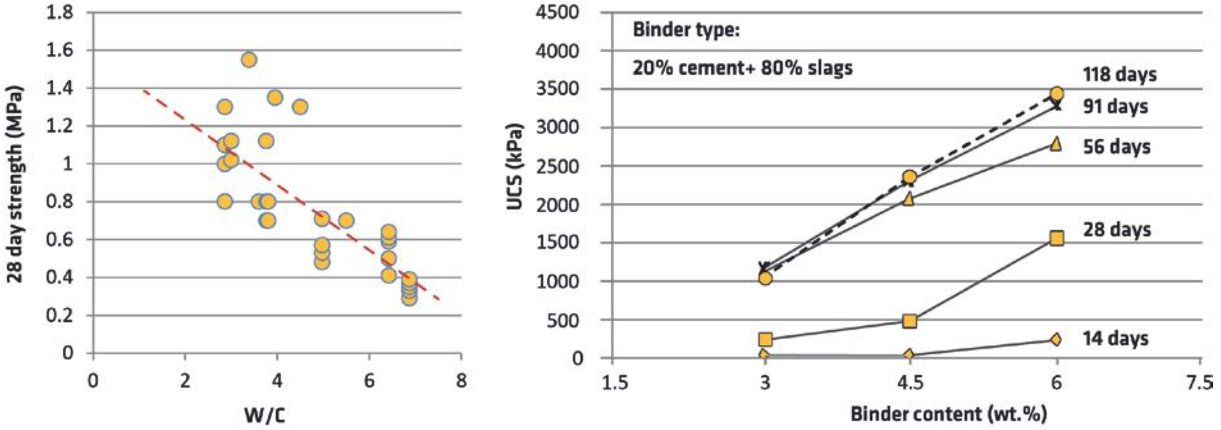

Figure 2. Left side: Water/binder ratio vs compressive strength after 28 days from different mine paste samples. Right side: Development of the compressive strength over curing time of the mine paste (after Benzaazoua et al. 2003)

To find the most effective admixture for a certain paste mix, a good understanding of the mineralogical composition of the paste mix and its effect on a certain admixture is important. As shown later in this paper, there is a very large variation in results when screening different PCE’s and older dispersants such as lignosulfonates and naphthalene based products (figure 6). This is not surprising when comparing the composition of different pastes with each other. A more or less inert, quartz rich paste from a high grade orogenic gold lode will interact much different with a given admixture than a complex paste derived from a strongly altered and pyllosilicate rich VMS deposit.

CASE STUDIES

Paste from a Polymetallic VMS Deposit, Europe

The paste from this mine is heavy in iron rich sulphides, which make up to 75% of total mass. Chlorite and Muscovite are the dominant phyllosilicate phases, as detected with a XRD (X-ray diffraction analytics, figure 3), which influence the rheological properties of the paste significantly. The paste needs to be engineered to reach the 28-day strength of 1.6 MPa at a cement dosage of 4.5%. Total solid content of the paste ranges between 78 to 84% and the required slump should be in the order of 18-20 cm to ensure pumpeability. Grain size is relatively fine with 90% passing 50 microns.

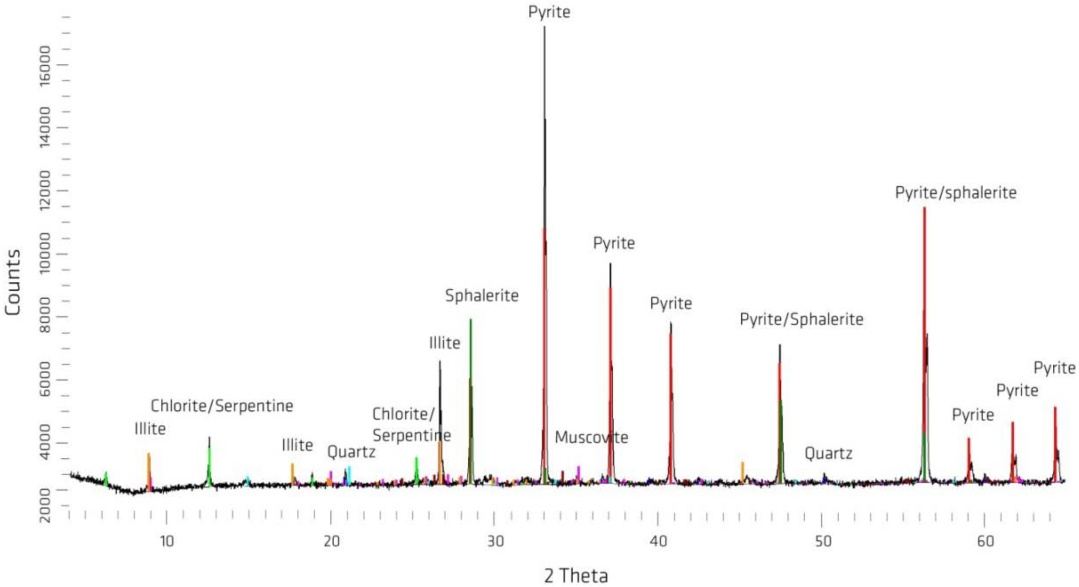

Figure 3. XRD analytical results from the VMS paste. A D8 ADVANCE from Bruker GmbH was used in the Sika laboratories in Zurich. Note the large and pronounced peaks of iron sulphides (mainly pyrite). Mineralogical composition: 78.5% Pyrite, 11.3% Quartz, 5.3% Muscovite, 2.6% Chlorite

It was not possible for the mine to reach the required strength with the current mix design of the paste. Hence, several admixtures were screened and it was found that by using the Sika® Stabilizer-302 MBF at a dosage of 1.8% bwoc (by weight of cement) the slump of the paste could be increased dramatically (figure 4) by keeping the original mix design constant. In a next step it was possible to reduce the water content in the tailings mix by around 30-40% which reduced the water-binder ratio to such degree that the required 28 day strength of 1.6 MPa could be easily reached. Binder consumption could be reduced by 25-30% and there is the possibility to change to a cheaper binder type available in the region. Bleeding was reduced to non-observable levels.

Figure 4. Paste mix from the mortar cone testing before adding admixtures (left) and after adding 1.8% Sika® Stabilizer-302 MBF

Paste from Epithermal Silver Deposit, Latin America

This paste has a solid content of 77-80% and the tails are relatively coarse with 90% passing 220 microns. Strength requirements are between 0.35-1.75 MPa depending if the paste is used for primary plug filling or second pours as well as the fill occurs in the primary or secondary stopes. Original mix designs were based on 6% binder for the low strength fill and up to 15% binder for the high strength fill. A slump of 22 cm is usually required to enable pumping of the mix. Mineralogy of the paste is complex and dominated by quartz and calcite phases. Sericite and biotite as well as kaolinite and to a lesser extend chlorite are present. Using 3% Sika® Stabilizer-301 MBF (bwoc), it was possible to increase the slump by more than 100% (figure 5) by keeping the original mix constant. Backed by this strong plasticizing effect (figure 5), cement could be gradually removed up to 50% while remaining within the slump requirements. No bleeding occurred with the optimized mix and the 1.5 MPa target at 28 days could be achieved by dosing 6% cement which is half the original cement dosage.

Figure 5. Paste mix from the mortar cone testing before adding admixtures (left) and after adding 3% Sika® Stabilizer-301 MBF

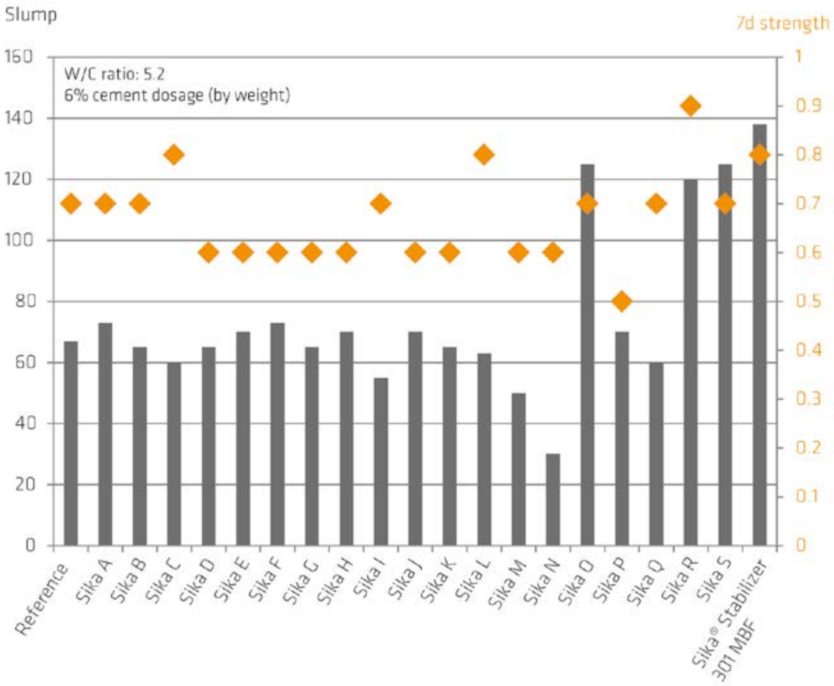

Figure 6. Screening of different polymers until the right one is found. Note the strong increase in slump (more than 100%) when finding the right admixture. Both water and binder content have been kept constant throughout the screening.

Orogenic Gold Deposit, West Africa

The paste from this long-hole stoping operation had originally a solid content of 80% and a required slump of 20-22. The paste is blended with crushed waste rock (figure 7) and to prevent segregation of the aggregates out of the fine paste matrix, the fill needs to be stable enough to maintain this coarser fraction within the mix. Mineralogy is typical for West African, Birimian gold lodes and dominated by quartz, Iron oxides and carbonaceous material to a lesser extent. Binder content varies depending on the 28 day strength requirement, which is 1 MPa at around 6% binder dosage for the secondary stopes and 2 MPa at around 8-9% binder content for the primaries and plugs. By using 2% (bwoc) of Sika® Stabilizer-305 MBF, the slump could be increased 3 fold by keeping the initial mix constant (figure 7). During the next step, cement content of the paste could be reduced by 25-30 percent and the targeted 28 strength was reached while maintaining well within the workability guidance of the paste plant (figure 8). Furthermore, the solid content of the paste increased, the bleeding was reduced to non-detectable levels and the combined aggregate-paste mix showed to be extremely stable (figure 8).

CONCLUSIONS

Backfill is a critical and costly component to underground cut and fill and long-hole stoping operations. With the current downturn in commodity prices, miners watch for any opportunity to improve efficiencies and reduce costs in order to optimize their resource. Chemical, polymer based admixtures present a viable option to optimize the cost performance in modern day paste backfill operations worldwide. Lab and on site mine trials have shown the powerful effect of the right admixture on the rheology of a given paste mix. A 30-40% binder reduction is very often well within the achievable limits at moderate admixture dosages. However, a fundamental understanding of the mineralogy, the particle size distribution and binder behavior of the paste is key, in order to find the right paste backfill admixture solution. By doing so, a whole range of parameters can be greatly improved including reduced maintenance costs for the paste fill infrastructure and equipment, improved pumpeablity, improved rheology, reduced binder consumption, increase in solids, increase in compressive strengths and the reduction in cure time.

Figure 7. Paste mix from the mortar-cone testing before adding admixtures (left) and after adding 2% Sika® Stabilizer-305 MBF (middle). In the right image, note the very homogeneous distribution of the added crushed aggregates when cutting the cured paste after 28 days.

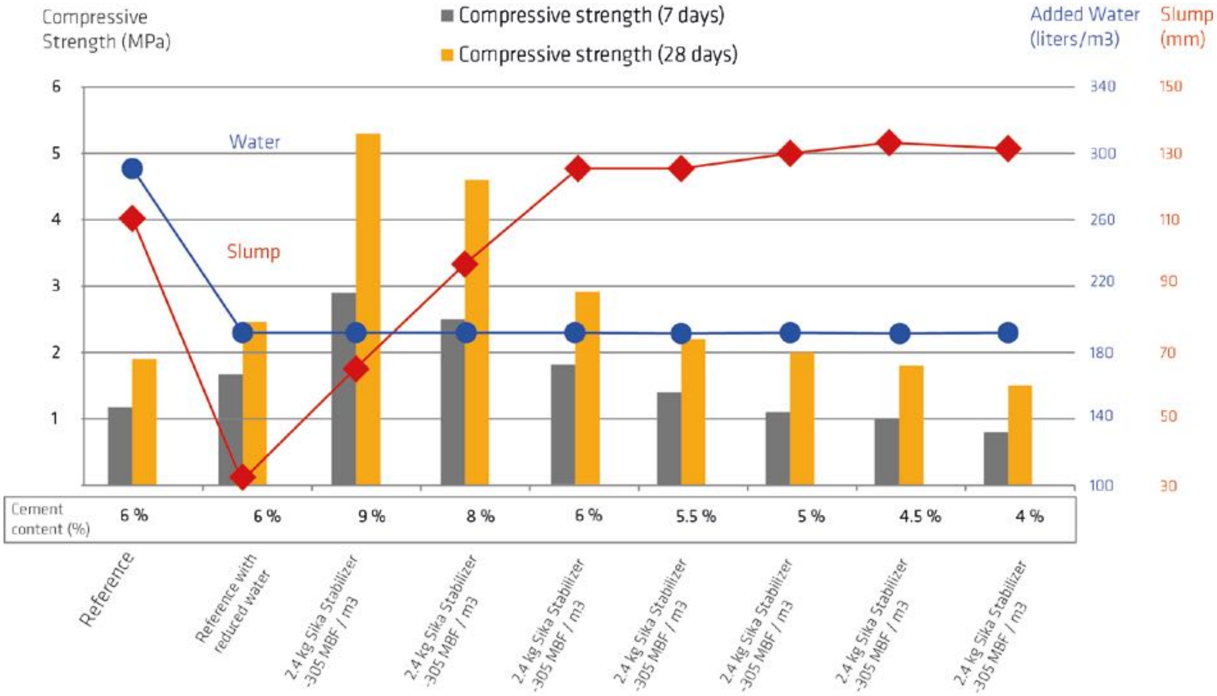

Figure 8. Reducing the amount of water in the paste mix leads to a strong loss of workability which is indicated by the strongly reduced slump ("Reference with reduced water"). By adding Sika® Stabilizer-305 MBF at low dosage, workability gets back to the required level (red line) while maintaining the required 28 day compressive strength of 1 MPa but at a much lower cement content.

REFERENCES

Abrams D.A. 1918, Design of Concrete Mixture, Bulletin 1, Structural Materials Research Laboratory, Lewis Institute.

Arribas A., Hedenquist, J.W., Itaya, T.,Okada, T.Concecion, R.A. and Garcia, J.S. 1995, Contemporaneous formation of adjacent porphyry and epithermal Cu-Au deposits over 300 ka in northern Luzon, Philippines. Geology, 23, 337-40.

Belem T., Benzaazoua M. 2004, An overview on the use of paste backfill technology as a ground support method in cut-and-fill mines. Proceedings of the 5th Int. Symp. on Ground support in Mining and Underground Construction. Villaescusa & Potvin (eds.),28-30 September 2004, Perth, Western Australia, Australia, Tayler & Francis Group, London, pp. 637 – 650.

Einaudi M., Meiner, L.D. and Newberry, R.J. 1981, Skarn Deposits. Economic Geology, 75th Anniversary Volume, 317-91.

Giraudeau C., Espinose de Lacaillerie, J.B., Souguir, Z., Nonat, A., Flatt, J.R. 2009, Surface and ntercalation chemistry of polycarboxylate copolymers in cementitious systems. J. Am. Ceram. Soc., 92 2471-2488.

Goodfellow W.D., Lydon, J.W., Turner, R.J.W. 1993, Geology and genesis of stratiform sediment hosted (SedEx) zinc-lead-silver

sulfide deposits. Geological Association Canada, Special paper, 40, 201-52.

Hagemann, S.G. and Cassidy, K.F. 2000, Archean orogenic lode gold deposits. Review in Economic Geology, 13, 9-68.

Moore D.W., Young, L.E., Modene, J.S., Plahuta, J.T. 1986, Geologic setting and genesis of the Red Dog zinc-lead-silver deposit, Western Brooks range, Alaska. Economic Geology, 81, 1696-727.

Robb, L.J. 2005, Introduction to ore forming processes.