Introduction

There seems to be general consensus throughout much of the global mining industry that the supply of base and precious metals and some other commodities (e.g., ferrous metals, uranium) is reasonably well assured into the foreseeable future because increases in total resources continue to keep pace with or outstrip global consumption. The basic assumption is that market forces and technological advances will combine to promote and perpetuate this trend (e.g., Tilton, 2003; Crowson, 2008). Others disagree, however, and predict that shortages are inevitable if metal consumption continues to escalate (Beaty, 2010).

It is already becoming clear that many known resources seem unlikely to be mined, irrespective of commodity prices, because of their low grade and/or quality. Hence, many mineral resources that were uneconomic in the early 2000s are likely to remain so, both today and into the foreseeable future because of increases in both the direct (e.g., energy, labor) and indirect (e.g., environmental, social) production costs. This situation is being further exacerbated by the perceived decrease, over at least the past decade, in the discovery rate of base and precious metal resources measured in terms of both the number of major discoveries made and the exploration dollars spent per discovery (e.g., Dummett, 2000; Horn, 2002; Schodde, 2004). There is also a suggestion that the discoveries made are, on average, becoming both smaller and lower grade. Therefore, it seems reasonable to ask whether current exploration practices and success rates are going to be adequate to provide for the massive increases in metal consumption that world population growth, rising living standards, and rapid industrialization and urbanization in China, India, and other emerging markets appear to portend. For example, Rio Tinto’s projections suggest that “by 2030 the additional supply required will be equivalent to replicating the iron ore output of the Pilbara region of Australia every five years, adding another aluminium production complex the size of Canada’s Saguenay every nine months, and developing another copper mine the size of Escondida in Chile each year. Future energy requirements are such that an entire Hunter Valley coal supply chain needs to be created each year plus a uranium mine the size of Ranger every four years” (Albanese, 2010, p. 7). Clearly, the exploration business has to become increasingly effective if it is to rise to the challenge of finding mineral resources of the right caliber to assure that this burgeoning demand can be adequately satisfied.

The articles in these two volumes highlight current understanding of several of the world’s major metallogenic provinces and ore deposit types, describe proven and more speculative exploration concepts and techniques, and document some notable recent exploration successes. In various ways, all the articles, many cited herein, can be framed in the broad context of where to conduct exploration: greenfields versus brownfields programs; mature, emerging, or frontier terranes; and exposed or concealed targets. The right mix and balance between these various options at the global scale is considered critical if the exploration business is to deliver the mineral resources needed by future generations.

Greenfields versus Brownfields Programs

The proportion of worldwide exploration budgets devoted to greenfields exploration has declined sharply over roughly the past decade at the expense of brownfields and advanced-stage expenditure (Metals Economics Group, 2010). Major mining companies are conducting less greenfields exploration for a variety of reasons, including the perceived high risk and limited chance of success, as well as the notion that they can simply buy deposits discovered by the junior exploration sector. Furthermore, merger and acquisition activity over the same time period has significantly reduced the number of major mining companies, which, as a consequence, resulted in exploration cutbacks. Most junior companies avoid greenfields programs because the lead times to discovery are simply too long to satisfy the expectations of their investors.

This is a serious situation because the discoveries of many major mineral deposits and, in particular, new metallogenic provinces, belts, and districts are mainly dependent on greenfields success. The ideas and innovation that fuel greenfields exploration may be directly compared with the research and development that underpin new product invention in other industries (e.g., pharmaceuticals; Hall and Redwood, 2008). Greenfields exploration, particularly in the 1960s and 1970s, resulted in discovery of several major ore deposits that, in turn, led to definition of new metallogenic provinces or belts (e.g., southwestern Pacific porphyry copper-gold province, Carajás iron province, Athabasca Basin uranium province, north-central Nevada Carlin-type gold trends). The Eagle’s Nest, Ontario, and Ntaka Hill, Tanzania, sulfide nickel deposits and the Kamoa, Democratic Republic of Congo, stratiform sediment-hosted copper deposit are three promising greenfields discoveries described in this volume (Mungall et al., 2010; Tirschmann et al., 2010; Broughton and Rogers, 2010), among the relatively few worldwide in recent years.

In order to promote renewed interest in greenfields activity, the exploration community needs to consider new corporate approaches to exploration, which allow seasoned practitioners to again think widely and conduct the necessary fieldwork relatively unencumbered by major company bureaucracy and the dictates of the junior market (Sillitoe,
Frontier terranes generally present higher risks both because there is no concrete evidence that major deposits exist and the fact that they are commonly located in remote and/or inaccessible parts of the world, as well as in unfavorable or untested jurisdictions. Therefore, experience and intuition play a greater role in the selection of prospective and suitable frontier terranes. The initial target in frontier terranes is typically an exposed orebody that can be discovered, using tried-and-tested methods, as exemplified by the discoveries of the La Colosa porphyry gold deposit in the Middle Cauca belt of Colombia (Lodder et al., 2010) and Oyu Tolgoi porphyry copper-gold-molybdenum deposits in the South Gobi belt of Mongolia (Perelló et al., 2001). However, where an appropriate exploration technique, such as airborne geophysics, proves effective, concealed deposits can also be successfully searched for in frontier regions, as exemplified by the recent Ni-Cu-PGE (including Eagle’s Nest; Mungall et al., 2010), volcanogenic massive sulfide, and chrome (e.g., Big Daddy) discoveries in the James Bay lowlands of northern Ontario.

Emerging terranes strike a happy medium between the heavily explored, mature and high-risk, frontier provinces, and may be considered as the setting for the Pequop, Nevada (Bedell et al., 2010), and Money Knob (Livengood), Alaska (Pon tius et al., 2010), discoveries. Following an important discovery, a frontier terrane soon acquires emerging status, as exemplified by the Middle Cauca and South Gobi districts and surrounding regions today. Additional major discoveries may ensue, whereas some emerging terranes are still defined by only one major deposit despite decades of exploration effort, as exemplified by the Bingham Canyon porphyry copper-gold-molybdenum deposit in Utah and Pueblo Viejo high-sulfidation epithermal gold-silver deposit in the Dominican Republic.

Exposed or Concealed Targets

It will have become apparent from the above that exposed mineralization is generally the prime target in frontier and many emerging terranes, whereas concealed targets become far more important in all brownfields situations and in greenfields exploration campaigns conducted in mature and, to a lesser degree, emerging terranes (e.g., Sillitoe, 2004). Thus, emerging terranes may be considered prospective for both exposed mineralization, such as the Navidad silver-lead deposit in the epithermal precious metal province of Argentine Patagonia (Lhotka, 2010; Williams, 2010), and blind orebodies, such as the Fruta del Norte epithermal gold-silver deposit in the Subandean zone of Ecuador (Leary et al., 2007) and Kamaoa (Broughton and Rogers, 2010). The concealed targets may lie beneath mainly barren, premineralization rocks (e.g., Fruta del Norte, Juanicío-Valdecañas, Kamaoa, Phoenix) or beneath postmineralization sedimentary (e.g., Centinela district), volcanic (e.g., Resolution), or even seawater (Hannington et al., 2010) cover.

It is clear that a progressively greater percentage of future mineral discoveries will be blind (e.g., Horn, 2002), a situation that will require greater reliance on geologic models that emphasize peripheral attributes (e.g., McGoldrick et al., 2010; Nickerson et al., 2010), as well as on indirect geochemical and geophysical techniques (e.g., Balch et al., 2010; Kelsey et al., 2010; White et al., 2010). Greater use of drilling as a geologic tool will also be a fundamental prerequisite.
Conclusions

The guaranteed provision of future mineral resources mandates increased greenfields exploration expenditure by both major and junior companies and, in the case of the major companies, a better balance between greenfields and brownfields programs and between mature, emerging, and frontier belts. If greenfields exploration in frontier terranes is not carried out, then the next generation of metallogenic provinces and belts will likely not be forthcoming. All future exploration will need to focus more on concealed targets, but should not ignore the undiscovered deposits that are undoubtedly at least partially exposed.

If this work is to be successful, it will need innovative research efforts to better comprehend regional-scale metal endowment (e.g., Kesler and Wilkinson, 2010); identify potentially new frontier metallogenic environments (e.g., Riple, 2010); amplify existing mineral deposit models (e.g., Burrows, 2010; Golightly, 2010; Layton-Matthews et al., 2010) and create new ones; develop more effective, deep-penetrating geochemical and geophysical techniques (e.g., Balch et al., 2010; Hamilton and Govett, 2010); and produce improved and cheaper drilling technology.

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