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NICKEL-SULFIDE AND PLATINUM-GROUP-ELEMENT DEPOSITS

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INTRODUCTION

The last comprehensive series of papers concerned with aspects of nickel-sulfide geology was published ten years ago as a portion of *Economic Geology,* Monograph 4. These papers were presented at the 1966 Society of Economic Geologists symposium on magmatic ore deposits. Since 1966 a great deal has been learnt about magmatic sulfide ores. For example, we now appreciate that ultramafic lavas extruding on the sea floor at temperatures up to 1650°C were a common and important stage in the development of many Archean greenstone belts and that high-grade concentrations of nickel sulfides were formed at this stage. Our knowledge of the distribution and mineralogy of Pt-group elements in sulfide ores has increased enormously (see, in particular, *Economic Geology,* 1976, No. 7). We also have a much better understanding of how sulfur dissolves in silicate magmas, how metals partition themselves between such magmas, sulfide melts and silicate minerals, and how to use these data to develop quantitative models against which we can test our ideas on ore genesis.

A ten-day field conference on nickel sulfide ores was held in October, 1978, during which forty geologists representing eleven countries visited exposures and mines in the Timmins, Sudbury and Thompson, Manitoba, areas. The conference concluded with a two-day symposium on nickel-sulfide and platinum-group-element deposits held at the University of Toronto.

This volume consists of 26 invited papers that were presented at the symposium. Some papers are reviews of major advances in thinking on the subject over the past twelve years; others describe deposits hitherto unreported in the literature, and yet others present new experimental and analytical data coupled with ideas that may spearhead how thinking will develop over the next ten years.

The front portion of the volume contains papers describing the host rocks to nickel sulfides. Arndt *et al.* contrast komatiites from Archean greenstone belts with those from the Proterozoic 'Ungava nickel belt', Nesbitt *et al.* discuss the geochemistry and genesis of these rocks, and Peredery describes, for the first time, ultramafic rocks of the Manitoba nickel belt, suggesting that these are also komatiites. Besson, reporting results of an intensive study of the host rocks for nickel ores undertaken in France over the last six years, presents an original view of their petrologic affinities, and Papunen *et al.* discuss the origin of the highly metamorphosed, nickel-bearing ultramafic rocks of the Baltic shield.

In the next section, concerned with nickel sulfide ores, von Gruenewaldt reviews recent concepts concerning the emplacement of the Bushveld complex and the development of sulfides within it; Pattison discusses host rocks of the sulfide ores of the Sudbury district, pointing out that the ores appear to predate emplacement of the main Irruptive; and the staff of

Falconbridge Nickel Mines Ltd. describe the extremely Cu-rich ore zone discovered recently deep in the footwall below the Strathcona ore body at Sudbury. Boyd & Mathieson describe mineralization related to the dominantly noritic Råna intrusion in the Caledonides of northern Norway, Misar reviews information on the Ni-bearing Ransko peridotite–gabbro massif of Czechoslovakia, and Coats *et al.* discuss the Maskwa nickel deposit in the layered mafic–ultramafic Bird River sill of southeast Manitoba. Turning from dominantly mafic-related deposits to those with an ultramafic association, Groves discusses current thinking in relation to the development of the komatiite-related ores of Western Australia, Williams describes the geology and geological setting of komatiite-related deposits in Rhodesia, and Muir & Comba describe a sulfide concentration in komatiitic rocks of Dundonald Township, Ontario. Usselman *et al.* present the results of thermal modeling of the cooling of komatiite ore-bearing flows, demonstrating that given certain constraints, the 'billiard-ball' model accounts for many of the features of these ores. Groves & Keays discuss postemplacement changes affecting large low-grade zones of mineralization in intrusive dunite bodies associated with the komatiitic ultramafic lavas of parts of W. Australia.

The third section is concerned with Pt-group elements (PGE); Crocket reviews data on the concentration of these elements in different classes of igneous rocks. Naldrett *et al.* present new PGE data on sulfide deposits with a wide range of igneous affiliations; Ross & Keays discuss PGE data in deposits at Kambalda, W. Australia, and Hoffman *et al.* discuss the distribution of PGE in three Sudbury deposits. Watkinson & Dunning present the first description of PGE mineralization of the Lac-des-Isles deposit, N.W. Ontario, whereas Conn discusses, also for the first time, the very important concentration of PGE ores in the banded zone of the Stillwater complex, Montana. Hiemstra addresses the very difficult problem of the formation of the high-grade PGE concentrations in the Bushveld complex.

The final section of this volume is concerned with experimental and theoretical modeling of ore formation. Buchanan & Nolan report the results of a new study on the solubility of sulfur in basaltic melts, Campbell approaches the problem of the partitioning of Ni between silicate melts and other phases such as olivine and sulfide through studying variations in the activity coefficient of NiO in silicate melts, and Duke shows how these and other data can be used to produce quantitative models of the fractional crystallization of silicate melts and variation in the composition of the ores forming from them.

IGCP PROJECT No. 161 AND A PROPOSED CLASSIFICATION OF Ni–Cu–PGE SULFIDE DEPOSITS

The occasion of the MAC Nickel Sulfide Field Conference was used for the inaugural meeting of International Geological Correlation Programme Project No. 161: *Magmatic sulfide ores associated with mafic and ultramafic rocks.* Members in attendance were M. Besson (France), R. Boyd (Norway), G. Czamanske (USA), M. Foose (USA), D. Groves (Australia), G. von Gruenewaldt (S. Africa), A. Naldrett (project leader, Canada), G. Nilsson (Sweden), N. Page (USA), H. Papunen (Finland), and W. Peredery (secretary, Canada).

The aim of the project is to stimulate interest in ores of this type through field conferences, [scheduled for Scandinavia (1980), S. Africa (1981) and Australia (1982)] and, in particular, to use a computer data-storage and -retrieval system (CRIB developed by the U.S. Geological Survey) to compile information on magmatic sulfide deposits, their host rocks and geologic setting from all over the world. The standard CRIB data collection form was extensively modified to suit the needs of the project. Anyone interested in association with the project is encouraged to write to their country's representative, or, if there is no representative, to the project leader.

In the course of discussions concerning modifications to the CRIB form, it became apparent that the process of data collection would be helped greatly if a classification of ores could be agreed upon. This was discussed and a classification devised based on the gross tectonic setting of the deposits and the associated ultramafic or mafic bodies. The scheme presented by Naldrett & Cabri (1976) formed a basis for the classification, but this has been extensively modified and extended as a consequence of the broad expertise and diverse experience of the Project No. 161 committee members.

The classification outlined below is regarded as distinctly tentative at the present time. It is published to stimulate discussion, and the committee welcomes criticism, preferably of a constructive nature. We very much hope that anyone with views on the scheme, with knowledge of a deposit or deposits for which it would seem inadequate, or with examples of associations in categories unrepresented in the present format will write to one of us so that your views can be considered at our next meeting in Finland in 1980.

One note of explanation: we realize that to some extent our classification makes a special case of Precambrian greenstone belts; ideally, it would be preferable to subdivide the tectonic settings here into those associated with (i) accreting and (ii) consuming plate margins. However, we consider that the tectonic regimes represented in greenstone belts are uncertain and that criteria for distinguishing rocks representative of these have yet to be agreed upon. In order to develop a practical classification scheme that can be used now with a minimum of controversy, we use the general heading 'synvolcanic deposits'.

A. Synvolcanic deposits (largely restricted to Archean greenstone belts)
  1. Deposits associated with komatiitic suites
    a) Deposits directly associated with volcanic rocks: *Kambalda, Langmuir, Inyati-Damba*
    b) Deposits in dunitic lenses and pods: *Mt. Keith-Perseverance, Dumont?*
    c) Deposits of uncertain type in tectonically reworked terranes: *Thompson, Shebandowan*
  2. Deposits associated with tholeiitic suites
    a) Deposits in synvolcanic stratiform intrusions: *Pechenga, Lynn Lake, Carr Boyd*
    b) Deposits in anorthositic bodies: *no known deposits*
  3. Deposits for which komatiitic or tholeiitic parentage is uncertain
    a) Deposits in synvolcanic stratiform intrusions: *Montcalm, Ontario*
    b) Deposits in iron-formations: *Sherlock Bay*
    c) Deposits in tectonically reworked terranes: *Pikwe-Selibe?*

B. Deposits associated with intrusive bodies emplaced in cratonic areas
  1. Deposits in large layered complexes unrelated to flood basalts
    a) Sheet-like
      (i) with repetitive layering: *Bushveld, Stillwater*
      (ii) without repetitive layering: *Sudbury*

   b) Dyke-like: *Great Dyke, Rhodesia; Jimberlana, W. Australia*
2. Deposits in intrusions related to flood basalts: *Insizwa, Duluth, Noril'sk*
3. Deposits in other medium- and small-sized intrusions: *Losberg, S. Africa*
4. Deposits in alkaline ultramafic rocks: *no known examples*

C. Deposits associated with mafic and ultramafic bodies emplaced during orogenesis

1. Deposits in synorogenic intrusions: *Råna, Norway; La Perouse, Alaska, Hitura and Kotalahti, Finland*
2. Deposits in tectonically emplaced bodies
   a) Deposits in ophiolite complexes: *Queen of Bronze, Oregon; Table Mtn., Newfoundland*
   b) Deposits in possible diapirs: *no known deposits*
   c) Deposits of uncertain association
3. Deposits in Alaskan-type complexes: *Salt Chuck, Alaska*
4. Deposits in bodies of uncertain type

Reference

Naldrett, A.J. & Cabri, L.J. (1976): Ultramafic and related mafic rocks: their classification and genesis with special reference to the concentration of nickel sulfides and platinum-group elements. *Econ. Geol.* 71, 1131-1158.