Plate Tectonics and Mineral Deposits: A View from Two Perspectives

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Abstract

Virtually all recent attempts to relate plate tectonics and mineral deposits have adopted a similar approach whereby major plate boundary regimes (e.g., spreading, subducting, transform faults, continental collision, etc.) are first described in broad terms. This is followed, or accompanied by, descriptions of the mineral deposits considered to be associated with each plate tectonic regime. A conventional approach such as this produces a list of plate-related deposits impressive in number and diversity. Closer examination of these documentation attempts, however, reveals that apart from porphyry coppers, volcanogenic massive sulphides and perhaps carbonatites, the deposit-types so considered are relatively small and inconsequential.

A different perspective is attained when instead of examining mineral deposits from the plate tectonic viewpoint (the conventional approach), plate tectonics are examined relative to a list of major deposit-types. When this is done, it is evident that many deposits cannot readily be assigned to plate tectonic regimes or processes (e.g., sandstone Cu-U-V; Precambrian banded iron-formations; Kupferscheifer Cu, etc.). Part of the problem is that many major deposit-types occur in the Precambrian for which plate tectonic processes can be documented only with difficulty, if at all. Some major Precambrian deposit-types apparently unrelated to modern-style plate tectonics would be: banded iron-formation, layered gabbroic (Sudbury) and komatiitic (e.g., Western Australia) Ni deposits, anorthosite Ti, layered mafic complexes (Cr, Pt), and conglomerate U-Au. Other deposits occur in stable regimes and, indeed, seem to require the *absence* of plate tectonics (e.g., sandstone Cu-U-V; Mississippi Valley Pb-Zn; stratiform barite and phosphorite). Thus correlation of plate tectonics and mineral deposits is hampered by: a) the difficulty in "pushing" plate tectonics into the oldest rocks where many of the world's major deposits occur, and/or b) the fact that many major deposit-types occur *on* the (continental) plate, not at the margins, and therefore must be considered the antithesis of plate tectonic-related deposits. With all these difficulties, one can only conclude, from the perspective of a spectrum of the world's major deposit-types, that plate tectonic theory is of limited use in understanding the origin and distribution of mineral deposits.

Introduction

The relationship between plate tectonics and mineral deposits has been discussed in the literature for less than a decade, the first papers having appeared about 1971 (e.g., Guild, 1971; Pereira and Dixon, 1971; Snelgrove, 1971). Since then authors have related mineral deposit genesis to sea-floor spreading (e.g., Sillitoe, 1972a) and plate collision (e.g., Sawkins, 1972; Sillitoe, 1972b). In 1976, a Geological Association of Canada Special Volume was devoted to the topic of metallogeny and plate tectonics (Strong, 1976). In view of the revolutionary impact the new global tectonics have had on most branches of earth sciences, it is instructive to evaluate the effect of these new concepts on our understanding of the origin and distribution of mineral deposits.

In the above papers, and in many others on the same general topic, the approach of all but a very few authors has been identical. First, the major tectonic sites are described in terms of relative plate movement (convergence, divergence) and accompanying lithologies. This is normally followed by a listing of mineral desposits or deposit-types believed to have resulted as a consequence of the relevant plate tectonic regime. This approach, i.e., to go *from* plate tectonics *to* mineral deposits, is by far the most common and will be referred to herein as the "conventional" perspective. The reverse approach, i.e., to go *from* mineral deposits *to* plate tectonics, has been almost entirely lacking in published discussions relating these two geological phenomena. It results in a somewhat different perspective referred to herein as the "unconventional" perspective. These two perspectives are outlined below.

Conventional Perspective

Rather than attempt to summarize the few dozen papers that have appeared since 1971 on the general topic of plate tectonics and mineral deposits, a recent paper by Mitchell and Garson (1976) is itself essentially an excellent summary of the literature to that date and is selected as a good example of the conventional perspective. Typically, the authors first present evidence for three main types of plate boundaries, viz. 1) constructive (i.e., spreading) plate boundaries for which such concepts as hot spots, incipient continental break-up, growing oceans, oceanic ridges, and aulocogens are developed; 2) destructive (i.e., subducting) boundaries in which two sub-types are recognized: i) Andean—oceanic lithosphere is forced under a continental margin, and ii) island arc—oceanic crust is pushed under oceanic crust or a segment of continent; 3) conservative (i.e., transform faulting) where one plate merely slides past another. Having established these three tectonic regimes, Mitchell and Garson (1976) suggest several mineral deposits or deposit-types formed in these environments. The best examples are summarized in Table I. Other authors may differ slightly in their examples but the deposit-types listed in Table I are at least representative of those compiled as a result of the conventional perspective of plate tectonics and mineral deposits.

Unconventional Perspective

In adopting or proposing the reverse perspective, i.e., examining plate tectonics from the mineral deposits vantage point, the author began with the presumption that if one is to relate mineral deposits to major global tectonic fea-

Table I
Major plate boundary types and mineral deposits considered to be related to them (modified from Mitchell and Garson, 1976).

I. Constructive plate boundaries

Intra-continental volcanic belts and rift zones

1) Sn-F-Nb in sodic granite plutons and ring dykes (e.g. Nigeria)
2) Carbonatites (e.g. South Africa)
3) Benue-type lead deposits (e.g. Nigeria)

Inter-continental rift zones

1) Red Sea metalliferous sediments

Ocean ridges and ocean floor

1) Cyprus-type volcanogenic massive sulphides (e.g. Cyprus, Turkey, Newfoundland)
2) Podiform chromite (e.g. Phillipines, Cuba, Oman)
3) Disseminated Ni and Pt sulphides in ultramafic rocks

II. Destructive plate boundaries

Island Arcs

1) Porphyry copper deposits (e.g. Bougainville)
2) Kuroko-type volcanogenic massive sulphides (e.g. Japan, Canada)
3) Gold veins (e.g. Solomon Islands; New Zealand; Fiji)
4) Besshi-type cupriferous massive sulphides (e.g. Japan)

Andean

1) Porphyry copper and molybdenum deposits (e.g. South American Cordillera)
2) Sn and W deposits (e.g. Bolivia, Peru)

Continent-continent collision

1) Sn-W deposits (e.g. SW England)
2) Irish stratiform Pb-Zn deposits

III. Conservative plate boundaries

1) localization of deep pools in Red Sea
2) Carbonatites (e.g. S.W. Africa, Brazil, Uruguay)

tures, then one is justified, indeed even possibly constrained to consider a spectrum of major, global deposit-types To do this requires identification of the more significant deposit-types in the world and this has been attempted in the following manner.

First, eight elements considered to be representative of important mineral commodities on a global scale were selected. These elements are: Cu, Pb, Zn, Ni, Mo, Fe, U, and Au. Then, the top three countries mining each of these elements, and the major deposit-types (or types) contributing to that production, were listed (Table II). For example, the U.S.A. is the non-communist world's leading lead producer and about 80 per cent of this comes from Mississippi Valley-type deposits of southeast Missouri. U.S.S.R. is the world's leading iron ore producer and a majority of this is produced from Proterozoic banded iron formation (B.I.F.). In the manner the major currently-productive deposit-types for these eight commodities were selected for a list of the world's more significant types of mineral deposits.

Second, to the list of deposit-types generated by the preceding method were added other major deposit-types for these and other commodities (Table III). Readers will no doubt have their own list in mind but might agree that most of the deposit-types listed in Table III constitute major types on a world scale.

Discussion

If a list such as presented in Table III is accepted as at least representative of major deposit-types and compared with that in Table I, readers will note that relatively few deposit-types are common to the two. This non-match can be accounted for in several ways among which are:

Table II
Major sources of eight selected commodities. Countries ranked according to 1977 mine production (data from Mining Annual Review, 1978; all commodities except iron refer to non-communist countries only).

Commodity	**Country**	**Deposit Type(s)**
Pb	1. U.S.A.	Mississippi Valley
	2. Australia	Shale-hosted stratiform
	3. Canada	Mississippi Valley; shale-hosted stratiform
Zn	1. Canada	Volcanogenic massive sulphide
	2. Peru	Carbonate replacement (?)
	3. U.S.A.	Mississippi Valley
	Australia	Shale-hosted stratiform
Cu	1. U.S.A.	Porphyry
	2. Chile	Porphyry
	3. Canada	Porphyry; volc. mass. sulphide, layered gabbro Ni
Ni	1. Canada	Layered gabbro Ni, komatiitic Ni (?)
	2. New Caledonia	Laterite
	3. Australia	Komatiitic Ni
Mo	1. U.S.A.	Porphyry
	2. Canada	Porphyry
	3. Chile	Porphyry
Fe	1. U.S.S.R.	Proterozoic iron formation
	2. Australia	Proterozoic iron formation
	3. Brazil	Proterozoic iron formation
U	1. U.S.A.	Sandstone U-V-Cu
	2. Canada	Conglomerate U-Au
	3. South Africa	Conglomerate U-Au
Au	1. South Africa	Conglomerate U-Au
	2. Canada	Auriferous quartz veins
	3. U.S.A.	Auriferous quartz veins, disseminated gold in interbedded carbonaceous shales and carbonates (i.e. Carlin-type)

Table III

Some major deposit-types of the world. Filled circles denote deposit-types significant in the Precambrian; open circles those in both Precambrian and Phanerozoic, unmarked are those significant in the Phanerozoic.

Deposit-Type	**Examples**
Porphyry Cu-Mo (-Au)	Butte, Endako
Mississippi Valley Pb-Zn	Pine Point; S.E. Missouri, E. Tennessee
Stratiform Ba	Yukon; Nevada
Stratiform P_2O_5	Australia
○ Kupferscheifer Cu	Poland; Germany; Zambian Copperbelt (?)
○ Carbonatite REE, Cb-Ta	Mountain Pass; Oka
○ Quartz vein Au	Yellowknife, Mother Lode, Larder Lake
○ Volcanogenic massive sulphide Cu-Pb-Zn	Kidd Creek; United Verde; Kuroko
○ Sandstone Cu-U-V	Colorado Plateau; Zambian Copperbelt (?)
○ Layered gabbro Ni	Sudbury, Noril'sk
○ Silver-arsenide veins	Cobalt; Great Bear Lake; Kongsberg
○ Shale-hosted stratiform Pb-Zn	Mt. Isa; Sullivan
● Conglomerate U-Au	Blind River, Witwatersrand
● Precambrian B.I.F.	Labrador Trough; Lake Superior; Brazil
● Komatiitic Ni	Western Australia, Thompson (?)
● Anorthosite Ti	Allard Lake
● Layered mafic complexes (Cr, Pt)	Bushveld

1) Most deposits or deposit-types typically "attributed" to plate tectonic processes (Table I) are relatively minor on a global scale. Apart from porphyry deposits, volcanogenic massive sulphides, and possibly carbonatites, the remaining deposits in Table I are insignificant by world standards. Benue-type lead deposits of Nigeria, for example, produced just over 9,000 tonnes of lead-zinc concentrates from fracture-filled veins. Neither the tonnage of these deposits in particular, nor vein-type lead-zinc deposits in general, can be considered globally significant. The Red Sea sediments, although containing a respectable metal content, must at present be placed in the "interesting" category of global deposit-types rather than the "significant".

2) Some deposit-types appear to require the *absence* of plate tectonics inasmuch as they form in tectonically undisturbed regimes. Examples might be Mississippi Valley-type lead-zinc deposits, sandstone uranium deposits, sedimentary barites and phosphates, and Superior-type iron formations; in short, any deposit-types requiring miogeoclinal or continental interior sedimentary conditions.

3) A notable majority of the world's major deposit-types listed in Table III occur either exclusively or dominantly in the Precambrian. The general difficulty in "pushing" plate tectonic processes back into the Precambrian, together with the fact that many of the world's major deposit-types occur in rocks of this age, probably precludes a match between Tables I and III on these grounds alone.

From a slightly broader viewpoint, it can be argued that certain major (plate) tectonic structures, called upon to "explain" the occurrence of some deposits, do not, in fact, contain deposits of that type. For example, Sawkins (1976) has proposed that Sullivan-type shale-hosted stratiform lead-zinc deposits are a result of incipient continental break-up; in effect, aborted rift zones. This being the case, where, then, are similar deposits in such well-known and documented rift zones as the East African rift, Keewenawan rift, the Rhine Valley graben, the St. Lawrence rift, the Oslo rift zone, or the East Arm of Great Slave Lake? Conversely, why are carbonatites, generally agreed to be a typical product of incipient rifting, not associated with shale-hosted lead-zinc deposits such as Sullivan, Rammelsberg, Meggen, McArthur River, or Mt. Isa?

The difficulty in attributing many major deposit-types to plate tectonic processes may also simply be due to the possibility (fact?) that, cited "evidence" to the contrary, the deposits were not a product of plate tectonics at all! After all, the main line of evidence linking the two is quite simply one of spatial association rather than a theoretical prediction generated from first principles (to the author's knowledge no new deposit-types have yet been predicted from plate-tectonic theory). A case in point would be volcanogenic massive sulphide deposits associated with island arc volcanics. These two distinct phenomena occur together so commonly at relatively modern (i.e., Mesozoic and Cenozoic) destructive plate boundaries, that it is either tacitly or explicitly assumed that *all* similar volcanogenic massive sulphides (excluding Cyprus-type) are genetically linked to subduction. Porphyry coppers are also commonly attributed to subduction in island arc regimes (Table I); in fact, massive sulphides and porphyry coppers are the two major deposit-types that nearly all authors agree are related to subduction. If this is the case, why then do massive sulphides occur so commonly in the Archean and Aphebian while porphyry coppers do not? If both are products of subduction, should they not be expected to develop equally as well? Even if large-scale subduction did "produce" island arc type massive sulphides in the Precambrian, and somehow didn't generate porphyry coppers, should not spreading (which must accompany subduction) also produce Precambrian Cyprus-type massive sulphides enclosed in oceanic basalts? In fact, neither Cyprus-type massive sulphides *nor* oceanic crust basalts are common in the Precambrian. One must therefore question whether plate tectonics were indeed responsible for the Mesozoic (and younger) massive sulphides. Conversely, if they were responsible for such deposits, there may be other, non-plate tectonic, means of generating massive sulphide deposits but not porphyry coppers; some of these processes may have been operative during the Precambrian.

Conclusions

The relationship between plate tectonics and mineral deposits has been briefly evaluated from two perspectives. The conventional viewpoint, i.e. from plate tectonics to mineral desposits, generates a list of mineral deposits impressive at first glance. From the opposite perspective, however, it becomes readily apparent that these deposits, with two or three exceptions, are not significant on a global scale. Several other deposit-types, emplaced in tectonically "quiet" areas, seem to have originated in the absence of plate tectonic processes. Moreover, because some of the world's major deposit-types occur only in the Precambrian, application of plate tectonic theory to their understanding is rendered all the more difficult. Recent published discussions relating plate tectonics and mineral deposits do so on an individual deposit-type basis. They do not explain why carbonatites and stratiform lead-zinc deposits do not occur together in proposed aborted rift zones nor why massive sulphides and pophyry coppers, both attributed to subduction, are not equally abundant in the Precambrian.

When viewed against a spectrum of the world's major deposit-types, modern plate tectonic theories are woefully inadequate to contribute to our understanding of the origin and distribution of mineral deposits. The author must still conclude, as he did several years ago (Sangster, 1975), that "... while plate tectonics may have revolutionized our concepts of earth history, it has not yet attained this stature in metallogenic studies".

References

Guild, P. W., 1971, Metallogeny: a key to exploration. Mining Engineering, vol. 23, 69-72.

Mitchell, A. H. G. and Garson, M. S., 1976, Mineralization at plate boundaries: Mineral Science Engineering, vol 8, no. 2, p 129-169.

Pereira, J. and Dixon, C. J., 1971, Mineralization and plate tectonics: Mineralium Deposita, vol. 6, p. 404-405.

Sangster, D. F., 1975, Plate tectonics and mineral deposits: Geol. Survey Canada, Report of Activities, Paper 75-1, Part A, p. 235.

Sawkins, F. J., 1972, Sulfide ore deposits in relation to plate tectonics: Journal of Geology, vol. 80, p 377-397.

Sawkins, F. J., 1976, Massive sulphide deposits in relation to geotectonics: in D. F. Strong, ed., Metallogeny and Plate Tectonics, Geol. Assoc. Canada, Special Paper 14, p. 221-240.

Sillitoe, R. H., 1972a, Formation of certain massive sulphide deposits at sites of sea-floor spreading Institute of Mining and Metallurgy, Transactions, vol. 81, p. B141-B148.

Sillitoe, R. H., 1972b, A plate tectonic model for the origin of porphyry copper deposits. Economic Geology, vol. 67, p 184-197.

Snelgrove, A. K., 1971, Metallogeny and the new global tectonics: Mineral Research and Exploration Institute, Bulletin 76, Turkey, p. 130-149

Strong, D. F., ed., 1976, Metallogeny and Plate Tectonics Geol. Assoc Canada, Special Paper 14, 660 p

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