Mobilization of Ore Deposits: Mineralogical and Geochemical Aspects

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With 2 Figures

Ever since the dawns of geology as a field of science, the mechanism of formation of ore deposits and the ultimate source of the elements they contain, especially of the ore minerals, were eagerly discussed. While in the old days, say up to the middle of the last century, field observation delivered almost all the arguments; by and by—and especially during the last few decades—results of laboratory experiments also contributed greatly to possible interpretations. Mobilizations of and within ore deposits form, of course, only part of the general problem of ore genesis.

That for the interpretation of the phenomena under discussion dry melting can in general play only an at most very subordinate rôle, is to be taken from the melting points of the ore minerals and of the gangue minerals in the mobilizates, as well as from the widespread availability of aqueous solutions. The problem is in principle similar to that of metamorphism, anatexis and hydrothermal alteration of common rocks, although occurring here mostly at much lower temperatures.

The most important methods of laboratory work besides classical mineralogy, ore microscopy and all kinds of analytical work (including microprobe analysis) are the experimental investigation of phase diagrams (with or without H_2O as one of the components), the investigation of liquid inclusions, and isotope measurements.

The reconciliation of the field evidence with the results of experimental work is often not at all easy. Many points of discussion arise either from the difficulties to draw unequivocal arguments from the field observation or from a not sufficiently critical transfer of the laboratory results to geology. In this respect, much remains to be done to achieve a better understanding between field workers and laboratory people.

During the last decades, a large body of experimental information relevant to ore geology has accumulated, containing extensive data on dry and hydrous phase diagrams. They are determined either directly or via thermodynamic computations

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(sometimes including the application of a molecular model). Pitfalls in the application to the field are (a) the uncritical extension of the published phase diagram to temperatures and/or pressures where it is not valid, (b) the application of the determined phase diagram to a system with a somewhat different chemical composition, and (c) the application of equilibrium phase diagrams to parageneses that have formed under non-equilibrium conditions.

As to difficulty (a) it is to be remarked that the consideration of the ore body together with its frame often allows the earth scientist to give the approximate pressure, and sometimes also to give at least the order of magnitude for the temperature at the time of the formation of the paragenesis. The informations come *e.g.* from the metamorphic facies of the country rocks and/or from the geologic reconstruction of the tectonic history of the region under consideration.

Difficulty (b) is often very serious, provided that no extensive study of fluid inclusions has been (and could be) made. In this connection it is to be borne in mind that the pure minerals themselves do not give the chemical composition of the solution they have crystallized form.

Point (c) may lead to serious misinterpretations, because many of the metamorphic ore parageneses—and even more so the mobilizates crystallized in veins—represent non-equilibrium parageneses. Besides classical mineralogical arguments and microscopy, microprobe investigations can be of great help to prove that one is dealing with a non-equilibrium assemblage: if neighbouring grains of a mineral with mixed crystal composition have different chemistry, the proof is conclusive. A very strong argument for an equilibrium paragenesis would be that all of its grains have fluid inclusions with the same composition.

For illustration of some of the general problems mentioned above, *the genetic problem of siderite deposits of the type Erzberg* is chosen (*cf.* also the article by A. BERAN in this Volume; there also references to the literature).

This type of iron ore deposits consists of siderite and ankerite in varying amounts; sulphides are subordinate to almost lacking. It occurs *e.g.* widespread in the Northern Graywacke Zone of the Eastern Alps. At the type locality it is clearly bound to calcarious sediments; the outcrops give in places clear evidence for metasomatic replacement.

A metasomatic origin within the concept of a more or less unitarian, young Alpine metallogenesis was for many decades generally accepted. The source of the iron (and magnesium) bearing solutions was hypothetical and, therefore, in detail always a point of discussion; but as both elements are common in the earth's crust, there are in principle no difficulties to postulate for them some plausible source. A puzzling problem was the lack of calcite veins in larger amounts which are to be expected if extensive replacement of $CaCO_3$ by $FeCO_3$ and $MgCO_3$ has taken place.

For some ten years now, several authors have left this concept, and have argued that the iron (and magnesium) content of the deposits has not come from a remote, unknown source, but that it was already present *in situ* in the old (palaeozoic) sediment—*i.e.*, the deposits are considered to be essentially of synsedimentary origin, with local metasomatism and mobilization as the consequence of one or several metamorphic events in the history of the geologic unit.

An important local argument for a synsedimentary origin is considered to be the discovery of fine grained, banded ore (grain diameter some tenths of a millimeter, contrary to several millimeters as usual) in which the magnesium content of the siderite varies from grain to grain definitely considerably more than in the usual types. They were interpreted as but slightly recrystallized remnants of the original iron rich sediment. The total amount of this clearly banded ore is, however, extremely small. There seems to be general agreement that these very unusual ore types show sedimentary structures, but the discussion on whether they are really sedimentary siderite, or a sideritized sediment wich well preserved its original texture does not seem to have come to an unequivocal decision as yet.

A contribution to the elucidation of the temperature and pressure conditions of the formation of the present form of the deposits comes from the application of the system $CaCO_3$–$MgCO_3$–$FeCO_3$ which was determined at several temperatures (Fig. 1). The critical observation is the occurrence of extremely Fe-rich ankerites in some ankerite rocks, as well as in vein ankerites. The experiments have shown that
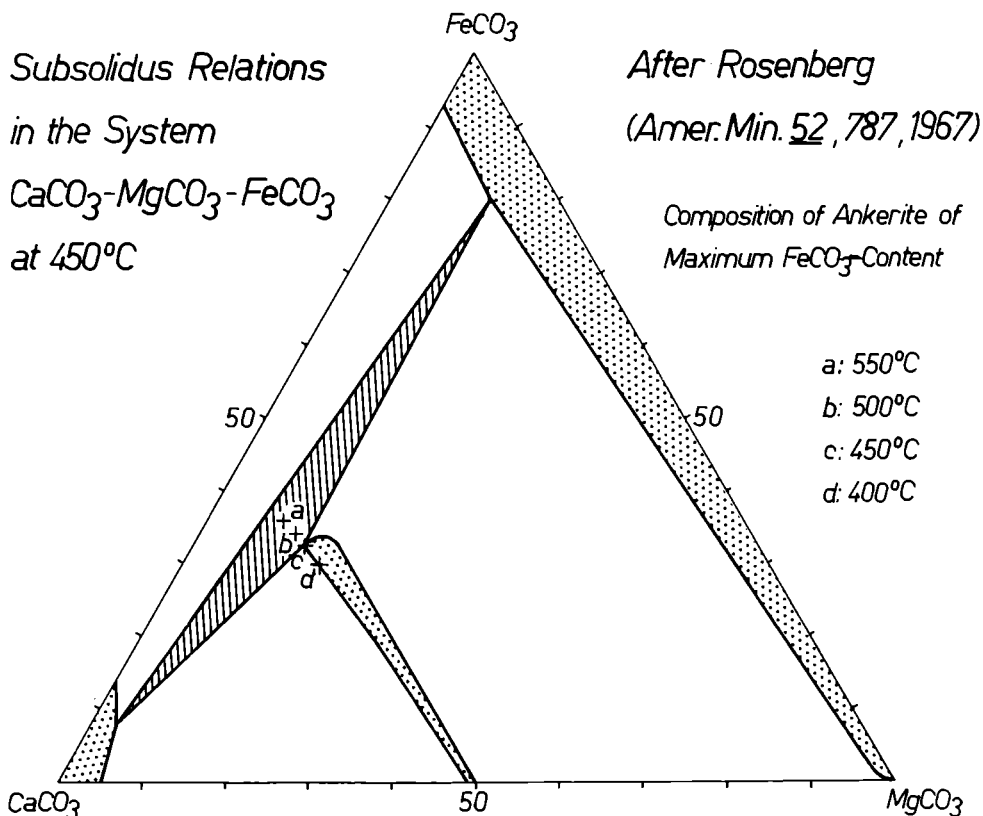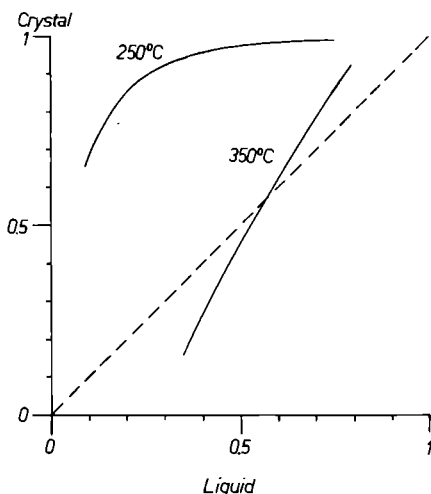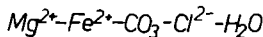

Fig. 1. Phase diagram $CaCO_3$-$MgCO_3$-$FeCO_3$ at 450 °C and 2–3 kbar. Dotted: one-phase fields, blank: two-phases fields, strippled: three-phases field.

Fig. 2. Equilibrium compostions between mixed crystals (Mg, Fe)CO$_3$ and coexisting solutions at 1 kbar (salt concentration 1,0 molal). Constructed from Figs. 2 and 3 of the paper cited.

the maximal possible Fe-content of an Ca(Mg,Fe)(CO$_3$)$_2$ mixed crystal increases with temperature. This leads to the conclusion that the ankerites richest in iron have formed at a temperature of $\geqq$ ca. 400 °C, provided that (a) the pressure estimation has been made correctely (or the pressure dependence of the solubility is small) and that (b) the crystals have formed under equilibrium condition. Requirement (b) is probably fulfilled in ankerite rocks where all the grains have practically the same chemical composition.

Of equal importance is the consideration of the system Mg^{2+}–Fe^{2+}–CO$_3^{2-}$–Cl$^-$–H$_2$O. Fig. 2 shows that at lower temperatures (250 °C) a solution is in equilibrium with a (Mg,Fe)CO$_3$ crystal much richer in iron than at 350 °C. This is in rough agreement with the old concept that magnesite deposits formed from hotter solutions than siderite deposits. It is, however, to be emphasized, that the application of this experimental diagram does not exclude a sedimentary origin of the deposits.

Unfortunately, detailed trace clement investigations, liquid inclusion investigations and isotope determinations are still missing for our deposits. They will undoubetly contribute to the solution of some of the many left problems.

The situation of research at the example given seems to be typical in several respects: Careful field observation remains to be one of the cornerstones for any geologic problem, laboratory work on geologically relevant specimes has to be done on an increasing number of samples and with an increasing number of methods, and the results of pure laboratory work, like phase diagrams, have critically to be reconciled with the field observation.