Sci. Géol., Mém., 72, p. 141 - 148, Strasbourg, 1983

PETROGRAPHICAL ASPECTS OF THE SUPERGENE WEATHERING OF GARNET IN THE "SERRA DOS CARAJÃS" (PARÃ, BRASIL).

J.C. PARISOT[1], J. DELVIGNE[1], and M.C.T. GROKE[2]

1. Mission O.R.S.T.O.M., Instituto de Geociências, Universidade de São Paulo, Caixa Postal 20.899, CEP 01498 SÃO PAULO, BRASIL
2. Instituto de Geociências, Universidade de São Paulo, Caixa Postal 20.899, CEP 01498 SÃO PAULO, BRASIL

ABSTRACT

The copper mineralization of Salobo 3A is associated with a schistose formation in which numerous facies are enriched in almandine garnet. During supergene weathering, the garnet is pseudomorphosed by iron oxi-hydroxides. Three stages are observed: 1- Appearance of a corona of amorphous iron oxi-hydroxides on the walls of the fissures; 2- Formation of a second concentric inner corona of well crystallized goethite; 3- Substitution of the inner garnet residue by cryptocrystalline or amorphous iron oxi-hydroxides. These transformations are isovolumetric with a part of the iron imported. Near the surface, the pseudomorphs of garnet form nodules with a still recognizable boxwork structure.

I. INTRODUCTION

The copper mineralization of Salobo 3A, located about 550 km SSW of Belem (50°W 6°S) in the southeastern part of the Amazonian forest, belongs to the recently discovered mineral province of Carajás. The evaluation work is being carried out by DOGEO (Subcompany of the "Companhia Vale do Rio Doce"). Geological and petrographical studies have shown that copper is associated with a schistose formation in which numerous facies are enriched in garnet (MARTINS et al.,1982). According to these authors, this formation underwent a metamorphism reaching the amphibolite facies and be found. The structure of this rock is granoblastic to lepidoblastic with a fine to large grain size (MARTINS et al., 1982). Garnets form irregular porphyroblasts ranging from 1 mm to 2 cm in diameter. Microprobe analyses show that they contain 77 to 82% of almandine (Table 1) and have the following average formula:

$$(Fe^{2+}_{4,89}, Mg_{0,47}, Mn_{0,55}, Ca_{0,15}) \quad (Fe^{3+}_{0,12}, Al_{3,88}) \quad (Al_{0,17}, Si_{5,83}) \; O_{24}$$

This formula is in accordance with the almandine composition quoted by DEER et al. (1962). Often, the garnets present a poikiloblastic structure with amphibole or quartz inclusions. Garnets are generally strongly fractured (Fig. 1.1). In numerous fissures and at the grain edges, chlorite and green biotite (Plate 1.a), originating from the retrometamorphism phases, is observed.

Table 1: Microprobe and mineralogical analyses of six garnet grains.

Chemical composition (%)

	1	2	3	4	5	6
SiO2	35,58	35,13	34,78	34,84	35,76	35,29
Al203	20,87	21,00	20,94	20,57	20,71	20,57
FeO	36,90	36,23	35,59	35,88	37,07	36,15
MnO	3,35	3,44	4,28	4,79	3,62	3,54
MgO	2,05	2,36	2,05	1,70	1,62	1,46
CaO	1,21	1,55	1,68	1,64	1,23	1,29
	99,96	99,71	99,32	99,42	100,01	98,30

Number of ions on the basis of 24 (O,OH)

	1		2		3		4		5		6	
Si	5,852	6	5,790	6	5,770	6	5,800	6	5,888	6	5,900	6
Al	0,148		0,210		0,230		0,200		0,112		0,100	
Al	3,889	4	3,862	4	3,857	4	3,828	4	3,900	4	3,945	4
Fe3+	0,111		0,138		0,143		0,172		0,100		0,055	
Fe2+	4,946	6,12	4,838	6,17	4,776	6,19	4,803	6,19	4,987	6,11	4,981	6,08
Mg	0,505		0,584		0,511		0,424		0,399		0,365	
Mn	0,460		0,479		0,600		0,674		0,504		0,499	
Ca	0,213		0,273		0,299		0,293		0,216		0,230	

Mol. % end members

	1	2	3	4	5	6
Almandin	80,7	78,4	77,2	77,6	81,7	82,0
Andradite	2,8	3,5	3,6	4,3	2,5	1,4

their first stage of weathering. In this stage, the weathering of the fissural chlorites into smectite begins, even as the iron segregation in the biotites and in the amphiboles. Our observations differ from those of SARAZIN et al. (1982) who observed also in Cameroon, a garnet pseudomorph consisting of amorphous or poorly crystallized iron oxi-hydroxides; well crystallized goethite appears only later, at the expense of these amorphous oxi-hydroxides.

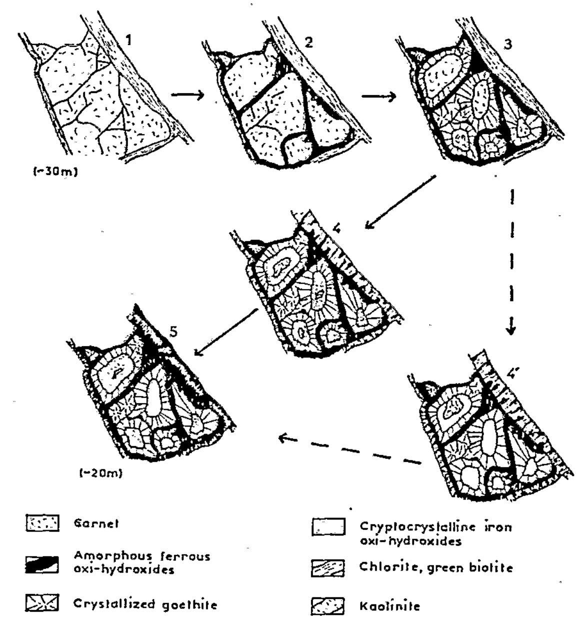

Fig. 1 : Schematic representation of garnet weathering

linite. As for biotite, the iron segregation phase is more advanced and one observes the beginning of its exfoliation. Amphiboles are completely transformed into iron oxi-hydroxides and into smectite. Once more, the rapidity of the garnet weathering is shown, since only 10 meters above the fresh rock no residual garnet is present. There is pseudomorphose of the garnet by iron oxi-hydroxides. Structures that have been formed remain stable up to the top of the profile, where they become rounded and form iron nodules. In these nodules, typical structure described above is still recognizable, although the well crystallized goethite shows a less massive aspect (see plate 2.d). In the superficial horizons, we never find the boxwork structure with central voids. Therefore one supposes that the voids are filled by iron oxi-hydroxides as described by EMBRECHTS and STOOPS (1982).

Table 2: Microprobe analyses of goethite end iron oxi-hydroxides (%)

	Ext 7	Med 8	Med 9	Med10	Med11	Int12	Int13	Int14
Fe_2O_3	75.58	76,16	74.33	75.13	71.88	73.85	72.09	69.25
Al_2O_3	6.80	6.58	6.04	6.96	7.25	8.97	7.62	6.80
SiO_2	3.93	3.56	3.80	4.00	3.36	6.53	3.53	4.70
TiO_2	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00
MgO	0.00	0.00	0.00	0.00	0.27	0.00	0.27	0.00
Σ	86,31	86,29	84.17	86.09	82.91	89.35	83.51	80.75
H_2O	13.69	13.71	15.83	13.91	17.09	10.65	16.49	19.25

Ext = External amorphous corona
Med = Medium corona of well crystallized goethite
Int = Internal poorly crystallized iron oxi-hydroxides
H_2O = Values are calculated by difference (eventually including P and Cu)

Microprobe analyses of different iron oxi-hydroxide coronas do not show important chemical differences (Table 2). Indepedently of their position and their degree of crystallization, coronas present concentrations of about 7% Al_2O_3, 4% SiO_2 and 73% Fe_2O_3. The spectre obtained with the microprobe shows also trace of copper even as a poorly defined pick which may be due to phosphorus. Its origin may be apatite present in these formations. The phosphorus fixation by iron oxi-hydroxides is described by numerous authors (CABRERA et al., 1977; RUSSEL et al., 1974).

III. DISCUSSION AND CONCLUSION

All the transformations described are isovolumetric (Fig. 1). Knowing the average concentrations of elements in garnet and in goethite, and using a minimum density for these minerals, we can calculate the percentage of gain and loss for each element during the garnet weathering as follows:

$$D = \frac{P_{go} - P_{gr}}{P_{gr}} \times 100 \quad ; \quad \text{as } p = \frac{P.C}{100} \text{ and } P = V.d \; : \; p = \frac{V.d.C}{100}.$$

As the transformations are isovolumetric, $V_{gr} = V_{go}$, and the formula can be writed:

$$D = \frac{d_{go}.C_{go} - d_{gr}.C_{gr}}{d_{gr}.C_{gr}} \times 100$$

where:
D = percentage of gain (+) and loss (-) ;
p = weight of element in mineral goethite (p_{go}) and garnet (p_{gr}) ;
P = weight of mineral
V = volume of mineral goethite (V_{go}) and garnet (V_{gr}) ;
C = concentration (%) of element in mineral goethite (C_{go}) and garnet (C_{gr}) ;
d = density of mineral goethite (d_{go}) and garnet (d_{gr}).

If we take a minimum density of 3.3 for goethite and 4.3 for garnet (FISCHESSER 1970), we find that the garnet does not contain enough iron to form the same volume of goethite (Table 3).

Table 3: Estimation of the gain and loss of elements during the isovolumetric garnet weathering in V%.

	C_{gr}	D_{go}	P_{gr}	P_{go}	D
Fe	28,22	51,33	1,21	1,69	+ 39,67
Al	11,00	3,77	0,44	0,12	- 74,47
Si	16,44	1,95	0,71	0,06	- 91,55

D = percentage of gain (+) and loss (-);
$C_{gr,go}$ = average concentration of element in garnet and goethite;
$P_{gr,go}$ = weight of element by unit volume in garnet and goethite (garnet density = 4.3; goethite density = 3.3).

As voids do not appear between the garnet and the goethite, we can estimate that, relative to the garnet iron, a minimum of 39% of the iron is imported. As for the inner filling of iron oxi-hydroxide, we obtain a density of 2,36, if we consider that only garnet-iron has contributed to its formation. This value would seem to be reasonable for the significantly porous cryptocrystalline goethite observed in the center of the boxwork cells (Plate 2.d). However, the presence of copper and phosphorus in the iron oxi-hydroxides suggests the possibility of an external source, at least for these elements.

In this paper we show that garnet weathers very quickly into iron oxi-hydroxides. Two evolutionary pathways are observed: pseudomorphose of the garnet by iron-oxi-hydroxides and congruent dissolution of the garnet with formation of a boxwork structure. In both cases the transformations occur at constant volume with external contribution of iron probably coming first from amphiboles and later from biotites.

AKNOWLEDGMENTS

Authors aknowledge professors G. BOCQUIER and Ph. ILDEFONSE for allowing the use of the SEM and the microprobe of the "Laboratoire des Sciences de la Terre" of the Paris VII Univeristy. This work was financed by the Conselho Nacional de Pesquisa(CNPq). Authors are also grateful to the Professors G. STOOPS, Algemene Geologie, Rijksuniversiteit van Gent, Belgie and D. PROUST, Laboratoire de Pédologie de l'Université de Poitiers, France, reviewers, for their helpful comments on the manuscript and to Professor M. UNGS, Instituto de Geociências, Universidade de São Paulo, Brasil, for translation of the original french manuscript.

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RÉSUMÉ

La minéralisation cuprifère de Salobo 3A est associée à une formation schisteuse dont de nombreux faciès sont riches en grenat almandin. Lors de l'altération superficielle, le grenat est pseudomorphosé en oxy-hydroxydes de fer. Trois étapes ont été observées: 1- Apparition d'une couronne d'hydroxydes de fer amorphes au contact des fissures périphériques ou internes; 2- Formation d'une seconde couronne, interne à la première, de goethite bien cristallisée; 3- Remplacement des résidus internes de grenat par des hydroxydes de fer cryptocristallins ou amorphes. Ces transformations sont isovolumétriques avec importation d'une partie du fer. Près de la surface les pseudomorphoses de grenat forment des nodules dont la structure interne cloisonnée, est encore reconnaissable.

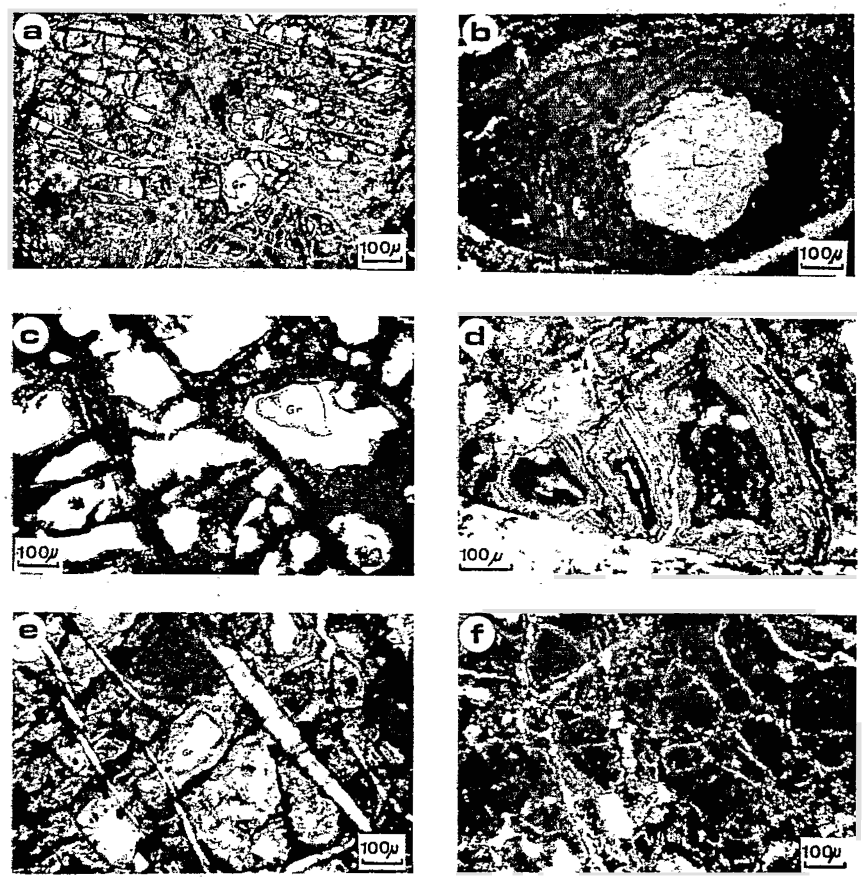

PLATE I : THIN SECTION MICROGRAPHS.

a : Unweathered garnet with chloritic fissures. - plain light.

b : Well crystallized goethite surrounding a garnet nucleus. Note the garnet relic in the goethtite. - plain light.

c : Boxwork structure of goethite with a garnet remnant (Gr) in the void. Note the amorphous corona and the inner well crystallized goethite. - plain light.

d : Infilling structure formed by amorphous or poorly crystallized iron oxi-hydroxides. - plain light.

e : Weathered garnet. Note the poorly crystallized corona (In) that appears between the well crystallized goethite (Go) and the garnet (Gr). In the fissure, chlorite is weathered into smectite. - plain light.

f : Completely weathered garnets into well crystallized goethite (clear peripheral coronas) and dark brown cryptocrystalline iron hydroxides cores. - plain light.

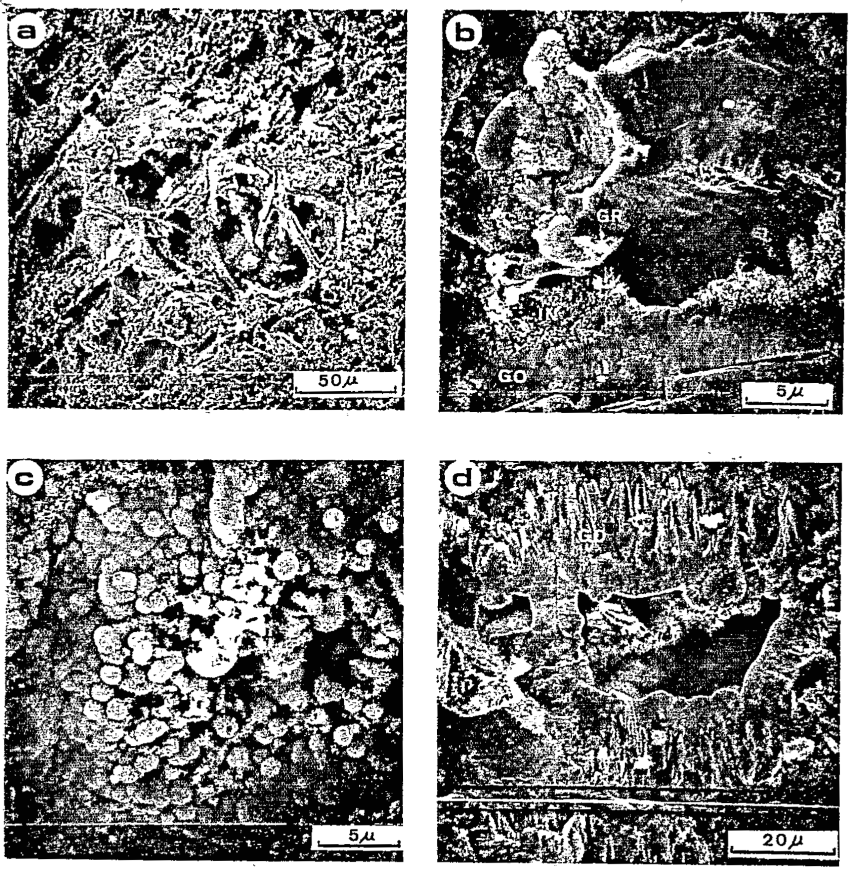

PLATE II : SEM PHOTOGRAPHS.

a : Goethite boxwork structure. Note the twin layers of iron hydroxide on both sides of the original fissural network and the open internal cavities.

b : Formation of cryptocrystalline iron oxi-hydroxides (IN) between well crystallized goethite (GO) and garnet (GR).

c : Completely weathered garnet. Note the increasing porosity from periphery to center.

d : Completely weathered garnet (sample near the surface). Note the less massive aspect of the well crystallized goethite (GO).