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Chromite deposits of Papua New Guinea— a future potential source of chrome

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Abstract: The chromite deposits of Papua New Guinea occur in the New Guinea ophiolite belt that comprises the peridotite-gabbro-basalt complex. The two most important of these deposits, the Ramu and Hessen Bay chromites occur disseminated in dunites, harzburgites and pyroxenites and are uneconomic in their primary forms. Parts of these deposits, however, had undergone weathering and natural concentration to produce economic grade ores. The Ramu ore estimated at about 225 million tonnes is lateritic and forms two layers; the top layer has a grade of 9 % Cr, 1.46 % Ni and 0.16 % Co, and the bottom layer has a grade of 6 % Cr, 1.12 % Ni and 0.06 % Co. The Hessen Bay chromite ore, however, is a beach ore of a grade in excess of 9 % Cr and its reserve is yet to be determined. None of these deposits is presently being mined.

The present work presents the investigation of the Ramu and Hessen Bay chromites by microprobe aided by chemical analysis and microscopic examination to assess the compositional variations, the source of the highly magnetic property of the chromites and the amenability of the chromite ores to upgrading. The results show that both chromites are similar in composition and exhibit characteristics typical of podiform type chromites, namely low Fe^{3+} and Ti but significant Al substitution for Cr. As a consequent of the high level of Fe^{2+}, the Cr/Fe ratios for Ramu and Hessen Bay chromites are 1.62 and 2.0 respectively. The results are compared with the data for other ophiolitic chromite deposits. By spiral and table concentration of the ores, a concentrate grade of 45 % Cr_2O_3 at 78 % Cr recovery for the Ramu ore and a grade of 37 % Cr_2O_3 at 54 % Cr recovery for the Hessen Bay ore were achieved.

INTRODUCTION

Chromite deposits are of two types—the stratiform (Bushveld) type and the podiform (Alpine) type. The chromite deposits of Papua New Guinea are said to belong to the latter type (Davies, 1971). In recent years many companies have shown interest in the two most important deposits, the Ramu and Hessen Bay chromites. Preliminary exploration work has revealed that the Ramu chromite has two lateritic layers of which the top layer has a grade of 9 % Cr, 1.2 % Ni and 0.16 % Co and the bottom layer has a grade of 6 % Cr, 1.12 % Ni and 0.06 % Co. The reserve was estimated at 225 million tonnes (Mining Magazine, 1982). No data are yet available on the Hessen Bay chromite. In the present work the characteristics of the chromites of these deposits have been investigated.

Geological Setting and Petrology

The chromite deposits of Papua New Guinea are found in the eastern Papua and the Marum river area. These deposits are emplaced in peridotite-gabbro-basalt complexes of the discontinuous ophiolite belt of New Guinea. The Ramu chromite occurs in the Marum area in northern New Guinea and the Hessen Bay chromite occurs in the north-eastern side of the Owen Stanley range in eastern Papua (Fig. 1). The ultramafic-gabbro-basalt complexes are believed to be emplaced during Eocene-Oligocene period as a consequence of the collision of the north moving Australian and

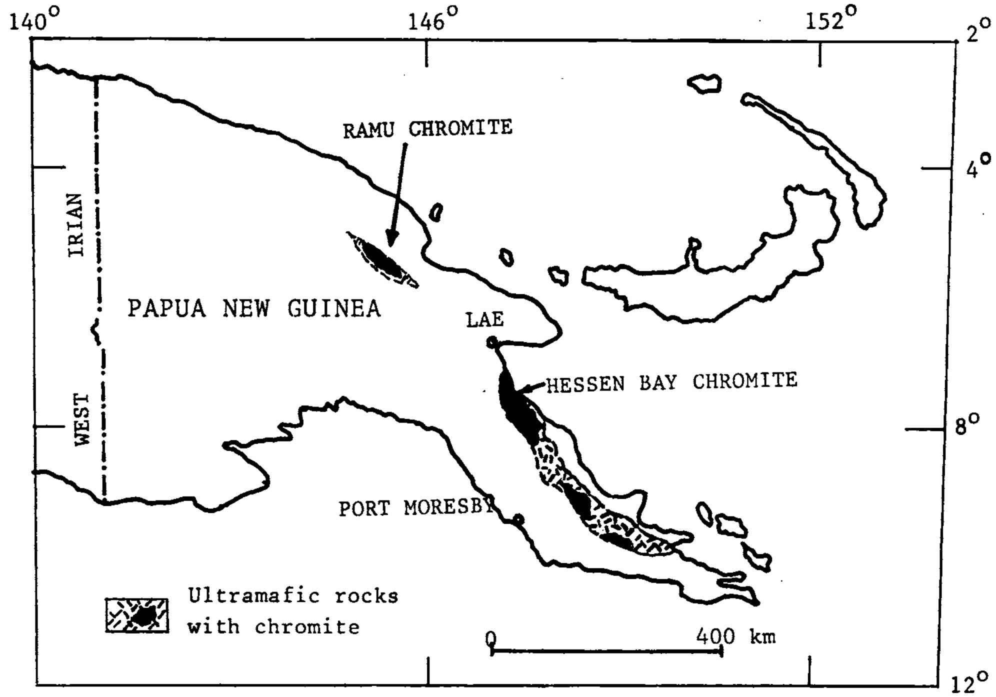

Fig. 1. The distribution of chromite ores in Papua New Guinea.

west moving Pacific plates. The collision of the plates led to the overthrusting of the ultramafics over the north moving Cretaceous sediments resulting in metamorphism at the thrust planes and extensive faulting indicated by the Owen Stanley and Fimeno faults in eastern Papua and the Bundi fault in the Marum ophiolite complex (Davies, 1971).

About 90% of the eastern Papua ultramafic is non-cumulus type and consists of harzburgite, dunite and orthopyroxenite. The harzburgite is the predominant rock type and consists of olivine, $Fo_{91.6-93.6}$ (60–80%), estatite, $En_{92.1-93.1}$ and accessory chromite. Microprobe analyses of the olivines coexisting with the Hessen Bay chromite present the composition of the olivines as $(Mg_{0\ 917}\ Fe_{0\ 08}\ Ni_{0\ 003})_2\ SiO_4$. This composition is within the range of olivine values reported by Davies (1971). The chromite in the enstatite pyroxenite is generally coarser (8–10 mm) than the chromite in the dunite and the harzburgite, which are about 0.1–0.2 mm size (Davies, 1971). Other accessory minerals include rutile, ilmenite and magnetite. In the Marum ultramafic-gabbro complex, the Ramu chromite is often disseminated in the dunite or serpentinite and also occurs occasionally in pyroxenite as euhedral crystals. The microprobe analysis of the composition of the olivines coexisting with the chromite is represented as $(Mg_{0\ 910}\ Fe_{0\ 08}\ Ni_{0\ 004})_2\ SiO_4$. Accessory minerals such as chromite, ilmenite and magnetite also occur in the gabbro (Dow & Dekker, 1964).

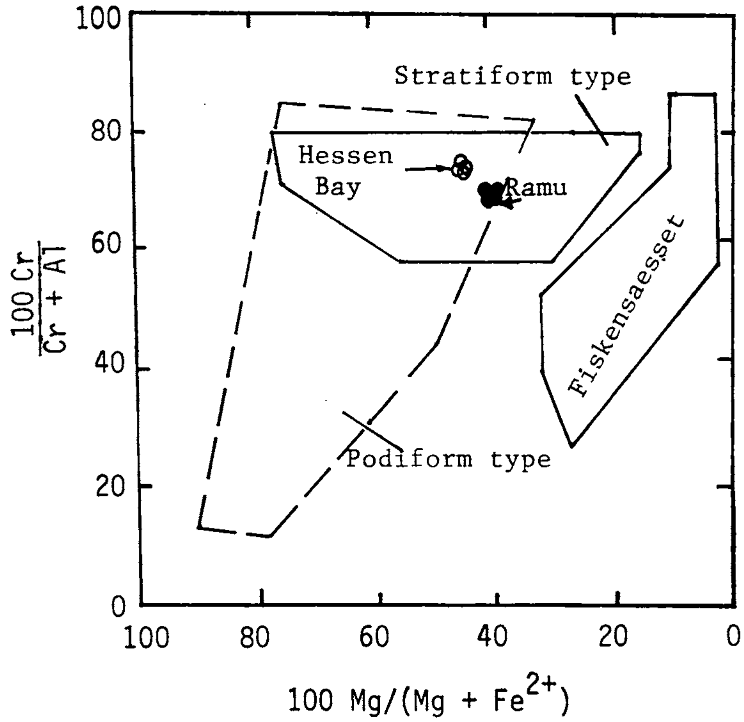

Fig. 2. Ramu and Hessen Bay chromites represented on the stratiform-and podiform-types chromite diagrams. (The plots are for mean chemical assay values. Chromite diagrams after Evans, 1980).

None of these chromite deposits is of any economic interest in their primary states. It is only when the chromite-bearing dunites had been lateritised and the chromites concentrated by natural agents that they are of economic importance. The Hessen Bay chromite is a beach deposit and the Ramu chromite a lateritic product.

NATURE OF THE CHROMITES

High purity samples prepared from the Hessen Bay and Ramu (lateritic top layer) chromites by tabling and HF leaching were analysed chemically, spectrographically and with the microprobe. Prior to spectrographic and chemical analysis the highly magnetic particles were removed by a hand magnet but the ilmenite was not removed. Nevertheless, no corrections were made for the presence of ilmenite. The RO/R_2O_3 ratio for the chromite calculated from the microprobe data is 1.02. This value was not normalised to correct for the values of Fe^{2+}, Mg and Mn.

The spectrographic data of the two chromite concentrates gave Cr, Fe, Al and Mg as the major elements, Mn, Ni, V, Ti and Si as the minor elements and Co as the trace element. Chemical analyses of both chromite types are presented in Table 1. The following features are apparent from the results; the Hessen Bay chromite has slightly a

TABLE 1

CHEMICAL ANALYSIS OF THE RAMU AND HESSEN BAY CHROMITES.

	Ramu	Hessen Bay
Cr_2O_3	49.09	52.85
Al_2O_3	13.80	12.83
FeO	20.88	18.68
Fe_2O_3	6.41	5.04
MgO	7.79	9.27
TiO_2	0.05	0.12
MnO	0.92	1.01
V_2O_5	0.11	0.14
CoO	0.20	0.20
NiO	0.11	0.12
SiO_2	0.06	0.08
	99.42	100.34
Cr/Fe	1.62	2.00
Cr/Al	4.60	5.33

higher chromium value and a lower iron content. The amounts of Al and Mg in both chromites are not markedly different. Based on the values of the major elements the chemical formulae for the Hessen Bay and the Ramu chromites have been represented as $(Fe_{4.10}\ Mg_{3.62}\ Mn_{0.22})(Cr_{10.96}\ Al_{3.97}\ Fe^{3+}_{0.97})O_{32}$ and $(Fe_{4.64}\ Mg_{3.10}\ Mn_{0.21})(Cr_{10.31}\ Al_{4.33}\ Fe^{3+}_{1.28})O_{32}$ respectively when Fe^{2+} and Fe^{3+} values have been assigned by assuming stoichiometry for the spinel structure.

Compositional Variations

The parameters considered in the study of the compositional variations are Cr/Fe and Cr/Al ratios and the relationship of $\frac{Cr}{Cr + Al}$ with $\frac{Mg}{Mg + Fe^{e+}}$.

The mean Cr/Fe ratios for Ramu and Hessen Bay chromites are 1.62 and 2.0 and the Cr/Al ratios are 4.52 and 5.33 respectively (Table 1) so that both chromites are of the general chemical grade (Raicevic, 1977). In spite of this, the Ramu chromite has been used to produce high carbon ferrochrome (Nafziger, 1983). A plot of the cation ratios of $\frac{Cr}{Cr + Al}$ against $\frac{Mg}{Mg + Fe^{2+}}$ for the two chromites indicates that both chromite types are either of podiform-or stratiform type. However, the low values of Fe^{3+} and Ti (Table 1 and Fig. 3) make them a podiform type.

Trivalent Cations

Fig. 3 shows the Cr, Al and Fe^{3+} cation variations obtained by microprobe analysis of the Ramu and Hessen Bay chromites. The substitution of Cr by Al is considerable and varied, and the substitution of Cr by Fe^{3+} is low. The Al substitution

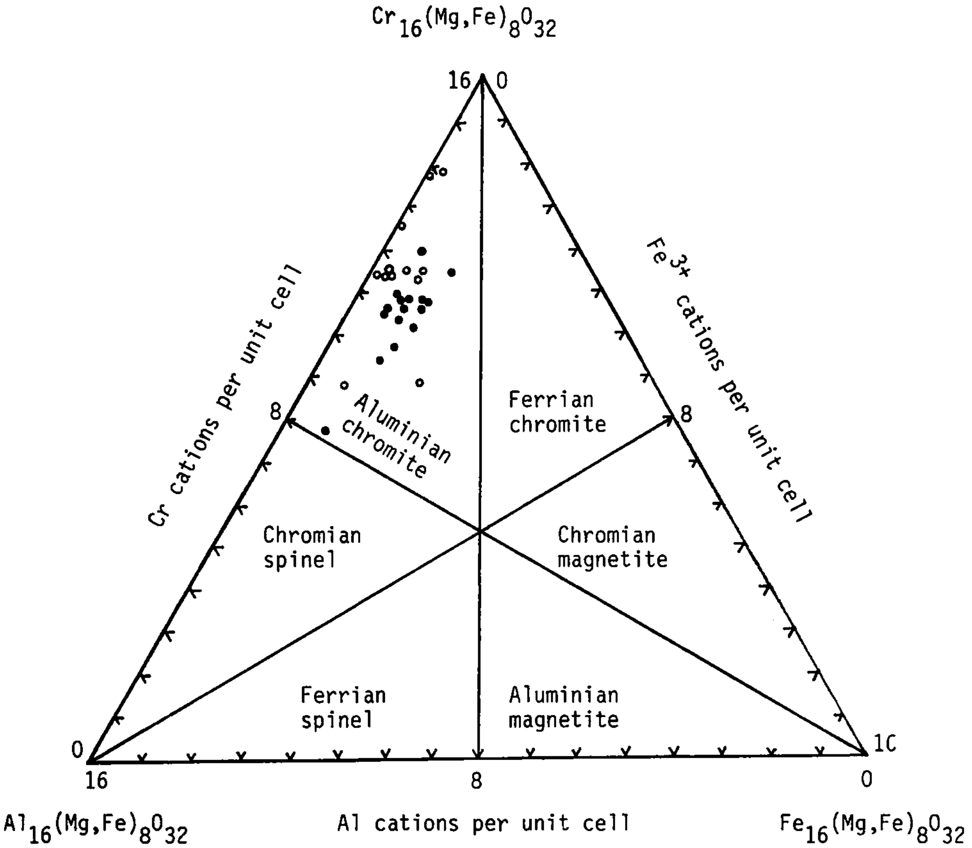

Fig. 3. The distribution of Ramu and Hessen Bay chromites in Cr_{16}-Al_{16}-Fe^{3+}_{16} triangle classification. (Ramu chromite is represented by closed circle and Hessen Bay chromite by open circle).

ranges from 2 to 8 cations but the Fe^{3+} substitution is generally below 2 cations. In the Hessen Bay chromite the Al substitution of the Cr is predominantly between 2 and 5 cations but in the Ramu chromite the predominant substitution range is 4–6 cations. With regard to Fe^{3+} substitution, the Hessen Bay chromite has slightly lower Fe^{3+} substitution for Cr. The level of Al and Fe^{3+} substitution for the Cr places the two chromites in the aluminia chromite classification. The low substitution of Fe^{3+} for Cr is better shown by Fig. 4 where the Cr cations plot against Al cations approximates a straight line. In addition, Ti which has a substantial substitution for Cr in the stratiform chromite has only a slight substitution for the Cr in each of the two chromites and does not exceed 0.2% TiO_2.

Divalent Cations

The important divalent cations in both chromites are Fe^{2+}, Mg and Mn in order of diminishing magnitude. The Mg plus Mn cations hardly exceed 4 cations in the (Fe,

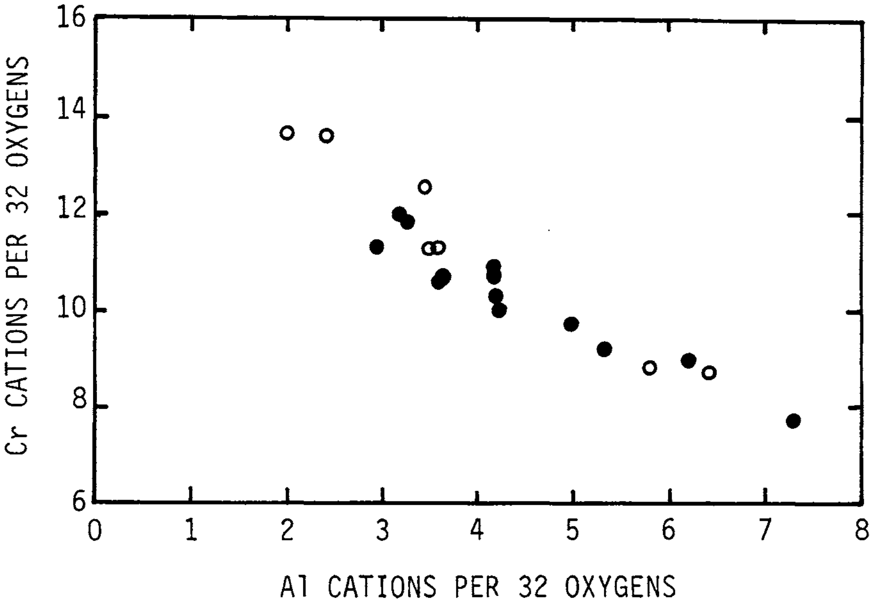

Fig. 4. A plot of Cr cation against Al cation for the Ramu and Hessen Bay chromites. Circles as in Fig. 3.

Mg, Mn)$_8$O$_8$ portion of the chromite structure. The high iron content in the Hessen Bay and Ramu chromites is thus largely due to divalent iron. This higher Fe^{2+} cation value than the Mg cation is not a common characteristic of podiform chromites. In this regard the two chromites resemble the stratiform chromite of the Stillwater Complex (Thayer, 1946) except that these have far lower TiO_2 contents than the Stillwater chromite. The reasons for the high content of Fe^{2+} and the extent of Al and Fe^{3+} substitutions of the Cr are attributed to the composition of the host rocks of the chromite, the low oxygen fugacity and the sequence of the silicate mineral phase fractionation during the chromite mineralisation.

In the study of Co and Ni distribution between the chromite minerals and their coexisting olivines it was observed that the Co level in the chromites is generally 2.6 times as high as its level in the equilibrated olivines but the Ni content in the same chromites is 0.6–0.4 times as high as its level in the olivines. The partition coefficients for Co and Ni between the olivine and chromite phases are 0.14–0.12 and 0.9–0.6 respectively, where the partition coefficient for Co, for example, for the olivine and chromite phases is expressed as

$$K = X^{ol}_{Co}/X^{Cr}_{Co} \text{ when } X = Co/(Co + Mg + Fe + Mn + Ni)$$

This shows that Co is highly partitioned into the chromite phase in contrast to Ni.

Effect of Chromite Composition on Size

The variation of Cr, Mg, Fe, Al with particle size is presented in Table 2. A

TABLE 2

VARIATION OF THE MAJOR ELEMENTS IN THE RAMU AND HESSEN BAY CHROMITES IN RELATION TO SIZE. (DATA OBTAINED BY CHEMICAL ANALYSIS AND EACH VALUE IS A MEAN OF THREE ANALYSES).

Size (μm)	+420	−420+300	−300+210	−210+150	−150+100	−100+75	−75	Mean
Ramu:								
%Mg	5.67	5.43	4.68	4.44	4.11	3.78	3.28	4.60
%Fe	17.50	17.40	19.30	19.70	20.20	21.90	26.1	19.45
%Cr	31.80	32.7	32.80	33.60	33.30	32.7	29.4	33.1
%Al	8.10	7.5	7.40	7.20	7.20	6.9	6.2	7.31
%Wt	3.8	8.3	29.7	40.6	14.7	2.7	0.2	
Cr/Fe = 1.70, Cr/Al = 4.5								
Hessen Bay:								
%Mg	5.87	5.39	5.74	4.35	3.996	3.89	3.57	4.81
%Fe	16.90	18.00	20.10	20.60	18.50	20.40	18.50	19.45
%Cr	36.10	36.00	35.70	36.70	36.80	34.40	36.2	36.1
%Al	8.24	8.18	7.17	6.87	7.18	6.92	6.89	7.30
%Wt	4.3	18.3	23.9	24.9	14.7	9.4	4.6	
Cr/Fe = 1.9, Cr/Al = 4.9								

prominent feature of both chromite types is the increase of Mg and Al values with increase of particle size. The Cr value, however, remains fairly constant in relation to all size fractions, but the iron content in the Ramu chromite appears to increase with decreasing size but this trend is not apparent for the Hessen Bay chromite. This effect might be caused by the crystallisation of a more refractory Mg-Al-rich phase at a higher temperature and crystallisation of a less refractory Fe-rich phase at a lower temperature. But how would such a temperature dependent crystallisation relate to particle size? A possibility is that the more refractory chromite particles crystallised in larger sizes. The second possibility is that the more refractory chromite grains were more resistant to weathering and disintergration than the less refractory particles that this resulted in the more resistant particles forming coarser particles. Of these two suggestions, the latter seems more plausible since both chromite types were derived from weathered dunites and had undergone some degree of disintergration during the process of natural concentration.

A better understanding of the variations of Mg, Al, Cr and Fe with particle size may be attained when microprobe analysis of the individual sized grains is made.

With regard to the Ramu chromite, the Cr/Fe ratio decreased from 1.82 (at +420 μm) to 1.13 (at −75 μm) to give a calculated mean ratio of 1.70 as compared with the head ratio of 1.62. On the other hand, the Cr/Al ratio increased from 3.94 to 4.74 to give a mean ratio of 4.5 in comparison with the head ratio of 4.60. For the Hessen Bay chromite, the Cr/Fe ratio varied from 2.1 to 1.78 giving a calculated mean of 1.9 as against the head ratio of 2.0. The Cr/Al ratio increased from 4.4 to 5.3 to give a mean value of 4.9 as against 5.33. These results demonstrate that the sizes of the Ramu and the Hessen Bay chromites were influenced by their compositional variations. These variations would have important implications for the mining of the deposits.

Magnetic Property

About 10–15% of the Ramu and Hessen Bay chromites are highly magnetic. Microprobe and microscopic examination of the highly magnetic and 'non-magnetic' fractions have revealed various degrees of chromite replacement by magnetite. The replacement textures include (a) magnetite rims around chromite grains, (b) ramifying lamellae of magnetite in chromite (c) straight lamellae of magnetite, some along the (111) crystallographic planes of the chromite grains (Fig. 5). Nafziger (1983) reported the presence of magnetite and maghemite as the magnetic phases associated with the Ramu chromite. In the present work the presence of maghemite was not conclusive. On account of the intimate association of the magnetite with the chromite, the use of magnetic separation technique to upgrade the chromite without prior grinding would result in the loss of a significant amount of chromite.

Comparison with other Ophiolitic Chromites

For purpose of comparison, ophiolitic chromite deposits of New Caledonia (Dupy and Leblanc, 1980), Acoje in the Philippines (Friedrich *et al.*, 1980), Troodos in Cyprus (Mousoulos *et al.*, 1976) and N.E. Iraq (Buda and Kiss, 1980) have been selected because, like the Papua New Guinea chromites, they are also emplaced in ophiolites, and experienced similar degrees of structural changes and metamorphism and are of Eocene to Miocene period. The analytical data for these chromites and those for Ramu and Hessen Bay are presented in Table 3. The common characteristics of all these chromites are their low TiO_2 contents, generally less than 0.2%, and the low substitution of Fe^{3+} for Cr leaving Al as the major substituent for Cr. These features are typical of podiform chromites found in ophiolites in contrast to chromites of the Bushveld (stratiform type) where the TiO_2 content is high and the Cr is significantly substituted by Fe^{3+}.

The Cr/Fe ratios for these chromites are variable. For instance, the Cr/Fe ratio for Acoje chromites from the lateritic zone is 2.1 and that for Al-rich chromite of N.E. Iraq is 2.1. These values are comparable with the Cr/Fe ratios for the Papua New Guinea chromites. The Cr/Fe ratios for the chromites of New Caledonia (3.5), Troodos in Cyprus (3.2) and Cr-rich chromite of N.E. Iraq (2.7) are higher than those of Papua New Guinea chromites (Table 3). The Cr_2O_3 content varies from 46.1% to 58% and the FeO value ranges from 12.2% to 20.9% while the Fe_2O_3 value varies from 2.9% and 7%. The MgO content also varies widely from 8% (Ramu) to 15.1% (New Caledonia). Similarly the Al_2O_3 value varies from 8% (Cr-rich N.E. Iraq) to 19.7% (Al-rich N.E. Iraq). Because of the great variation of the Al content, the podiform type chromites often give rise to metallurgical and/or refractory grades.

Upgrading the Chromite Ores

By analysing the size fractions of the two chromite ores it was observed that 86% of the weight of the Ramu ore is -75 μm and this contains 14% of the total Cr (i.e.

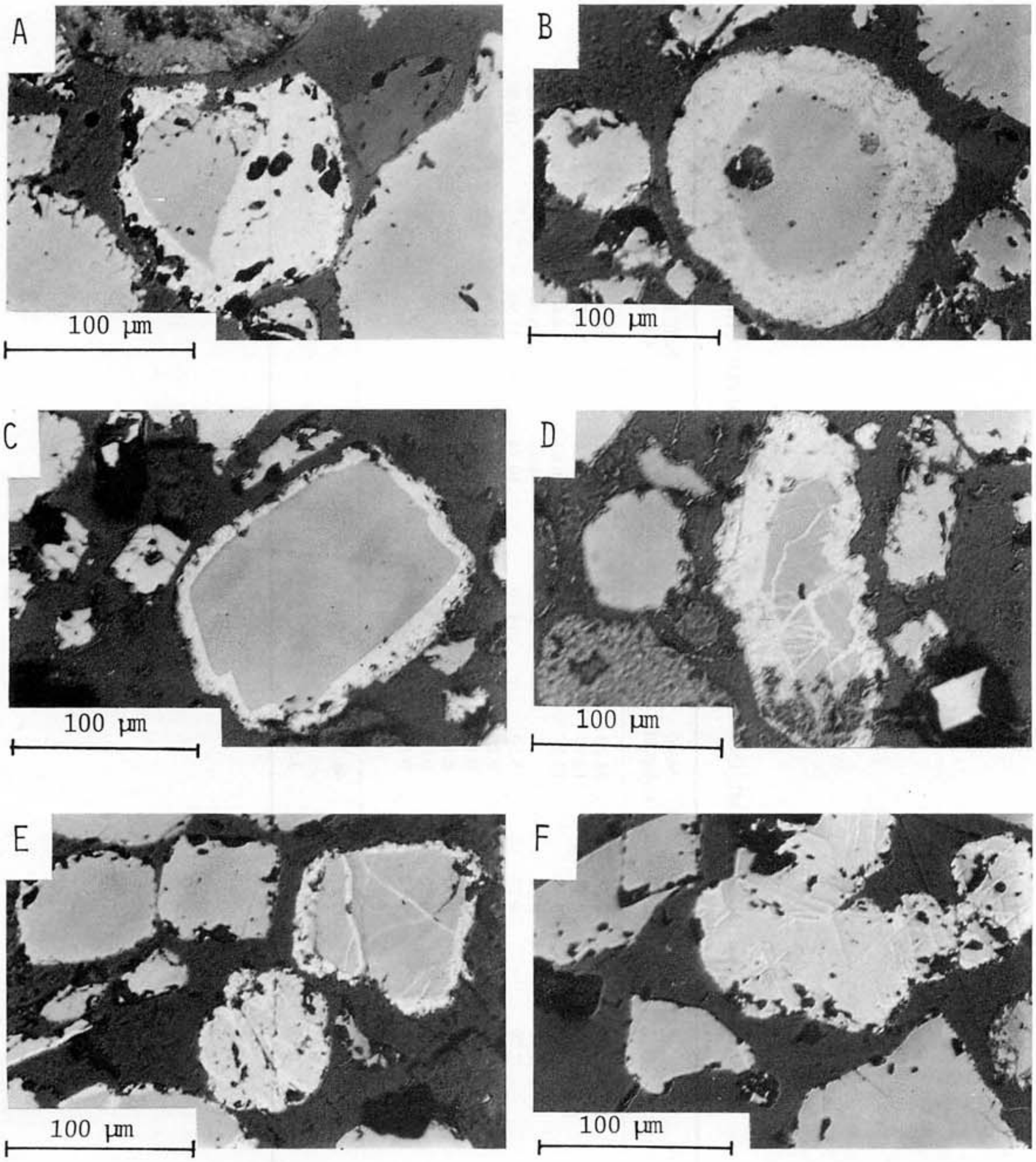

Fig. 5. Textures of magnetite in Ramu and Hessen Bay chromites.

(A, B, C) magnetite (white) replacing chromite grains at the rims.
(D, E) ramifying lamellae of magnetite replacing the chromite grains.
(F) straight magnetite lamellae along (111) crystallographic plane of a chromite grain.

TABLE 3

PAPUA NEW GUINEA CHROMITES COMPARED WITH OTHER OPHIOLITIC CHROMITES.

	Ramu	Hessen Bay	New Caledonia	Troodos Cyprus	N.E. Iraq Al-rich	N.E. Iraq Cr-rich	Acoje, Philippines Lateritic zone
Cr_2O_3	49.09	52.85	54.23	56.23	46.11	58.00	53.10
Al_2O_3	13.80	12.83	14.97	13.14	19.68	8.32	11.70
FeO	20.88	18.68	13.57	12.20	16.62	14.60	18.30
Fe_2O_3	6.41	5.04	-	3.20	4.83	6.01	6.95
MgO	7.79	9.27	15.10	14.10	10.74	11.96	10.30
TiO_2	0.05	0.12	0.10	0.19	0.14	0.09	-
MnO	0.92	1.01	0.14	0.14	0.46	0.35	-
V_2O_5	0.11	0.14	0.15	-	-	-	-
CoO	0.20	0.20	0.03	-	-	-	-
NiO	0.11	0.12	0.10	-	-	-	-
SiO_2	0.06	0.08	-	0.24	-	-	-
	99.42	100.34	98.39	99.45	98.58	99.33	100.35
Cr/Fe	1.62	2.00	3.56	3.2	2.1	2.7	2.1

+ 75 μm size fraction which is 14% of the total weight carries 86% of the total Cr). On the other hand, almost all the Hessen Bay chromite ore is + 75 μm size. Consequently gravity concentration techniques were used for upgrading the ores. The Ramu ore was deslimed prior to tabling whereas the Hessen Bay ore was directly tabled.

A plant-size spiral concentrator, GEC Eliot 2CR 175, 17½ inch pitch, and a laboratory Wilfley table of dimensions 25 cm by 60 cm were used to concentrate the ores. The spiral concentrator was operated on 12.5% solid and the concentrates were collected after 3 minutes when the circuit stabilised. The results are summarised in Table 4.

Because of the fine lateritic material in the Ramu chromite ore about 17% of the Cr was lost during the desliming operation prior to table concentration. But even so the table concentration produced a recovery of 77.9% Cr at a concentrate grade of 45% Cr_2O_3. The recovery can be improved if more chromite fines could be recovered, but even so it may be difficult to achieve a recovery greatly in excess of 86% Cr. Although the concentrate produced was of satisfactory grade, it contained large, hard clay balls and relatively coarse quartz particles which were difficult to separate from the chromite by the concentration methods employed. The discarded spiral tailing is rich in Ni and Co and might be useful as a source material for Ni and Co extraction.

The close-sized and fairly coarse nature of the Hessen Bay chromite warranted the employment of direct table concentration. The concentrate produced gave a grades of 37.4% Cr_2O_3 and a recovery of 54% Cr. In further batch tests, concentrate grades in excess of 45% Cr_2O_3 were obtained but the recoveries were around 43% Cr. When the ore was ground finer in order to improve chromite liberation prior to concentration, the recovery was only 64% and the grade remainded low. The low recovery was due to the presence of silicate minerals eg. olivine (S.G. 3.2) in the chromite (S.G. 4.5) and relatively larger quartz particles in the ore. It is therefore recognised that table concentration alone cannot succeed in producing a high recovery at an acceptable grade. Consequently further work on upgrading the ore will use other processes.

TABLE 4

RESULTS OF SPIRAL AND TABLE CONCENTRATION OF RAMU AND HESSEN BAY CHROMITES.

Product	%Wt	%Cr	%Cr_2O_3	% Recovery	%Cr	%Cr_2O_3
Ramu:						
Feed	100	4.8	7.0		5.0	7.3
Spiral conc.	36	11.7	17.1	83.4		
Spiral tail.	64	1.3	1.9	16.6		
Table conc.	12.7	30.8	45.0	77.9		
Table tail.	23.3	1.2	1.8	5.5		
Hessen Bay:						
Feed	100	11.9	17.4		11.5	16.8
Table conc.	24.1	25.6	37.4	53.7		
Table tail.	75.9	7.0	10.2	46.3		

CONCLUSION

The nature and the extent of the compositional variations of the Ramu and Hessen Bay chromites and their similar host rocks suggest that these chromite ores have similar genetic source.

Both chromites have characteristics typical of the podiform chromites namely, that Al is the major substituent for Cr, the level of Fe^{3+} and Ti substitution is low. The TiO_2 does not exceed 0.2%.

Of the two chromite ores, the Ramu ore is amenable to gravity concentration to produced a concentration grade of 45% Cr_2O_3 and a recovery of 78% whilst this process does not achieve a high recovery and an acceptable grade for the Hessen Bay chromite.

The two chromite deposits are best suited for a chemical grade. But the recent advances in chromium technology which allow the use of high-iron chromite in the production of high-carbon ferrochromium could open the way for the Papua New Guinea chromites for ferrochromium production.

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