Acta Geologica Hungarica, Vol. 40/3, pp. 337–353 (1997)

Chromite deposits of the Sagua–Baracoa range, Eastern Cuba

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The Sagua–Baracoa range includes one of the most significant chromite-producing areas of Cuba. Chromite deposits are associated with ophiolitic assemblages and show typical features of podiform chromitites: irregular shape, nodular and other characteristic textures, bimodality in Cr/Al ratio, etc. Al-rich chromites are related to the ultramafic cumulates, whereas Cr-rich ores occur in the tectonite. However, this connection is believed to be indirect and related to various compositions of successive magma batches, generated under slightly varying circumstances in the upper mantle. Chromite settled along the path of ascending magma in a spreading zone, in magma chambers and traps of various size and at various levels, as a function of the composition of the multiple magmas and equilibrium conditions. The location of this process was presumably below a marginal basin.

Key words: chromites, ophiolites, mineralogy, major oxides, microprobe analyses, origin, Eastern Cuba

Introduction

The Cuban ophiolite belt extends more than 1000 km parallel to the geographic axis of the island. The ultramafic and related rocks are exposed discontinuously forming several large massifs with a varying width of 10–50 km. In 1987–1990, in the framework of the cooperation between the Geological Institute of Hungary and the *Expedición Geológica de Santiago de Cuba*, geological mapping and ore prospecting were carried out in the Sagua–Baracoa area (Gyarmati et al. 1990) which covers roughly the easternmost massif (Fig. 1). The purpose of the work was to evaluate the mineral potential of the area which is one of the most important chromite-producing zones of Cuba.

Chromite occurrences of eastern Cuba were discovered in the 19th century, although they were described as iron ores. They have been exploited since 1916.

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Received: 14 August, 1996

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Fig. 1
Location of the studied area (shaded) and complexes of the Cuban ophiolite belt. 1. Cajálbana; 2. Matanzas; 3. Santa Clara; 4. Camagüey; 5. Holguín; 6. Mayarí; 7. Moa–Baracoa

Early comprehensive papers were published in the 1940s (Thayer 1942; Guild 1947) providing virtually the only sources of information on the chromite deposits of eastern Cuba to date. Subsequent reviews are based exclusively on these accounts (e.g., Guilbert and Parks 1986), as the results of later investigations have appeared in publications of more limited distribution (e.g., Semenov 1968; Pavlov et al. 1985). This paper presents an up-to-date account based on the recent field work and subsequent laboratory investigation.

Geological setting

The studied area (approx. 2400 km^2) is situated in Eastern Cuba, between Sagua de Tánamo and Baracoa. It is a spectacular subtropical area with variable relief ranging from sandy beaches to poorly accessible, mostly uninhabited mountainous ranges (1175 m). The region is composed largely of a Jurassic–Cretaceous ophiolite sequence (Fonseca et al. 1984) of the Moa–Baracoa massif (Fig. 2). Partly metamorphosed Cretaceous island arc volcanic rocks occur below the ophiolites as a result of Late Cretaceous obduction. The overthrusting was accompanied by formation of coarse-grained sediments (conglomerate, sandstone, olistostrome) and tectonic melange. Cenozoic formations are represented mainly by calcareous sediments and subordinate felsic tuffs. Nickeliferous laterite and refractory chromite are the most important mineral deposits of the area.

All units of the typical ophiolitic sequence are presumed to be present. The ultramafic rocks are mainly serpentinized harzburgite and dunite, but subordinate pyroxenite, wehrlite, lherzolite and plagioclase-bearing peridotite also occur. Features such as abundant kink-bands in olivines, euhedral chromite grains, and cataclastic fabrics in harzburgites and interlayered dunites suggest a large distribution of tectonite, mainly in the western part of the studied area. The other ultramafic rocks presumably belong to the cumulate assemblage. Along with more differentiated rock types (gabbroids), they are more frequent in the east. Limits of both units are obliterated by the almost complete serpentinization and deformation.

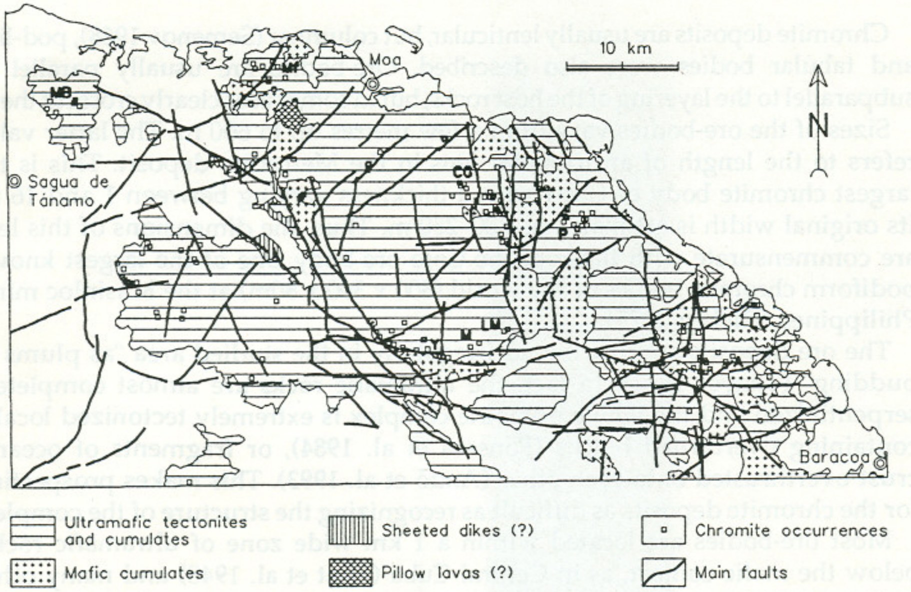

Fig. 2
Generalized map of the ophiolite suite of the Sagua–Baracoa range (after Gyarmati et al. 1990). Deposits and prospects: MB – Monte Bueno; Mf – Miraflores; CG – Cayo Guam; P – Potosí; Y – Yarey; M – Mercedita; LM – La Melba; LC – La Constancia; A – Amores

Mafic cumulates are represented largely by gabbros of both layered and massive varieties. They are mostly in tectonic contact with the ultramafic cumulates but sometimes a gradual transition through alternating layers may occur. Gabbronorite, olivine gabbro, troctolite, leucocratic gabbro, anorthosite, microgabbro and gabbro-pegmatite are also present in the mafic suite and locally have been intruded into the ultramafic rocks.

More felsic units (plagiogranites) are uncommon. The presence of sheeted dykes, pillow lavas and pelagic sediments is debatable. Abundant diabase was mapped in two areas at the border of the ultramafic rocks and the island arc volcanic rocks, but they could belong to the latter suite. The intensely weathered hyaloclastite found in the Sagua–Moa roadcut and in a nearby borehole also have ambiguous (tholeiitic and calc-alkaline) chemical character. The similarly weathered radiolarite described in the same exposure also requires further investigation.

Field relations

About 200 podiform-type (Thayer 1964) chromite occurrences are known in the studied area (Fig. 2). They are mostly small (less than 10 m in diameter) and without economic significance. Of the four largest deposits, Cayo Guam and Potosí are abandoned while Mercedita and Amores are under exploitation.

Chromite deposits are usually lenticular, but columnar (Semenov 1968), pod-like and tabular bodies were also described. Ore-bodies are usually parallel or subparallel to the layering of the host rocks, but in some cases clearly crosscut them.

Sizes of the ore-bodies vary from a few metres up to 600 m. The latter value refers to the length of an irregular lens in the Mercedita deposit. This is the largest chromite body of Cuba with a thickness varying between 1 and 16 m. Its original width is estimated as 200–250 m. Thus, the dimensions of this lens are commensurate with those of the Coto ore-body, one of the largest known podiform chromite bodies of the world (600 x 300 x 80m) at the Masinloc mine, Philippines (Dickey 1975).

The ore deposits are distributed irregularly in the studied area "as plums in pudding" (Thayer 1942). In fact, the ultramafic rocks are almost completely serpentinized and the whole ophiolite complex is extremely tectonized locally containing overturned blocks (Fonseca et al. 1984), or fragments of oceanic crust overthrusted onto each other (Andó et al. 1993). This makes prospecting for the chromite deposits as difficult as recognizing the structure of the complex.

Most ore-bodies are located within a 1 km wide zone of ultramafic rocks, below the mafic contact, as in Central Cuba (Flint et al. 1948) and many other regions of the world. The uppermost ore-bodies in the Amores mine are located in plagioclase-bearing peridotite, 50 m below the layered gabbro. As chromite deposits may be formed at the bottom of, or below, the cumulate magma chamber, a thin ultramafic cumulate suite with thickness of not more than a few hundred metres is inferred for the region.

The tectonite complex also contains numerous chromite lenses, such as in the Monte Bueno block in the western part. Their largest diameter is 20 to 30 m.

Residual ore-bodies are found in the lateritic cover. Chromite remains virtually intact and is considerably concentrated while the host serpentinites are totally lateritized and compacted. These *float ores* (Thayer 1942) may also have economic importance (e.g., Friedrich et al. 1980), and thus deserve further investigation.

Ore-bodies are often cut by dykes. Serpentinized ultramafic dykes are ubiquitous, whereas dykes of gabbro (Fig. 3), gabbronorite and troctolite are known mainly from the Cayo Guam, Potosí and Amores mines. Most gabbroic dykes are pegmatitic and crystals as large as 10 to 15 cm are frequent; Guild (1947) depicted 90 cm crystals of augite in the gabbro-pegmatites at the Cayo Guam mine. Coarse-grained gabbro also occurs, whereas medium- and fine-grained varieties are rare. The grain size, however, may vary within the same dyke. For example, in a dyke crossing a massive ore-body at Potosí, the grain size increases from the wall toward the centre, ranging from micro-gabbro through gabbro to gabbro-pegmatite (Fig. 4). The rapid cooling and crystallization near the contact implies that significant time might locally lapse between ore segregation and gabbro intrusion, in contrast to Thayer's (1964) conclusion that dykes formed simultaneously or "very soon after" the country rocks. However, such variability in grain size is rare and most dykes are equigranular.

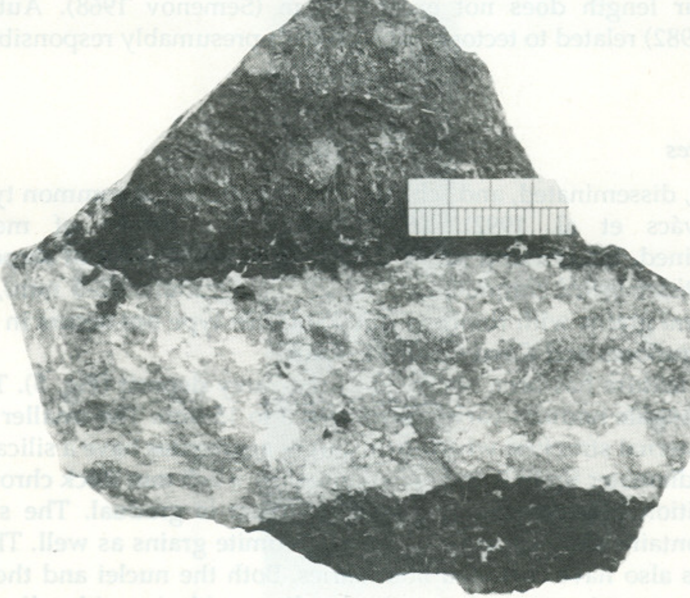

Fig. 3
Massive chromite with gabbro dyke, Amores mine. The length of the scale is 2 cm

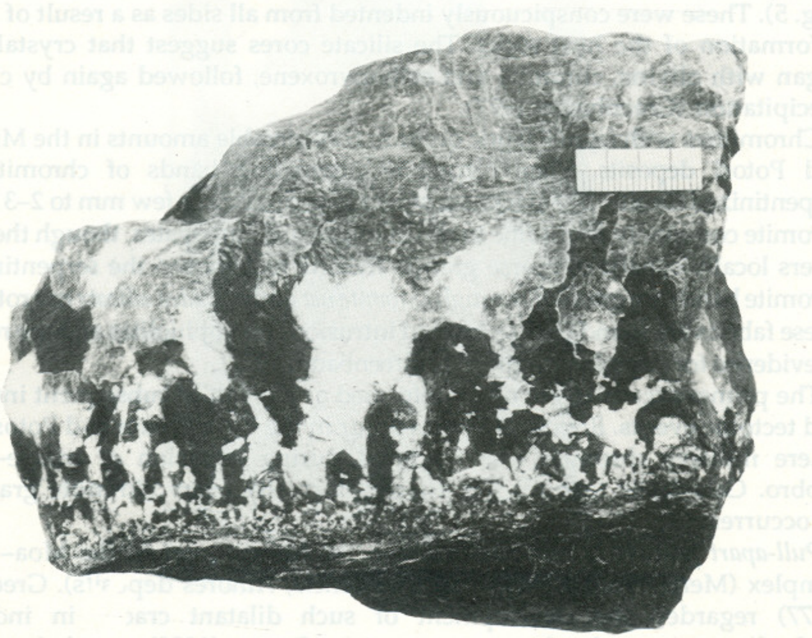

Fig. 4
Gabbroic dyke, ranging in composition from microgabbro to gabbro-pegmatite (black on the bottom: massive chromite), Potosí mine. The length of the scale is 2 cm

The dykes range in width from a few mm to 1.5 m (Thayer 1942; Semenov 1968); their length does not exceed 15 m (Semenov 1968). Autointrusion (Hughes 1982) related to tectonic movement is presumably responsible for their formation.

Ore textures

Massive, disseminated, and schlieren ores are the most common types in the area (Kovács et al. 1992). *Massive* chromites consist of medium- to coarse-grained, interlocking subhedra with a small amount of serpentine and chlorite. *Disseminated* chromites are mostly equigranular (2–5 mm), anhedral, or subhedral grains with resorbed rims. *Schlieren* type ore occurs in the Monte Bueno, Miraflores and Cayo Guam deposits.

Nodular texture has been observed in the Yarey deposit (Fig. 5). The round, slightly elongate nodules vary in size from 3 to 15 mm. The smaller ones have massive internal structure whereas the larger aggregates have a silicate-bearing core with diameter up to 8 mm, surrounded by a 2–5 mm thick chromite crust. The transition between the core and the crust is gradual. The silicate-rich nucleus contains fine, strongly corroded chromite grains as well. The nodules themselves also have corroded boundaries. Both the nuclei and the matrix of the nodules contain serpentine and subordinate chlorite with relics of olivine and pyroxene.

Most cored nodules in the Yarey deposit show pronounced concave contours (Fig. 5). These were conspicuously indented from all sides as a result of tectonic deformation of the host rocks. The silicate cores suggest that crystallization began with olivine, chromite and orthopyroxene, followed again by chromite precipitation (Greenbaum 1977).

Chromitites with *layered* fabric occur in considerable amounts in the Miraflores and Potosí deposits. They consist of alternating bands of chromitite and serpentinized dunite. The thickness of bands varies from a few mm to 2–3 cm. The chromite commonly forms fine to medium-grained aggregates, though the thicker layers locally consist of coarse grains. Transitions between the serpentinite and chromite bands are gradual through *chromite net* and *occluded silicate* microtextures. These fabrics are found both in layered intrusions and ophiolites and are regarded as evidence for cumulus origin (e.g., Greenbaum 1977).

The primary textures are often deformed as a result of subsequent intrusions and tectonic events. *Brecciated* fabrics occur in the Cayo Guam and Potosí mines where massive chromite was fractured during intrusion of coarse-grained gabbro. Cataclastic textures has affected virtually every chromite grain from all occurrences.

Pull-apart texture is more frequent in the eastern part of the Moa–Baracoa complex (Mercedita, La Melba, La Constancia, Amores dep[illegible]s). Greenbaum (1977) regarded the development of such dilatant crac[illegible] in individual ore-bodies as a result of mass movements. Brown (1980) s[illegible]ed that tension

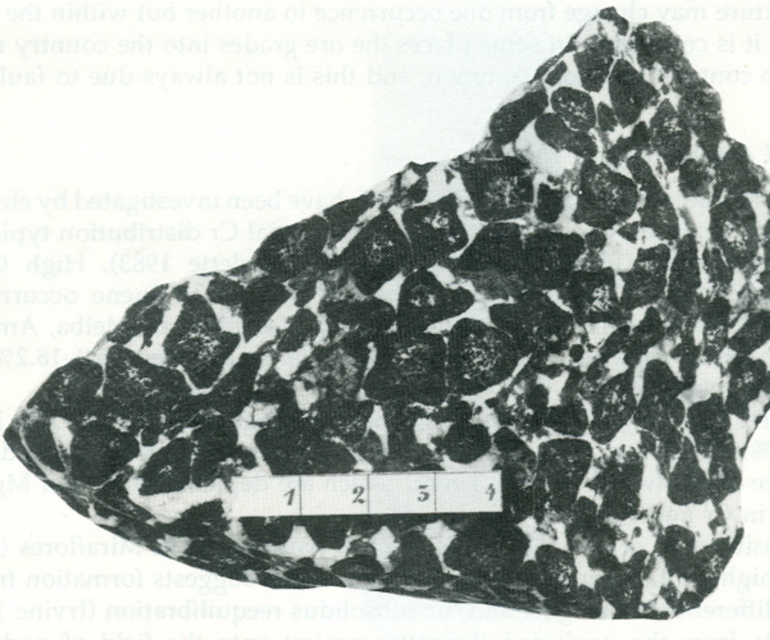

Fig. 5
Nodular chromite, Yarey deposit. Note the concave contours of most nodules. Scale in centimetres

fractures were formed by tectonic deformation and were perpendicular to the maximum direction of stress. However, tectonic pressure is more likely to result in irregular, cataclastic fracture patterns rather than subparallel cracks. The wide-spread distribution of the pull–apart texture in most podiform chromite districts (Thayer 1964) suggests extension on a regional scale, whereas subparallel orientation of fissures, as well as general lack of displacement along them implies the effect of a single couple of opposed forces.

Extension, which forms in the convex side of a flexed plate on the outer slopes of trenches and collisional foredeeps (Bradley and Kidd 1991), might give rise to such fracturing. Accordingly, pull–apart texture should be more common in ore bodies associated with the upper part of the ophiolite assemblage and less frequent downward in the sequence as the strain gradually decreases with depth (as far as a "neutral surface" at about half the thickness of the plate, below which contraction arises due to bending). In the extended side of the folded slab, opening of tension cracks is confined to the uppermost part (Bradley and Kidd 1991). This model may be applied to the studied area as the chromite deposits in the eastern part generally represent a higher stratigraphic level. The flexing probably took place before obduction.

Ore texture may change from one occurrence to another but within the same ore-body it is consistent. In some places the ore grades into the country rocks, but sharp contacts are more common, and this is not always due to faulting.

Chemical composition of chromite

Chemical composition of chromian spinels have been investigated by electron microprobe analyses. Ore chromites show a bimodal Cr distribution typical of podiform deposits (Dickey 1975; Leblanc and Violette 1983). High Cr_2O_3 contents (50.7–54.6 wt%) are characteristic of the Monte Bueno occurrences (Table 1), while the other deposits (Miraflores, Mercedita, La Melba, Amores) have low Cr_2O_3 contents (35.7–37.9%). Al_2O_3 varies between 15.0–18.2% and 27.5–31.8%, respectively.

MgO and FeO vary within a relatively narrow range (FeO: 10.6–17.3%; MgO: 11.0–17.4%). Alteration along rims and cracks of chromite grains formed high reflectance zones (width up to 0.4 mm) which are depleted in Al and Mg and enriched in Cr and Fe (Table 1).

Compositions of accessory chromites from harzburgite in Miraflores (Table 1) show higher Fe/Mg ratio than in the ores which suggests formation from a slightly differentiated magma and/or subsolidus reequilibration (Irvine 1967).

All data from the unaltered chromites project onto the field of podiform chromites in the Cr/(Cr+Al) vs. $Mg/(Fe^{2+}+Mg)$ diagram (Fig. 6a). TiO_2 does not exceed 0.44 wt% and does not show any positive correlation with major oxides, which is also characteristic of podiform chromites (Dickey 1975).

Low-chromium, high-alumina ores are known also from other ophiolite complexes, but Cr_2O_3 less then 38 wt% and Al_2O_3 more than 31% as well as $TiO_2 \geq 0.40\%$ in chromitites are rather rare. However, these values compare well with the results of previous chemical (Guild 1947; Pavlov et al. 1985; Fig. 6b) and microprobe (Ukhanov et al. 1985) data.

Samples from Amores have the lowest values of Cr/(Cr+Al) ratio (Fig. 6a, b). Consequently, a compositional series can be identified from the Cr-rich (metallurgical) ores in tectonites to the Cr-poor, Al-rich (refractory) chromites in cumulates, including the Amores deposit which appears in the highest stratigraphical level and provides the most aluminous ore (Kovács et al. 1993). Kenarev (1966) found a similar trend within the Potosí deposit.

The compositional data imply that, geologically, the Monte Bueno block belongs to the Mayarí massif rather than to the Moa–Baracoa complex (cf. Fig. 6a, b). The former, located west of the studied area (Fig. 1), is composed mostly of mantle tectonites (Fonseca et al. 1984) containing metallurgical chromite (Thayer 1942; Semenov 1968).

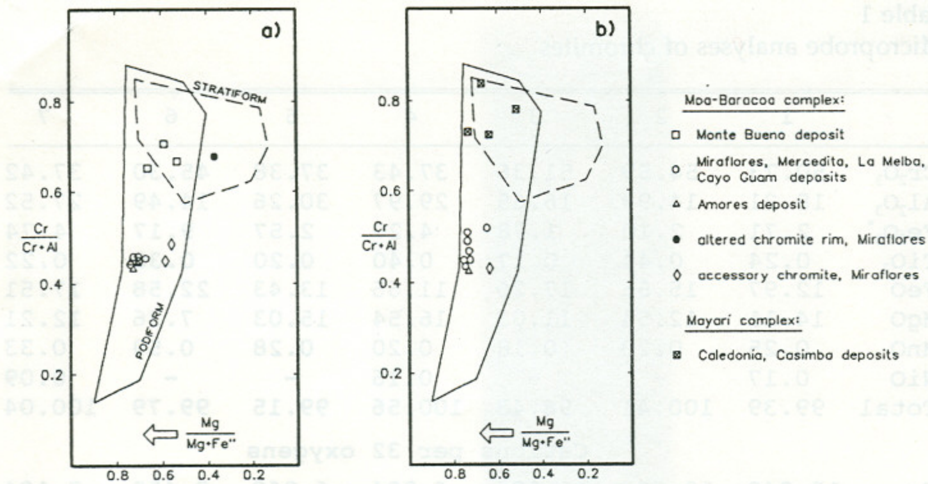

Fig. 6
Compositional diagram of chromites of the studied and adjacent areas. Atomic proportions based on: a) microprobe analyses (Table 1), and b) chemical analyses (Guild 1947; Pavlov et al. 1985). Fields of stratiform and podiform ores after Irvine (1967).

Mineral composition

Serpentine and chlorite are the most common silicates in the ore-bodies, with some relics of olivine and pyroxenes (enstatite, rarely Cr-diopside). Locally chlorite is the dominant gangue mineral (Table 2). Its formation is obviously due to the release of Al and Mg from chromite along selvedges and fractures during serpentinization (Whittaker and Watkinson 1986; Buda 1988). Amphiboles are less frequent. In the cumulates, olivines of host rocks are richer in Fe ($Fo_{90.5-91.5}$) than olivine inclusions in the ores ($Fo_{94.3-95.1}$; Table 3). However, relict olivine from ore deposits in the tectonite environment has not been found.

Microprobe analysis has revealed millerite, pyrrhotite, and a platinum-group mineral with dominant Ru and Fe and minor Os and Ir occurring as inclusions in chromite (Fig. 7). The latter has been discovered in the Monte Bueno occurrence.

Chromian garnet is a typical pathfinder mineral of chromite. Though it is essentially absent in the western part of the Sagua–Baracoa range, it occurs in numerous deposits (Mercedita, La Melba, Amores, etc.) to the east, essentially at the same places where Al-rich chromite and pull-apart textures are developed. Fine (<1 mm) euhedral garnet crystals occupy major fractures. Chemical data (Table 3) indicate compositions between grossular and uvarovite.

Table 1
Microprobe analyses of chromites

	1	2	3	4	5	6	7
Cr_2O_3	50.73	54.59	51.36	37.43	37.38	45.30	37.42
Al_2O_3	18.21	14.99	16.65	29.97	30.26	14.49	27.52
Fe_2O_3*	2.71	2.10	1.78	4.20	2.57	9.17	4.74
TiO_2	0.24	0.44	0.17	0.40	0.20	0.30	0.22
FeO	12.97	15.55	17.26	11.66	13.43	22.58	17.51
MgO	14.11	12.54	11.03	16.54	15.03	7.36	12.21
MnO	0.25	0.20	0.18	0.20	0.28	0.59	0.33
NiO	0.17	–	–	0.16	–	–	0.09
Total	99.39	100.41	98.43	100.56	99.15	99.79	100.04
			Cations per 32 oxygens				
Cr	10.040	10.936	10.506	6.904	6.960	9.455	7.184
Al	5.368	4.475	5.075	8.224	8.392	4.485	7.864
Fe^{3+}	0.512	0.398	0.346	0.736	0.456	1.835	0.864
Ti	0.040	0.082	0.031	0.064	0.034	0.060	0.032
Fe^{2+}	2.704	3.295	3.736	2.264	2.644	4.995	3.544
Mg	5.264	4.731	4.251	5.736	5.272	2.875	4.416
Mn	0.040	0.043	0.039	0.032	0.058	0.135	0.056
Ni	0.032	–	–	0.024	–	–	0.016

* Fe_2O_3 is calculated from total FeO assuming spinel stoichiometry

Sample location and lithology:
1. Monte Bueno, massive ore (average of 6 analyses)
2. Monte Bueno, massive ore (average of 4 analyses)
3. Monte Bueno, schlieren ore (average of 4 analyses)
4. Miraflores, massive ore (average of 6 analyses)
5. Miraflores, schlieren ore (average of 5 analyses)
6. Miraflores, altered rim of the former grains (average of 2 analyses)
7. Miraflores, borehole PE-2 25.9 m, harzburgite (average of 6 analyses)

Fine euhedra of secondary magnetite, presumably precipitated during serpentinization, have also been determined. Pyrite, chalcopyrite and gold minerals (electrum, native gold, calaverite) were identified in a few samples by microscopic methods.

The original wall rocks, if they are not totally obscured by serpentinization, always are dunite, as is typical of podiform chromitites (Dickey 1975). Thickness of the dunitic rim varies from 1–2 cm to several metres (Semenov 1968).

Discussion and conclusions

All chromite deposits associated both with cumulate and tectonite sequences are interpreted to be generated by cumulus processes (Thayer 1964), as textural

Table 1
Continued

	8	9	10	11	12	13	14
Cr_2O_3	37.38	37.91	37.24	37.92	36.82	35.66	37.01
Al_2O_3	30.47	30.85	31.81	29.99	30.42	31.52	31.06
$Fe_2O_3^*$	2.89	3.20	3.41	4.26	4.57	3.68	2.32
TiO_2	0.02	0.31	0.18	0.40	0.28	0.23	0.16
FeO	16.72	11.83	10.60	11.01	10.70	11.20	10.97
MgO	13.17	16.53	17.35	17.05	17.06	16.67	16.59
MnO	0.28	0.22	0.24	0.19	0.20	0.07	0.16
NiO	0.07	0.21	0.24	0.18	0.17	–	–
Total	101.00	101.06	101.07	101.00	100.22	99.03	98.27
			Cations per 32 oxygens				
Cr	6.992	6.936	6.760	6.944	6.776	6.606	6.888
Al	8.488	8.408	8.592	8.176	8.328	8.703	8.619
Fe^{3+}	0.512	0.552	0.592	0.744	0.800	0.590	0.412
Ti	0.000	0.048	0.032	0.064	0.040	0.041	0.028
Fe^{2+}	3.296	2.280	2.024	2.128	2.080	2.195	2.160
Mg	4.632	5.688	5.920	5.872	5.904	5.822	5.824
Mn	0.048	0.032	0.032	0.032	0.032	0.015	0.033
Ni	0.016	0.032	0.040	0.032	0.032	–	–

* Fe_2O_3 is calculated from total FeO assuming spinel stoichiometry

Sample location and lithology:
8. Miraflores, borehole PE-2 466.0 m, harzburgite (average of 5 analyses)
9. Mercedita mine, massive ore (average of 6 analyses)
10. Mercedita mine, massive ore (average of 6 analyses)
11. La Melba, massive ore (average of 6 analyses)
12. Amores mine, massive ore (average of 6 analyses)
13. Amores mine, massive ore (average of 3 analyses)
14. Amores mine, massive ore (average of 2 analyses)

and experimental evidence do not support a residual origin for significant amounts of spinel (Dickey and Yoder 1972). Dickey (1975) explained this feature by gravitational sinking of chromite pods as solid autoliths from the zone of segregation into the underlying tectonite peridotite. Ukhanov et al. (1985) suggested a similar mechanism for the origin of the Mercedita deposit.

However, the ubiquity of dunitic envelopes around the ore-bodies as well as the apparent relation between the ore composition and the position of deposits in the vertical rock sequence as observed in the Sagua–Baracoa range and in many other chromite districts of the world, are not compatible with this hypothesis (Brown 1980). Therefore, the process of fractional crystallization from a rising magma was suggested, which began beneath the main magma

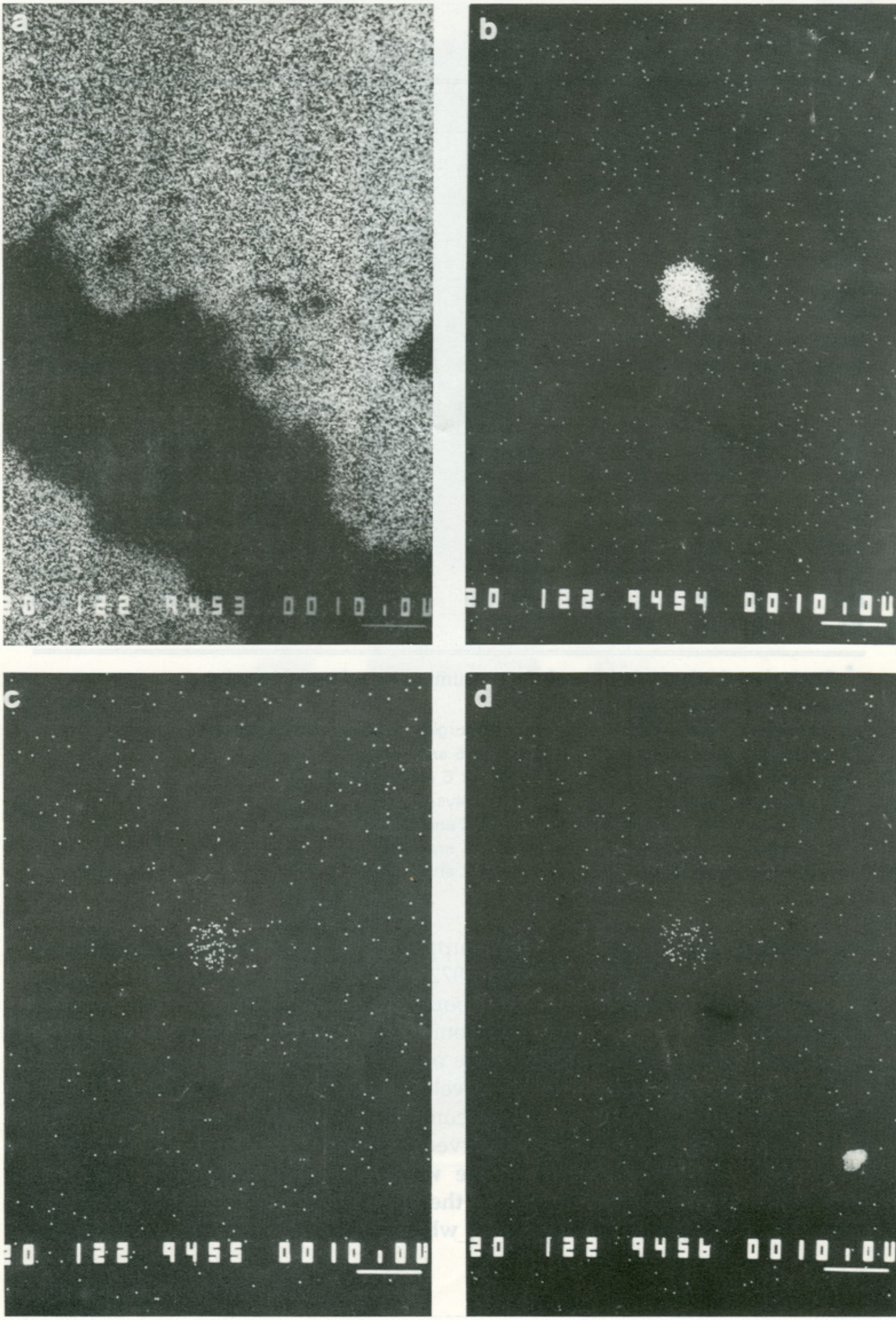
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Table 2
Microprobe analyses of orthopyroxenes (opx), clinopyroxenes and chlorites

	1	2	3	4	5
	opx	clinopyroxenes		chlorites	
SiO_2	56.55	52.34	52.61	32.14	33.08
Al_2O_3	2.02	2.68	3.05	16.49	12.95
TiO_2	0.04	0.11	0.25	n.a.	n.a.
Cr_2O_3	0.69	1.17	1.30	1.84	2.95
FeO	5.75	1.78	1.99	0.83	1.50
MnO	0.16	0.07	0.08	n.a.	n.a.
MgO	33.51	16.90	16.54	34.43	34.61
CaO	1.28	23.65	23.46	–	–
Na_2O	–	0.32	0.36	0.01	–
K_2O	n.a.	n.a.	n.a.	–	0.05
H_2O	n.a.	n.a.	n.a.	12.65	12.46
Total	100.00	99.02	99.64	98.39	97.60
	Cations per 6 oxygens			per 16 OH	
Si	1.953	1.923	1.919	6.096	6.37
Al^{IV}	0.047	0.072	0.081	1.904	1.63
Al^{VI}	0.035	0.039	0.053	1.781	1.31
Ti	0.001	0.002	0.006		
Cr	0.019	0.034	0.037	0.276	0.45
Fe	0.166	0.055	0.061	0.132	0.24
Mn	0.004	0.002	0.002		
Mg	1.724	0.925	0.899	9.732	9.93
Ca	0.047	0.931	0.917	–	–
Na	–	0.023	0.025	0.006	–
K				–	0.01
		Ca 48.7	48.8		
En	91.0	Mg 48.4	47.9		
Fs	9.0	Fe 2.9	3.3		

n.a. - not analyzed

Sample location and lithology:

1. Miraflores, borehole PE-2 25.9 m, harzburgite (average of 4 analyses)
2. Miraflores, borehole PE-2 25.9 m, harzburgite (average of 2 analyses)
3. Miraflores, borehole PE-2 41.5 m, harzburgite (average of 4 analyses)
4. Amores mine, massive ore (1 analysis)
5. Monte Bueno, schlieren ore (1 analysis)

←Fig. 7
Platinum-group mineral in chromite, Monte Bueno deposit: a) Fe, K_α X-ray image; b) Ru, L_α X-ray image; c) Ir, M_α X-ray image; d) Os, M_α X-ray image. The lengths of the bars are 10 μm

Table 3
Microprobe analyses of olivines and uvarovites (uv)

	1	2	3	4	5	6
	olivines					uv
SiO_2	40.60	40.64	41.39	42.17	42.41	37.88
FeO	8.98	9.06	8.24	5.57	4.79	n.a.
MgO	48.94	48.76	50.45	52.18	53.08	n.a.
MnO	0.13	0.11	0.11	0.08	0.07	n.a.
CaO	0.01	0.01	0.01	0.06	0.03	36.32
NiO	0.34	0.29	0.37	–	0.54	n.a.
Cr_2O_3	–	–	–	0.10	–	12.31
Al_2O_3	n.a.	n.a.	n.a.	n.a.	n.a.	12.75
Total	99.00	98.87	100.57	100.16	100.92	99.26
	Cations per 4 oxygens					12 ox*
Si	1.002	1.005	1.002	1.010	1.007	2.994
Fe	0.185	0.187	0.166	0.112	0.095	–
Mg	1.800	1.796	1.820	1.864	1.878	–
Mn	0.002	0.002	0.002	0.002	0.001	–
Ca	0.001	0.001	0.001	0.001	0.001	3.076
Ni	0.006	0.005	0.006	–	0.010	–
Cr	–	–	–	0.002	–	0.769
Al	–	–	–	–	–	1.187
Fo	90.56	90.47	91.52	94.30	95.10	
Fa	9.44	9.53	8.48	5.70	4.90	

n.a. - not analyzed

* Cations per 12 oxygens

Sample location and lithology:
1. Miraflores, borehole PE-2 25.9 m, harzburgite (average of 12 analyses)
2. Miraflores, borehole PE-2 41.5 m, harzburgite (average of 4 analyses)
3. Miraflores, borehole PE-2 466.0 m, harzburgite (average of 8 analyses)
4. Amores mine, massive ore (average of 2 analyses)
5. Mercedita mine, massive ore (average of 7 analyses)
6. La Melba, massive ore (average of 3 analyses)

chamber, within the mantle, in "mini chambers" (Brown 1980) or "cavities" (Lago et al. 1982). Thus, the persistence of dunitic halos could be explained by a fractionation sequence olivine–chromite. The Cr–Al reciprocal relationship was interpreted as a result of gradual enrichment in Al and impoverishment in Cr of the magma as olivine and chromite were precipitated (Brown 1980).

According to this assumption, the different positions of podiform ore-bodies with respect to the enclosing rocks could also be elucidated. Parallel and subparallel deposits are likely to have formed in the main chamber and in

small pockets below the former, while columnar and other discordant ore-bodies have probably segregated along the path of the ascending magma.

Podiform chromite deposits tend to be confined to certain lithostratigraphic levels at several localities (e.g., Peters and Kramers 1974; Leblanc and Violette 1983) as in the Sagua–Baracoa area. This feature is generally interpreted as a consequence of abrupt changes of oxygen fugacity and/or pressure in the magma chamber (e.g., Roberts 1988). The latter process might cause indented nodules in the Yarey deposit; however, it seems likely that fluctuations in oxygen fugacity are also, if not mainly, responsible for enhanced chromite precipitation in a certain stage during the cumulus process (Peters and Kramer 1974; Watkinson and Mainwaring 1980).

The reason for the lack of correlation between the chemical composition of the ores and their stratigraphic position which may also occur (Brown 1980; Leblanc and Violette 1983) probably lies in the recurring character of the partial melting process and the fluctuation in the equilibrium conditions (Greenbaum 1977) which certainly cannot remain permanent in such a dynamic zone as a constructive plate margin. Thus, consecutive batches of magma of slightly differing bulk composition (Gass 1980) ascend in a narrow zone between the divergent lithospheric plates. As the temperature and pressure decrease upward, fractional crystallization begins at a certain depth depending on the magma composition, temperature, pressure, oxygen fugacity, etc. Primitive magma yields Cr-rich chromite as well as Mg-rich olivine (and, occasionally, platinum-group minerals) which may be precipitated below the oceanic crust, in small pockets. Therefore, somewhat differentiated melt reaches the main magma chamber, resulting in more aluminous chromite. There are numerous indications that the appearance of Al-rich chromite is roughly coeval with that of clinopyroxene and plagioclase which implies a genetic relation (Leblanc and Violette 1983). The reduced ratio of ultramafic cumulates to mafic suite, as well as high proportions of low-Cr, high-Al chromites suggest that the degree of partial melting was lower than in other ore districts.

Formerly it was thought that the site of chromite segregation was a mid-ocean ridge setting (e.g., Dickey 1975; Brown 1980). However, Miyashiro (1973, 1975), Pearce (1975) and Dewey (1976) had serious doubts about the midoceanic origin of some ophiolites which were subsequently ascribed to island arc environments (Hawkins 1980; Pearce et al. 1984). Roberts (1988) concluded that generation of the Tethyan chromites was more likely in marginal (fore-arc or back-arc) basin spreading zones. This inference may be valid also for the chromites of Cuba, as recent paleogeographic reconstructions have implied that the Cuban ophiolites represent an oceanic crust formed in a small ocean basin (Iturralde-Vinent 1988; Ross and Scotese 1988) which opened in the Middle Jurassic between Yucatan and South America. This Proto-Caribbean basin was generated by rifting in a NE–SW trending ridge, apparently independent of subduction processes. Nevertheless, the spreading centre was situated in the mantle wedge above the northeastward subducted Farallon plate, behind the

Proto-Greater Antilles island arc (Ross and Scotese 1988). This may explain the above-mentioned ambiguity of chemical compositions of the diabase dykes and pillow basalts of the study area.

Acknowledgements

We gratefully acknowledge P. Gyarmati, Zs. Peregi (Geological Institute of Hungary) and L. González (Expedición Geológica de Santiago de Cuba) for their support and assistance during field work. We also thank G. Dobosi (Laboratory for Geochemical Research, Hungarian Academy of Sciences) who performed a notable part of the microprobe analyses.

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