

Compositional variation in chromite from the Eastern Desert, Egypt

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Abstract

Electron microprobe analyses of chromite ores from Baramiya, Seifein, Siwigat, Ashayer, Um Salatit and Ras Shait, Egypt, reveal two compositional groups. The unaltered chromites from Baramiya and Seifein have high Al and low Cr contents [$Cr/(Cr + Al) = 0.56$] whereas the remainder have low Al and high Cr contents [$Cr/(Cr + Al) = 0.73$]. Such bimodality characterises Alpine-type peridotites. The second group probably crystallised at higher T and lower P than the first group and has a composition characteristic of a type III alpine-type peridotite, i.e. of arc or possibly ocean plateau origin but not of mid-ocean ridge origin. The crystallisation setting of the first group is less certain but not inconsistent with the same environment as the second group so that considering the likely higher pressure of crystallisation of the first group overall favours plutonic crystallisation in the roots of an arc for both groups.

Rim, patchy and fracture alteration of the chromite occurred possibly partly of late magmatic (deuteric) origin but mainly connected with fluid movements, serpentinisation and tectonism. The final composition of the resultant ferritchromite is variable and depends largely on the original chromite composition; the composition of the ferritchromite developed in highly cataclased chromites deviates markedly from that of the original chromite presumably due to unmixing and migration.

KEYWORDS: chromite, ferritchromite, Eastern Desert, Egypt.

Introduction

THE main chromite occurrences in Egypt (Fig. 1) lie in the central part of the Eastern Desert (Afa and Imam, 1979) and have been considered by Amin (1948), Anwar *et al.*, (1969), Basta and Hanafy (1970), El-Sharkawi and El-Bayoumi (1979), and Takla and Noweir (1980). El-Haddad and Khudeir (1989) described six of these deposits at Um Salatit, Baramiya, Ashayer, Seifein, Siwigat, and Ras Shait (Fig. 1). The chromites are enclosed in massive to schistose serpentinites as gently folded tabular sheets and lenses, mullions, boudins and pods, up to 3 m thick and up to 7 m long. Relics of the parental rocks of the serpentinites are rare, but where present are harzburgite with subordinate dunite.

The serpentinites do not seem to be parts of one disrupted body but rather a series of late Precambrian sheets or slices often associated with silt-

stones or volcanic sequences (sometimes pillow lavas). Many are allochthonous ophiolitic melanges according to Ries *et al.* (1983) who give the best general account of the geology and state that they have no evidence as to the original environment of crystallisation of the ophiolites, whether mid-oceanic ridge or other setting. This account aims to provide some indication. The different chromites studied here come from discrete tectonic units but were emplaced during a subduction episode which is of late Precambrian age. Tectonisation is common at Ras Shait and to a lesser extent at Um Salatit. The chromite lenses and enclosing serpentinite of Ras Shait are highly deformed due to their occurrence along the sole thrust separating the obducted Pan-African ophiolitic melange from the underlying infrastructural rocks of the Hafafit swell (El-Gaby *et al.*, 1988). The serpentinites are moderately to intensely transformed into talc-carbonates, par-

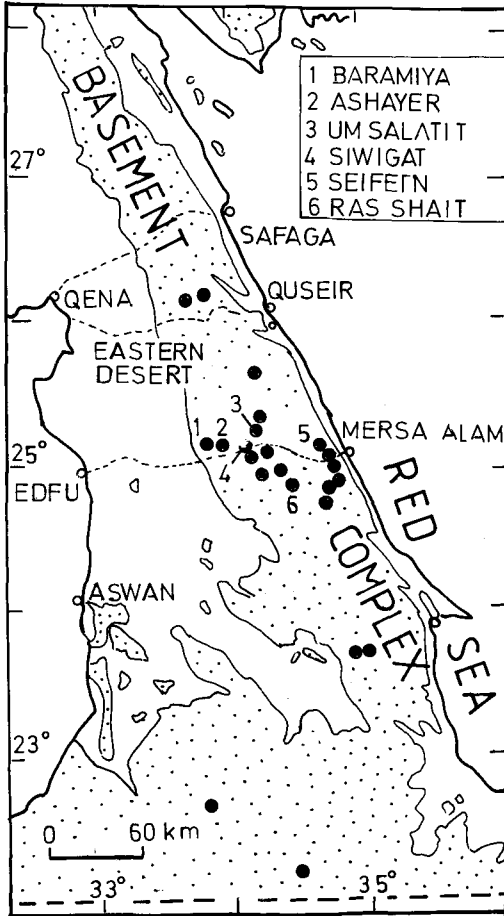


Fig. 1. Locations of chromite deposits in the Eastern Desert of Egypt after Afia and Iman (1979) with the six studied localities named.

ticularly along faults and shear zones. Because the chromite grains are not of uniform composition and displayed varying degrees of transformations, electron microprobe analysis of the grains was performed to elucidate the petrogenetic significance of the chemical variations previously observed (El-Haddad and Khudeir, 1989) and to study the secondary changes in chromite.

Microscopy

Microscopy confirmed the previous discrimination of the chromitites into massive, nodular and disseminated (El Haddad and Khudeir, 1989). Cumulate texture is usually characteristic. The massive ore is commonly dissected by two

closely-spaced sets of fractures (e.g. Baramiya) or brecciated (e.g. Ras Shait). The nodular chromite (e.g. Siwigat) shows subrounded coarse grains or aggregates, while the disseminated chromite occurs generally as idiomorphic to subrounded grains. The matrix in the less altered ores consists mainly of antigorite, with subordinate amounts of chlorite, magnesite and talc. The alteration of chromite to ferritchromite occurs along grain boundaries and fractures or in patches. The matrix in the altered varieties is largely composed of magnesite, chlorite and a little antigorite. Magnesite-filled fractures, and sheaths of chlorite around altered chromite occur with some Cr-chlorite. Small chromites in disseminated ore (e.g. Ashayer) are largely to wholly altered to ferritchromite. Chromite in the massive (e.g. Baramiya) and nodular (e.g. Siwigat) ores has rim alteration and wide altered zones along fractures. Reflectivity increases gradually or abruptly across the contacts between the chromite relics and the altered parts. Rim and some patchy alterations are present in the least deformed chromites. The alteration of chromite to ferritchromite may have initiated during the late magmatic stage but is mainly connected with serpentinisation and tectonism. The mechanism of ferritchromite formation is not resolved (Takla, 1982), but highly sheared chromite (e.g. Ras Shait) is almost entirely transformed into Al-poor, Cr-rich ferritchromite.

Chemistry

Electron microprobe analyses on chromites from the six localities were carried out in the Department of Geology and Applied Geology, University of Glasgow and 49 representative results are given in Table 1.

The chromites from Baramiya (B) and Seifein (Sf) generally possess a narrow composition range (Cr_2O_3 : 45.23–47.27%), while Siwigat (Sw) and Ashayer (A) chromites are slightly richer in Cr (Cr_2O_3 : 54.6–55.7%)—similar to fresh chromite from Um Salatit (Us). Altered chromite (Us 14) tends to be somewhat higher in Cr_2O_3 (61–62%) and FeO, but lower in Al_2O_3 and MgO than the associated unaltered chromite. Strongly deformed Ras Shait samples (Rs 14, 17) are generally highly altered, with rare fresh chromite relics. Less deformed samples (Rs 11, 12) contain more fresh chromite relics, so alteration is dependent on the degree of deformation. The fresh chromite relics are similar (Cr_2O_3 : 51–53%) to those from Um Salatit, Ashayer, and Siwigat. The altered chromite, optically identified as ferritchromite, is enriched in Fe_2O_3 , Cr_2O_3 and

FeO at the expense of Al_2O_3 and MgO in fresh chromite relics.

Petrogenesis

On a Cr_2O_3 - Al_2O_3 -(MgO + FeO) plot (Fig. 2) the unaltered chromites cluster in two groups: those of Seifein with Baramiya and those of the other localities. The plots of the altered parts (ferritchromite) which occur as rims and patches are always shifted to the left-hand side of the diagram, reflecting the loss in Al_2O_3 . The unaltered chromites fall in the field of aluminian chromite of Stevens (1944) close to the Cr-Al side line, while the ferritchromite spans the fields of Al-chromite and ferrian chromite (Fig. 3), depending on the degree of Al loss.

Irvine (1967), Thayer (1970), and Hutchison (1972) have found that Al content increases at the expense of Cr in alpine-type chromites, while stratiform chromites become progressively richer in total iron with decreasing Cr content. Another interesting difference is that stratiform chromites have characteristically a unimodal and restricted Cr range while alpine-type or podiform chromites have a much wider range of Cr which is characteristically bimodal (Thayer, 1970) as in the present samples where Cr per unit cell displays two peaks around 8.75 and 10.75. The Mg/Fe^{2+} ranges between 1.08 and 3.4 while the Cr/Al lies between 1.26 to 2.93 (Table 1). The chromites from Baramiya and Seifein have lower Fe^{2+}/Mg than the remaining samples suggesting that the latter

are more differentiated. The Ashayer chromites have a higher Fe^{3+} and may have crystallised under higher f_{O_2} (Fig. 4). The reciprocal variation between Cr and Al (at near constant total iron content) and the relatively limited increase in Fe^{2+} and Fe^{3+} besides the bimodal range of Cr favour an alpine-type mode of origin.

The bimodal nature of the samples is displayed in Figs. 5 and 6. The Fe_i content shows narrow variation relative to the wide range of Cr content (Fig. 5B). Irvine (1967), Bryan (1972), Frey *et al.* (1974) and Dick and Bullen (1984), have all agreed that high-Al spinels in alpine podiform dunites have crystallised at higher pressures in the mantle than lower Al samples. Thus, it is inferred that the chromites of Baramiya and Seifein crystallised at higher pressures than the remaining samples (El-Haddad and Khudeir, 1989).

The plots of fresh chromite in Fig. 6 fall outside the field of abyssal spinel peridotites (Dick and Fisher, 1983) and correspond to Type III alpine peridotites (Dick and Bullen, 1984) similar to the chromites from the Twin Sisters Dunite and Troodos complex (Fig. 5). According to Dick and Bullen (1984), the spinels in alpine-type peridotite Type III have $\text{Cr} \times 100/(\text{Cr} + \text{Al}) > 60$ similar to present-day arc-related lavas from SE Alaska and continental layered intrusions and oceanic plateau basalts. This would appear to preclude a mid-ocean ridge origin. The Siwigat chromites as plotted on Fig. 6 are close to, but not identical with, the Jijal chromites from chromitites in NW Pakistan which after extensive investigations by Jan and Windley (1990) were believed to be

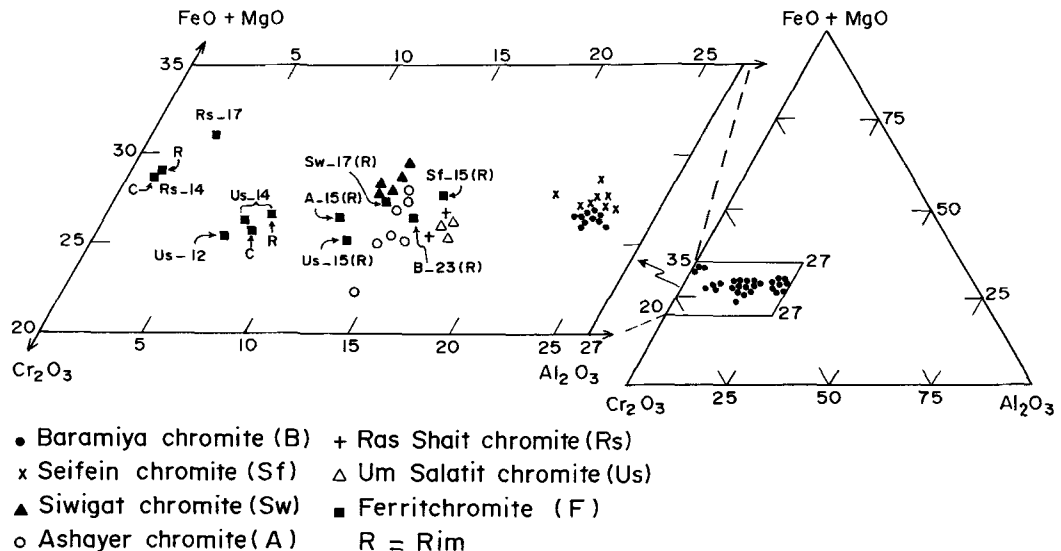


FIG. 2. Plot of Al_2O_3 - Cr_2O_3 -(FeO + MgO) showing unaltered chromite.

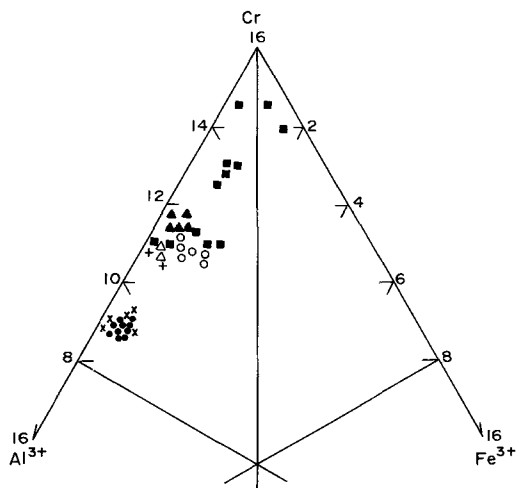


FIG. 3. Composition of the studied chromites and ferritchromites on Stevens' (1944) classification diagram. Symbols as in Fig. 2.

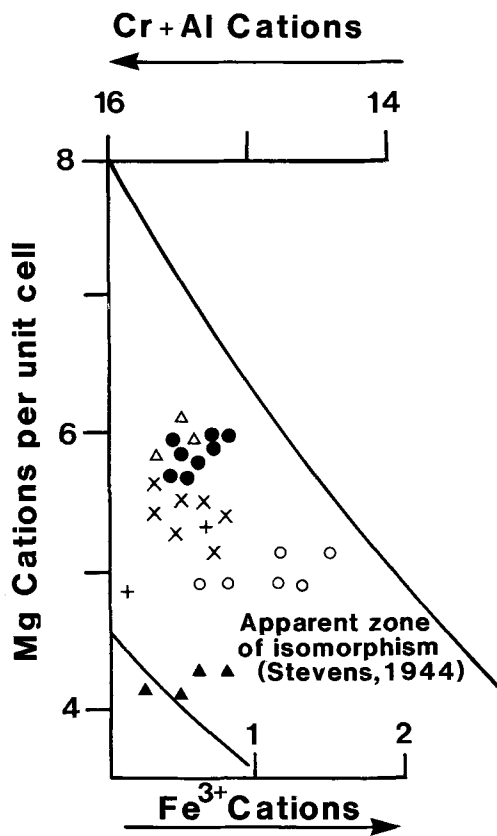


FIG. 4. Plots of fresh chromites on Stevens' (1944) diagram. Symbols as in Fig. 2.

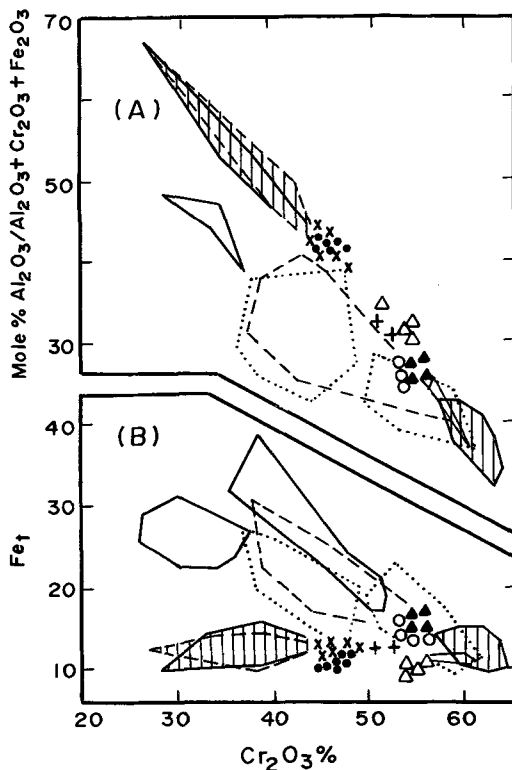


FIG. 5. Compositions of the analysed chromites in relation to the compositional ranges of different stratiform complexes (blank outlined areas) and alpine-type complexes (ruled areas) as delineated by Thayer (1970). Symbols as in Fig. 2.

formed in the plutonic roots of an island arc, a situation which is therefore suggested as the source region of the present rocks.

Zoning and alteration

The cation variations across representative chromite grains are illustrated in Fig. 7. The composition of the broad cores, assumed to reflect the original crystallisation conditions of the chromite bodies, depict smooth regular variation within a narrow range and do not reveal primary zoning similar to that described by Takla (1982) and Ozawa (1983).

The passage from fresh core to altered patches or rim is gradual or abrupt with general increase in Fe²⁺, Fe³⁺ and sometimes Cr accompanied by loss of Al and Mg. Cr and sometimes Cr + Fe³⁺ replaced Al while Fe²⁺ or Fe²⁺ + Mn replace Mg. In a few cases Fe³⁺ increases at the expense of

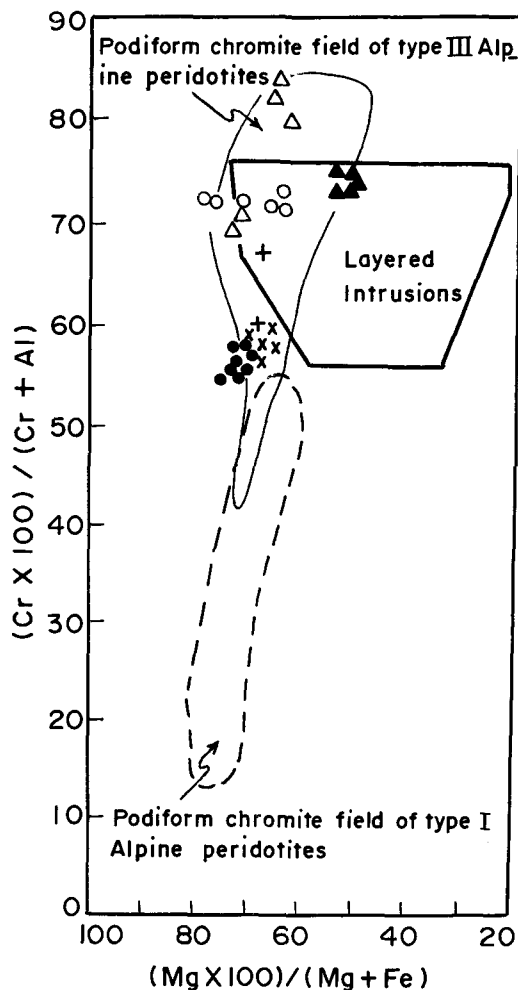


Fig. 6. Variation in $\text{Cr}/(\text{Cr} + \text{Al})$ versus $\text{Mg}/(\text{Mg} + \text{Fe}^2)$ showing the fields Type I and III alpine peridotites (Dick and Bullen 1984) with the field of layered intrusions delineated by Irvine (1967). Type I alpine peridotites are abyssal spinel peridotites. Symbols as in Fig. 2.

Fe^{2+} indicating oxidation although Cr and Al contents remain almost constant (Fig. 7, A-15). The chemical changes vary within a wide range and increase with the intensity of deformation but in general Al and Mg were removed from chromite to form chlorite or serpentine. The most likely mechanism of movement is by late post-magmatic hydrothermal solutions. Cr, which has only a limited solubility (Engin and Aucott, 1971) is mainly but not entirely left behind to combine with the added Fe which is displacing the removed

Al and Mg. This process of producing ferritchromite is well recognised (e.g. Beeson and Jackson, 1969; Engin and Aucott, 1971; Jan and Windley, 1990) and is probably related to unmixing accelerated by the presence of fluids as miscibility gaps develop with falling temperature in the chromite system (Zakrzewski, 1989). Cr becomes more mobile when fluid movement is combined with intense cataclasis and Si movement also occurs giving quartz veinlets at Ras Shait. Here the introduction of Si (+ Fe^{2+}) observed in Rs 14, 17 (Fig. 7, Table 1) is at the expense of Cr and Fe^{3+} giving Al-poor, Cr-rich ferritchromite which is very different from the original chromite composition. Magnesite indicates the presence of CO_2 in the fluid phase.

Although ferritchromite has a wide range of composition and a simple formula cannot be given (Fig. 2) most of it falls within the aluminian chromite field of Stevens (1944) and could be referred to as aluminium ferritchromite. The final composition depends largely on the original chromite composition, i.e., each chromite group has its own ferritchromite composition (Fig. 2). This applies only as long as cataclasis is not intense otherwise the composition is shifted far away from the position of the original chromite ore (RS 14, 17; US 12, 14; Fig. 2).

Summary and conclusion

Massive, nodular and disseminated chromitites exhibit cumulus textures, were variably cataclased and altered to ferritchromite. Rim, patchy and fracture alteration occur. Rim and patchy type alterations are earlier than the fracture alteration which is tectonically controlled. The ferritchromite is variable in composition and mainly controlled by the original composition of the chromite host unless cataclasis was intensive.

Geochemical studies reveal that the largely unzoned chromitites belong to podiform chromitite deposits occurring in type III of alpine-type peridotites. The large reciprocal variation of Cr and Al (Thayer, 1970) at a narrow range of $\text{Mg}/(\text{MgO} + \text{FeO})$ (Irvine, 1967), the wide range of Cr content, the tendency to a bimodal distribution of Cr content and the absence of iron enrichment as Cr falls, all point to an alpine-type peridotite formed in the upper mantle under varying pressures signified by varying Al content. The most probable source region was the plutonic root of an island arc.

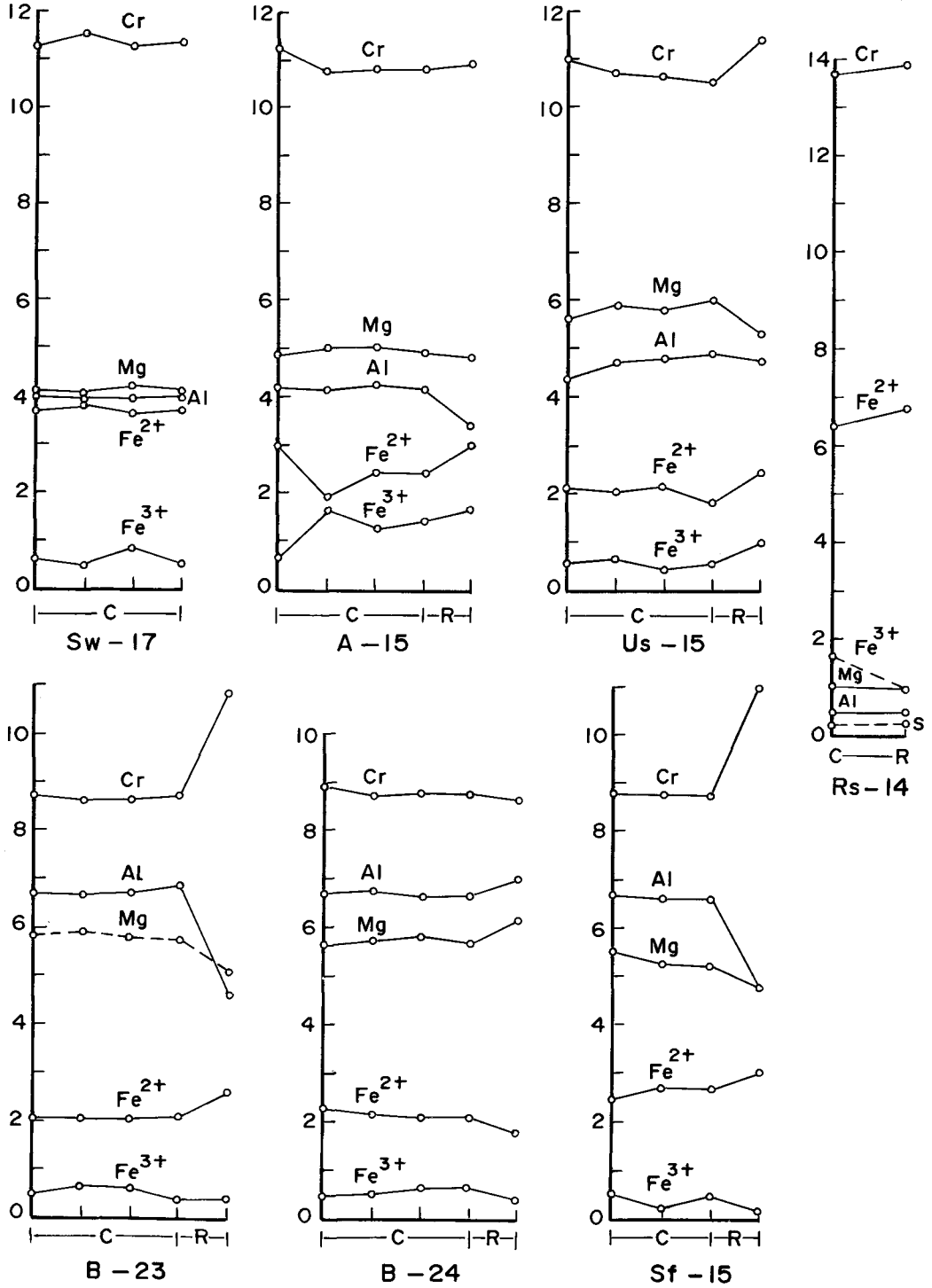


FIG. 7. Distribution of cations per unit cell (from core C to rim R) in some of the studied chromites. Upper plots with more than 10 Cr ions per unit cell, lower plots with less than 9.

References

- Afa, M. S., and Iman, I. (1979) *Mineral map of Egypt, Scale 1:2000000, with explanatory notes and lists*. Geol. Surv. Egypt., 44P.
- Amin, M. S. (1948) Origin and alteration of chromites from Egypt. *Econ. Geol.*, **43**, 133–53.
- Anwar, Y., Kotb, H., and Zohny, N. (1969) Geochemistry of Egyptian chromites. *Bull. Fac. Sci., Alex. Univ., Alex. Egypt.*, 142–82.
- Basta, E. Z. and Hanafy, M. A. (1970) Alteration of some Egyptian chromites. *Proc. Egypt. Acad. Sci.*, **23**, 1–7.
- Beeson, M. H. and Jackson, E. D. (1969) Chemical composition of altered chromites from the Stillwater Complex, Montana. *Amer. Mineral.*, **54**, 1084–1100.
- Bryan, W. B. (1972) Mineralogical studies of submarine basalts: *Carnegie Inst. Wash. Yearb.*, **71**, 394–402.
- Dick, H. J. B. and Bullen, T. (1984) Chromian spinel as a petrogenetic indicator in abyssal and alpine-type peridotites and spatially associated lavas. *Contrib. Mineral. Petrol.*, **85**, 54–76.
- and Fisher, R. L. (1983) Mineralogic studies of the residues of mantle melting. *Proceedings 3rd International kimberlite Conference*. Developments in Petrology Series, Elsevier.
- El-Gaby, S., List, F. K. and Tehrani, R. (1988) Geology, evolution and Metallogenesis of the Pan-African belt in Egypt: In *The Pan African Belt of Northeast Africa and Adjacent areas*, Viewegverlag. (S. El-Gaby and R. D. Greiling, eds).
- El-Haddad, M. A. and Khudeir, A. A. (1989) Geological and geochemical studies on some chromite deposits in the Central Eastern Desert, Egypt. *Bull. Fac. Sci., Assiut Univ.*, **13** (1-F), 141–58.
- El-Sharkawi, M. A. and El-Bayoumi, R. (1979) The ophiolites of Wadi Ghadir, E. D., Egypt. *Annals Geol. Surv. Egypt*, **9**, 125–35.
- Engin, E. and Aucott, J. W. (1971) A microprobe study of chromites from the Andizlik-Zimparalik area, south-west Turkey. *Mineral. Mag.*, **38**, 76–82.
- Frey, F. A. Bryan, W. B. and Thompson, G. (1974) Atlantic Ocean floor: Geochemistry and petrology of basalts from legs 2 and 3 of the Deep-Sea Drilling Project. *J. Geophys. Res.*, **79**, 5507–27.
- Hutchison, C. S. (1972) Alpine-type chromite in north Borneo, with special reference to Darvel Bay. *Am. Mineral.*, **37**, 835–56.
- Irvine, T. N. (1967) Chromian spinel as a petrogenetic indicator, Part 2, Petrologic applications. *Canad. J. Earth Sci.*, **4**, 71–103.
- Jan, Q. M. and Windley, B. F. (1990) Chromian spinel-silicate chemistry in ultramafic rocks of the J. ijal complex, NW Pakistan. *J. Petrol.*, **31**, 667–715.
- Ozawa, K. (1983) Evaluation of olivine-spinel geothermometry as an indicator of thermal history for peridotites. *Contrib. Mineral. Petrol.*, **82**, 52–65.
- Ries, A. C., Shackleton, R. M., Graham, R. H., and Fitches, W. R. (1983) Pan-African structures, ophiolites and melange in the Eastern Desert of Egypt: a traverse at 26°N. *J. geol. Soc. Lond.*, **140**, 75–96.
- Stevens, R. E. (1944) Composition of some chromites of the Western hemisphere. *Am. Mineral.*, **29**, 1–34.
- Takla, M. A. (1982) Chromites from the Bergen arcs ultramafics, southern Norway, *Neues Jahrb. Mineral., Abh.*, **144**, 56–72.
- and Noweir, A. M. (1980) Mineralogy and mineral chemistry of the ultramafic mass of El-Rubshi, Eastern Desert, Egypt. *Ibid.*, **140**, 17–28.
- Thayer, T. P. (1970) Chromite segregations as petrogenetic indicators. *Geol. Soc. S. Africa, Spec. Publ.* **1**, 380–90.
- Zakrzewski, M. A. (1989) Chromian spinels from Kusa, Bergslagen, Sweden. *Am. Mineral.*, **74**, 448–55.

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