ON THE COMPOSITION OF SOME INDIAN CHROMITES*

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Abstract

Chemical analyses and a study of the composition of some Indian chromites are presented for the first time. Complete analyses of nine samples of separated chromite and partial analyses of 29 samples of chrome ore are given. The samples have been collected from the States of Andhra, Bihar, Madras, Mysore and Orissa. One of the samples completely analyzed is from Baluchistan in Pakistan. On plotting the unit cell compositions of the nine samples of chromite on the triangular diagram, they are all found within the field of aluminian chromites. The Orissa deposits are mostly of metallurgical grade with Cr:Fe ratio exceeding 3:1. In the chromite from Singhbhum, Bihar, there is an appreciable amount of normative magnetite. In the case of the Kondapalle deposit, Andhra, there is a little normative magnetite in the chromite of the reef ore, which is absent in the chromite of detrital ore. The spinel content also is less in the detrital ore. This may be due to leaching of iron, some magnesia and alumina during weathering. In the Mysore chromite normative magnetite is high. The samples from Sittampundi, Madras, show high aluminum and total iron with low chromium.

Introduction

The aim of the present investigation was to study the chemical composition of some Indian chromites, as thus far no complete analyses of pure Indian chromites have been published. The materials are representative of some of the Indian chromite deposits in Andhra, Bihar, Orissa, Mysore and Madras, and include one specimen from Baluchistan in Pakistan. The location of the main chromite deposits of India is indicated on the accompanying sketch map.

Uses of Chromite

Chromite is used for various purposes which can be classed as metallurgical, refractory and chemical. For metallurgical purposes chrome ore is first converted into ferrochrome containing 60–70 per cent chromium. Ore suitable for this purpose should have at least 48 per cent chromic oxide, with a chromium:iron ratio of not less than 3:1. Silica should be low and combined alumina and magnesia should be less than 25 per cent.

Chromite as a refractory has a high resistance to corrosion and thermal changes and has a neutral character towards slags. Refractory grade chromite should have over 57 per cent of total chromic and aluminum oxides and not more than 5 per cent silica and 10 per cent iron.

For chemical purposes chromite is converted into alkali chromates or bichromates, some of which are used for (i) tanning leather, (ii) manufac-

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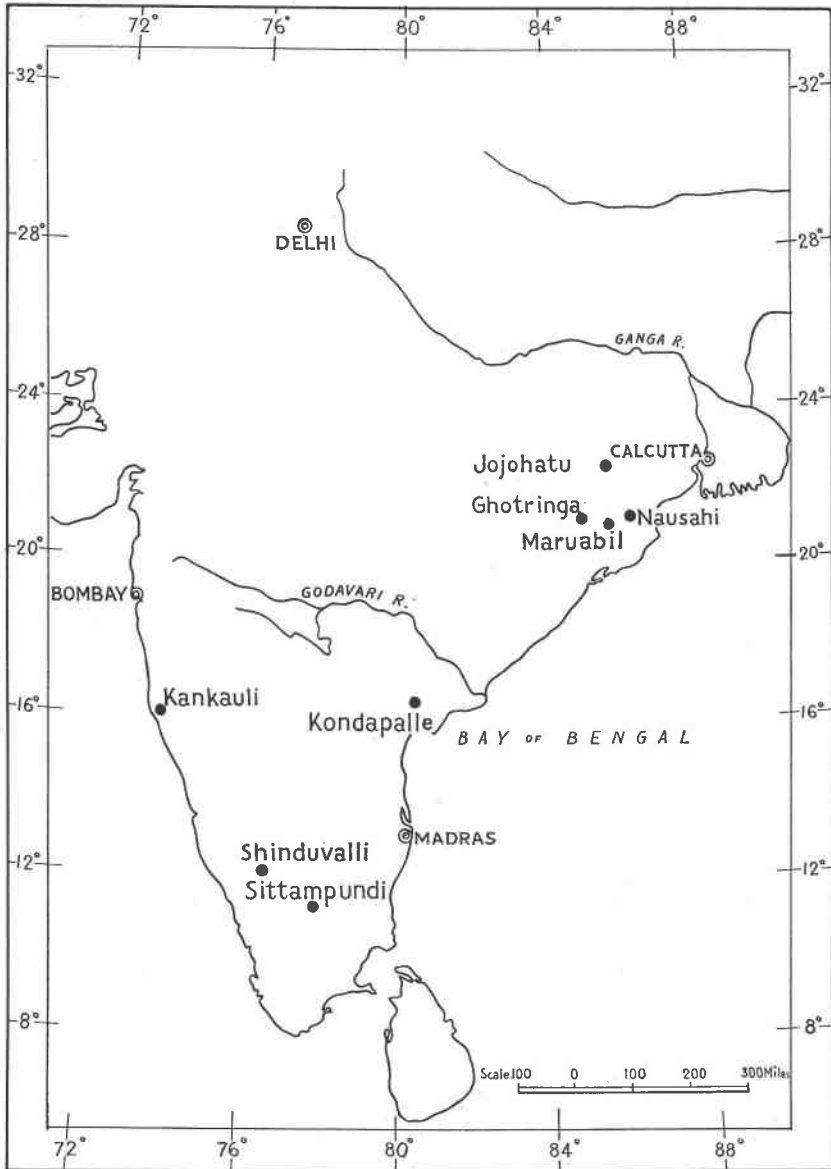* Published by permission of the Director, Geological Survey of India.

Fig. 1. Map showing major chromite deposits of India.

ture of pigments, (iii) for dyeing and (iv) for the surface treatment of metals. Chemical grade chromite should have a minimum of 45 per cent chromic oxide with a chromium:iron ratio of about 1.6:1. Silica should generally not exceed 8 per cent while the iron content may be high.

GEOLOGY OF CHROMITE DEPOSITS

Chromite deposits have been classified by Sampson (1942) into the following types: (1) Evenly scattered (or disseminated), (2) Schlieren-banded, (3) Stratified (with a bedded appearance), (4) Sack-form (or pockety) and (5) Fissure form (or vein-like). The deposits in India fall into these types. A brief description is given of the localities where the chromites studied in this paper have been taken.

Shinduvalli, Mysore. Here the chromite occurs as lenses and veins in a narrow band of peridotite running N–S for a couple of miles. The deposits are of the fissure-filling type or locally sack-form. Some of the lenses extend to a depth of 560 feet after which they fray out.

Kondapalle, Andhra. The chromite is found segregated into numerous small lenses and pockets in partly serpentinized ultrabasic charnockites consisting largely of enstatite and hypersthene. Much disseminated ore is also seen.

Sittampundi, Salem District, Madras. Here the chromite occurs in amphibolized pyroxenite rocks which occur as layered sheets with anorthosite. The ultrabasics are intrusive into biotite-gneisses. The chromite forms veins, lenses and disseminated bodies.

Singhbhum, Bihar. About 10 miles W.S.W. of Chaibasa, Singhbhum District, there are three laccolithic bodies of ultrabasics consisting of serpentinized peridotite, saxonite, dunite and pyroxenite, which are intrusive into shales. Chromite occurs as bands and segregations at or near the junction of the different types of rocks. The sides of the laccoliths are nearly vertical and faulted while the central portions are flat dipping.

Keonjhar, Orissa. The chromite deposits are situated on the southeastern fringe of Boula State forest, where the strike of the iron-ore series suddenly changes from N.E.–S.W. to W.N.W.–E.S.E. Into this disturbed zone of iron-ore series are intruded a group of rocks consisting of gabbro, peridotites and dunites associated with chromite, and anorthosite with vanadifrerous and titaniferous magnetite. The chromite forms schlieren bands, massive lenses and dissemminations in serpentine.

Cuttack and Dhenkanal, Orissa. The deposits here are found in a shear zone 30 miles long with a E.N.E.–W.S.W. strike in the eastern part (Sukinda area) and a N.W.–S.E. strike in the western part (Dhenkanal), the strike changing south of Maruabil (Dhenkanal). The shear zone is roughly parallel to the major shear between the Eastern Ghat facies

(khondalite-charnockite-granulite) and the iron-ore series. The chromite was intruded along the junction between quartzite and ultrabasics (south of Kaliapani, Sukinda), into the shear zone of peridotite (south of Maruabil) and along the marginal shears in quartzite (at the junction with granophyric granite?) near Ghotringa.

The deposits at *Hindubagh in Baluchistan, Pakistan*, are found as veins and irregular segregations in saxonite and dunite.

Geochemistry of Chromium

According to Goldschmidt (1937) the crystallization and separation of minerals are influenced greatly by the size of the ions of the principal metallic constituents. The smaller ions form a tighter bond and would be concentrated in the early crystals of an isomorphous series. The ions Al''' (ionic radius 0.57 Ångstrom), Cr''' (0.64 Å), Fe''' (0.67 Å), and Ti''' (0.69 Å) have similar ionic radii and consequently form isomorphous series, at least to a limited extent. Since these elements have relatively small ionic radii, they are differentated early during the crystallization of a magma. With the exception of iron, these elements are lithophilic and remain in the silicate magma even if a sulfide phase separates out early. Although iron is siderophile or thiophile, due to its abundance over sulfur in a normal magma, most of it must remain in the silicate-oxide phase.

As the ionic radii of Al''' and Cr''' are smaller than those of Fe''' and Ti''', it should be expected that they are more abundant in the early formed crystals, while iron and titanium will become concentrated in the later crystals of an isomorphous series. The divalent cations in chromite are MgO and FeO. Since Mg'' (0.78 Å) has a smaller radius than Fe'' (0.83 Å), it will be concentrated in comparison with iron in the early formed crystals. Thus, early formed chromite should be expected to be rich in aluminum, chromium and magnesium, while the later segregations should be progressively enriched in ferrous and ferric iron and titanium. Due to low iron in the early formed chromites, these are expected to have a high chromium:iron ratio. The end member ferrochromite, $FeO \cdot Cr_2O_3$ (32 per cent FeO and 68 per cent Cr_2O_3) cannot occur as a magmatic mineral because a natural magma always contains an abundance of aluminum and magnesium.

Separation of Chromite From the Gangue Minerals

When the chromite was ground to pass 100 mesh and separated by the use of heavy liquids, it was found that it still contained 3–4 per cent of closely adhering impurities or inclusions. A finer grinding to minus 200 mesh was adopted therefore, so as to reduce the impurities to about 1

per cent. An electric centrifuge was used for the separations. The material was examined under the microscope to ensure that it was clean for the purpose of chemical analysis.

GENERAL PLAN OF ANALYSIS

A number of methods are available for the decomposition of chromite. Fusion with a mixture of sodium carbonate and potassium nitrate (10:1 mixture) was used in the initial stages of the work. This method involves not only repeated fusions for the complete decomposition of the mineral but there is also an appreciable attack on the platinum crucible used. Fusion with sodium carbonate only in an oxygen atmosphere (Malhotra, 1954) was found to completely decompose the mineral in a single fusion in about 2 hours, without any notable attack on the platinum crucible. A stream of oxygen from a cylinder was directed on the surface of the melt by means of a bent platinum tube. Completion of the reaction was indicated by the cessation of the rise of gas bubbles in the melt. Silica, alumina, ferric oxide, titania, chromic oxide, manganous oxide, lime and magnesia were determined by the scheme of analysis shown below. Ferrous oxide was determined by the method of Gilbert (1943).

(1) Fuse 0.5 gm. chromite with 5 gm. sodium carbonate, completing the fusion by the supply of oxygen on the melt. Extract with water, add a few drops of alcohol and filter. Wash with 0.1 per cent sodium carbonate solution.

(2) Filtrate contains sodium chromate, sodium aluminate and sodium silicate. Add excess of sulfuric acid, oxidize with persulfate and neutralize with ammonium hydroxide. Redissolve and reprecipitate.

 (a) Combined filtrate contains sodium chromate. Titrate with potassium permanganate after acidifying with sulfuric acid, adding excess of ferrous sulfate, using o-phenanthroline ferrous complex as indicator.

 (b) Precipitate from (2) contains hydroxides of Al and Si. Fume with sulfuric acid, separate and estimate silica. Neutralize filtrate with ammonium hydroxide, filter, ignite and weigh as Al_2O_3 (1).

(3) Residue from (1) contains Fe, Ti, Al, Mn, Ca, Mg and silica. Dissolve in dilute HCl, bake to dehydrate silica. Dissolve in dilute HCl, filter off silica, ignite and hydrofluorize.

(4) Neutralize filtrate from (3) with ammonium hydroxide. Redissolve, reprecipitate and filter. Ignite the precipitate and weigh as $Fe_2O_3+Al_2O_3+TiO_2$. Estimate Fe_2O_3 and TiO_2, getting Al_2O_3 by difference. Add this to Al_2O_3 (1).

(5) Filtrate from (4) contains chlorides of Mn, Ca and Mg. Precipitate and weigh as pyrophosphates after ignition. Separate Ca as $CaSO_4$ with alcohol and estimate Mn colorimetrically,* obtaining Mg by difference.

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* It is better to reprecipitate Mn and Mg as phosphates in the alcoholic solution after separating $CaSO_4$. If this solution is evaporated to drive off alcohol, an explosive mixture is formed. Mn, Mg phosphates are then dissolved in sulfuric acid for the colorimetric determination of Mn.

The exact locality of the samples analyzed is given below:

(1) Surface lode sample of chromite deposits near Maruabil (21° 03':85° 43'), Dhenkanal district, Orissa. Collected by M. N. Deekshitulu and P. Perraju.

(2) Chrome ore produced by the Baluchistan Chrome Company, Hindu Bagh, Baluchistan.

(3) Chrome ore from Jojohatu (22° 31':85° 38'), Singhbhum district, Bihar.

(4) Detrital chrome ore derived from disseminated ore in serpentinized pyroxenite; from deposit on hill 2 miles NW. of Kondapalle (16° 37':80° 32½'), Kistna district, Andhra. Collected by M. S. Krishnan.

(5) Chrome ore from vein in pyroxenite. Locality near No. 4. Collected by M. S. Krishnan.

(6) Chrome ore produced by the Mysore Chromites Ltd., from Shinduvalli, Mysore.

(7) Chrome ore from Kolhan Government Estate, Singhbhum district, Bihar. Collected by H. C. Jones.

(8) Roro line of Badchambera chromite mine, Chaibasa, Bihar.

(9) Chromite from Nausahi (21° 17':86° 20'), Keonjhar district, Orissa.

TABLE No. 1. COMPLETE ANALYSES OF INDIAN CHROMITES

Locality	1 Maru-abil	2 Hindu Bagh	3 Jojo-hatu	4 Konda-palle	5 Konda-palle	6 Shindu-valli	7 Holhan govt. estate	8 Chai-basa	9 Keon-jhar
Cr_2O_3 %	61.44	56.46	49.38	55.17	49.98	51.52	52.77	57.38	55.93
Al_2O_3	10.66	12.35	13.80	15.17	15.86	11.56	13.36	10.63	12.19
Fe_2O_4	1.67	3.35	5.83	—	3.99	7.67	2.87	2.62	0.96
TiO_2	0.15	0.23	0.61	0.18	0.33	0.22	0.69	0.43	0.88
FeO	9.86	11.05	16.91	19.29	17.78	12.11	19.20	16.33	18.30
CaO	trace	trace	0.19	0.36	0.25	0.34	0.28	0.25	0.21
MnO	trace	trace	0.17	0.25	0.15	0.17	0.20	0.22	0.41
MgO	15.90	15.38	12.25	9.77	11.86	15.21	10.31	11.77	10.30
SiO_2	0.65	1.34	0.84	0.26	—	0.66	—	0.14	0.16
H_2O	trace	—	0.08	—	—	0.18	—	—	0.12
Total	100.33	100.16	100.01	100.45	100.20	99.64	99.68	99.77	99.46
RO/R_2O_3	0.95	1.00	1.04	1.01	1.07	1.09	1.05	1.04	1.00
Cr	42.06	38.66	33.78	37.74	34.22	35.27	36.13	39.28	38.29
Fe	8.83	10.93	17.20	14.99	16.61	14.78	16.93	17.13	14.89
Cr/Fe	4.76	3.54	1.96	2.52	2.06	2.39	2.13	2.29	2.57
% Cr_2O_3 in ore	56.0	52.30	47.0	52.53	39.40	49.00	38.20	50.60	38.42
% chromite in ore*	91.20	93.76	95.0	95.02	78.80	95.15	72.36	88.16	68.60
Impurity	Talc	Talc	Talc	Talc	—	Talc	—	Talc	Talc

Chromite separations and analysis by P. D. Malhotra.

* This has been obtained by dividing the chromium content of the ore by that of the purified mineral.

The following are the partial analyses of some run of mine Indian chrome ores:

TABLE 2

No.	SiO₂	Al₂O₃	Cr₂O₃	Total iron as FeO	MgO	Cr:Fe
1	25.08		37.18	14.12		2.3:1
2	20.40		43.86	15.21		2.5:1
3	12.08		51.08	15.67		2.9:1
4	16.92		50.31	12.41	3.6	3.6:1
5	16.60		48.50	17.06		2.6:1
6	15.12		45.92	16.44		2.5:1
7	16.80		49.79	13.81		3.2:1
8	16.76		47.98	13.03		3.2:1
9	7.18		50.47	12.99		3.4:1
10	7.62		49.96	13.38		3.3:1
11	8.74		48.94	12.80		3.4:1
12	6.40		51.23	13.57		3.3:1
13	11.66		46.38	11.82		3.5:1
14	12.50		43.20	13.08		2.9:1
15	6.18	5.24	52.12	18.12	15.38	2.6:1
16	7.84	1.53	56.64	16.67	16.09	3.3:1
17			54.21	12.48		3.8:1
18			55.98	12.42		4.0:1
19	0.68	17.90	46.16	23.06	9.2	1.8:1
20	6.32	17.35	38.89	22.75	10.21	1.5:1
21	4.60	17.80	45.80	20.80	9.2	1.9:1
22	0.90	19.80	48.30	21.80	8.5	2.0:1
23	3.32	16.32	49.90	20.36	10.0	2.2:1
24	6.18	24.04	24.44	34.50		0.6:1
25	13.32	41.31	21.73	22.53		0.9:1
26	14.36	29.98	28.20	22.38		1.1:1
27	0.25	25.62	32.98	27.96	5.41	1.0:1
28	1.54	27.76	36.08	30.21	10.02	1.1:1
29	1.56	13.29	50.63	18.51	14.65	2.4:1

Nos. 1 to 14: Surface lode samples of Boula chromite deposit, Keonjhar district, Orissa. Collected by P. K. Ghosh, G. H. S. V. Prasada Rao and S. V. P. Iyengar. Analyzed by P. D. Malhotra.

Nos. 15 & 16: Hand dressed ore from Boula chromite deposits Keonjhar district, Orissa. Collected by G. H. S. V. Prasada Rao. Analyzed by P. D. Malhotra.

Nos. 17 & 18: Surface lode samples of chromite deposits near Maruabil, Dhenkanal district. Collected by M. N. Deekshitulu and P. Perraju. Analyzed by P. D. Malhotra.

Nos. 19 & 20: Chrome ore near Kondapalle, Kistna district. Collected by M. S. Krishnan. Analyzed by Geological Survey of India.

Nos. 21 & 22: Chrome ore near Kondapalle, Kistna district, Andhra. Collected and analyzed by N. Venkatappayya.

No. 23: Chrome ore concentrate from Kondapalle, Kistna district, Andhra. Beneficiated by tabling by Mr. P. I. A. Narayanan.

Nos. 24 to 26: Chrome ore from Sittampundi, Salem district, Madras. Collected by N. K. N. Aiyengar and A. P. Subramaniam. Analyses by Geological Survey of India.

Nos. 27 & 28: Chrome ore concentrate from Sittampundi, Salem district, Madras. Collected by N. K. N. Aiyengar and A. P. Subramaniam. Analyzed by P. T. Ramacharlu.

No. 29: Chrome ore from Shinduvalli, Mysore, B. Rama Rao, (1945).

COMPOSITION OF CHROMITE

Chromite is a member of the spinel group of minerals and has the general formula $RO''.R_2'''O_3$, where R'' stands for a bivalent metal (mainly ferrous iron and magnesium) and R''' represents trivalent chromium, aluminum, iron and titanium. The formula may be written as $(Fe, Mg)O \cdot (Cr, Al, Fe)_2O_3$. The analyses in Table 1 show that Fe_2O_3 is a minor constitutent in all the specimens excepting the detrital specimen from Kondapalle. Following the method of Thayer, the composition may be expressed in terms of molecular ratio of RO and R_2O_3 constituents. The formulae for the nine complete analyses are as follows:

No. 1	$(Mg_{78} Fe_{22})$	$(Cr_{78} Al_{20} Fe_2)$
No. 2	$(Mg_{71} Fe_{29})$	$(Cr_{72} Al_{24} Fe_4)$
No. 3	$(Mg_{57} Fe_{43})$	$(Cr_{66} Al_{27} Fe_7)$
No. 4	$(Mg_{49} Fe_{51})$	$(Cr_{71} Al_{29})$
No. 5	$(Mg_{58} Fe_{42})$	$(Cr_{63} Al_{30} Fe_7)$
No. 6	$(Mg_{71} Fe_{29})$	$(Cr_{66} Al_{22} Fe_{12})$
No. 7	$(Mg_{50} Fe_{50})$	$(Cr_{70} Al_{26} Fe_4)$
No. 8	$(Mg_{57} Fe_{43})$	$(Cr_{76} Al_{21} Fe_3)$
No. 9	$(Mg_{51} Fe_{49})$	$(Cr_{75} Al_{24} Fe_1)$

It is thus seen that except for the detrital chromite from Kondapalle (No. 4) and the chromite from Singhbhum (No. 7), the rest of the chromites show a high molecular percentage of magnesium.

Ionic content of chromite unit cells

Following Bragg and Stevens, the unit cells of spinel structure are assumed to contain $8 (R''O \cdot R''_2O_3)$. Taking this as the unit cell content, the number of atoms of each metal present in the unit cell was calculated from the complete analyses in Table 1.

The method of calculation is as follows: Molecular ratios of oxides were first obtained by dividing the percentage of each oxide by molecular weights. After deducting the calculated amounts of silicate and ilmenite impurities the ratio of (RO) to (R_2O_3) was calculated. In all the analyses except No. 5 and No. 6 the ratio of RO to R_2O_3 was equal to 1, within experimental error (.95 to 1.05). But the values of ratios in No. 5 and No. 6 were 1.07 and 1.09, respectively. The Fe atoms in these analyses were adjusted between FeO and Fe_2O_3 so as to give the ratio of RO to R_2O_3 exactly equal to 1. The molecular ratios are then recalculated to atoms per unit cell, assuming 8 bivalent and 16 trivalent atoms in each unit cell.

The calculations for analysis No. 1 is given below as an example:

ANALYSIS NO. 1

	Per cent	Mol wt.	Molecular ratio	Atoms per unit cell	
Cr_2O_3	61.44	152.02	0.40415	Cr	12.454
Al_2O_3	10.66	101.94	0.10457	Al	3.224
Fe_2O_3	1.67	159.68	0.01046	Fe'''	0.322
			0.51918		16.000
FeO	9.86	71.84	0.10904−.00188[a] =0.10716	Fe''	1.732
MgO	15.90	40.32	0.39437	Mg	6.268
MnO	trace	70.93	—		—
CaO	trace	56.08	—		—
			0.50341−.0100[b] = .49341		8.000
TiO_2	0.15	79.90	.00188		
SiO_2	0.65	60.06	.00182		

$$RO/R_2O_3 = \frac{.49341}{.51918} = 0.95037$$

(a) Subtracting .00188 for ilmenite.
(b) Subtracting .00188 for ilmenite and .00812 for talc.

The number of trivalent and bivalent metallic ions per unit cell of the chromites are given in the table below:

No.	Cr.	Al	Fe'''	Fe''	Mg
1	12.46	3.22	0.32	1.73	6.27
2	11.57	3.78	0.65	2.30	5.70
3	10.46	4.36	1.18	3.46	4.54
4	11.35	4.65	—	4.12	3.88
5	10.10	4.78	1.12	3.38	4.62
6	10.54	3.53	1.93	2.29	5.71
7	11.19	4.23	0.58	4.03	3.97
8	12.12	3.35	0.53	3.45	4.55
9	11.93	3.88	0.19	3.92	4.08

The spinel triangular prism of composition: Variations in the chemical composition of chromite can be studied by plotting the unit cell compositions in the triangular prism devised by W. D. Johnston Jr. and described by R. E. Stevens. The six corners of the prism are occupied by
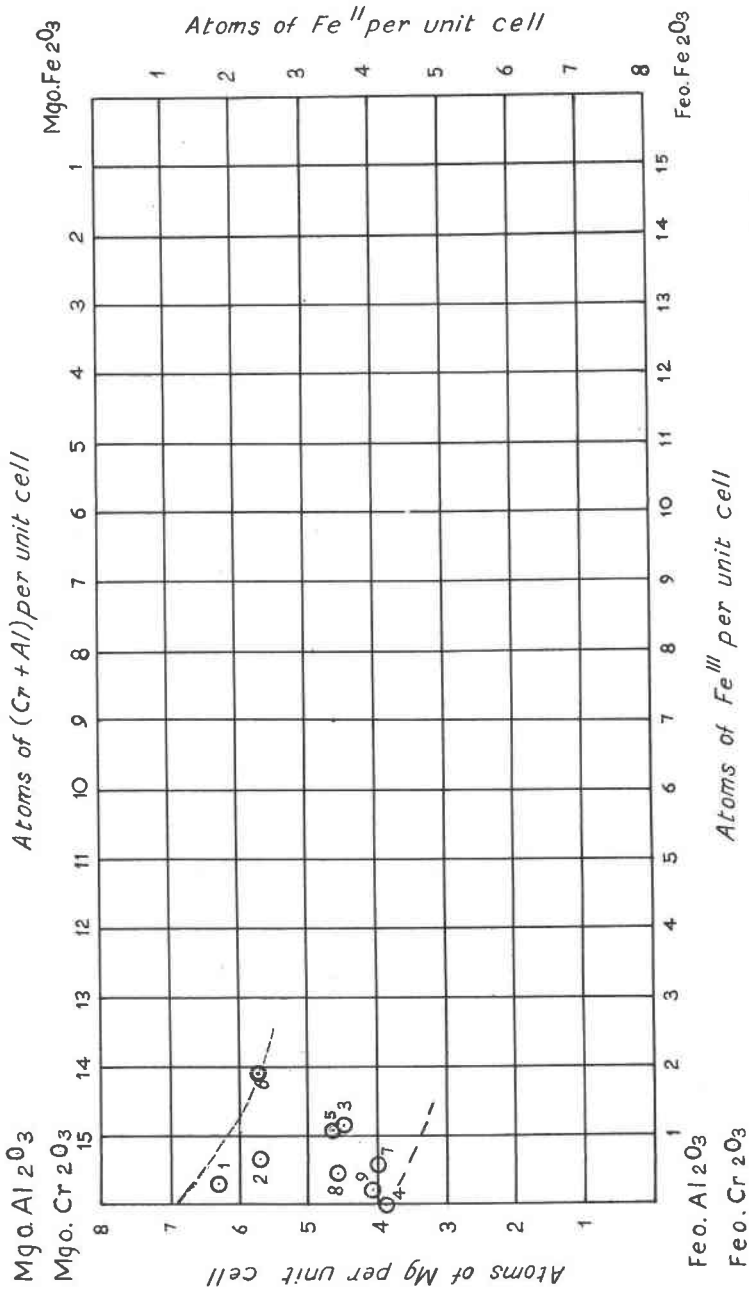
Fig. 2. Graph showing view of spinel triangular prism of composition along line of sight parallel to lines of equal ferric oxide content, showing zone of isomorphism.

$FeO \cdot Cr_2O_3$ (ferro-chromite), $FeO \cdot Al_2O_3$ (hercynite), and $FeO \cdot Fe_2O_3$ (magnetite) at the base of the prism and by $MgO \cdot Cr_2O_3$ (magnesio-chromite), $MgO \cdot Al_2O_3$ (spinel), and $MgO \cdot Fe_2O_3$ (magnesio-ferrite) at the top. Thus as the top of the prism is approached the magnesium content increases. The zone of isomorphism obtained by plotting the values can be seen in Fig. 2.

Triangular diagram: The triangular diagram (after R. E. Stevens) is divided into six fields by joining the apices of the triangle with the centers of opposite sides. The apices of the triangle are occupied by $(Mg \cdot Fe)$
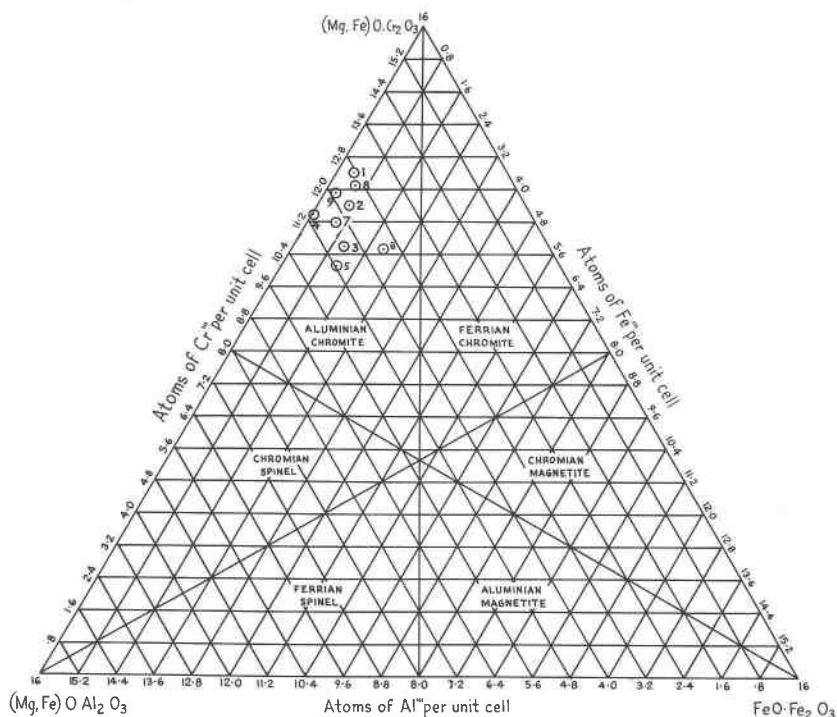

Fig. 3. Triangular diagram showing composition of Indian chromites.

$O \cdot Cr_2O_3$, $(Mg \cdot Fe)O \cdot Al_2O_3$, and $FeO \cdot Fe_2O_3$. Compositions falling in the upper two segments in which Cr_2O_3 is the major constituent in R_2O_3 radical, are classified as *chromites*. Those falling in the pair at lower left may be classed *spinels* and those falling in the pair on the right as *magnetites*. Plotting of the Indian chromites in this diagram shows that all of them are within the field of aluminian chromite (Fig. 3).

Expression of analyses in terms of end members: The end member system devised by Stevens, suited to express the chemical composition of Indian chromites is spinel-magnesiochromite-ferrochromite-magnetite.

The assignment of particular ions to particular end-member in this method is an arbitrary one adopted for comparing composition. The end member formulae per unit cell are obtained by the following equations:

$$Spinel = Al/2$$
$$Magnesio\text{-}chromite = Mg - Al/2$$
$$Ferro\text{-}chromite = (Cr + Al)/2 - Mg$$

where each element is given in atoms per unit cell. Magnetite can be obtained by subtracting the other end members from the eight formula weights taken as a unit cell.

TABLE 3

	End member percentages				
	1	2	3	4	5
Formula percentage					
Analyses Nos.					
(Table 1)					
Spinel	20.2	23.6	27.2	29.1	30
Magnesio-chromite	58.2	47.6	29.5	19.4	28
Ferro-chromite	19.6	24.8	35.9	51.5	35
Magnetite	2.0	4.0	7.4	—	7
Weight percentage					
Spinel	15.1	27.3	20.1	21.3	22.2
Magnesio-chromite	59.2	42.6	29.4	19.2	28.0
Ferro-chromite	22.3	25.8	41.6	59.5	41.3
Magnetite	2.4	4.3	8.9	—	8.5
Formula percentage					
	6	7	8	9	
Spinel	22.1	26.5	21.0	24.2	
Magnesio-chromite	49.3	23.1	35.9	26.8	
Ferro-chromite	16.6	46.8	39.8	47.9	
Magnetite	12.0	3.6	3.3	1.1	
Weight percentage					
Spinel	16.4	19.3	15.3	17.6	
Magnesio-chromite	49.6	22.8	35.3	26.3	
Ferro-chromite	19.5	53.6	45.6	54.7	
Magnetite	14.5	4.3	3.8	1.4	

Formula percentages are obtained by multiplying the formulae per unit cell by 100 and dividing by 8. The weight percentages of the end members are obtained by multiplying the formulae per unit cell by molecular weight and recalculating them to a total of 100. Table 3 shows formula percentages and weight percentages of the end members for the Indian chromites.

Summary

The chromites from the Keonjhar deposits show high chromium content and high Cr:Fe ratio. For Keonjhar one complete analysis, 14 partial analyses of lode samples and two analyses of dressed ore are presented. Most of them show a Cr:Fe ratio of more than 3:1, reaching 3.6:1 in one case. When the analysis is expressed in terms of end members, the ferrochromite content is higher than magnesio-chromite. But together with normative spinel, magnesium exceeds iron.

One complete analysis of chromite and two partial analyses of the samples from Dhenkanal are given. The Cr:Fe ratio is higher than 3.8:1 reaching 4.76:1 in the pure mineral. Here magnesio-chromite content exceeds ferro-chromite. On geochemical grounds, the chromite of Dhenkanal area appears to be an earlier differentiate than that of other areas.

The Singhbhum deposits are associated with peridotites, dunites and pyroxenites which are free from feldspar. Three complete analyses are presented with Cr:Fe ratio ranging from 1.96:1 to 2.29:1. The molecular composition varies from $(Mg_{57} Fe''_{43}) (Cr_{66}Al_{27}Fe'''_{7})$ to $(Mg_{57}Fe''_{43}) (Cr_{76} Al_{21} Fe'''_{3})$. In the end member composition, ferro-chromite is more than magnesio-chromite. There is appreciable magnetite content, but the total magnesium, together with the metal represented in normative spinel, is more than iron.

The Kondapalle deposits are found in pyroxenite and norite which are associated with acid to intermediate charnockites. From these, two complete analyses (one reef and one detrital sample) and four partial analyses are presented. The Cr:Fe ratio in the reef ore ranges from 1.5:1 to 2.06:1. In the end members, the composition of ferro-chromite is more than magnesio-chromite. Spinel is particularly high, this showing magnesium far in excess of iron. In the detrital ore the Cr:Fe ratio is 2.52:1. A little normative magnetite present in the reef sample is absent, while spinel is less than in the reef sample. This may possibly be interpreted as due to the leaching of iron, some magnesia and alumina during weathering, though one cannot be sure to what extent leaching does take place.

The Shinduvalli deposits occur in peridotites associated with dunites. One complete analysis and one partial analysis are given. The Cr:Fe ratio is 2.4:1. In the end members, the content of magnesio-chromite is in excess of ferro-chromite. Normative magnetite is appreciably high.

The Sittampundi chromite is in (aluminan) pyroxenite bands which are closely interbanded with anorthosites. They are represented by three partial analyses, with very high aluminum and total iron and low chromium. Cr:Fe ratio varies from 0.6:1 to 1.1:1.

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