Composition of Cr-spinel – an ore genetic indicator of Kathpal Chromite Deposit, Sukinda Ultramafic Complex, Orissa, India

Cr-spinel is a ubiquitous mineral in the ultramafic/ultrabasic rocks. When Cr-spinel crystallizes as an essential mineral (>50% by volume), the rock is termed as 'chromitite'. Compositionally, Cr-spinel is a solid solution[1] having the general formula $(Mg, Fe^{2+})O.(Cr, Al, Fe^{3+})_2O_3$. The major factors responsible for compositional control of Cr-spinel are: (i) composition of parent melt, (ii) composition of minerals crystallizing with Cr-spinel, (iii) melting behaviour of mantle – congruent/incongruent, (iv) nature of crystallization (equilibrium/fractional) and (v) physico-chemical parameters – temperature, pressure, fO_2, etc. The $Mg/(Mg + Fe^{2+})$, $Cr/(Cr + Al)$ and $Fe^{2+}/(Fe^{2+} + Fe^{3+})$ ratios of Cr-spinels are, thus, dependent on the above parameters. Application of Cr-spinel composition in deciphering the stratiform or podiform nature of the host intrusive is well-known[2–6]. In

the present study, the compositions of the Cr-spinel from the chromitite layer and the enclosing ultramafics are compared. The possible reasons for the variation in Cr-spinel composition are constrained in the light of ore genesis of the Kathpal Chromite Deposit, Sukinda Ultramafic Complex (SUC), Orissa, India. It may also be possible to predict how the physico-chemical conditions controlled the formation of chromitite. Samples for the present study were collected from hard and compact ore of Jungle Pit underground mine (–40RL), Kathpal.

The SUC occurs within Iron Ore Group (IOG) of rocks and spreads over >40 km^2 in a NE–SW direction from Tomka (east) to the present study area of Kathpal (west)[7] (Figure 1 a). The detailed geology of the SUC is available in published literature[7,8]. The SUC is a syncline and the

chromitite layers were co-folded with the older IOG rocks, indicating pre-folding intrusion of the chromite-bearing ultramafics[7,9]. In Kathpal area, ore bodies occur as discontinuous and randomly oriented small lenses. Both podiform[7] and stratiform origin[10–12] of chromite deposits of the SUC have been proposed. The role of fO_2 in the formation of chromitite layers is also advocated[11,12].

Under a microscope, the Cr-spinels in chromitite are polygonal shaped and show massive honeycomb texture with well-developed triple point junctions (Figure 1 b). At places, chromitite is affected by fracturing. The silicate gangue (<5% by volume) is thoroughly serpentinized. The proportion of silicate phases is higher in the contact zone. The Cr-spinel grains in the enclosing serpentinized ultramafic rocks are few and <5%. These grains are nor-
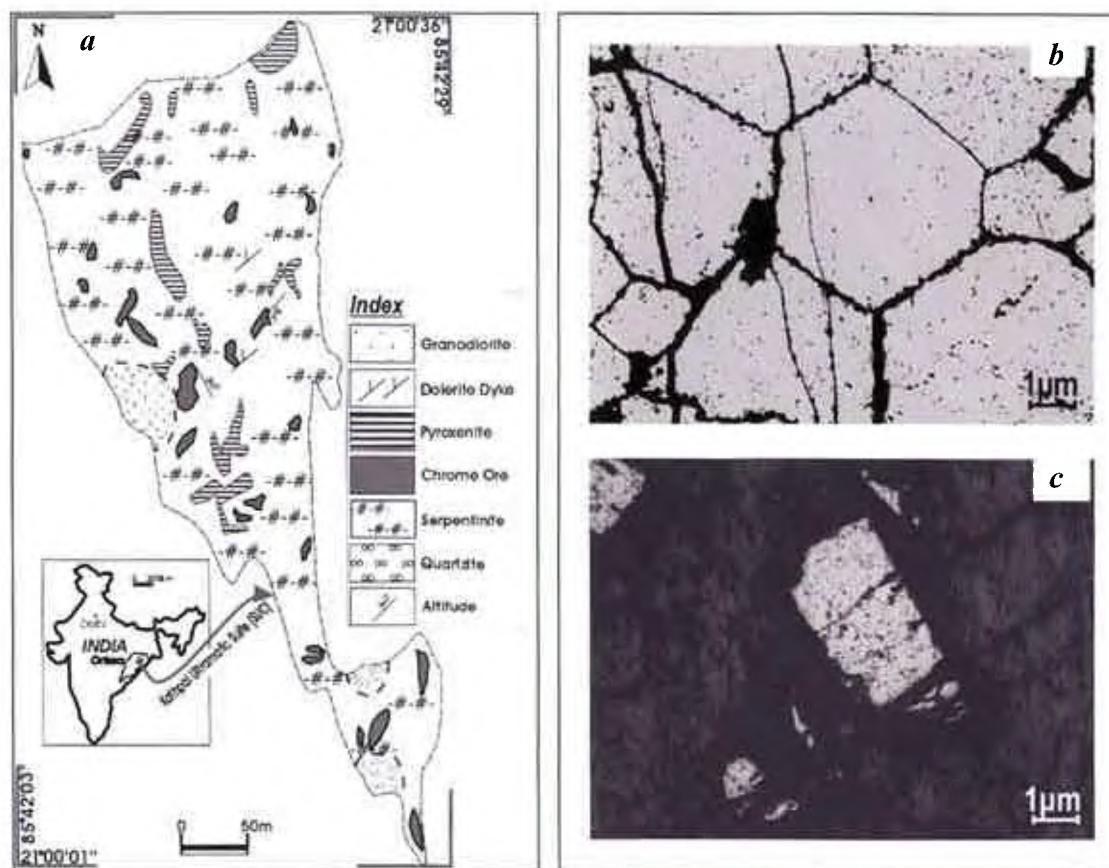

Figure 1. *a*, Geological map of Kathpal area[7]; *b*, Cr-spinel in chromitite, showing well-developed triple point junction; *c*, Cr-spinel in enclosing rock.

Table 1. Chemical composition (wt%) of Cr-spinel and various ratios from ore, contact zone and enclosing rocks

	Chromitite					Chromitite–hangingwall contact				Footwall rock					Hangingwall rock		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
$_2O_3$	58.56	60.71	60.23	58.15	59.24	61.40	60.55	61.29	61.04	55.58	55.99	55.69	55.98	55.83	54.75	55.22	55.14
$_2O_3$	12.73	11.46	11.94	11.92	12.02	9.38	10.77	10.61	10.22	12.16	12.04	12.52	11.92	11.67	12.61	12.57	12.99
$_2O_3^a$	4.71	2.88	3.64	6.74	3.01	3.98	2.51	2.47	2.94	2.80	2.68	2.77	3.09	4.22	3.07	3.84	3.31
	17.45	16.65	17.61	18.53	16.90	14.41	14.34	14.58	14.42	10.44	10.72	10.97	10.54	11.27	9.84	10.52	9.79
a	7.57	8.32	7.40	5.93	7.52	11.66	11.54	11.40	11.61	17.32	16.82	16.77	17.34	16.34	18.58	17.91	19.01
	0.09	0.10	0.28	0.18	0.05	0.13	0.04	0.10	0.16	0.11	0.09	0.14	0.13	0.14	0.13	0.17	0.07
2	0.25	0.23	0.23	0.27	0.26	0.31	0.32	0.34	0.36	0.38	0.36	0.33	0.35	0.32	0.25	0.33	0.37
	101.36	100.35	101.33	101.72	99.00	101.27	100.07	100.79	100.75	98.79	98.70	99.19	99.35	99.79	99.23	100.56	100.68
$-R^b$	0.8044	0.7811	0.8094	0.8477	0.8004	0.6878	0.6890	0.6950	0.6889	0.5179	0.5319	0.5384	0.5202	0.5516	0.4857	0.5115	0.4787
$-R^c$	0.7553	0.7803	0.7719	0.7660	0.7678	0.8146	0.7904	0.7948	0.8002	0.7540	0.7572	0.7489	0.7591	0.7625	0.7444	0.7466	0.7401
$-R^d$	4.6901	5.2580	5.3340	4.5812	5.4762	3.8094	4.1492	4.2544	4.0478	2.6489	2.7508	2.7342	2.6299	2.6211	2.4254	2.4437	2.3709
$-R_1^e$	0.6411	0.7622	0.6928	0.4945	0.7350	0.7650	0.8362	0.8371	0.8143	0.8731	0.8746	0.8707	0.8612	0.8115	0.8704	0.8383	0.8647
$-R_2^f$	0.5599	0.3120	0.4435	1.0221	0.3605	0.3072	0.1959	0.1946	0.2281	0.1454	0.1434	0.1485	0.1604	0.2323	0.1488	0.1929	0.1565

Recalculated; [b]$Mg/(Mg + Fe^{2+})$; [c]$Cr/(Cr + Al)$; [d]$Cr/(Fe^{2+} + Fe^{3+})$; [e]$Fe^{2+}/(Fe^{2+} + Fe^{3+})$; [f]$Fe^{3+}/Fe^{2+}$.
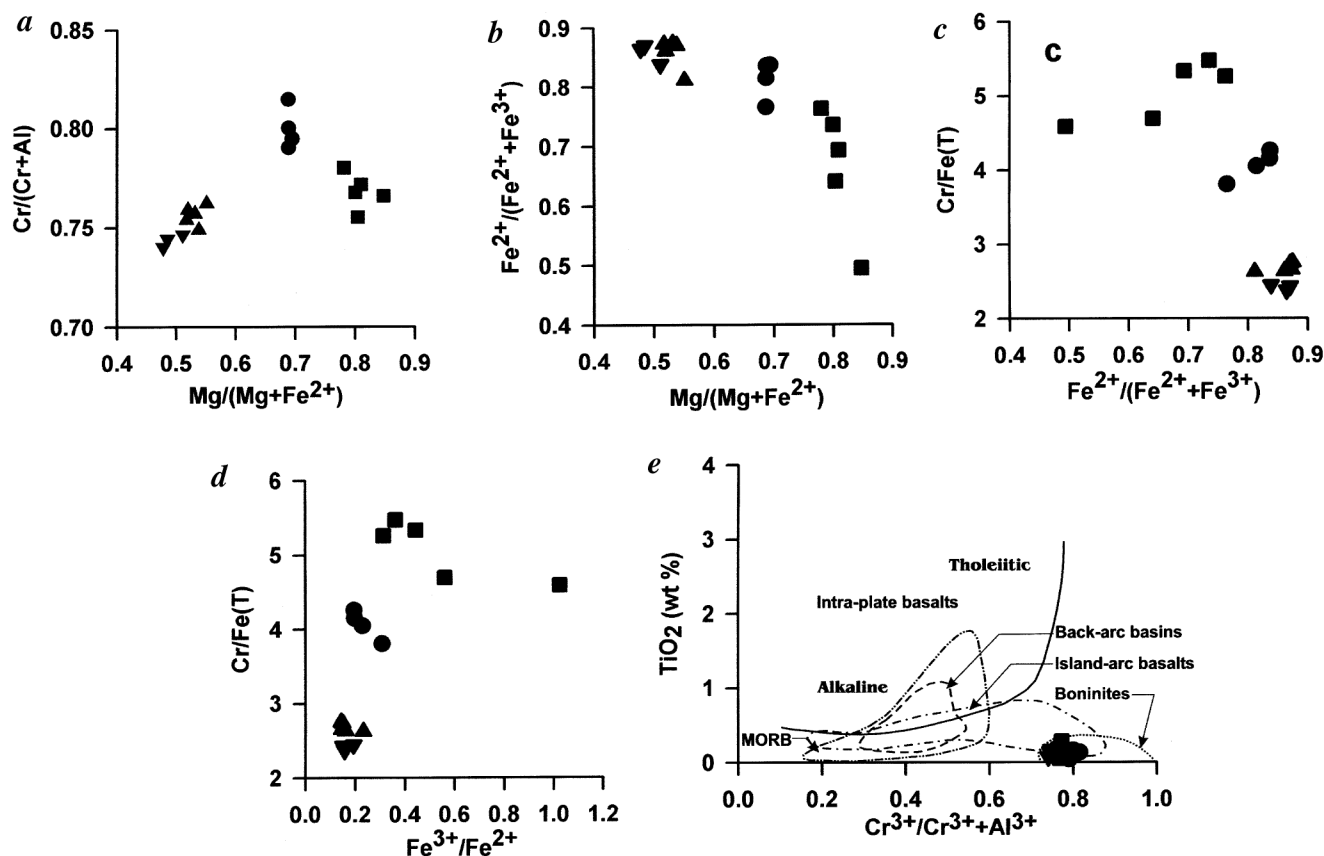
Figure 2. Plot of variation diagrams. *a*, $Mg/(Mg + Fe^{2+})$-$Cr/(Cr + Al)$; *b*, $Mg/(Mg + Fe^{2+})$-$Fe^{2+}/(Fe^{2+} + Fe^{3+})$; *c*, $Fe^{2+}/(Fe^{2+} + Fe^{3+})$-$Cr/Fe(T)$; *d*, Fe^{3+}/Fe^{2+}-$Cr/Fe(T)$; *e*, TiO_2-$Cr^{3+}/(Cr^{3+} + Al^{3+})$. Symbols: ore (■), contact (●), footwall (▲), and hangingwall (▼).

mally fresh, but at places show corroded grain boundary probably developed during serpentinization (Figure 1 *c*). The reflectivity of these grains is higher than that of Cr-spinels from chromitite. One sample each from ore body, ore body–hangingwall contact, hangingwall and footwall was chosen for EPMA (JEOL Superprobe: JXA-8600 M) studies. The chemical composition (wt%) of Cr-spinels is furnished in Table 1. FeO and Fe_2O_3 values were recalculated on the basis of cation distribution. The $Mg/(Mg + Fe^{2+})$, $Cr/(Cr + Al)$, $Fe^{2+}/(Fe^{2+} + Fe^{3+})$ and $Cr/Fe(T)$ ratios were calculated using ionic proportion.

Low TiO_2-content (0.04–0.28%), high $Cr/Fe(T)$ ratio (>4.0) and low Fe^{3+}/Fe^{2+} ratio (mostly <0.5) of Kathpal chromite indicate podiform nature, but the $Mg/(Mg + Fe^{2+})$, $Cr/(Cr + Al)$ values fall within the overlap zone of both stratiform/podiform types. These observations may also indicate the composition of the parent magma (Mg and Cr-rich) and crystallization in active tectonic conditions.

The Cr-spinels from chromitite and enclosing rocks do not show much differ-

ence in Cr_2O_3, Al_2O_3 and Fe_2O_3 content. Slight enrichment in Cr_2O_3 and Fe_2O_3 content is seen in the Cr-spinels from the ore body and higher Al_2O_3 content in the Cr-spinels is found in the contact zone. The amount of MgO is maximum in Cr-spinels from the chromitite layer, followed by the contact zone and the enclosing rocks. Expectedly with respect to MgO, FeO shows an opposite trend.

The $Mg/(Mg + Fe^{2+})$ ratio in Cr-spinels from chromitite is highest (≈ 0.8), followed by the contact zone (≈ 0.7) and the enclosing rocks (≈ 0.5). Increase in $Mg/(Mg + Fe^{2+})$ ratio in Cr-spinels from chromitite may indicate a relative rise in temperature during formation of chromitite layers compared to the enclosing rocks. Alternately, as no other silicate phase was crystallizing at that time, Mg was incorporated only in the Cr-spinel structure resulting in high $Mg/(Mg + Fe^{2+})$ ratio. The $Cr/(Cr + Al)$ ratio does not show much variation (≈ 0.75) barring a slight increase in value in the Cr-spinels from the contact zone (≈ 0.8; Figure 2 *a*), indicating minor increase in total pressure at

the beginning of chromitite formation. Considering the chromites in the chromitite formed in a narrow temperature range[13] of 1250 ± 100°C, increase in the Fe^{3+}/Fe^{2+} ratio in chromite may possibly indicate an increase in fO_2. This may be confirmed by a gradual decrease in $Fe^{2+}/(Fe^{2+} + Fe^{3+})$ values with concomitant increase in $Cr/Fe(T)$ and Fe^{3+}/Fe^{2+} ratio in Cr-spinels from the enclosing rock to the chromitite (Figure 2 *b–d*).

It is proposed that the podiform character of the chromitites in Kathpal is due to ultrabasic (boninitic) composition of the parent melt as indicated by TiO_2-$Cr^{3+}/Cr^{3+} + Al^{3+}$ plot[14–16] (Figure 2 *e*). This area may be remnant of a feeder pipe for magma injection in the main SUC. The tectono-magmatic character of the feeder zone may be similar to that observed in podiform-type evniroment. Such a zone is expected to be tectonically more active compared to the main intrusive body. Within this feeder zone, crystallization of magma was controlled by fluctuation of temperature, total pressure and fO_2. Singificant and abrupt variations in $Mg/(Mg + Fe^{2+})$,

$Fe^{2+}/(Fe^{2+} + Fe^{3+})$, Cr/Fe(T) and Fe^{3+}/Fe^{2+} values in Cr-spinels from the enclosing rocks to the chromitite layer are unlikely to be caused by serpentinization or metamorphism. These observations are consistent in all Cr-spinel analyses (Table 1). However, minor modification of Cr-spinel composition by these processes cannot be ruled out[17]. It may be concluded that the Kathpal part of the SUC represents a feeder zone for intrusion of Mg-rich boninitic magma which produced the layered chromite deposit in the SUC. The formation of chromitite zones within the ultramafic rocks in Kathpal is controlled mainly by fluctuation of fO_2, with minor influence of temperature and total pressure that existed in the magma chamber.

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Recovery of airborne palynodebris from Continental Ice Sheet, Schirmacher Oasis, East Antarctica

Climate changes have a significant effect on the periglacial region in front of the large inland ice masses of Antarctica. They also affect the glaciers and permafrost soil. Information on environmental changes during the recent history of the earth is stored in the deposits found there, especially the huge continental ice sheet and polar lake bottom sediments which could be the important data archives of palaeoenvironmental condition. Glacier ice, like other accumulating sediment, incorporates fossil pollen and spores[1]. The potential for pollen analysis of polar ice was first tested by Fredskild and Wagner[2] on four melt water samples from Greenland ice core and dated back to 8800 and 14,390 yrs BP. The pollen count was not enough for suitable percentage calculation from low amount of water samples. Later, Lichti-Federovich[3] analysed large volumes of melt water for better results and proved the potentiality of palynological interpretation from polar ice samples. This is an attempt on the palynological study of glacial ice from huge east–west-oriented continental ice sheet in the Schirmacher Oasis, a

group of low-lying hills and ice-free high-polar rock desert covering 34 km² in the eastern Dronning Maud Land, East Antarctica (70°45′39.4″S and 11°44′8.6″E; Figure 1). The climate is relatively mild due to the low altitude, with air temperature over the glacier ice between −7 and +8°C during midsummer (December–January), when melt water is abundant. Ten bulk ice samples were taken from the exposed wall of the ice sheet (Figure 2) and allowed to melt up to at least 1 l. After centrifuging and proper sieving, the same was made up to 10 ml and stored with 50% glycerine in a vial. Then 100 ml of water samples from flowing glacial stream were directly centrifuged and stored in the same manner. Entire samples were studied under Olympus BX-50 microscope. Pollen–spore counts are not sufficient for formulating pollen spectra (15–30 per sample).

The picture thus obtained from pollen spectra of ten bulk ice samples reflects overall dominance of algal elements (*Nostoc, Oscillatoria, Pediastrum*, dinocyst, etc.), desmids (*Cosmarium* spp.), diatoms

like *Navicula, Pinnularia, Fragilaria, Nitzchia*, etc. The angiosperm nonarboreal pollen taxa comprise Poaceae (30–40 μm), Caryophyllaceae, Chenopodiaceae, Asteraceae (Tubuliflorae), etc. However, *Pinus, Larix, Betula, Ulmus*, Urticaceae–Moraceae, etc. are the only arboreal taxa recovered from the samples. The algal remains, including desmids, diatoms and Acritarchs are of local origin. Occurrence of only monolete fern in the 9th sample is interesting. The occurrence of reworked palynomorph (Figure 3) is significant, which indicates the nearness of Gondwana sedimentary rocks in Eastern Antarctica. Presence of fungal remains in good value is indicative of humid climatic condition, in which it might have travelled along with long-distance transported pollen and got incorporated in the sediment and may be saprophytic in nature. The pollen concentration in the flowing water samples does not cohere with that of ice sheet samples, which needs detailed investigation. The pollen concentration in Antarctic ice samples is low compared to other surface samples like moss turfs, frozen