in the Otago schists of New Zealand (Turner, 1933); like many similar Alpine schists they also contain tschermakitic hornblendes. The Warsak tuffs could have formed originally, together with the meta-igneous rocks, possibly as lavas, in an inter-plate tectonic environment; the high Al content of the hornblende, which is typical of many amphiboles from the surrounding alpine environment in North-West Pakistan, and other mineralogical evidence in the region support a high-pressure environment for the metamorphism of the rocks to just within the amphibolite facies, at moderate temperatures of approximately 465 °C.

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Magnetic chromites from Kondapalli, Andhra Pradesh, India

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THE Kondapalli region (16° 37′ N. 80° 32′ E.) in the Eastern Ghats, Andhra Pradesh, consists of high-grade granulite facies rocks: charnockites, hypersthene granites, and enderbites are plutonic intrusives into khondalites—garnetiferous sillimanite granites, garnetiferous granites, sillimanite-garnet quartzites, and quartzites. Pyroxene granulites of gabbroic and noritic compositions are distinct basic intrusive bodies, occurring as sills and dykes.

Chromite orthopyroxene nodules are enclosed in serpentinite and carbonate rock, formed from altered peridotite; they are younger than the charnockites and pyroxene granulites and are confined to the cores of south-eastern-plunging overturned isoclinal anticlines. The chromites are massive in coarse-layered pyroxenites and granular in fine-layered rocks; those found at Gangineni are magnetic and are associated with bronzite (En_{77-85}), those from the Binny and Loya mines are non-magnetic and associated with enstatite (En_{88-95}).

Chemical analyses and X-ray powder data are given for five specimens, including both types. The magnetic susceptibility appears to increase with increasing Fe^{3+}. The unit-cell size is negatively correlated with Cr^{3+}, Al^{3+}, and Mg^{2+} and positively with Fe^{2+} and Fe^{3+}.

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MAGNETIC CHROMITES FROM KONDAPALLI, ANDHRA PRADESH, INDIA

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The Kondapalli (Lat: 16°37'N and Long: 80°32' 30"E) region in the Eastern Ghats of Andhra Pradesh, India is made of high grade granulite facies rocks - khondalites, charnockites and pyroxene granulites. The charnockites, hypersthene granites and enderbites, are the plutonic intrusive bodies into the khondalites - garnetiferous sillimanite granites, garnetiferous granites, sillimanite-garnet quartzites and quartzites. Pyroxene granulites of gabbroic and noritic composition are distinct basic intrusive bodies found as sills and dykes in the khondalites and charnockites. The regional foliation is NNE and occasionally changed to NW due to cross folding and dips eastward.

Chromite orthopyroxenite nodules of varying dimensions are enclosed in serpentinite and carbonate rock, formed from altered peridotite. They are younger than the charnockites and pyroxene granulites and are confined to the cores of southeastern plunging overturned isoclinal anticlines. The ore bodies have attained the similar isoclinal structural pattern. The chromite pyroxenites exhibit prominent primary layering. Slip planes and shear zones in the chromite pyroxenites have promoted recrystallization and segregation of orthopyroxene veins. A fine net work of carbonate and quartz minerals occur in the ultramafic rocks. Finally, palingenetic granites and dolerites intrude the whole sequence of rocks.

The chromites are massive in coarse layered pyroxenites and granular in fine layered rocks. They are subhedral to rarely euhedral and replaced by pyroxenes. Less often chromites replace pyroxenes around grain margins and also along minor shear zones. The absence of marginal granulation in chromites and the mutual replacements with eutectic textures suggest primary crystallization. The chromites found at Gangineni in the Kondapalli region are magnetic and are in association with bronzite (En_{77-85}). Non-magnetic chromites are more common in the Kondapalli region (Binny and Loya mines) and associate with enstatite (En_{88-95}). The grain size of chromite varies from 0.5 to 3 mm in granular varieties. The chromites show shades of grey colour under reflected light. Reflectance measured in green light is 15.5 percent. The chemical and X-ray and magnetic susceptibility data of chromite samples - 5 - from Kondapalli are given in Tables I and II. Although magnetic chromites are not uncommon (Thayer, 1956) the data presented on magnetic chromites from Kondapalli region is the first from India.

The analysed Kondapalli chromites are aluminian (Samples 1B 4, 4A) and ferrian (Samples 4B, 4C) types (Stevens, 1944). Although Samples 4 and 4A are termed aluminian, Fe contents of 29.7 and 39.9% as FeO, two to three times the Al_2O_3 content, mark them as unusually rich in Fe. Samples 4B and 4C are so rich in Fe^3total Fe that one may suspect the presence of ferritchromit and inhomogeneity. Polished sections reveal no exsolution, resorption or zoning. Electron-probe scanning across the chromite grains supports the homogeneity. The magnetic susceptibility (K) apparently increases with the magnetite end-member percentage in the chromites.

Fig. 1. indicates that all the samples lie in a definite zone agreeing with isomorphous substitutions. A linear relationship has been established between the weight percentage of Al_2O_3 and Cr_2O_3+ Fe_2O_3 and the unit cell dimension in chromites (Clark and Ally, 1932); McGregor and Smith, 1963; Chakraborty, 1965; Chakraborty and Mallik, 1971). The unit cell dimension, a Å, of the Kondapalli chromites is negatively correlated with Cr^{3+}, Al^{3+}, Mg^{2+} and positively with Fe^{2+} and Fe^{3+} (fig. 2).

The overall composition of orthopyroxenes and chromites from Gangineni resemble the assemblages in Critical series of the Bushveld igneous complex (Wager and Brown, 1968). The sympathetic compositional variations in orthopyroxenes and magnetic chromites in the chromite pyroxenites reflects the difference in magmatic conditions during the crystallization of chromite. The high Fe_2O_3 content in the bronzites (2 - 3%) and the magnetic chromites suggests a high oxygen partial pressure. The high enstatite content of orthopyroxene with the non-magnetic chromites in the pyroxenites suggests that the minerals are primary accumulates in the ultramafic magma. The iron-rich solid solutions of the spinel, magnetite and chromite series present in the Kondapalli layered chromites fall in the stratiform type of Thayer (1956, 1964).

Table I. Chemical analyses of chromites from Kondapalli

	1B	4	4A	4B	4C
Cr_2O_3	57.57	46.80	37.29	35.82	34.80
Al_2O_3	11.96	12.45	12.95	9.99	10.28
TiO_2	0.13	0.26	0.91	1.26	0.80
Fe_2O_3	3.99	11.35	18.40	20.98	21.50
FeO	13.19	19.50	23.37	26.56	25.60
MgO	12.90	8.90	6.47	4.03	4.93
CaO	<0.01	<0.01	<0.01	<0.01	<0.01
MnO	0.17	0.32	0.29	0.30	0.29
NiO	0.00	0.00	0.25	0.11	0.20
V_2O_3	<0.09	<0.10	<0.15	<0.22	<0.15
SiO_2	0.00	0.00	0.14	0.25	0.35
Total*	99.91	99.58	100.07	99.30	98.75
	Number of ions on the basis of 32(O)				
Cr	11.71	9.82	7.94	7.92	7.73
Al	3.63	3.89	4.11	3.30	3.41
Ti	0.03	0.05	0.18	0.27	0.17
Fe^{3+}	0.77	2.26	3.72	4.42	4.54
Subtotal	16.14	16.02	15.95	15.91	15.85
Fe^{2+}	2.84	4.32	5.26	6.23	6.01
Mg	4.94	3.52	2.59	1.68	2.06
Mn	0.03	0.08	0.06	0.07	0.07
Ni	-	-	0.05	0.02	0.05
Subtotal	7.81	7.92	7.96	8.00	8.19
	End member percentages (formulae) of chromites				
Spinel	22.70	24.3	31.31	20.62	21.3
Magnesio-chromite	39.06	19.7	1.06	0.38	4.4
Ferro-chromite	34.12	41.7	42.94	49.12	43.9
Magnetite	4.12	14.3	24.69	29.88	30.4

* CaO and V_2O_3 not taken into account.
Zn = <0.1; Mo = <0.05; Pb = <0.01; Co = <0.01
Cu = <0.01; Zr = <0.02 (in all the samples)

1B - Non-magnetic chromite from chromite pyroxenite from Binny mine.
4 - Feebly magnetic chromite from chromite pyroxenite.
4A - Feebly magnetic chromite from chromite pyroxenite.
4B - Magnetic chromite from fine layered chromite pyroxenite.
4C - Strongly magnetic chromite from coarse layered chromite pyroxenite.

The last four samples were collected 2 feet apart from one another from crest to the overturned limb of the Gangineni fold.

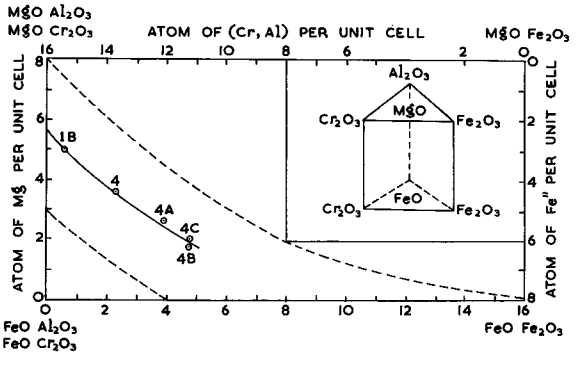

Fig. 1. Graph showing a view of spinel triangular prism of composition with a zone of isomorphism for the Kondapalli chromites.

Table II. X-ray and magnetic susceptibility data of chromites from Kondapalli

hkl	Visual intensity	1B d Å obs.	1B d Å calc.	4 d Å obs.	4 d Å calc.	4A d Å obs.	4A d Å calc.	4B d Å obs.	4B d Å calc.	4C d Å obs.	4C d Å calc.
111	3	4.76	4.79	4.77	4.80	4.77	4.80	4.78	4.81	4.78	4.81
220	2	2.916	2.935	2.920	2.941	2.920	2.941	2.925	2.946	2.931	2.944
311	10	2.489	2.503	2.496	2.508	2.498	2.508	2.497	2.512	2.501	2.511
222	½	2.390	2.396	2.382	2.401	2.390	2.401	2.395	2.406	2.393	2.404
400	6	2.065	2.075	2.069	2.080	2.071	2.080	2.073	2.083	2.073	2.082
422	1	1.688	1.694	1.691	1.698	1.694	1.698	1.694	1.701	1.697	1.700
511	7	1.592	1.598	1.596	1.601	1.597	1.601	1.600	1.604	1.601	1.603
440	8	1.464	1.467	1.466	1.471	1.468	1.470	1.468	1.473	1.470	1.472
531	½	1.400	1.403	1.402	1.406	1.405	1.406	–	–	1.408	1.408
620	½	1.310	1.313	1.312	1.315	1.312	1.315	1.315	1.318	1.316	1.317
533	2	1.263	1.266	1.266	1.269	1.267	1.268	1.269	1.271	1.269	1.270
622	1	1.247	1.251	1.252	1.254	1.254	1.254	1.254	1.256	–	–
444	1	1.196	1.198	1.198	1.201	1.200	1.201	1.201	1.203	1.200	1.202
711	½	1.159	1.162	1.163	1.165	–	–	–	–	–	–
642	½	1.107	1.109	1.112	1.112	1.110	1.112	1.112	1.114	1.110	1.113
731	4	1.079	1.081	1.083	1.083	1.083	1.083	1.085	1.085	1.084	1.084
800	2	1.037	1.038	1.039	1.040	1.039	1.040	1.041	1.042	1.040	1.041
751	2+	0.9579	0.9585	0.961	0.961	0.961	0.961	0.9624	0.9622	0.9618	0.9615
662	1	0.9515	0.9522	0.955	0.954	–	–	–	–	–	–
840	2	0.9278	0.9281	0.930	0.930	0.9302	0.9300	0.931	0.932	–	–
931_{K_1}	2+	0.8700	0.8702	0.8722	0.8721	0.8720	0.8720	0.8734	0.8735	0.8730	0.8729
931_{K_2}	1	0.8702	–	0.8721	–	–	–	–	–	–	–
844_{K_1}	4	0.8471	0.8472	0.8492	0.8491	0.8488	0.8490	0.8507	0.8505	0.8498	0.8499
844_{K_2}	2	0.8469	–	0.8489	–	–	–	–	–	–	–
1020_{K_1}	1	–	–	0.8155	0.8157		–	–	–	–	–
1020_{K_2}	½	–	–	0.8155	–	–	–	–	–	–	–
951_{K_1}	2	0.8026	0.8025	0.8040	0.8042	0.8042	0.8041	0.8061	0.8056	0.8050	0.8050
951_{K_2}	1	0.8026	–	0.8041	–	–	–	–	–	––	–
a Å		8.301 ±0.001		8.319 ±0.002		8.318±0.003		8.333 ±0.003		8.327	± 0.002
Magnetic susceptibility (K) in C.G.S. units		8.35×10^{-5}		31.19×10^{-3}		49.43×10^{-3}		61.96×10^{-3}		62.6×10^{-3}	

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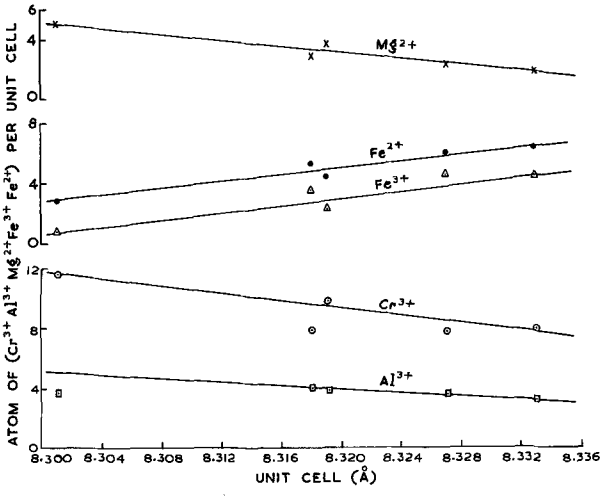

Fig. 2. Correlation of unit cell (Å) and Cr^{3+}, Al^{3+}, Fe^{3+}, Fe^{2+}, Mg^{2+} atoms per unit cell in the Kondapalli chromites.